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Cold Climate Utilities Delivery

Design Manual

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COLD CLIMATE UTILITIES

DELIVERY DESIGN MANUAL

prepared by
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FOREWORD

The concept for this manual emerged at the symposium on 'Utilities Delivery in Arctic Regions' organized by Environment Canada in Edmonton, March 16-18, 1976. The several U.S. and Canadian agencies responsible for environmental improvement in the north were requested to assemble a team of experts which would pool its knowledge to create a 'state-of-the-art' design manual on planning and servicing northern communities. In the ensuing months efforts in both countries resulted in the creation of a steering committee, and the commitment of staff and funding to allow this undertaking. Meetings of the committee took place in Anchorage, Seattle, Yellowknife, and Edmonton. Each member of the committee was assigned lead responsibility for one or more sections.

The purpose of the manual is to provide guidance and criteria for the design of utility systems in cold regions to an engineer experienced in southern municipal engineering practice. He or she may be working for government, consulting engineers or industry, and would be involved in the planning, design, construction or operation of utility services in a northern community or industrial establishment. It is hoped that this manual will help to improve the level of services provided and to avoid many of the mistakes made in the past by transferring 'southern engineering' to the North without proper modifications. Often, a new approach utilizing basic environmental engineering principles suitable to the north is required.

It is recognized that errors and omissions may have occurred during the preparation of this manual. The authors would apppreciate comments and supplemental information which could be incorporated into revisions of the manual. It is the belief of the authors that this manual must be updated periodically. Comments and recommendations should be sent to the:

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AVANT-PROPOS

Ce manuel a été conçu à la suite du colloque sur la "Distribution et l'évacuation des eaux dans les régions arctiques", organisé à Edmonton par Environnement Canada les 16, 17 et 18 mars 1976. On avait invité, lors de cette réunion, les organismes canadiens et américains responsables de l'amélioration de l'environnement dans le Nord, à former une équipe de spécialistes. Ceux-ci devaient mettre leurs connaissances en commun en vue de créer un manuel de conception à jour, destiné à planifier l'installation des localités nordiques et les services essentiels dont elles ont besoin. Par la suite, les deux pays se sont concertés pour créer un comité directeur et ont affecté les fonds et le personnel nécessaires au bon fonctionnement de l'entreprise. Le comité s'est réuni à Anchorage, Seattle, Yellowknife et Edmonton. Chaque membre s'est vu confier la responsabilité d'une ou de plusieurs sections.

Le manuel se propose de fournir, aux ingénieurs formés aux techniques courantes dans les municipalités du Sud, des conseils et des critères applicables à la conception de réseaux de services pour les régions du Nord. Ces ingénieurs peuvent être au service du gouvernement, d'une firme d'ingénieurs conseil ou d'une industrie et participer à la planification, à la conception, à la construction ou à l'exploitation du réseau de services d'une localité ou d'une industrie situées dans le Nord. Il est à espérer que ce manuel aidera améliorer la qualité des services et à éviter les erreurs commises dans le passé où les pratiques de technogénie applicables aux communautés du Sud étaient mises en oeuvre, sans modifications préalables, dans les localités du Nord. La nouvelle façon d'aborder ces questions repose sur les principes fondamentaux de technogénie environnementale adaptés aux régions nordiques.

Certaines erreurs ont pu se glisser dans ce manuel lors de sa préparation. Les auteurs vous sauraient gré de leur faire parvenir vos commentaires ou des renseignements qui pourraient s'ajouter au texte lors des révisions périodiques. L'adresse est la suivante:

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SECTION 1

INTRODUCTION

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1 INTRODUCTION

"Cold climate" in this manual means the climate experienced in the arctic and subarctic regions of the United States and Canada.* They include Alaska, the Yukon and Northwest Territories, northern parts of some of the Canadian provinces and some high altitude areas of the northern contiguous United States. The special problems of providing utility services in these regions are addressed in this manual, which may also be helpful for other cold climate regions, such as the Antarctic, Greenland, Scandinavia and the U.S.S.R.

A vast, frozen land inhabited by but a few people; that is the impression most 'southerners' have of Alaska, the Yukon and the Northwest Territories. Much of the evidence supports this impression. About 500,000 people live in Alaska, about 30,000 in the Yukon Territory and about 45,000 in the Northwest Territories. Disregarding national boundaries, this vast land stretches over 5,000 kilometres, from Davis Strait in the east to the Bering Sea in the west. It extends 2,500 kilometres from the northern parts of the Canadian provinces to uninhabited lands near the North Pole. The recent interest in the energy and material reserves of the North have made people more aware of these regions and of the modern communities of sizeable population, such as Anchorage (200,000), Fairbanks (45,000) and Barrow (3,000) in Alaska, and Whitehorse (16,000) in the Yukon Territory, and Yellowknife (12,000) and Frobisher Bay (2,500) in the N.W.T., to name some of the larger ones. In total there are about 250 communities with populations between 100 and 1,000 people. Most settlements were established long before the provision of municipal services was considered important. Their location and haphazard layout were based on survival and personal preferences. This has now resulted in high cost for services, which in turn delays the extension of modern community services to these settlements.

Several factors cause special problems to the development of services in northern communities. Among them are: permafrost, climate, remoteness, lack of planning for services, inadequate housing, and often lack of an economic base. The degree of influence of these factors

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* Terms throughout this manual are defined in the glossary.

varies considerably over this huge land. Permafrost occurs where the mean annual ground temperatures are below 0°C for several years. Its thickness varies with location and can be up to 600 metres. Climatic variations are great. Minimum and maximum temperatures may average as low as -50°C and as high as 30°C. Mean annual total precipitation (rain and snow) varies from about 15 to 45 cm, quite low compared to southern areas.

The remoteness of most communities results in high transportation costs. Most of the materials used for services must be imported. The spread-out, low density layout of existing settlements results in further high costs. Replanning of a settlement, including relocation of roads and houses, is, or should be, a prerequisite to construction of piped water and sewer systems. In some cases, complete relocation of a settlement may be the most economical solution for servicing the community. Upgrading existing housing and construction of low and high density housing for permanent and transient populations are required. Central commercial, educational and recreational facilities must be incorporated in the community plan. Any useful and practical plan, be it for housing, schooling or servicing, must be both technically and economically sound, and most important, socially acceptable to all groups of the community, both natives and newcomers.

1.1 Water Supply

All traditional sources of water are present in most parts of the cold regions but conditions peculiar to these regions require special consideration of these sources prior to selection of a community water supply. For example, although there are many lakes, they are generally quite shallow and many freeze to the bottom, or their effective storage capacity is severely reduced by thick ice that forms each winter. This also tends to concentrate minerals in the unfrozen water, which may render it unsuitable for consumption. Surface water is often highly coloured from the organic material washed into lakes by runoff. Because of low precipitation, water contained in lakes may be the result of many years' accumulation. Attempts to utilize large amounts of this water may drain the lake and cause loss of supply. During the winter, clean water can be obtained from beneath the ice of rivers, but during breakup, floating ice and other debris carried by the flood waters are a hazard to any permanent installation, such as a water intake. Following breakup, the silt content of the river is extremely high, possibly rendering the water unusable for several weeks. Small rivers and creeks often freeze to the bottom, and so their use as a water source may be limited to certain times of the year. They may also be polluted from waste discharges. Reservoirs are difficult to construct where the underlying soil has a high ice content; any attempt to pond water will cause melting of the underlying permafrost and possible settlement of the dykes.

Groundwater is an excellent source of supply in remote northern locations. However, in continuous and discontinuous permafrost regions a reliable groundwater source normally must be obtained from beneath the frozen zone. This often means expensive wells due to thermal protection requirements. In addition, the well water may be highly mineralized. In some locations, ice and snow are melted for water, but the high cost of fuel or electricity makes this source of water uneconomical if adequate quantities are to be provided. Water consumption rates show large variation depending on the method of distribution and the plumbing facilities. A water supply objective of 50 litres per person per day is generally considered minimum for adequate drinking, cooking, bathing and laundering purposes. Only piped systems or a well-equipped trucked water system can meet this objective. In many communities, houses without plumbing that are currently served by a trucked water system, only 10 litres per person per day is supplied and used.

1.2 Water Distribution and Sewage Collection

The dominant characteristic of cold regions utility systems is the need to prevent both the water and sewage lines from freezing. Heat may be added to the water or to the mains, and continuous circulation maintained to prevent freezing. The degree of freeze protection required depends on whether the pipes are buried or built above ground. Buried water and sewer lines are preferred for community planning, aesthetic and engineering reasons. In areas with subarctic climate (arbitrarily defined as one in which one to three calendar months have mean monthly temperatures above 10°C), such as Anchorage, Fairbanks, Whitehorse and

Yellowknife, underground systems are used. They differ from southern systems in that various methods of freeze protection are provided, such as insulation, heating, recirculation and water wasting. Insulation around pipes also prevents thawing of ice-rich permafrost and consequent settling of pipes. In the past, underground services were considered to be not feasible, technically and economically, in ice-rich permafrost areas. Therefore, above-ground utility systems were constructed in such areas. They are generally more expensive, cause difficulties with roads and drainage, are subject to vandalism, and are not desirable from community planning and aesthetic points of view. Recent engineering developments may allow underground construction in areas where this was thought not possible in the past. This will reduce future use of above-ground utilidors. However, above-ground utility systems will still be necessary in thermally-sensitive, ice-rich, permafrost areas, or where excavation equipment is not available for installation and maintenance or for temporary facilities.

Trucked delivery of water and pickup of sewage is an alternate means of providing services. Water storage tanks used for homes vary from an open reused oil drum (180 L) to proper tanks of 1200-litre or more capacity. In some settlements, water is delivered only to some homes. Others must pick up water in pails from a number of water points within the settlement. When the house is equipped with complete indoor plumbing, all wastes are generally discharged to a holding tank, which must be pumped out several times per week. When indoor plumbing is not available, toilet facilities may consist of pit privies or chemical toilets of various designs; however, they usually consist of "honey bags", plastic bags in a container under the toilet. "Honey bags" are picked up daily or several times per week on a community-wide basis. Wash water wastes, kitchen sink wastes, and laundry water are usually disposed of to the ground surface in the immediate vicinity of the home, often contributing to localized drainage and health problems.

1.3 Waste Disposal

Very few communities have sewage treatment plants, although there are now many package-type plants at industrial facilities in Alaska which were built as a consequence of the oil discovery and pipeline construction. Sewage lagoons are the most common method for the treatment of wastewater. Few of these meet recommended design and operating criteria. In the past, they were often constructed by utilizing existing lakes or low areas with suitable addition of dykes. For most of the year they provide long-term storage of wastewater, with some anaerobic decomposition taking place. It is during the summer that extensive biological activity occurs, with resulting reduction in organic matter. The relatively lower effectiveness of lagoons for wastewater treatment is offset by their lack of need for skilled and costly operation and maintenance. In certain subarctic locations, septic tanks and tile fields are used. In communities near the ocean, disposal of wastewater is often to the sea. This practice may not be permitted without a special study of local conditions or some degree of treatment in the future.

1.4 Solid Waste Management

Human feces in "honey bags" are often disposed of without any treatment in a dump, together with solid waste. In some cases, pits have been constructed. In other cases, the contents are emptied into a lagoon which also receives wastewater. Solid waste disposal has, until recent years, been the most neglected area of sanitation. Where a community collection system exists, disposal is generally at a dump. Because of lack of proper cover material, sanitary landfill cannot be practised in most places. Few dumps are fenced, contributing to widespread and uncontrolled dumping. In some cases, ill-chosen dump sites contribute to water pollution. Other forms of refuse disposal, such as incineration, shredding, baling, etc., have found limited application due to high maintenance and operational costs.

1.5 Fire Protection

One of the most serious hazards to life and property in remote northern locations is fire. The seriousness of fire is aggravated by the problems of providing adequate quantities of water to fight fires during the extremely cold periods of the year, the extreme dryness of wood and organic materials, and the dependence on heating systems for survival. Fire protection techniques must be approached at all levels: the use of fire retardant materials, development and use of early warning devices, the provision of fire control equipment and personnel, and educational efforts towards fire prevention.

1.6 Energy Management

Conservation of energy becomes especially important in cold climate areas. The costs of heating buildings, lighting, hot water, and operation of appliances are generally much higher than in southern areas. Heating expenses can be reduced by heavy insulation of buildings and increased use of waste heat from generating stations. Oil, gas, coal, wood and hydro-generated electricity are now most commonly used as energy sources. These may be supplemented by geothermal, solar, and wind energy where and when feasible.

1.7 Summary and Future Needs

An evaluation of the present level of sanitation in most of the smaller northern communities shows that the overall situation is more primitive than in comparably-sized southern communities, but that the situation is steadily improving. Goals have been set out broadly, for instance, in the "Proposed Water and Sanitation Policy for Communities in the N.W.T., 1973". Implementation of these goals will, to a large extent, depend on available funds.

Development of the northern areas of Canada and of Alaska will undoubtedly increase in the next few decades, but the scale and pace of development is still somewhat uncertain. Resource development, including oil, natural gas, mining, hydro-electric works and transportation facilities, such as pipelines, roads, railroads, bridges, harbours and airports, will be built. Several different types of communities will have to be developed, such as construction and permanent camps, the expansion and improvement of existing communities, and the building of new towns. The engineering community must be ready to plan, design, construct and operate facilities appropriate for the conditions encountered.

SECTION 2

PLANNING AND PRELIMINARY CONSIDERATIONS

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2 PLANNING AND PRELIMINARY CONSIDERATIONS

It is advisable to apply the principals of good planning to new developments and to extensions of existing communities. Moving to a new location or rearranging the present layout according to good planning practices must be considered because the addition of utilities will "anchor" a community to a specific location.

Utilities are required and are being installed in many existing communities whose locations and layouts originated from a subsistence economy. They were located close to hunting grounds, and near the ocean or rivers for transportation and fishing. Many of these locations were also influenced by the RCMP, missionaries, Hudson Bay Company outposts, and government. Requirements beyond the immediate needs were not considered; population growth, utilities, housing, and other modern "essentials" were usually neglected in the community location and layout. Many of the present villages slowly evolved from a temporary fishing or hunting camp. For example, nearly all the Eskimo communities along the west coast of Alaska are located on sand spits projecting into the ocean (see Figure 2-1). These sites suffer from erosion, flooding, lack of room for expansion, and long distances to a freshwater source. The "old timers" say that they located there to be near the seal hunting and salmon fishing, as well as to be where they could see and prepare for the raiding Indians from the interior of Alaska.

2.1 Objectives

The objectives of planning are to reduce the cost of construction, and operation and maintenance (O&M) of utility systems, while at the same time, providing a healthy, functional, convenient, usable, attractive community or site.

2.1.1 Health

The primary purpose of providing safe drinking water and sanitary waste disposal is to improve public health (see Figure 2-2). Protection against water-carried diseases such as intestinal disorders, hepatitis, typhoid, polio and cysts, to name a few is provided. Also, the provision sufficient water for personal hygiene, laundry, and cleaning of the home reduces the occurrence of impetigo and other skin

FIGURE 2-1. UNALAKEET, ALASKA.

The bottom of the picture is Norton sound and the water body in the centre is a salt water tidal slough.

FIGURE 2-2. ICE STACKED TO BE MELTED FOR DRINKING WATER - KOTZEBUE, ALASKA

diseases. A third health consideration is drainage in and near communities. Swampy or low areas become contaminated, stagnant ponds, which support mosquitos and other insects which can carry diseases and be a general nuisance.

Different degrees of overall health improvement are accomplished with various types of sanitation facilities [1,2,3]. The provision of a safe source of water within a community, but outside the home, will facilitate health improvement. The improvement is limited, however, because:

1) It is impractical to have the source near all homes and many people will continue using the original unsafe source, particularly if it is closer.
2) Since all water must be hauled, it is used sparingly and seldom used for personal hygiene, house cleaning, laundry or other uses than cooking and drinking.
3) Even though safe water is supplied at a watering point, it often becomes contaminated during transport or storage in the home.

A considerably greater health improvement can be accomplished by safely distributing the water to the individual users. Individual wells are not common in permafrost areas; therefore, the two most common ways of distributing water are through pipelines and water-hauling vehicles. Greater quantities of water are made available and the risk of contamination during delivery is reduced, although the possibility is greater for hauled delivery than for piped delivery.

In many cold regions, conditions such as deep frost, permafrost, poor soils and rock may preclude the use of individual outhouses or septic tank systems. Therefore "organized" community systems are necessary. In communities where "organized" sewage collection is not provided, toilet wastes and grey water tend to be disposed of in an unsanitary and unhealthy manner. Several recent hepatitis outbreaks have been traced to this problem. A sanitation facility feasibility study conducted for the towns of Wabasca and Desmarais near Lesser Slave Lake in northern Alberta, Canada, showed that a completely subsidized hauled water system would provide the government a return on their investment of at least 62% in one year from health cost savings alone [3,4]. The discomfort and work time missed because of intestinal disorders, etc., that would not be reported to the government-operated hospitals and clinics were not considered.

Cold region communities are usually isolated; therefore, health problems are usually caused by self-contamination rather than inter-community contamination. The health risks from discharges of domestic wastes to the ocean or large rivers can be greatly reduced if outfalls are designed and constructed to protect shellfish beds and the water source for the individual site or community. Discharge standards or guidelines established for heavily populated areas should not be applied without considering local conditions. This will avoid the installation of costly treatment schemes which are designed to provide greater protection of water uses than necessary, and which are usually far beyond the ability of small communities to operate and maintain. Pathogens have longer survival times in cold waters and can be preserved for thousands of years in the frozen state. Therefore, the potential public health risk is greater in cold regions. However, the low population density renders this somewhat irrelevant for some locations, especially coastal areas.

2.1.2 Social/economic

The World Health Organization (WHO) has stressed the importance of adequate water, sewer, and garbage services to the economic and social development of a community. There will be poor health in a community without basic sanitation and there is little prospect of socio-economic development without good health. Sick or incapacitated people cannot contribute or participate in the labour market. Moreover, a healthy person can relocate to a place of employment more readily than a sick or unhealthy person.

Watering points and central facilities provide a safe community water supply. However, commercial or industrial buildings, such as hotels, schools or fish processing plants must be directly connected to the water source by a pipeline. A sufficient quantity of water cannot be practically or economically distributed by truck to large industrial or commercial users. Water and sewer services act as a catalyst to industrial development. The location of government centres, canneries or cold storage plants is often determined by the availability of the municipal services.

The provision of sanitary conditions is probably the largest single factor in improving the "standard of living" of a rural area. The indigenous societies in rural northern Alaska and Canada are changing from subsistance to cash-oriented economies. The stresses of this transition are major cause of the high suicide and alcoholism rates in northern areas. Safe water, adequate sanitary facilities and a healthy environment will improve productivity and assist in this transition.

The introduction of sanitary facilities in a rural community often provides the initial contact with such matters as bookkeeping, bill collection, tax withholding, workmen's compensation and, usually, unemployment insurance. These along with management and technical experience, provide a basis for social growth. Proper planning requires local meetings and decisions, which promote community involvement.

Participation in the development and implementation phases of the facilities encourages a feeling of community ownership and responsibility. The participation promotes responsible operation and maintenance, thus increasing the life of the facility. If outside assistance, especially funding, is needed in a community to provide for the O&M of the facilities, care should be taken to preserve the community's sense of self-reliance and avoid further dependance on government assistance. It is important that outside technical assistance be made available to the local operators. There are several different philosophies as to what degree, if any, of the O&M costs of facilities should be subsidized by the government:

a) A facility should not be constructed unless it is competely within the community's financial ability to operate, maintain, and manage.
b) The entire O&M and management costs should be subsidized by, or the facilities operated by, the government.
c) The facility O&M costs should be subsidized to the extent of the savings in health services which are realized by installation of the facility. In almost all instances involving indigenous people, 100% of the health services are presently government-subsidized.

There have been instances where well-intended assistance programs actually contributed to community disorganization. Thorough examination of the social and economic implications of a project are necessary to select the type and sophistication of facility that is best suited for a given community. Legislative, administration, and local constraints can increase the chance of project failures because they may limit the types of projects which can be considered.

2.2 Regulations and Legislation

There are many permits or clearances which must be obtained before construction can proceed. This can be time-consuming, and thus expensive, and must be budgeted into a project in the beginning. The major regulations to be followed and clearances to be obtained are listed below. Requirements differ in individual Canadian provinces and territories, and the U.S. in several instances. Regulations and procedures change frequently, and it must be emphasized that one should check with the applicable agencies before proceeding with a project.

2.2.1 Water rights

In Alaska, the Alaska Department of Natural Resources* determines water rights and issues water use permits. They also issue and administer permits for rights-of-way or easements, use of tidelands, and special land use on State lands. In the Yukon and Northwest Territories, the Territorial Water Boards conduct public hearings related to applications for water licenses to ensure that a license applicant submits sufficient information and studies for the Board to evaluate the quantitative and qualitative effects of a proposed water use, and sets water quality standards. Provincial authorities must be consulted for their regulations and procedures.

2.2.2 Water discharge permits

Waste discharge permits are required for any discharge (solid or liquid) to surface or groundwaters. Permits are issued by the Alaska Department of Environmental Conservation**. Further information is

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* Division of Land and Water Management, 323 East 4th Avenue, Anchorage, Alaska 99501.

**Pouch O, Juneau, Alaska 99811.

available from the U. S. Environmental Protection Agency*, which also administers oil spill prevention and control plans.

Any stream supporting anadromous fish in Alaska must receive clearance from the Alaska Department of Fish and Game**. Waste discharges in the Territories are regulated by the respective Territorial Water Boards. Within the provinces, each authority must be consulted.

2.2.3 Archaeological clearances

Archaeological clearances must be obtained if excavation or construction will take place at any possible archaeological sites. The Alaska Department of Natural Resources*** administers these clearances and permits if federal funds are involved. In the Canadian Territories, archaeological clearances are dealt with under land use permits.

2.2.4 Environmental assessments or impact statements

An environmental assessment or impact statement is necessary in the U. S. for any federally funded or "major" state or private project changing the environment, for the better or worse. Which one of the two is required is usually governed by the degree of the change.

In the U.S., requirements can be obtained from the U.S. Environmental Protection Agency. There were requirements for environmental assessments or impact statements in the Yukon or N.W.T. at the writing of this manual.

2.2.5 Rights-of-way and easements

Rights-of-way for construction and O&M must be obtained where lines will cross private property or other parcels of land not owned by the constructing agency. They must include a legal description of the crossing and be obtained from the property owner. They must state exactly what is allowed, and be legally recorded. In Alaska the U. S. Department of Interior****, issues rights-of-way across Bureau of Land Management (BLM) managed lands. In Canada, these are covered under land use permits.

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* Alaska Operations Office, 701 C Street, Anchorage, Ak 99513
** Habitat Protection Section, Subport Bldg., Juneau, Ak 99810
*** Division of Parks, 619 Warehouse Avenue, No. 210, Anchorage Ak 99501
**** Bureau of Land Management,555 Cordova, Anchorage, Ak 99501

2.2.6 Land use permits

Land use permits are issued by the Department of Indian and Northern Affairs. The regulations are not applicable within the individual communities.

2.2.7 Safety standards during construction

There are many different safety standards. In the United States, Occupational Health and Safety Authority (O.S.H.A.) standards usually must be followed. However, there are some government agencies, such as the U.S. Army Corps of Engineers, which have their own safety standards and enforce them. Within the State of Alaska, the Department of Labor* administers safety standards. In Canada these are covered in the land use permit.

2.2.8 Structures in navigable waters

Permits must be obtained before structures can be placed near or in navigable waters. In the U.S., two different agencies issue permits depending on the conditions. They are the U.S. Army Corps of Engineers and the U.S. Coast Guard. The Corps of Engineers** issues permits for any activity in navigable waters and wetlands. This is mainly for dredge and fill operations and for the placement of any structures in navigable waters. The U.S. Coast Guard*** issues permits for any bridge construction over navigable waters.

2.2.9 Safe drinking water regulations

In the U.S. the Safe Drinking Water Act stipulates the allowable concentrations of impurities in drinking water. The act is administered by the individual state or the U.S. Environmental Protection Agency. It is discussed in more detail in Section 4 of this manual. In Alaska, the Alaska Department of Environmental Conservation should be contacted. The Canadian Drinking Water Standards and Objectives, 1968, are similar to U.S. regulations. Further information can be obtained from the Federal Department of National Health and Welfare, Ottawa, and from the Territorial Governments in Yellowknife and Whitehorse.

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* Division of Occupational Safety and Health, P.O. Box 1149, Juneau, Alaska 99811.

** P.O. Box 7002, Anchorage, Alaska 99501.

*** P.O. Box 3-5000, Juneau, Alaska 99802.

2.2.10 Clearing houses

The Alaska State Clearing House* clears projects for compliance with federal regulations, while the Department of Environmental Conservation clears projects for compliance with state regulations. The Alaska Department of Environmental Conservation must review and approve plans and specifications of all privately and state-funded water supply and sewerage projects. It also reviews and comments on all federally-funded projects.

2.3 Type of Installation or Site

Temporary constructions or military camps, resource development camps, semi-permanent military installations, and new and existing cities or communities are the types of installations present in cold regions. The economic base, stability, growth potential and physical permanence of an installation or community will have very strong influence on the type of utility system which would best serve that community or site. Examples of delivery and collection systems are discussed later.

2.4 Site Considerations

2.4.1 Permafrost

Permafrost is not a material; it is the state of any material which stays below $0^{o}C$ for two or more years. Solid rock in this state would not usually create an unusual construction problem. "Beaded" streams (Figure 2-3) and "frost polygons" (Figure 2-4) are two indicators of ice-rich permafrost. The frost polygon "lines" are actually ice wedges, as shown in Figure 2-5. Marginal or "warm" permafrost is much harder to work with than cold (less than $-4^{o}C$) permafrost because small physical disturbances at the surface have a greater thermal effect on the depth of the active layer. The construction method used in permafrost will depend on the structure or facility being designed and the ground stability upon thawing. The ground's stability is determined by its moisture (ice) content and soil gradation.

Active or passive construction methods have been defined for application in permafrost areas. Active construction is essentially the

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* Office of the Governor, Pouch O, Juneau, Alaska 99811.

FIGURE 2-3. "BEADED" STREAM

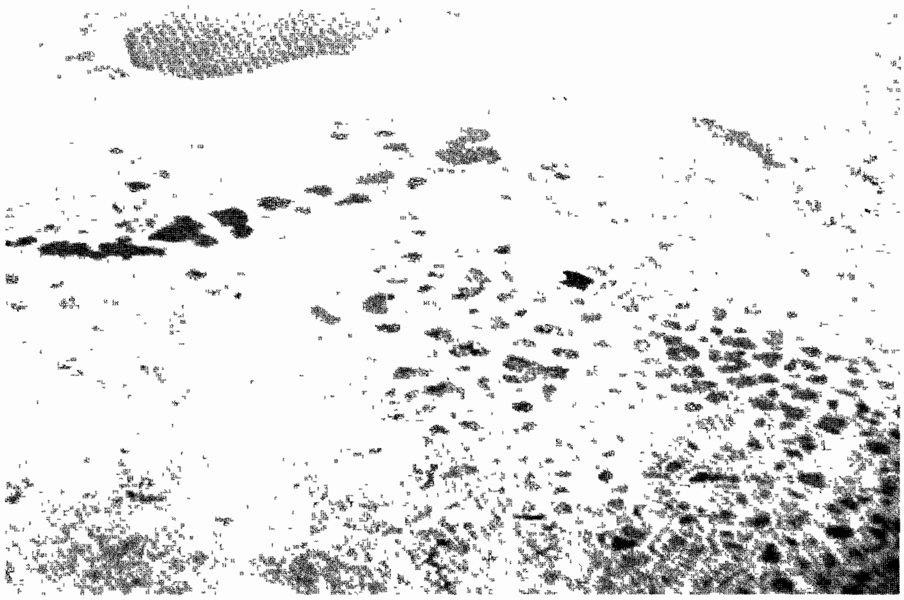

FIGURE 2-4. FROST POLYGON ON ALASKA'S NORTH SLOPE

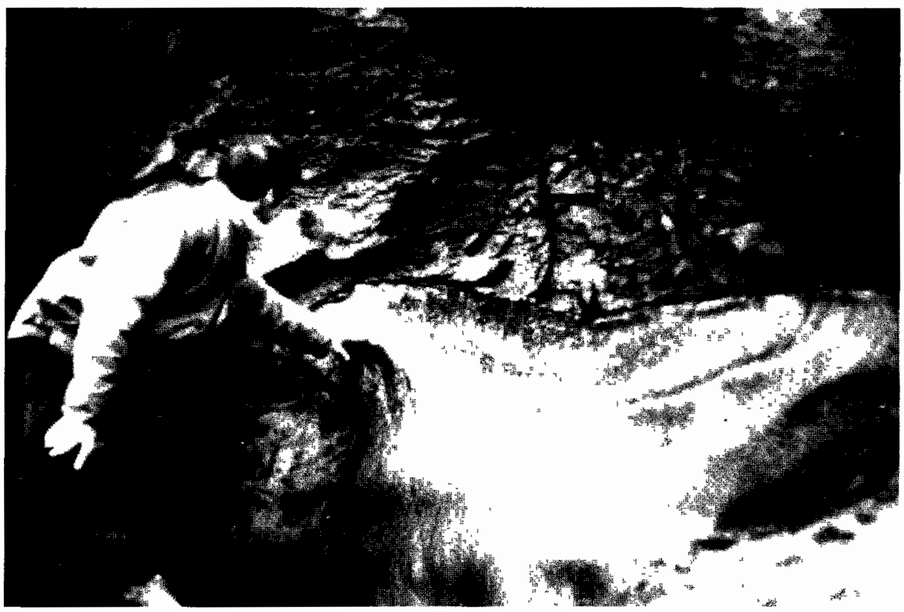

FIGURE 2-5. ICE WEDGE

prethawing and/or removal of the permafrost or frost-susceptible materials and their replacement with gravel or some non frost-susceptible material. Passive construction usually maintains the frozen state of the permafrost by construction above the ground on piles, use of refrigeration (such as thermopiles), or insulating the ground surface.

The distribution of permafrost in the Northern Hemisphere is shown in Figures 2-6, 2-7 and 2-8. Definitions of the extent of the permafrost at a given location (discontinuous or continuous) are covered in the glossary.

2.4.2 Location

2.4.2.1 Access. Access is of prime importance when selecting a location for a new community, camp, or installation. The method, and thus the cost, of access to a site or community can vary greatly with remoteness and the factors discussed below.

Because of the importance of air transportation, the site should provide a suitable location for a runway, considering prevailing winds, natural obstacles (mountains, etc.) and the availability of construction materials. Ships or barges are also a major transportation system in the North, especially for heavy and bulky items. Consideration should be given to whether a deep, protected harbor is available. If not, could one be dredged and, if so, would continuous dredging be necessary? Natural beaches suitable for beaching materials must be available. Highway and railroad systems are also access considerations in some parts of the North. Access roads to main highways and main rail lines and availability of construction materials for them are items which should be considered if a road system is present or planned.

In most rural or remote locations, snowmachine and dogsled trails should be considered since they are still important means of transportation.

New developments such as low pressure tire, off-road vehicles and air-cushioned vehicles are being tested and may be access considerations in the future. In northern Canada and Asia "cat trains" are used to deliver materials in the winter. These often travel on frozen river and lake surfaces. They may be especially useful in delivering

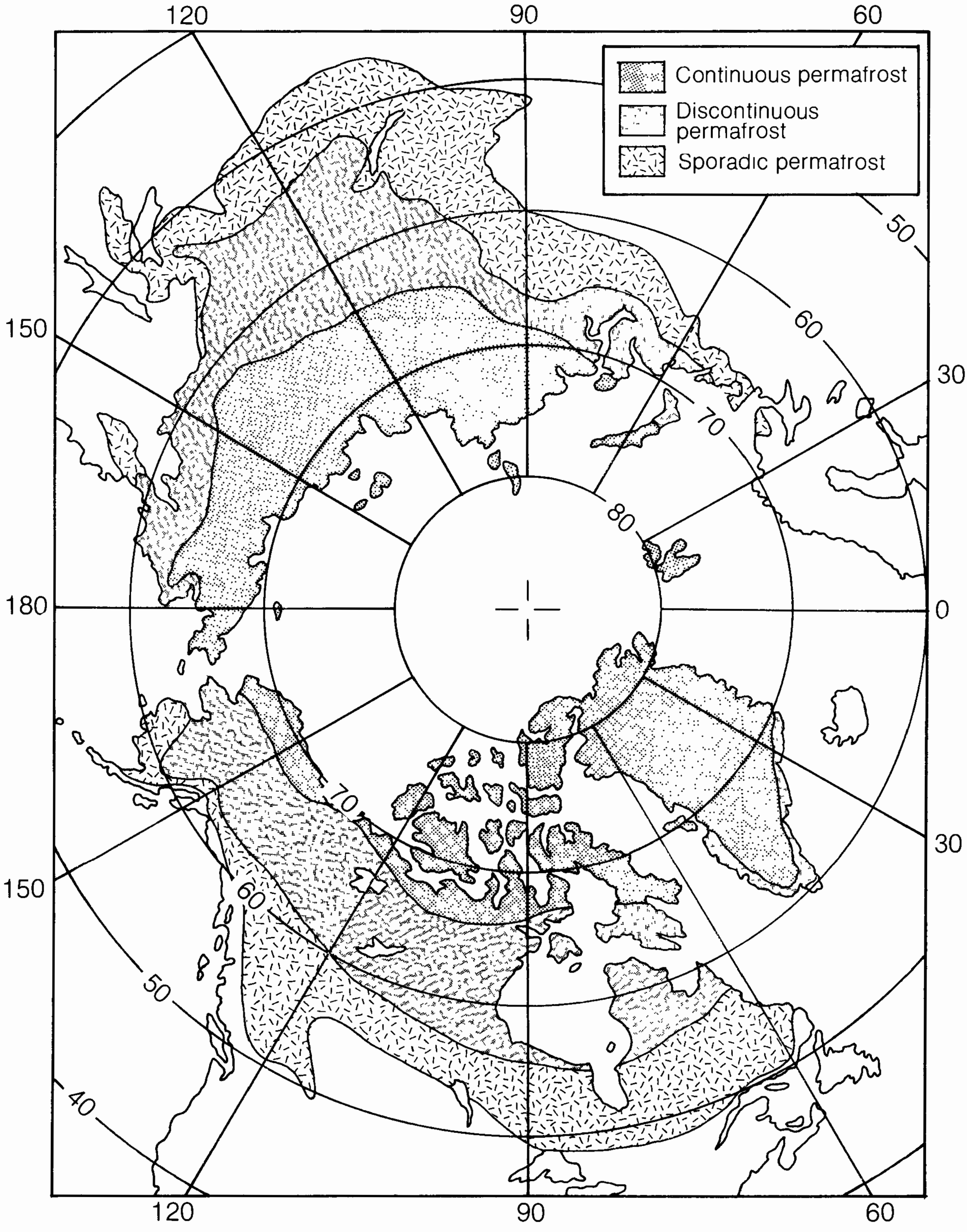

FIGURE 2-6. AREAL DISTRIBUTION OF PERMAFROST IN THE NORTHERN HEMISPHERE

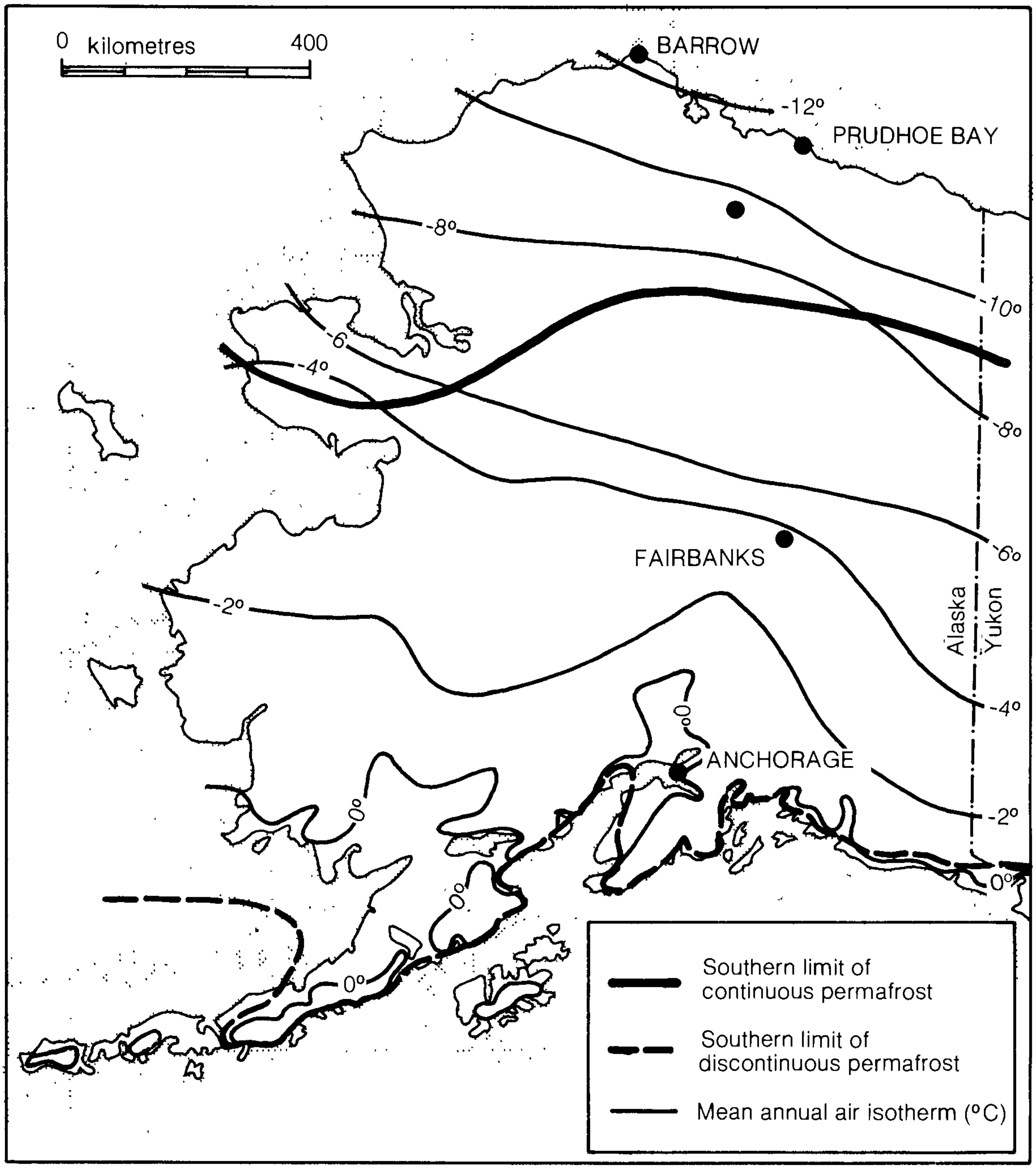

FIGURE 2-7. PERMAFROST IN ALASKA

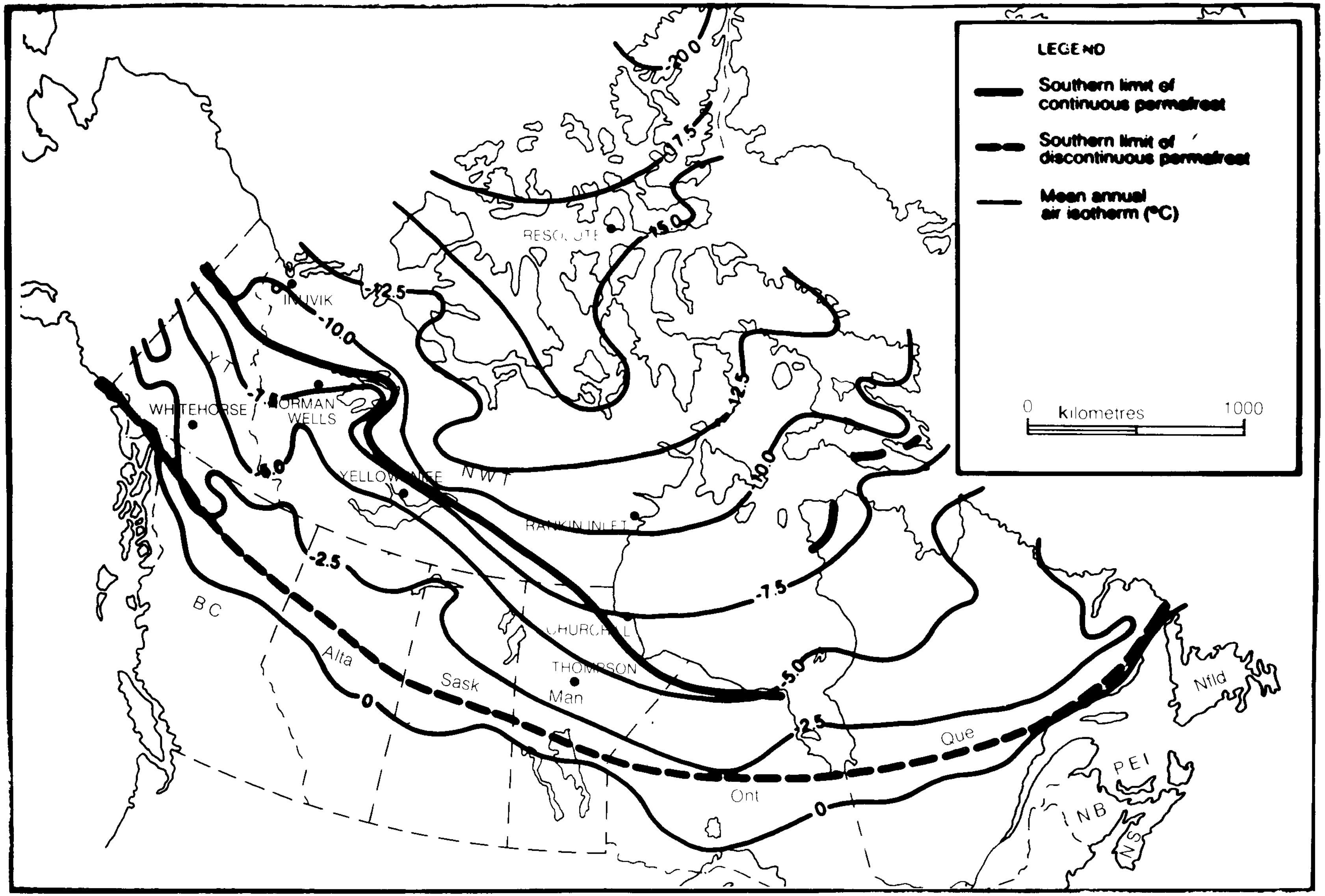

FIGURE 2-8. DISTRIBUTION OF PERMAFROST AND GROUND TEMPERATURE OBSERVATION SITES IN CANADA

materials or equipment for initial construction before permanent access routes can be developed. Information concerning construction and maintenance of ice roads is available from the State of Alaska, Department of Highways, and the U.S. Army, Cold Regions Research and Engineering Laboratory (CRREL) [7,8,9].

2.4.2.2 Soil conditions. Another very important consideration in locating and assessing a site, camp, or community is the local soil conditions. A complete soils analysis of the site is important and must include:

1) percent of soil passing and retained on various sieves;
2) accurate in-place moisture or ice contents;
3) penetration rates;
4) shear valves ("vane" shear tests on organic soils, etc.);
5) chloride content and freezing point at different depths; and,
6) organic content.

Surface vegetation can be helpful in predicting subsurface conditions [6]. Also, soil conditions can vary considerably over a short distance.

Temperature profiles are extremely important; however, few sites have instrumentation and temperature records. These should be obtained as soon as possible. Thermo-couple or thermister strings are usually used [10]. Information has been published on their installation and monitoring. Temperature information will indicate presence or absence of permafrost, ground temperatures, and the depth and temperature variation of the active layer. The changes expected in active layer and ground temperatures due to disturbances of the surface vegetation cover must be taken into consideration.

It is usually best to avoid permafrost where possible, by selecting south slopes in discontinuous permafrost areas, or by selecting locations near large rivers or lakes which have thawed the permafrost over time. To lessen the resulting settlement and instability when permafrost thaws, sites having soils with low or no ice content should be selected. These are usually well-drained, coarse-grained soils, rather than fine-grained marshy soils.

Frost heaving and jacking must be considered in both permafrost and non-permafrost areas. A frost-susceptible soil has been defined as a soil having more than 3 percent passing a no. 200 sieve. However, moisture content also has much to do with frost heaving. Piling must be imbedded in the ground to a depth sufficient to resist the upward pull created by the freezing of the active layer. Considerations for frost jacking and heaving will not be covered in detail in this manual [11,12].

The prevention of seasonal freezing under a structure in a non-permafrost area would be one method of solving frost heave problems. The subsurface soil analysis and depth to bedrock, if present, will help determine the types of foundations possible for a given structure. In permafrost areas, the possibilities are essentially piling or gravel pads with the final choice depending on the availability of materials (gravel and/or piling) and the permafrost temperature. Several studies [13] have demonstrated reductions in gravel depth are possible with the addition of layers of plastic foam insulation.

2.4.2.3 Topography. Topography should also be considered when selecting the best site for an installation, building, camp or community. The site should be sloping so it will drain (about 1 percent). Natural obstacles which would promote snow drifting should be avoided. Most communities in the North are located along rivers, lakes, or the ocean and flooding is often a problem. Serious consideration must be given to its frequency and extent, its cause (ice jam, precipitation, etc.) or whether or not there is current and ice chunks which would cause damage to surface structures. (See Figures 2-9 and 2-10.) Erosion by rivers or wave action and/or thermal erosion are sometimes significant (Figure 2-11) and should be considered when selecting a site. South facing slopes receive more incident sunlight and solar energy, in addition to providing better protection from colder north winds.

2.4.2.4 Resources. An important item in selecting a location is the availability of potable water. This will be discussed in detail in Section 3 (Water Sources). The quality and quantity of water source must be evaluated, realizing that both will change with the seasons of the year. Late winter or early spring is the critical time for any surface

FIGURE 2-9a. ICE CHUNKS DEPOSITED BY OCEAN WAVES, UNALAKLEET, ALASKA

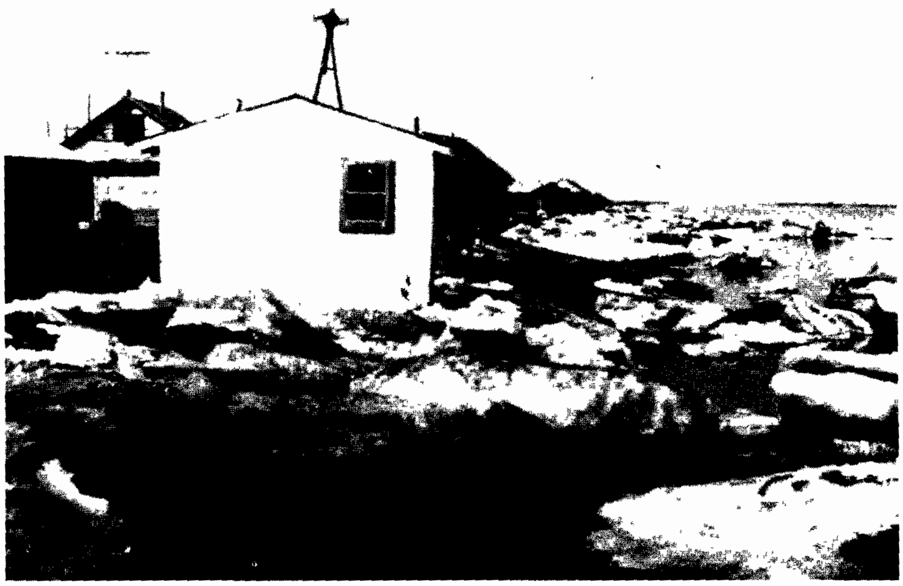

FIGURE 2-9b. ICE DEPOSITED BY RIVER, NAPASKIAK, ALASKA

FIGURE 2-10. BUILDING DAMAGED BECAUSE ICE AROUND THE PILING WAS LIFTED BY FLOOD WATERS, UNALAKLEET, ALASKA

FIGURE 2-11. EROSION AT BETHEL, ALASKA, CAUSED BY FLOODING OF RIVER

or shallow groundwater source. Recharge from precipitation through the surface is essentially non-existent. When ice thickness on lakes and rivers is at a maximum, most of the impurities that were in the water are concentrated in the remaining water under the ice. In many cases, it becomes unfit for domestic use. Water absorbs tannins or lignins from the mosses and lichens as it seeps through the tundra surface in the summer [14]. Thus, the best quality water is usually obtained in spring when the melting snow flows over the still frozen ground surface.

Energy sources available locally, such as hydropower, wood, coal, oil and natural gas, should be considered in selecting a site, as well as the logistics and cost of importing fuel.

A very important consideration in site selection is the availability of local construction materials. Probably the most important materials are sand and gravel.

Almost any structure or facility will need gravel and sand for foundation pads, backfilling around pipes, making concrete and building paths, and airstrips. In many communities along Alaska's west and north coast, gravel is non-existent. In Bethel, for example, barges must go over a hundred miles upriver to obtain coarse sand, and farther for gravel. It is sometimes less expensive to barge gravel from Seattle at a cost of about $26/cubic metre. If bedrock or hardrock outcroppings are present, they can be blasted for "shot rock" and crushed for fill. Trees suitable for building logs, lumber and piling can be an important construction material, and reduce dependence on importing.

2.4.3 Layout

The topography must be considered when laying out facilities. The slope of the site should be utilized to prevent ponding of water. Stagnant water becomes polluted and provides mosquito breeding grounds, both of which can create health problems. Ponding also causes thermal degradation of permafrost. Snow drifting problems should be avoided in the location and design of structures. Airports should be located to allow for future expansion. Most will start with a single strip and develop a cross-runway as needed. The runway should be oriented with the prevailing winds and above the surrounding terrain to reduce snow drifting.

Tank farms should be located away from the community, and water sources protected from possible oil contamination by diking or some other means.

Like runways, if the roads are built above the surrounding terrain they will usually blow free of snow, thus reducing snow removal efforts and costs. Therefore, cuts should be avoided where possible. Roads should be constructed up and down the slope where possible. Roads constructed across the slope inhibit drainage and act as dams. The backed up water will cause ponding, and saturate and destroy the roadway subbase and even building foundations uphill from the roads (see Figure 2-12). Culverts placed through roads to prevent ponding will usually fill with ice at breakup time when they are needed the most. They can be steam thawed just before breakup but this is expensive and time consuming. The most satisfactory solution is to eliminate the problem by orienting the roads up and down the slopes.

FIGURE 2-12. DETERIORATED ROADS IN BETHEL, ALASKA, CAUSED BY POOR DRAINAGE

It is not advisable to design layouts with dead end roads. Because of the need to circulate water mains in cold regions, dead ends are difficult and expensive to service. Snow removal is also more difficult. Roads should be designed so there is ample area to place snow plowed from the road. Docks provided for loading and unloading barges or ships should be designed to withstand tides, ice movement, spring floods, and erosion.

The importance of thorough soils analysis was discussed earlier, but additional borings should be taken throughout the site. The size and complexity of the utilities or structures to be built and the variations in the ground conditions will determine the number of soil borings necessary and the years of record desirable to determine ground temperatures. More structures have failed because of inappropriate foundation design, probably due to inadequate soils testing, than for any other reason. Additional borings should be taken to better define the soils underlying each building at the site.

Several factors should be considered in locating buildings. Consideration should be given to moving existing structures to provide more functional and useful layout. Taller buildings should be located so they do not "shade" smaller ones from either sun or wind. Where snow drifting is a potential problem, placement of small structures on the windward or leeward sides of larger ones must be avoided. One storm could completely bury a conventional size house located leeward of a large building or storage tank. The size of snow drifts can also be reduced by orienting buildings so the long axis is with the wind.

The community layout should be as compact as practicable to reduce utility construction and O&M costs (see Figure 2-13). Utilidors with central heating lines can cost $2000 per metre, and buried water and sewer lines $1000 per metre. Placing unserviced areas and large open spaces such as parks, school playgrounds, and industrial yards on the outskirts of a camp or community is recommended.

A typical cost breakdown for a northern utility project (utilidor extensions in Inuvik, N.W.T.) is 50 percent for construction, 33 percent for materials (on site), and 17 percent for engineering (7 percent for design and 10 percent for inspection).

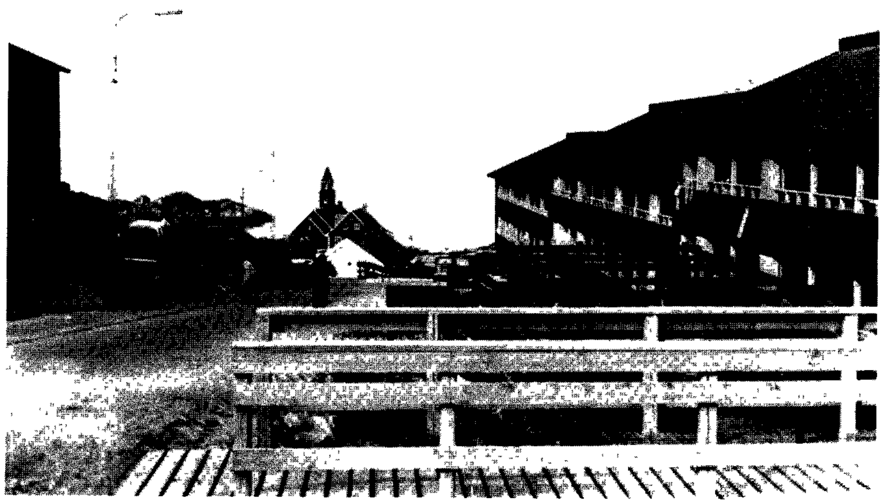

FIGURE 2-13. MEDIUM DENSITY APARTMENT BUILDINGS IN GODTHAAB, GREENLAND

An evaluation of existing communities in the Northwest Territories provided the following approximate figures for the length of water and sewer lines required:

Community Population	Length of water line plus sewer line per capita* (metres)
Less than 300	8
300 to 600	7
600 to 1000	6
1000 to 2500	4.5
Greater than 2500	3.5

* These figures are based on five persons per residence and do not include service lines. They are also based on utilidor systems or systems with the water and sewer lines in the same trench.

Alaskan experience differs somewhat. The systems installed are usually buried pipes with water and sewer lines in separate trenches. The figures above should be increased 1.5 times for Alaskan communities.

Seventy-five percent of the above pipe lengths was water and sewer together, 15 percent was sewer line only and 10 percent was water line only. These figures should be used for rough estimates only. Actual conditions will make adjustments necessary, for instance, for a community that is spread out along a river. A community of 200 persons could be estimated to have 1600 m of water and sewer lines. One thousand two-hundred metres would be water and sewer together (600 m of water and 600 m of sewer), 160 m would be water line only and 240 m would be sewer line only.

For a well laid out site, the following lengths of pipe per capita are provided as a guide:

Single family subdivision	3 to 4 m/capita
Multi-family area	0.2 to 2 m/capita
Apartment area	0.02 to 1 m/capita

A compact layout may make a central heating plant practical, and this can reduce heating costs by reducing energy consumption. The risk of fire, which is a major cause of accidental deaths in cold regions, is also reduced. Most home fires are caused, directly or indirectly, by heating stoves and a central plant will eliminate the need for these. The main disadvantage of central heating is the difficulty of expanding the core system when the community or camp unexpectedly expands. Heat is also lost during transmission. Heat loss is much higher with above-ground distribution.

Service lines are the source of most water distribution and sewage collection line freezing problems. Buildings should be located as close to the utility lines as possible to minimize service line lengths. If the water and sewer lines are to be placed in the street or alley rights-of-way, the buildings should be placed on the lot within 18 m of the lines, if possible.

There are advantages to placing the main lines along rear lot lines in a right-of-way. The snow is usually not removed, as it would be in the street, providing warmer ground temperatures. In non-permafrost areas the frost penetration is usually significantly greater under snow cleared or packed areas. They are also not as likely to be damaged by vehicles. Service lines to both rows of houses are shorter because the rights-of-way for alleys or utilities do not need to be as wide as the streets in front of the lots, and houses can be placed close to service lines since "back yards" are not used very much in northern communities, especially in the winter. Manholes, lift stations and valve-boxes can be terminated above-grade, making maintenance easier. Also, with above-ground utilities the service connection will not require a road crossing.

Figure 2-14 and Table 2-1 show an example of the savings possible when the layout of a community is properly planned.

2.4.4 Energy

Energy is expensive and requirements are high; therefore, facilities must be designed to conserve energy. One example is to install heat exchangers on the cooling water jacket and exhaust stack of power plants, which can more than double the total energy extracted from fuel oil. Usually only 30% of the fuel energy is used. The cold temperatures can also be used as a resource. Examples of this are self-refrigerating thermo-piles (Figure 2-15), desalinization using the freezing processes, and ice roads.

2.4.5 Utilities

Utility systems must serve the "total" community. For example, it is not economical to have several small generators serving separate buildings or complexes when one larger unit could serve the entire community.

In planning communities or camps, it is important to provide recreation facilities which can be used during the long, dark, cold winters (Figure 2-16). These facilities reduce the social and psychological problems ("cabin fever") prevalent in isolated, cold regions. Communities or camps should have large buildings such as gymnasiums and arenas that can be used for basketball, volleyball, curling, hockey, and other popular indoor games. Swimming pools can also be a very worthwhile addition. Very few of the indigenous people have learned to swim, even though they continuously use the ocean and rivers for transportation, because of the low water temperatures, even during the summer. Swimming pools could remedy this in addition to providing exercise and recreation during the winter. A useful side benefit to having a swimming pool in a school or recreation complex is that it can double as a fire protection reservoir, which is usually an important but expensive addition to buildings in cold regions.

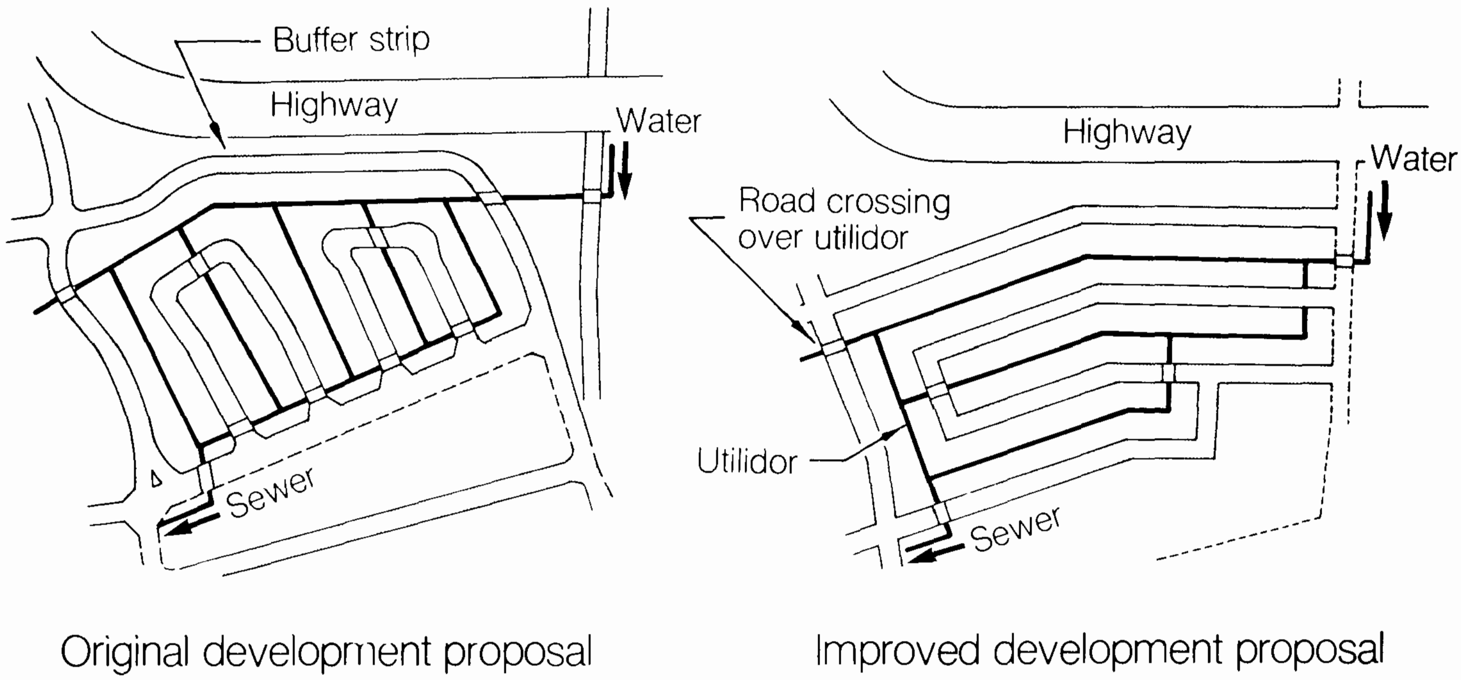

FIGURE 2-14. EXAMPLE OF PROPER PLANNING

TABLE 2-1. EXAMPLE OF SAVINGS WITH PROPER PLANNING

ITEM	ORIGINAL	IMPROVED	DIFFERENCE	NET SAVINGS (1973 DOLLARS)
Length of New Roads (m)	1936	1887	49	3,000
Utilidor Length (m)	1917	1646	271	109,000
Road Crossings	10	6	4	40,000
Water System Loops	4	2	2	2,000
Approximate Lots	140	152	12	84,000
Junctions & Bends	12	11	1	2,000
TOTAL				$240,000

FIGURE 2-15. SELF-REFRIGERATING THERMO-PILES IN GALENA, ALASKA

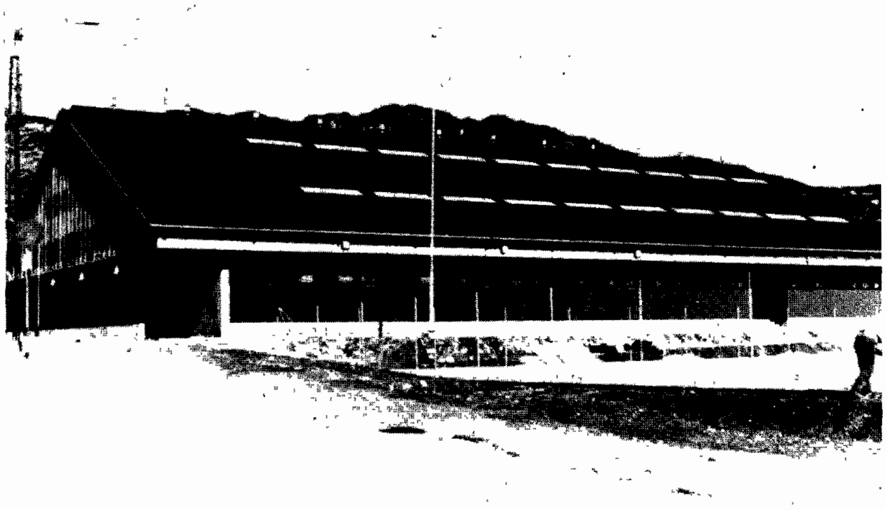

FIGURE 2-16. SPORTS COMPLEX IN GODTHAAB, GREENLAND

Most communities and camps in cold regions are remote with only intermittent service, even by air, from larger population centres. Therefore, it is very important to provide complete standby for all essential components of any utility. Alarms and safeguards, such as low water temperature alarms, low flow alarms, and low or high voltage alarms must be provided to warn operators of any pending problems. The importance of a reliable, knowledgeable operator will be discussed later.

Longer lead times must be allowed when requesting utility services. Requests for electrical service to a project site must be made to the local electric utility. In most remote Alaskan communities this is the Alaska Village Electric Corporation. In the Northwest and Yukon Territories, it is usually the Northern Canada Power Commission.

When constructing a building or facility requiring water and sewer service, notice should be given well ahead of when the service is needed. It may be necessary to expand the source or storage, which could mean bringing materials in on the one and only barge per year.

2.4.6 Building design

Buildings should be designed for multiple use wherever possible. It is expensive to heat and maintain a building continuously when it is only used a few days each week (such as a church) or part of the day (such as a school). Medium height cubical buildings should be used rather than low and spread out types. They are more efficient from a heat loss standpoint and provide a more compact arrangement for utility service. There is somewhat more danger in case of fire, but fire protection must be designed into any building. Open areas with plants are important from an exercise and psychological point of view, and have been provided in large buildings in the USSR (Figure 2-17) and Prudhoe Bay, Alaska.

Windows are necessary but they are a high heat loss and maintenance item and should be designed to provide the most benefit with the smallest area. Window orientation toward the south, multiple glazing, and wood casings maximize insulation and energy savings. Windows extending above or below eye level should be avoided but it is important to be able to see out sitting or standing. Windows are of no value during

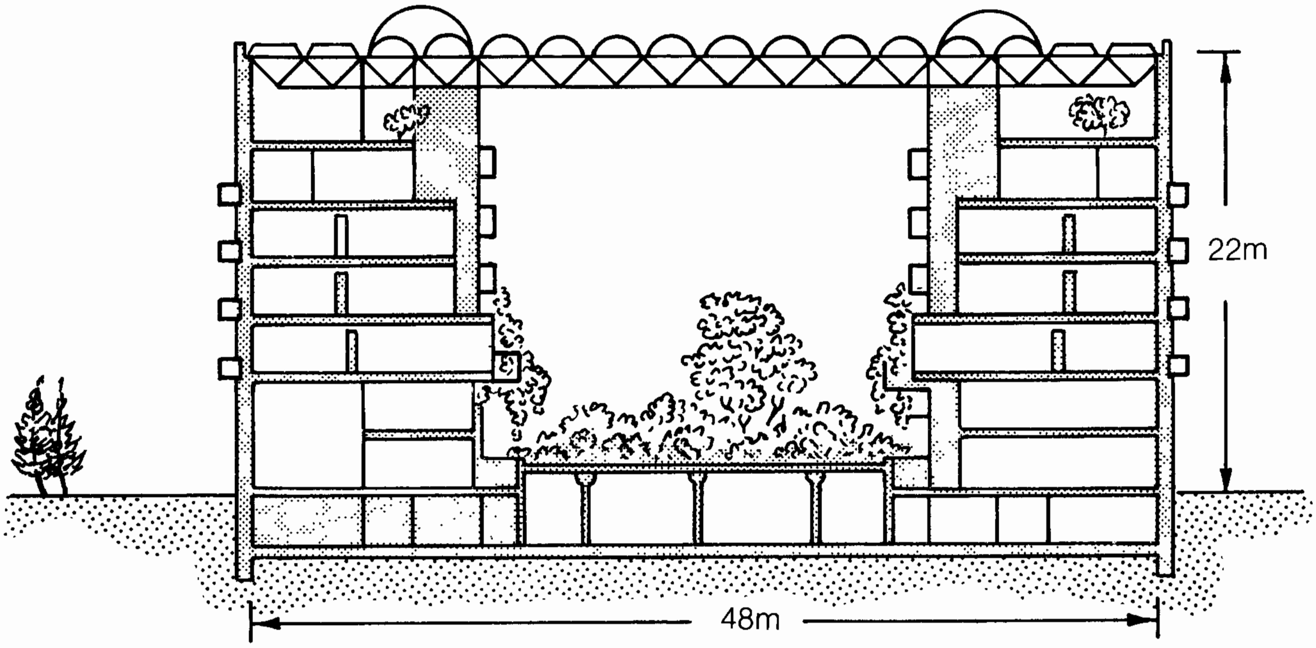

FIGURE 2-17. OPEN AREA BUILDING CONSTRUCTION IN THE USSR

darkness, therefore, insulated shutters should be provided to reduce heat loss.

Buildings should be well-insulated to minimize the total annual cost of heat and amortization of the insulation costs. (See Section 14). Vapor barriers are also a very important part of any building in cold regions. Information is available concerning vapor barriers and types of insulation suitable for different applications [15,18]. Insulation must be kept dry. Absorption of 8 percent moisture (by volume) will reduce the insulating value by one-half. An impermeable or low water absorption insulation should be used in damp or wet locations. The reduction of air exchange is as important as insulation in reducing building heat losses. Some air exchange in a room or building is necessary. Quantities vary with use and are usually stipulated in building codes, but anything over these minimums should be avoided.

In areas where snow drifting is a problem, aerodynamic design of the building exterior can reduce drift size, and also move the drifts which do build up further from the building [16] (Figure 2-18).

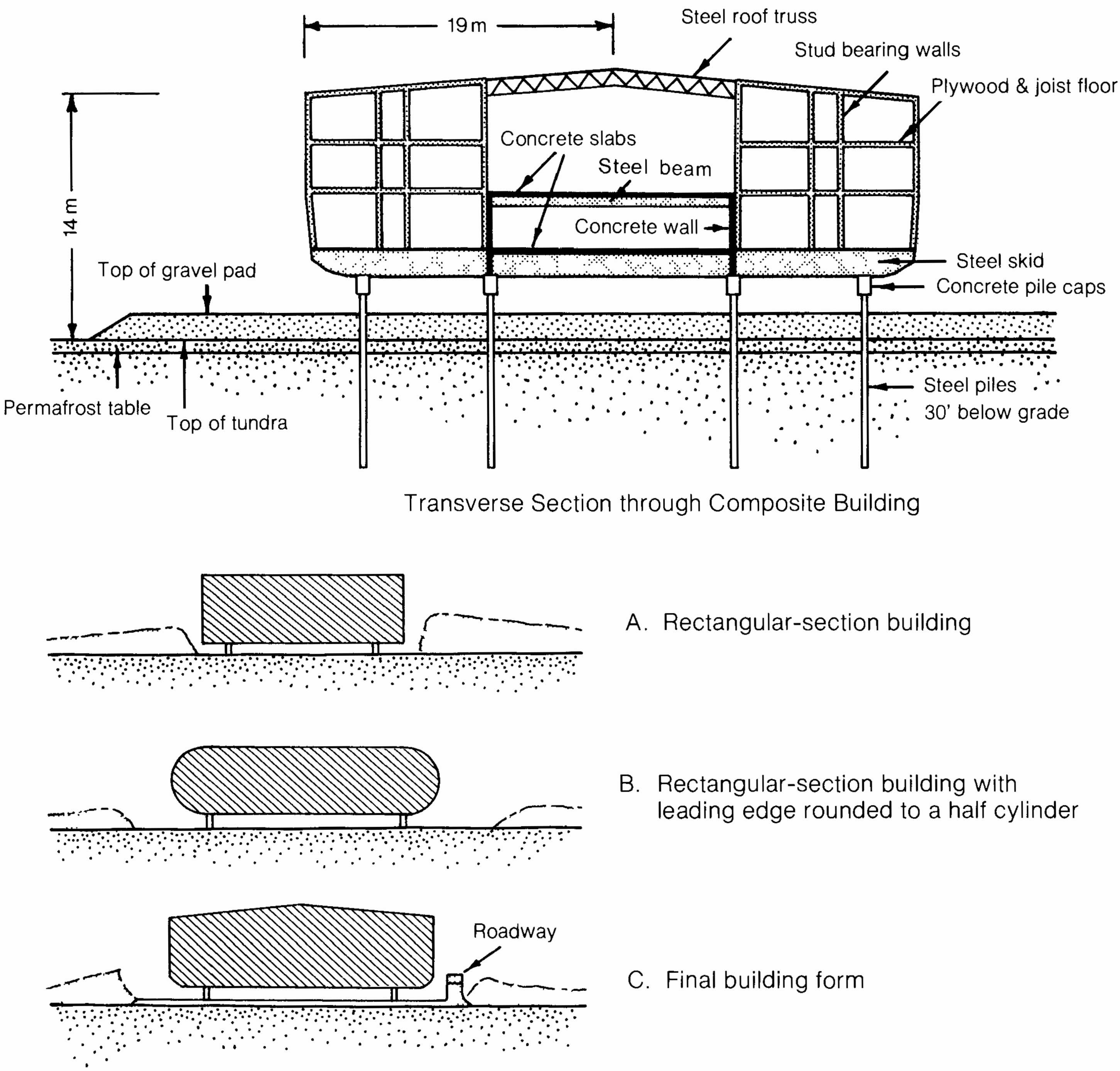

FIGURE 2-18. AERODYNAMIC BUILDING DESIGN TO REDUCE SNOW DRIFTING PROBLEMS, PRUDHOE BAY, ALASKA.

Building entrances should not be placed in the windward or leeward sides of buildings. If possible, all doors should be double doors with a space between them large enough so one is closed before the second one is opened. This will greatly reduce the air exchange when going in or out of the building. All doors and entrances must be protected from snow and ice falling from the roof (see Figure 2-19). Serious accidents have been caused by ice falling on someone leaving a building when a door is slammed.

Roofs probably cause more problems than all other building components combined in cold regions. Hip roofs should be used if possible, with flat roofs being the last choice. It is very important that all roofs be well insulated and provided with a very tight vapor barrier [17].

Building heating systems must be as fool-proof as possible with standby pumps and boilers provided for emergencies. Hot water circulating systems in remote, cold region areas should be charged with a glycol

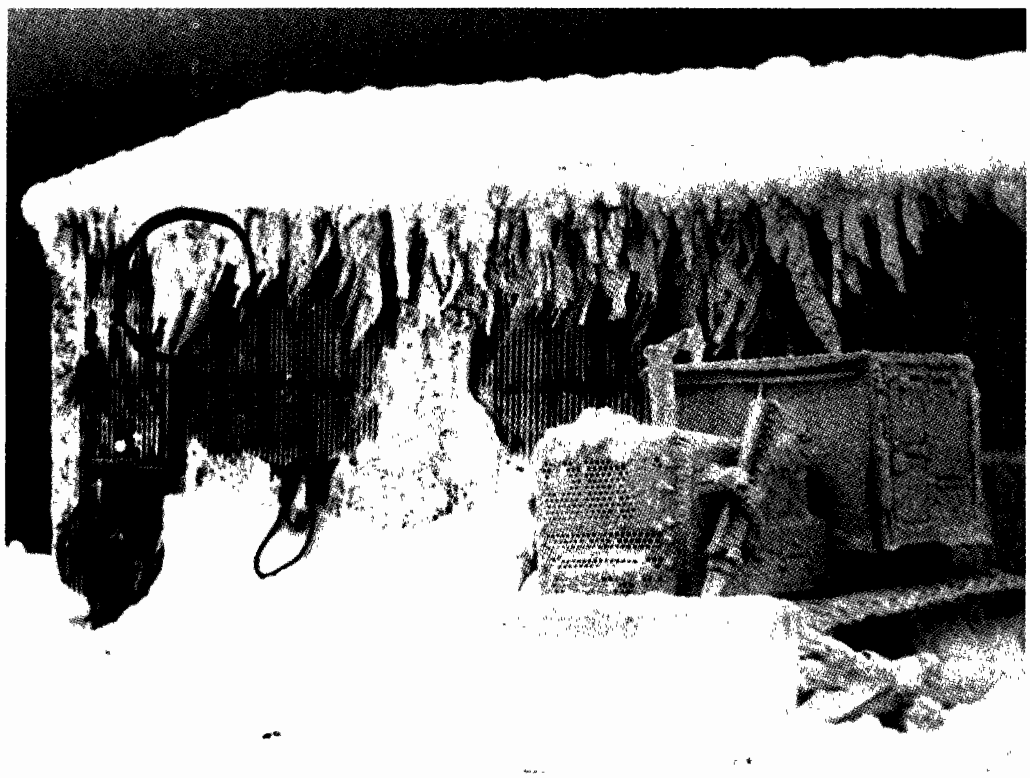

FIGURE 2-19. EXAMPLE OF ICE-FALLING PROBLEMS ON BUILDING IN WAINWRIGHT, ALASKA

solution, but this must be taken into account in the sizing of boilers, pumps, expansion tanks and other system components [18].

Humidity is an important consideration in cold regions, especially inland. Humidity drops extremely low with cold winter weather. For comfort, as well as to prevent damage to furniture, the humidity should be kept at about 30 percent by using humidifiers. High humidity (above 50 percent, depending on temperature) can cause equally as numerous and serious problems due to condensation on windows, walls and in insulation. During warm spells or in the spring this frozen condensate can ruin paint, insulation, and even destroy the building by inducing wood rot. In very humid areas, such as pumphouses or sewage lift stations, moisture control or dehumidifiers are necessary.

Building foundations will not be covered in this manual but information is available elsewhere to help the designer with this most crucial component of building design in cold regions [19,20,21].

2.4.7 Revegetation

Revegetation will usually be required where the natural vegetation has been damaged or removed by construction. It is necessary to prevent erosion and make the site more aesthetically pleasing. The purpose of seeded plants is primarily to provide some growth to protect the soil until the natural vegetation returns. The U.S. Soil Conservation Service and the Alaska State Division of Aviation have developed the following recommendations for seeding tundra areas [22]. The best time for seeding is before mid-summer and after break-up. However, scattered seeding has been successful even when the seeds were broadcast on the snow in the spring. The grasses will probably die out in four to five years but the natural vegetation should be well on its way to recovery by then.

Recommended seed rates are:

1) Meadow Foxtail (common) = 22.4 kg/ha
2) Hard Fescue (Durar) = 22.4 kg/ha
3) Red Fescue (Arctared) = 33.6 kg/ha
4) Annual Ryegrass (Loliun Multiflorum) = 33.6 kg/ha

   TOTAL = 112 kg/ha

The mixture should be seeded, and fertilized immediately and at the beginning of the second year with the following fertilizers and rates:

1) 10-20-10 - 448 kg/ha,
2) 33-0-0 - 112 kg/ha.

2.5 Project Management

Project management is an extremely important part of planning for remote, cold regions installations.

2.5.1 Construction season

The length of the construction season varies with factors such as soil conditions, length of daylight, and climate. However, construction cannot start in any location until the materials and equipment are on-site. Barges normally arrive in Barrow, Alaska and the Eastern Arctic around the first of September, which is near the end of the construction season. This means that materials must be shipped one year in advance for construction to start the following summer. The length of the normal construction season varies from two to three months along the Arctic coast, to six or eight months in more southern areas.

Some soils, such as low moisture contents sandy-gravelly soils, can usually be excavated more easily when frozen. When they are thawed, shoring is necessary to prevent the trenches from caving in. Some muskeg or highly organic soils are also easier to excavate in the frozen condition (see Figure 2-20). When thawed, such soils often will not support equipment or even people. On the other hand, saturated gravelly silts are nearly impossible to dig when frozen and must usually be either thawed or blasted.

The weather (temperature, wind, snow, rain, etc.) greatly affects the amount of work accomplished during a constrution period. Studies have indicated that temperature affects workers and equipment as shown in Figure 2-21 when other environmental factors are considered ideal. Darkness, wind and rain will reduce productivity further. The effects of cold temperatures on oils, diesels, antifreeze solutions, steels, woods, and plastics are shown in Appendix A. It is important that these be understood before cold temperature construction is attempted.

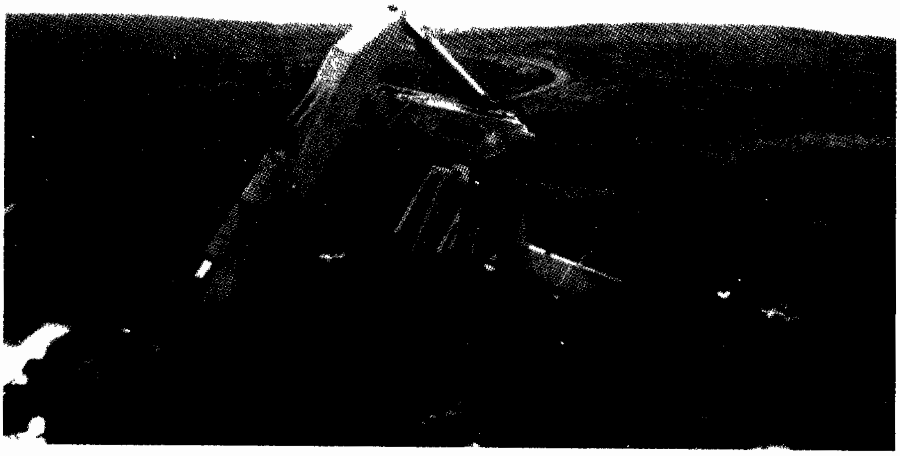

FIGURE 2-20. PROBLEMS OF SUMMER CONSTRUCTION ON MUSKEG, ST. MARY'S, ALASKA.

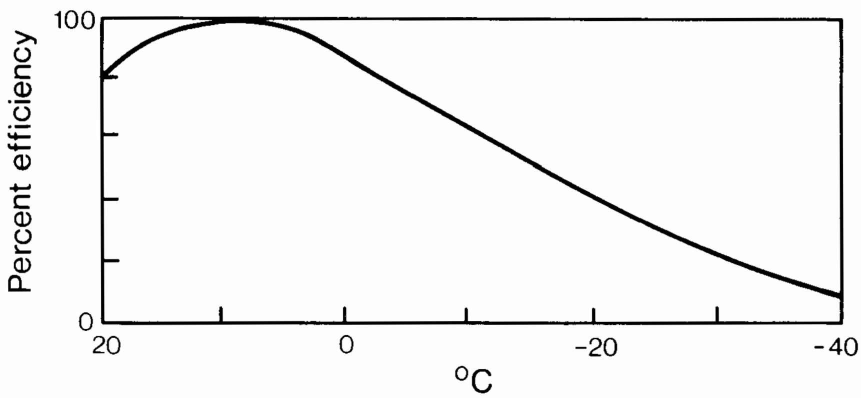

FIGURE 2-21. TEMPERATURE EFFECTS ON WORKER PRODUCTIVITY

The lack of light can be partially corrected by using artificial light. A chart showing the hours of daylight at various latitudes is included in Appendix H. Daylight values will be shortened, of course, in a location having mountains or other local terrain variations.

More and more contractors in cold regions are attempting winter construction of buildings to stretch out the construction season and take advantage of lower transportation and equipment costs with cheaper and more available labour. Concrete work must be kept warm and aggregates must be kept from freezing or thawed before use. Excavation should usually be done before the ground freezes. (See Figure 2-22).

FIGURE 2-22. TYPICAL WINTER CONSTRUCTION PROBLEM, KOTZEBUE, ALASKA

Winter construction can create severe moisture problems in buildings. Portable heaters used to keep the interior warm produce considerable amounts of water in the combustion process and, unless they are vented to the outside, this water accumulates in the building interior where it can cause problems for years to come.

The decision must be made as to whether to work longer hours and pay overtime, or extend construction into the winter and/or another construction season. This is an economic consideration which may depend on weather, overhead costs, and other local conditions. Also, studies have shown that working overtime for an extended period of time is not cost effective.

2.5.2 Transportation

2.5.2.1 Methods of shipping. Construction materials and equipment are delivered to many construction sites by barge or ship. It is very important to investigate the following items to avoid delays in project construction.

1) The number of sailings per year and the chances of nondelivery due to shore ice not moving out, rivers being too low, or other natural factors should be known.

2) Delivery schedules should be determined so that materials and equipment can be at dockside at the point of disembarkment. There is usually a specific and limited period of time during which materials will be accepted.

3) The rates charged and the criterion that they are based on (volume or weight) should be checked. There often are demurrage charges on shipping company containers. Rates for barge transportation have steadily increased over the past few years. There is also a daily charge for non-scheduled stops (communities not normally on the route).

4) On many scheduled barges space must be reserved in advance. It is important to check the capacity of barges serving the area and the capacity of off-loading docks and equipment before ordering materials and equipment.

5) Chartering barges should also be considered. The economics of chartering will depend on the amount of materials to be shipped and whether the location is a scheduled stop on an established route.

6) The facilities available for off-loading at the site should be determined. If there are no docks, are there

suitable beaches for beaching the barge? What equipment (such as cranes, trucks, cats, etc.) is available? Can the barge or ship be brought into shore or must landing barges be used to shuttle materials between the ship and shore? Ship or barge landings or docking must usually be coordinated with the tide.

Air transportation is becoming more and more competitive in cold regions and is the only transportation method to some sites in the Arctic and Antarctic. The following should be investigated:

1) The landing strip capabilities should be determined. Is the strip useful year-round or just in the winter? Even year-round strips usually have seasonal limitations, such as soft spots in the spring and cross-wind limitations, depending on the aircraft. Temporary strips can be constructed on lakes or river ice or on compacted snow during the winter [9] (Figures 2-23 and 2-24). Lake ice is usually smoother than river ice and is thus suited for a wider range of aircraft and heavier loads. Equipment must be available locally or brought in to construct ice or snow landing strips. Some other items which must be considered are: runway length, approaches, type of surface, navigational aids, runway lights, and elevation.

2) A check should be made into the available aircraft and their capabilities. Size limitations, which are usually defined by the size of the loading door and cargo space, and weight limitations must be determined for the different sizes and kinds of planes. The costs (both flying time and standby time) are needed, along with the performance limitations for each plane. Some planes require special fittings for use on gravel strips. What type of facilities for loading and unloading are available at the site? The available facilities should be compared with the requirements of the aircraft.

FIGURE 2-23. TEMPORARY RUNWAY CONSTRUCTED ON LAKE ICE, NONDALTON, ALASKA

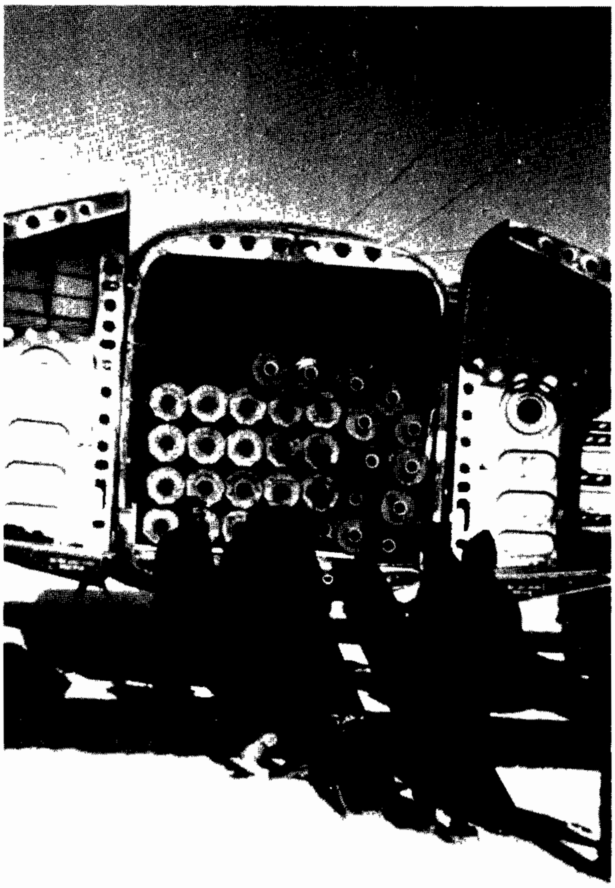

FIGURE 2-23. UNLOADING C-119 AIRCRAFT AFTER LANDING ON TEMPORARY ICE RUNWAY

Similar considerations are necessary in areas served by roads and/or railroads. Are the roads useful year-round or are they seasonal, and do they carry load restrictions during the spring? Rates by the weight or volume and the size and weight restrictions must be considered. A check on demurrage charges on railcars or containers should be made.

2.5.2.2 Transportation costs. When comparing the benefits and costs of the different methods of transportation available, consider:

1) the gain in construction time achieved by using air transportation;
2) the number of times the materials and equipment must be handled (the amount of shipping damage is directly related to the number of loadings or off-loadings needed);
3) the true shipping costs (i.e., including demurrage cost, lighterage costs and long-shoring);
4) the difference in costs for chartering vs. using scheduled carriers for any alternative.

Cost adjustment indexes have been developed for the cold regions of North America. Figure 2-25 shows a Canadian cost of living index with an index of 1.0 based on construction in the Great Lakes area [23]. Table 2-2 indicates construction cost factors for Alaska for the construction of repetitive type facilities, such as buildings, with an index of 1.0 assigned to Washington, D.C.

The Alaskan and Canadian cost indexes cannot be directly compared because the Alaskan index is for straight construction costs while the Canadian index is only a "cost of living" comparison between different points in northern Canada.

2.5.2.3 Shipping considerations. Because of harsh environment, the shipper's or carrier's liability for loss and damage of the shipment must be investigated. Loss or damage of one important component could delay completion of the project for one year or more. Materials and equipment must be packed to prevent damage during shipment. Crating and protection needed during transit must be specified. Items usually must be handled several times. Also, they may be vulnerable to salt water while on barges.

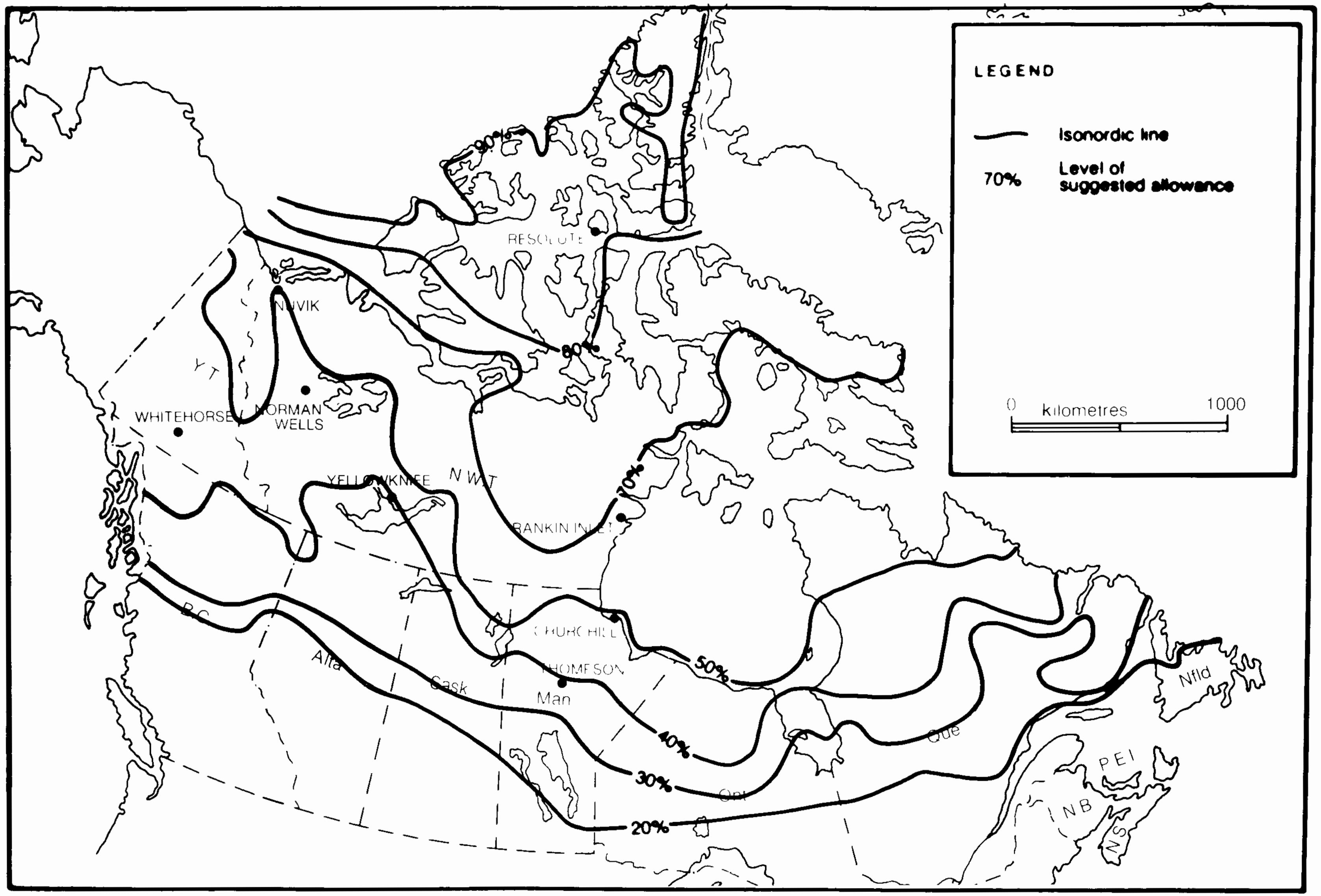

FIGURE 2-25. COST OF LIVING COMPARISON FOR NORTHERN CANADA

TABLE 2-2. CONSTRUCTION COST FACTORS FOR ALASKA

NOTE: The following location factors are applicable to the construction of repetitive type facilities, such as dormitories, dining halls, BOQ's, administrative buildings, fire stations, warehouses etc., which make maximum use of local skills, materials, methods and equipment. They are not applicable to more complex facilities.

The location factors are multiples of the basic value of 1.0 assigned to Washington, D.C.

Taken from U.S. Air Force Publication 83-008-1, Dated 3/1/62

LOCATION	FACTOR
Aleutian Islands	3.0
Adak	3.0
Attu	3.0
Cold Bay	3.0
Dutch Harbor	2.5
Shemya	3.1
Anchorage	1.7
Barter Is., North Coastal Area	5.2
Bethel	3.8
Clear	1.7
Coastal Area, North of Aleutians	3.5
Eielson AFB	1.9
Elmendorf AFB	1.7
Fairbanks	1.9
Fort Greely (Big Delta)	2.2
Fort Yukon	2.6
Inland Area, North of Aleutians	4.0
Juneau	1.8
Kanakanak	2.1
Kenai Peninsula	2.1
Kodiak	2.5
Kotzebue	3.0
Naknek	2.1
Nome	2.3
Northway, Highway Area	2.3
Point Barrow	4.6
Tanana	3.2
Whittier	1.9
Seattle	1.0
Galena*	3.0

* Building cost (heated) $\sim$ \$150/ft^2 with 3 stories and 50 000 ft^2.

Items such as foam insulation components, paints, polyelectrolytes, adhesives and other materials must not be allowed to freeze.

2.5.3 Equipment

The type of equipment purchased and the careful preparation of equipment for cold weather work are very important time and money savers.

Equipment must be in top shape before it is sent to a remote location. Equipment and tools for repair are usually limited in remote areas, and importing mechanics and parts is expensive in addition to the cost of "down time". A large inventory of critical spare parts is recommended and standardization of equipment to reduce the parts inventory will prove economical. Standby units should be provided for critical equipment so the job is not stopped completely.

Equipment should be planned carefully before the initial shipments to the job site, especially large pieces that cannot be flown in at a later date. For mobility, select equipment that can be flown from one location to another in the available aircraft. Equipment selection for the conditions that will be encountered, such as heavy-duty rock buckets for digging frozen ground, and grousers on backhoes, is important. However, equipment selected should not be too highly specialized in order to reduce the number of pieces needed. Preventative maintenance is extremely important. Schedules should be established and adhered to. Good maintenance records are important as they will:

1) provide back-up data when the time comes to decide which brand of equipment to select for future projects,
2) help pinpoint weaknesses and reduce the spare parts inventory,
3) provide checks to ensure that preventative maintenance is being performed on schedule.

<u>The initial cost of a piece of equipment is usually not as important as its reliability</u>. Equipment should be selected for which there are reliable dealers with adequate parts inventories, service facilities and staff nearby.

2.5.4 Labour and inspection

Labour costs are presently escalating at a higher rate than material costs and now attribute to 50% of a project's total expenses. Studies and experience indicate that it is better to use local labour whenever practical.

There are several reasons for this:

1) Local people are more familiar with, and adapted to, local conditions, including weather.
2) If they live near the project site, camp facilities will not be required.
3) If they live in the community receiving the facilities they have more at stake because they have to live with the final facilities. Knowledge gained during the installation will also facilitate repairs.
4) Local hiring provides an economic boost to the area in addition to the benefits provided by the project.
5) Local people can be trained as equipment operators, carpenters, and plumbers, which will help them obtain jobs in the future. Productivity of these trainees is usually lower than experienced labour.

There are some special problems which must be kept in mind:

1) In some locations there are not enough skilled and reliable workers.
2) Local customs and politics must be recognized and honoured.
3) Supervisors and specialists will probably still have to be imported. They must be selected carefully, and they must be able to work and communicate with the local people. They must also be willing to tolerate the remote conditions. This hardship is usually offset by high wages.
4) Union contracts may preclude using non-union local labour.

Safety precautions are very important in cold, remote locations because of the distance to hospital facilities and the harshness of the weather conditions. In cold weather, workers should use the "buddy system" whether working or traveling. This way there is always someone to help in case of an accident. Inspection methods and frequency are extremely important. A small mistake, or a case of poor workmanship can cause an entire facility to fail. Once equipment is removed it is very expensive to return it to repair mistakes. Thorough inspection is even more critical when the contractor is from the south and not familiar with the problems of cold regions. Inspectors should keep in mind the following items:

1) All irregularities or possible problem areas in the field should be documented immediately. Polaroid (or equal) photographs will enable the inspector to mark discrepancies immediately on the photograph, and he can see that he has a good picture at the time he takes it. Also, thorough daily written reports and verbal communications with the supervisor and/or contract officer are extremely important.

2) Changes from the original design must be recorded accurately, and as-built drawings of the project prepared.

3) The contract documents must be thoroughly understood, and who has authority to make changes. It is important that the inspector does not permit changes in the field that he is not authorized to make.

4) Regular contact with the project engineer and contracting officer must be maintained. They should be well-informed as to problems and progress of the project.

5) Accurate measurements of actual quantities of material used must usually be made for payment purposes. Most of the above duties must also be performed by the on-site supervisor of force account jobs who, in addition, must keep equipment maintenance records and coordinate all labour on the project.

2.5.5 Type of construction

The two most frequent methods of construction are contract and force account. There can also be a combination of the two on the same project.

2.5.5.1 Force account. Force account construction is where the funding source hires its own crews, purchases its own materials and equipment, and accomplishes the construction.

The following are some of the advantages of force account construction:

1) It tends to utilize local labour or contractors to a greater extent.
2) It is usually lower in cost.
3) Training of the operators and users can take place during construction.
4) Equipment used during construction can more easily be left at the site for operation and maintenance of the completed facility.
5) It is easier (and less expensive) to phase a project or make major changes during construction should unforeseen difficulties arise.
6) Shorter lead times are usually possible for materials and equipment ordering. (Contracts have to be advertised, awarded, etc., and the successful bidder still must purchase his materials.)
7) There is more flexibility to fit into the local environment and social conditions.

2.5.5.2 Contract construction. Contract construction is where the funding agency supplies plans and specifications and contracts with a private firm to accomplish the construction. Advantages of this contracting method are as follows:

1) There is usually more control on the job, and inspection is usually more thorough.
2) Completion times are sometimes shorter because they are specified in the contract.
3) The owner or funding agency does not take as high a risk and also does not need as large a work force on-site (inspectors only).

Some jobs will combined force account and contract. For instance, there are usually parts of a job for which the owner does not have qualified crews to perform and he must contract those portions. Large welded (on-site) steel storage tanks, erection of prefab metal buildings, construction of sewage treatment plants, electrical work, control and alarm systems and installation of piling are examples of these specialities.

2.5.5.3 Construction techniques. There are three main construction techniques: "stick built", "prefab", and "modular". In stick built construction the materials are shipped to the site, and all cutting and fabricating is done on-site. Prefab construction is where parts of a structure, etc., are prefabricated at the point of manufacture and assembled at the site. Modular construction means large components are constructed at the point of manufacture and shipped to the site already constructed.

Each technique can be useful under different circumstances. Modular construction has a definite advantage when there is a short construction season, a labour shortage, or labour is expensive at the site. Shipping limitations may dictate stick built or possibly prefab rather than modular construction. Modular construction may allow the facility to be placed in operation with most of the defects worked out at the point of manufacture, but field changes to fit varying site conditions are more difficult and expensive to make.

2.5.5.4 Above or below-ground. The decision whether to place utilities above or below-ground must be made. The major engineering consideration is the soil conditions at the site. Poor soil conditions (see Section 2.4.1) and lack of non-frost susceptible backfill will usually force construction above-ground. Otherwise below-ground installation is preferable. Important considerations are:

1) Above-ground lines are subject to vandalism and traffic damage.
2) The allowable heat losses and the cost of energy (heat) required for above-ground lines must be assessed.

3) The necessity of holding grades with above-ground gravity flow pipelines will greatly increase the cost.
4) Below-ground systems are less expensive to install because they eliminate the need for piles and road and sidewalk crossings.
5) Below-ground systems allow for more normal town planning and do not artificially dissect the community.
6) More expensive equipment is necessary to maintain below-ground lines.

Heat loss is directly proportional to the difference between the inside and outside temperatures. An above-ground utilidor or pipeline will have about three times the heat loss of a similiar line buried just below the surface.

If lines are buried, the depth of bury should be carefully determined. This will be covered in detail in Section 14. Heat losses from buried lines are considerably less but excavating frozen ground to find and repair a leak, etc., can be difficult. Also, a pipeline leak can travel under the frozen surface layer and surface through a ground tension crack several feet away.

2.6 Water Delivery and Waste Collection Systems

2.6.1 Types of systems including construction, operation, and maintenance costs

The major types of water delivery and waste collection systems used in cold regions are discussed in the following paragraphs. There are many variations and alterations which can be made to the basic types presented here. Detailed descriptions and design information will be presented in later sections of this manual.

Consideration should be given to phasing facilities. The first phase could be a central watering point, with a piped or hauled system following a few years later. This would lessen the economic and cultural shock to the community of the immediate installation of a complete system.

Initial construction or installation costs are presented for the different types of systems. They are based on 1977 construction costs and should be considered rough estimates only. Actual costs can vary considerably, depending on the sophistication of the facility, the degree of water and sewage treatment necessary, foundation problems and other factors.

Operation and maintenance (O&M) costs are also presented for the different types of sanitation facilities. For most facilities, labour costs are by far the most significant part of the O&M budget. A military site could be an exception because labour is covered under "general overhead".

Two other large O&M costs are oil and electricity. Both of these items are largely dependent on the delivered cost of oil. If no surface transportation is available it is necessary to fly in oil. A complicated water or sewer treatment process will make the cost of chemicals and their transportation a major O&M item. The approximate O&M costs presented for each type of facility do not include amortization of the initial construction costs. They do include funds to replace short-lived components such as boilers, pumps, and vehicles (items with less than 10 years design life). Construction and O&M estimates are summarized in Table 2-3.

2.6.1.1 <u>Central watering point with individual haul of water, sewage, and refuse</u>. This involves the development of a safe water source from which individuals will haul their own water. More than one source may be needed in a larger community. In some instances it may be feasible to develop a source at each dwelling. A self-haul system seldom results in enough water at the homes for adequate personal and household sanitation.

In some instances it is feasible to provide septic tanks, waste bunkers, or privies at each dwelling. In other cases users must be responsible for delivering wastes to a central treatment and disposal facility. Treatment and disposal of the wastewater could consist of a lagoon or treatment plant. Refuse would usually be hauled (by individuals to a landfill or fenced disposal site.

Central watering points with individual hauling are lower in initial cost but provide the least health improvement and convenience compared to other types of facilities. Costs run from $250 000 to

TABLE 2-3. COST OF WATER DISTRIBUTION AND SEWAGE COLLECTION FACILITIES IN COLD REGIONS (1977).

TYPE OF SERVICE	CONSTRUCTION COST	OPERATION AND MAINTENANCE COSTS[1]	REMARKS
Individual-Haul	$300 000	$600/month	Per facility
Vehicle-haul	$500 000	$70/month/house	30 homes[3]
Pipe Facilities (with minimal fire protection)	$35 000/house	$50/month/house	30 to 40 homes[3]
Central Facility with Individual-Haul	$900 000	$140/month/house[2]	60 homes[3]
Central Facility with Vehicle-Haul	$1 300 000	$180/month/house[2]	60 homes[3]

[1] Amortization of initial construction costs is not included. However, cost for replacing critical components such as pumps, boilers, vehicles, etc., is included.

[2] Approximately $30/family/month can be recovered by using coin-operated showers, saunas, washers, and dryers. Additional costs can be recovered if nearby facilities such as schools can be serviced directly.

[3] Five to six people/house.

$350 000 per facility. The number of watering points needed in a given community will depend on how scattered the houses are, ground conditions throughout the community, possible water sources, and other factors.

Individual-haul facilities also have the lowest O&M costs but provide the least service. Costs of $500 to $950 per month per facility are known. The variance is primarily due to the sophistication of the water and sewage treatment facilities needed.

2.6.1.2 Central watering point with vehicle delivery of water and collection of sewage and refuse. This involves the development of a safe water source from which a community or contractor will deliver water to storage containers in the users' buildings. Sewage is collected from holding tanks or in "honeybuckets", and delivered to a treatment/disposal facility. Refuse is also collected by vehicle and transported to a disposal point. The sophistication of the plumbing within the individual buildings can vary considerably, from individual pressure systems with a full complement of plumbing fixtures to an open container.

Vehicle-haul facility costs will vary with the facilities installed in the individual buildings, distance to the source/disposal point, storage, and the truck fill point facility. Initial installation costs vary from $450 000 to $550 000.

Operation and maintenance costs for vehicle-haul systems will depend on the above items plus the sizing of the building and vehicle storage and holding tanks. The O&M costs run between $60 and $80 per house per month. In northern Canadian communities, total costs for vehicle delivery and collection run between 1 and 2¢ per litre, but the cost to the consumer is subsidized by the government. Wheeled vehicles seem to have a useful life of about four years in remote cold regions and tracked vehicles even less. Vehicle-delivery systems are extremely labour intensive (50 percent of total delivery cost), although this usually provides several jobs in the community.

A typical cost breakdown for a vehicle-delivery system in the Northwest Territories is: vehicle capital = 15 percent (four-year life), vehicle O&M = 21 percent, garage capital = 9 percent (10-year life), garage O&M = 5 percent, and labour = 50 percent (@ $13 per hour for two persons).

2.6.1.3 Central facility watering point with laundry and shower facilities. A central facility would provide water, laundering, bathing, and toilet facilities. The fixtures and facilities are usually coin-operated. "Honeybucket" wastes can also be deposited at the facility and handled with the wastewater from the facility. More sophisticated central facilities include incinerators for refuse disposal and treatment of grey water for reuse.

The initial costs for a central facility with laundry, showers, and water provided will depend primarily on the degree of water treatment necessary and the type of sewage treatment and refuse disposal selected. Either individual or vehicle-haul can be used in conjunction with a central facility. A facility with individual-haul will cost from \$700 000 to \$1 100 000 and serve about 60 dwellings. One providing vehicle-haul would cost between \$1 000 000 and \$1 600 000 depending, again, on the degree of fixture sophistication within the houses (type of tanks, flush toilets, etc.). Central facilities which provide bathing and laundry facilities would have to be financed and maintained by the homeowners who would have the other fixtures in their homes.

The O&M costs of a central facility would be \$65 to \$80 per family per month with individual-haul and \$90 to \$120 per family per month with vehicle-haul. A part (approximately \$30/family/month) of the O&M costs for central facilities can be recovered by using coin-operated saunas, showers, washers, and dryers. The remainder would have to be collected by billing the users and/or coin dispensing of water. Some costs can be offset by providing water and sewer service to nearby facilities such as schools and health clinics.

2.6.1.4 Complete piped water delivery and sewage collection. Safe water is distributed from the source to each building and sewage is collected and transported to a treatment facility using above or below-ground piped systems. Refuse is still collected by vehicle. Piped water systems may provide fire protection or domestic consumption only. The sewage collection system could be gravity, vacuum, or pressure operated.

Initial construction costs for complete piped facilities vary greatly with the community layout and building density, soil conditions, whether an above or below-ground system is used and other factors. Initial costs are higher than with the other alternatives but the greatest health improvement and convenience is offered.

Costs usually run between $30 000 and $40 000 per house, including the cost of service lines but not house plumbing. It would cost another $2000 to add a sink, toilet and lavatory with the proper plumbing accessories to an existing house. Piped facilities have lower O&M costs than vehicle-distribution and collection systems. O&M costs range from $40 to $65/family/month depending on the type of system used (i.e., above or below-ground, pipe or utilidor, gravity, or pressure or vacuum), labour costs, compactness of area to be served, and degree of treatment needed. These costs do not include heating water or the electricity used in the individual buildings for laundry and bathing.

2.6.2 Design life

For the most part, the design life for facilities and equipment in cold regions is shorter than for the same units operated in more temperate climates. This is especially true of equipment which must operate outside in the winter. The following list presents some commonly used design lives for cold regions:

Component:	Design Life (years)
Wells	30
Pumps and controls	5
Boilers	5
Storage tanks	40
Water distribution lines	40
Meters	10
Valves	10
Septic tanks	5 to 10
Drainfields	5
Sewage collection lines	30
Lift stations (not pumps)	30
Trucks	4
Tracked Vehicles	2 to 3
Buildings	30

Paint (outdoor)	10
Service connections	10 to 15
Backhoes (occasional use)	6 to 10
Compressors	5

2.7 Operation and Maintenance

2.7.1 Community and operator training

Where the community operates its own system, successful operation is very dependent upon the training and dedication of people in the community, especially the operator. The operator's dedication and acceptance of responsibility is a direct indication of how successful and how long the facility will operate well. It is usually easier to ensure proper operation for government-operated systems. Training must be geared to the operator's education level. In remote areas, experience has shown that training carried out with the individual operator at his own plant is more successful (also, more expensive) than bringing several operators to a central location or educational institution for training. Probably a combination of individual and group training is desirable. At least two operators should be trained for each facility to allow for back-up when the main operator is not available. Operator training should be provided in progressive levels, such as:

Level 1 would provide basic emergency measures to minimize facility damage (e.g. to drain the system or start standby pumps or boilers in case of a failure of an important part). It would be desirable to have several people in the community trained to this level.

Level 2 would provide training for minor repairs to boilers, pumps, chlorinators, etc., to get them back on line, in addition to the Level 1 responsibilities. This level would not include much preventative maintenance, but would provide primarily day to day operation. Both the main and standby operator should have this level of training.

Level 3 would include Level 1 and 2 training, and preventative maintenance, such as keeping the boilers in adjustment, etc. The main operator should be trained to this level at least.

Level 4 would provide capable and interested Level 3 operators with training to a level where they would be able to qualify for formal certification as water and sewage treatment plant operators.

First priority would be Level 1 training and then on up to Level 4. Most operators in remote native villages would not need Level 4 training. However, local laws or requirements may now, or in the future, specify Level 4 training of all operators. At construction camps or government installations it is probably desirable to train operators to standards higher than those above because facilities are usually more sophisticated.

Ideally, the operator and alternate operator should be selected at the beginning of construction so they can receive on-the-job training throughout construction. The selection should be made by the community, with technical help from the constructing or training agency, because the community must accept and support the operators after they assume O&M responsibilities for the facilities. The operator should be selected for dedication and abilities, not because of political connections within the community. Operator training is not a one-time responsibility; it is on-going. Operators move on to better jobs, community administration changes and new operators are appointed, etc., making it necessary to carry on a continuous training program. The operators must be paid enough to keep them on the job and to provide a comfortable living.

Community education is also an important part of the training process. The community must realize the importance of the operators and support them morally as well as financially. A community appreciation of the health and convenience benefits the facilities bring will promote this support.

In a small community the operator may be responsible for collection of the user fees. In large communities an administrative staff handles collections, and this should be considered for any community. It will be more difficult for an operator to hold the community's support if he is also shutting off their water for non-payment of bills.

The community administration or the operator must be trained in bookkeeping, billing, employment forms (tax withholding, workmen's compensation, etc.), and the other functions needed to operate a utility. The community must also pass and administer ordinances to regulate the utilities. Homeowners must often be trained in the correct use and care of the new facilities installed in their homes.

Whether or not O&M subsidies are provided, technical and management help must always be available to the operator and community.

Occasional trips should be made to the community to meet with the operator and discuss any problems he may be having with his facilities. In cold regions it is important that one of these visits be made in the fall so any problems or repairs that need to be made can be done before winter, especially those that would jeopardize the integrity of the system. On these visits, all critical components should be inspected to make sure they (and their standby units) are operating properly. Another visit should be during the summer when all lines can be flushed and fire hydrants operated and cleaned.

2.7.2 Operation and maintenance manuals

Operation and maintenance manuals are extremely important if the operator is to correctly care for his facilities [25]. They should be written during construction so that they are available for system start-up. They should include many pictures of all components discussed. Arrows can indicate exactly what part is being discussed. They must also be written for the individual operator's education level and include:

1) accurate and complete as-built drawings (layout of system, piping, diagrams, etc.);
2) complete parts list and suppliers' names and addresses for all equipment, chemicals, etc., that must be maintained;
3) step-by-step troubleshooting lists of all possible problems;
4) step-by-step repair and maintenance lists for all equipment and parts;
5) a good index so the operator can quickly find the items he needs;

6) the names and phone numbers of people the operator can call day or night in case of an emergency that he is unable to handle without help;
7) a definition of each part of the facility, what its function is, and why it is important.

2.7.3 Reliability

The reliability of utility systems depends mainly on the quality and quantity of the preventative maintenance performed by the operator. Reliability is important because of the expense involved in replacement or repair in remote areas in cold regions, and because of the consequences of catastrophic failure of the entire facility because of the failure of an inexpensive control. Reliability must be a major consideration in selecting components and equipment. This includes the availability of repair parts and service.

Because of the unreliability of power in cold regions, standby generation capability must be provided for all critical components of a facility.

A facility that is less automated and, therefore, needs more operator attention will be very reliable if the operator is competent. However, if he is not, a facility which is automated to a high degree will prove more useful, in spite of the tendency for sophisticated equipment to malfunction.

2.7.4 Management backup

In addition to training operators and making occasional visits, a responsive backup system to help operators solve problems is essential. This support involves helping the operator get parts he needs, helping the bookkeeper work out problems, being readily available to help the operators with technical advice and working out complex problems on-site, responding with qualified people and materials during emergencies, and making regularly scheduled visits several times a year to help the operators maintain a sound preventive maintenance program.

2.8 References

1. Ryan, William L., "Design and Construction of Practical Sanitation Facilities for Small Alaskan Communities". Permafrost: The North American Contribution to the Second International Conference, National Academy of Sciences, Washington, D.C., 1973.

2. U.S. Public Health Service Monograph No. 54-1958. PHS Publication No. 591, U.S. Government Printing Office, Washington, D.C., 1958.

3. Associated Engineering Services, Ltd., "Wabasca - Desmarais, Water and Sanitation Feasibility Study", prepared for the Northern Development Group, Alberta Executive Council, Government of the Province of Alberta, 1974.

4. Gamble, D.J., "Unlocking the Utilidor", Proceedings of the Symposium on Utilities Delivery in Arctic Regions, Environmental Protection Service, Environment Canada, January, 1977 (Report No. EPS 3-WP-77-1).

5. Puchtler, Bert, "Water-Related Utilities for Small Communities in Rural Alaska", Report to Congress authorized by Section 113 Public Law 92-500, U.S. Environmental Protection Agency, Washington, D.C., 1976.

6. Muller, Siemon William, Permafrost or Permanently Frozen Ground, and Related Engineering Problems, J.W. Edwards, Inc., Ann Arbor, Michigan, 1947.

7. Buvert, V.V. et al, "Snow and Ice as Materials for Road Construction", translation # 54, U.S. Army Corps of Engineers, (CRREL), 1957.

8. Tomayko, D.J., "Elevated Snow Roads in Antarctica", The Military Engineer, No. 429, January - February, 1974.

9. Clark, E., et al, "Expedient Snow Airstrip Construction Technique", U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory Special Report # 198, 1973.

10. Hansen, B.L., "Instruments for Temperature Measurements in Permafrost", Proceedings of the First International Permafrost Conference, Purdue, 1963.

11. Crory, F.E., "Pile Foundations in Permafrost" Proceedings of the First International Permafrost Conference, Purdue, 1963.

12. Penner, E., "Frost Heaving in Soils", Proceedings of the First International Permafrost Conference, Purdue, 1963.

13. Berg, R., "The Use of Thermal Insulating Materials in Highway Construction in U.S.", U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Report # MP 539, 1974.

14. Smith, D.W. and Justice, S.R., "Clearing Alaskan Water Supply Impoundments. Management Laboratory Study and Literature Review", Institute of Water Resources, Report No. IWR-67, University of Alaska, Fairbanks, 1976.

15. Carlson, A.R., "Heat loss and Condensation in Northern Residential Construction", and "Design of Floors for Arctic Shelters", Proceedings of Symposium on Cold Regions Engineering, University of Alaska, College, Alaska, 1971.

16. Floyd, P., "The North Slope Center: How Was It Built?", The Northern Engineer, Vol. 6, No. 3., 1974.

17. Tobiassion, W., "Deterioration of Structures in Cold Regions", Proceedings of the Symposium on Cold Regions Engineering, University of Alaska, College, Alaska, 1971.

18. ASHRAE Handbook of Fundamentals (latest edition), American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc.

19. Pritchard, G.B., "Foundations in Permafrost Areas", Proceedings of the First International Permafrost Conference, Purdue, 1963.

20. Tobiasson, W., "Performance of the Thule Hanger Soil Cooling System", Proceedings of the Second International Permafrost Conference, Yakutsk, USSR, 1973.

21. Miller, J.M., "Pile Foundations in Thermally Fragile Frozen Soils", Proceedings of the Symposium on Cold Regions Engineering, University of Alaska, College, Alaska, 1971.

22. Seeding Recommendations for Revegetation of Arctic and Subarctic Soils, personal discussions with U.S. Dept. of Agriculture, Soil Conservation Service, Anchorage, Alaska; Institue of Agriculture, University of Alaska, Palmer, Alaska; and Alaska State Division of Aviation, Anchorage, Alaska, 1974.

23. Hamelin, L.E., "A Zonal System of Allowances for Northern Workers", MUSK-OX, Publication 10, 1972.

24. Gordan, R., "Batch Disinfection of Treated Wastewater with Chlorine at Less than 1^{o}C.", U.S. EPA # 660/2-73-005, September 1973.

25. Squires, A.D., "Preparation of an Operations and Maintenance Manual", In Symposium on Utilities Delivery in Arctic Regions, Proceedings published as Environmental Protection Service Report No. EPS 3-WP-77-1, Environment Canada, January, 1977.

2.9 Bibliography

Alaska Department of Commerce and Economic Development, Directory of Permits, Juneau, Alaska, 1978.

Christensen, Vern, and Reid, John, "N.W.T. Water and Sanitation Policy and Program Review", Department of Planning and program Evaluation, N.W.T., Canada, December, 1976.

Cooper, I.A., and Rezels, J.W., "Vacuum Sewer Technology", prepared for the U.S. EPA Technology Transfer Seminar Program on Small Wastewater Treatment Systems, 1977.

Grainge, J.E., and Shaw, J.W., "Community Planning for Satisfactory Sewage Disposal in Permafrost Regions", paper presented at Second International Symposium on Circumpolar Health, 1972.

Grainge, J.W., "Study of Environmental Engineering in Greenland and Iceland", Canadian Division of Public Health Engineering, Department of Health and Welfare, Report No. NR-69-5, 1969.

Heinke, G.W., "Report on Environmental Engineering in Greenland and Northern Scandinavia", Dept. of Civil Engineering, University of Toronto, October, 1973.

Kreissl, J.F., "Status of Pressure Sewer Technology", prepared for the U.S. EPA Technology Transfer Design Seminar for Small Flows, 1977.

Simonen, E., and Heinke G., "An Evaluation of Municipal Services in the Mackenzie River Delta Communities", Publication No. 70-60 Dept. of Civil Engineering, University of Toronto, 1970.

Tsytovich, N.A., The Mechanics of Frozen Ground, McGraw-Hill and Scripta Book Company, New York, 1975.

SECTION 3

WATER SOURCE DEVELOPMENT

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3 WATER SOURCE DEVELOPMENT

3.1 General

Cold climate conditions require special attention when selecting and developing water sources. Hydrologic conditions in northern latitudes differ from those in sourthern regions in several important respects. This is true of both groundwater and surface water in areas of continuous permafrost. Throughout much of the cold region of North America, precipitation is light, terrain in populated regions is relatively flat, and yearly runoff is concentrated in the short period during ice breakup. There are many small, shallow lakes and ponds and numerous rivers and creeks. Ice cover varies according to local conditions, but generally lasts from six to 10 months. Hydrologic data on northern lakes, streams and groundwater are scarce and typically cover periods of short duration. This makes it difficult to predict reliable yields for water supply purposes.

Permafrost is impermeable for all practical purposes. Runoff from melting and precipitation tends to occur in a shorter period and is more complete than in areas without permafrost. This phenomenon also greatly reduces the recharge of aquifers. Any construction in permafrost regions requires special consideration and unique engineering, particularly in regard to cost and the technical problems of maintaining water flow. Often, permafrost conditions prevent the application of standard techniques and preclude the development of available groundwater sources. The costs of developing, maintaining, and operating a water source in cold climates are greater in all respects than in temperate regions. Costs will vary with each location; however, they generally increase with decreasing mean annual temperature and remoteness of the site.

Regardless of the apparent merits of a source under consideration, there is no substitute for detailed preliminary engineering studies and direct observation of local conditions prior to final selection. Some type of water source may be developed in virtually any part of the cold region of North America, but the physical difficulty of operation and maintenance or the associated costs may be highly unattractive.

The governments of both the United States and Canada support the collection and publication of basic data of value in planning water supply systems.

The Canadian Department of Environment publishes an annual report entitled "Surface Water Data - Yukon and Northwest Territories", which lists stream flows at selected stations in the Northwest Territories. This publication is prepared by:

Inland Waters Directorate
Water Survey of Canada
Environment Canada
Ottawa, Ontario K1A OE7

The annual U.S. Government publication, "Water Resources Data for Alaska", includes information on stream flows and water quality for selected streams. This publication is available from:

U.S. Geological Survey
District Chief, Water Resources Division
218 "E" Street
Anchorage, Alaska 99501

In addition to these publications, special reports may be available from the U.S. Geological Survey agency on particular locations dealing with short-term data, groundwater, or special water quality studies. Both nations maintain agencies concerned with weather and other climatological factors which regularly publish their data. One example is "Ice Thickness Data for Canadian Selected Stations". Precipitation is also recorded and published. For this information the following offices should be contacted:

Atmospheric Environment Service
Environment Canada
Ottawa, Ontario K1A OH3

National Weather Service Forecast Office
632 6th Avenue
Anchorage, Alaska 99501

3.2 Water Sources

Water in cold regions comes from the same basic sources as in temperate areas, but there are some peculiarities to arctic and subarctic surface and groundwater hydrology which merit comment.

3.2.1 Surface water

Surface water results from precipitation and snowmelt and is replenished through the hydrologic cycle. In northern latitudes surface waters in shallow lakes and small streams may be effectively eliminated in the winter because of complete freezing. Larger streams and deep lakes may remain liquid beneath an ice cover but flows and volumes are reduced since there is no contribution from precipitation until warm weather returns. In some cases, pressure between the stream bed and downward-growing ice cover forces flows to the surface through cracks and along the shores where it then freezes. Frozen water of this type is called "aufeis" and is essentially not available until breakup and thaw occur. This has a smoothing effect on the runoff hydrograph by reducing the peak and increasing the flow during the melt. Large snow drifts also contribute to runoff in this manner. Thus, it becomes apparent that because of the cold climate and quantity of ice, not all surface sources are available for continuous water supply. Sources which are suitable for continuous supply are large rivers and large lakes. Figure 3-1 shows a hydrograph for a typical medium-sized arctic river.

3.2.1.1 Rivers. Rivers are an excellent water source in winter because sediment transport is minimal and overland flows, which tend to lower water quality, do not occur. The disadvantages of rivers as a supply source include low water temperatures and flowing ice during freeze-up and break-up periods, which may damage or destroy water intake structures. Also, in alluvial streams it is difficult to locate a permanent channel beneath the winter ice.

Summer river flows, which tend to be much higher, frequently contain sediments or glacial flour from overland runoff or melting glaciers which cause difficult treatment problems.

3.2.1.2 Lakes. Lakes may be a good continuous source of water, depending upon the size (area and depth) and the severity of the climate.

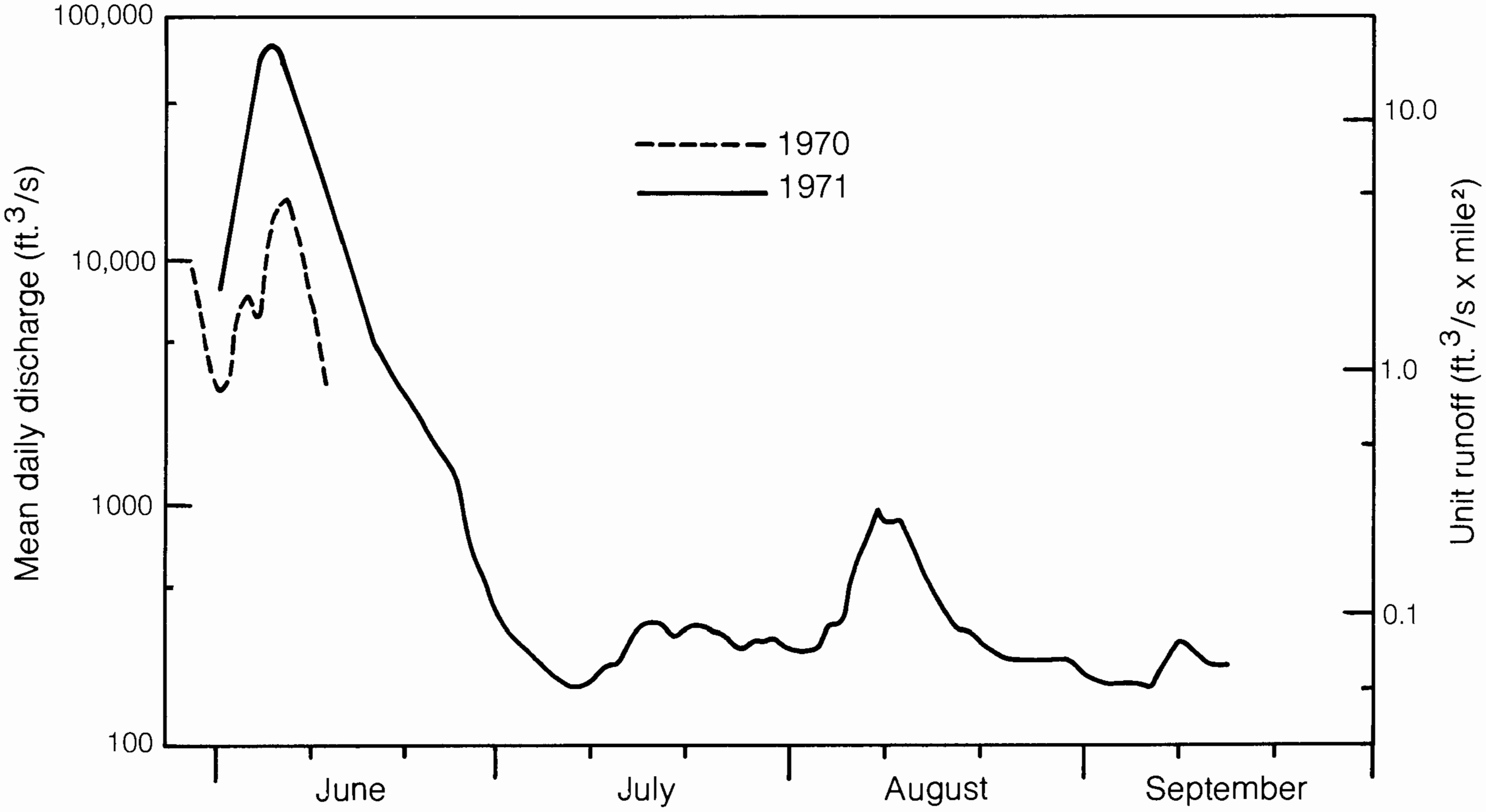


FIGURE 3-1. HYDROGRAPH OF MEAN DAILY DISCHARGE, KUPARUK RIVER
(Data Source: U.S. Geological Survey).

Shallow lakes may freeze to the bottom in arctic regions or may freeze-concentrate impurities below the ice to the extent that the water is no longer of acceptable quality. Ice formation is proportional to the air temperature. A general expression of this phenomenon is called Steffan's equation:

$$X = \sqrt{\frac{2kI_f}{L}} \tag{3-1}$$

in which: X = ice thickness,

I_f = freezing index,

L = volumetric heat of fusion of water,

k = thermal conductivity of ice (see Section 15).

Impurities, such as most salts, are rejected from the freezing water, making the ice relatively pure. The more slowly ice is formed, the more efficient this process becomes. The net effect of this phenomenon is that impurities become concentrated in the water beneath the ice. It may be generalized that if the liquid content of a lake or pond is reduced 50 percent by ice formation, dissolved salt concentrations will double. Careful thermal and chemical analyses are required to identify a lake or pond which may freeze deep enough to create this condition. (For details see Section 15.)

3.2.1.3 Watershed yield and quality improvement. The amount of water yielded by a given watershed is related to the precipitation received by the watershed. Other factors which influence yield are evaporation to the atmosphere and transpiration by vegetation.

To estimate runoff or yield, records of the precipitation, evaporation and temperature are needed. The agencies listed in Section 3.1 maintain current data for many locations. Some agencies, such as the U.S. Geological Survey, calculate and publish watershed yields for specific stream locations. When no other information is available these data should be used as a guide. For large projects where accurate information is critical, data should be collected for several years prior to final design to assure that the required yield will, in fact, be available.

In cold regions, particularly in the Arctic, most precipitation is in the form of snow. However, due to winds it does not necessarily remain where it fell initially. This fact has been used to increase the annual water yield of small watersheds by inducing the occurrence and growth of snow drifts. Near Barrow, Alaska the U.S. Army augmented the fresh water supply by using snow fences. This work provided valuable information for evaluating the technique. Accumulation of at least 10.1 m^3 of water for every metre of 1.5-metre high snow fence is possible. The cost of this water (in 1975) indicated that over a 10-year amortization period for snow fences, 0.2 m^3 of water could be produced annually for about one penny [1].

In some areas it may be more economical to develop only an intermittant source and depend upon artificial storage for periods when the natural supply is low, e.g., when all surface water freezes during the winter, or during periods of highly turbid river water.

3.2.2 Groundwater

Groundwater may be considered the most desirable source of water in cold regions for several reasons. Normally, groundwater temperature in the winter is warmer than surface water and is nearly constant year-round. Mineral quality of groundwater is more constant than surface water. Also, subpermafrost groundwater is almost always a year-round source of supply, so that alternate or dual source systems need not be developed.

The cost of exploring, drilling, developing and maintaining wells in cold remote areas can be high.

3.2.2.1 Groundwater in permafrost. Groundwater in areas of continuous permafrost may be found in three general locations: 1) above permafrost, within the active layer (suprapermafrost); 2) within permafrost in thawed areas (intrapermafrost); and 3) beneath permafrost (subpermafrost).

Waters found in the active layer above the permafrost are generally unsuited for potable water supplies without extensive treatment. Such water is usually found within three to eight metres of the surface and frequently has a high mineral content. Because they are shallow, such aquifers are also subject to contamination from privies and septic tanks. The quantity of this water source is often low and unreliable. A system for use of suprapermafrost water was developed for Port Hope, Alaska [2].

Intrapermafrost water is quite rare and usually very highly mineralized. Such water must contain high concentrations of impurities which depress the freezing point below that of the surrounding permafrost. There is no reliable method to locate pockets of intrapermafrost water with present state-of-the-art techniques. For these reasons it is not normally a suitable water source.

Subpermafrost groundwater is the most reliable and satisfactory groundwater source in permafrost regions. Recharge of subpermafrost aquifers occurs beneath large rivers and lakes where there is no permafrost. In general, when fine-grained soils are frozen the movement of groundwater is effectively prevented. Satisfactory wells have been located near rivers or large lakes since the ground in these areas may not freeze.

Subpermafrost groundwater is generally deficient in dissolved oxygen. As a result, high concentrations of some salts, such as those of iron and manganese which may readily dissolve under these conditions, are present. Hardness is also common in subpermafrost groundwater. Occasionally groundwater will contain dissolved organic materials in addition to hardness, iron and other minerals.

Costs for drilling and well maintenance are higher in permafrost areas. The water must be protected from the cold permafrost and the permafrost needs to be shielded from the heat of the water. This often requires special well castings, grouting methods and heat-tracing water lines, all contributing to increased cost.

A computer simulation of the effect of a meandering river on permafrost has been developed [3]. Figure 3-2 shows a typical example of this type of calculation. The application of this information is greater for groundwater development than for surface water. A well might conceivably be located where it would penetrate an aquifer being continuously recharged by a river.

3.2.2.2 Estimation of groundwater yield. The predictable yield of groundwater from a watershed may be estimated in a manner similar to that

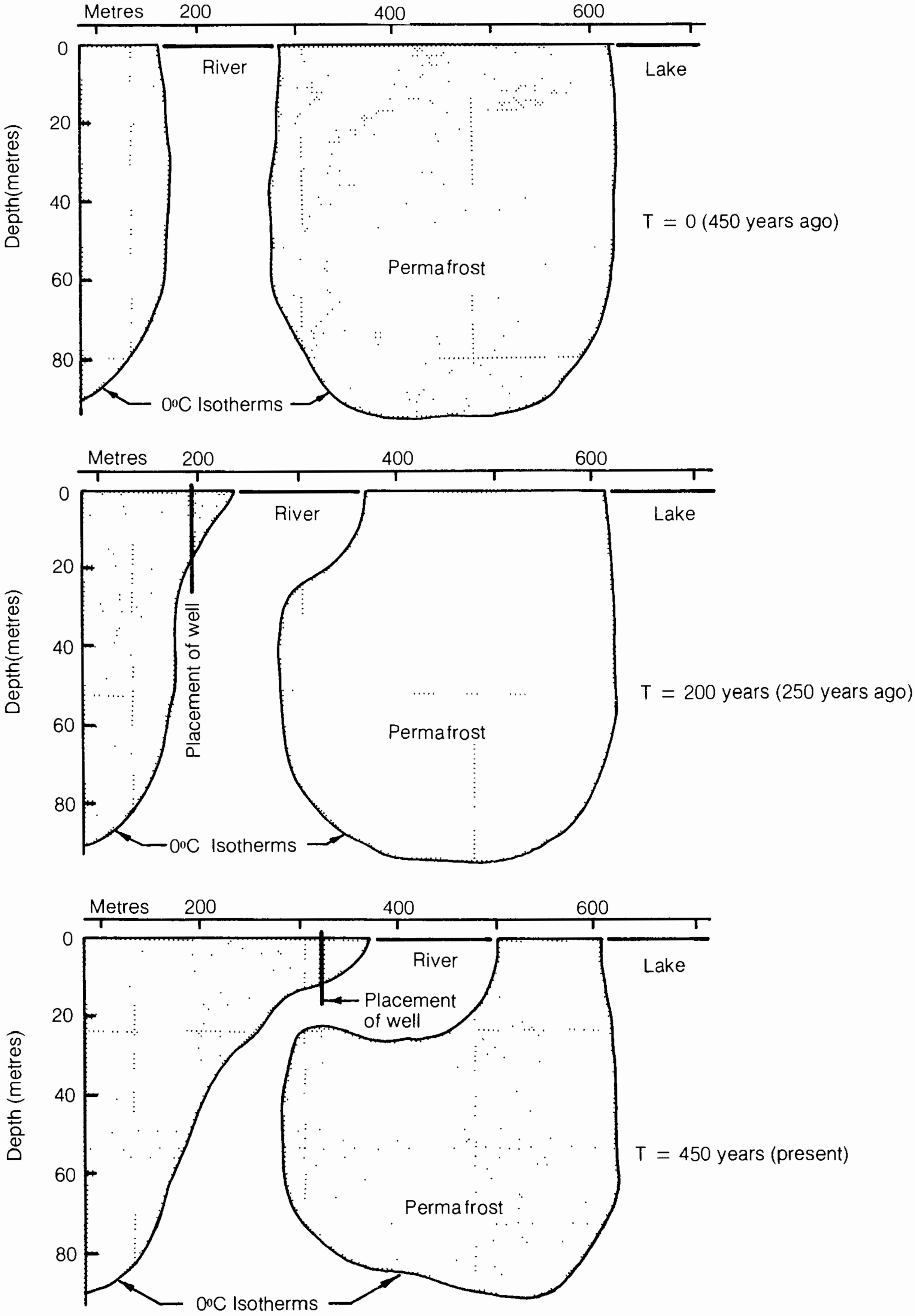


FIGURE 3-2. COMPUTER SIMULATION OF THE EFFECT OF A RIVER ON PERMAFROST

for estimating surface runoff. The concept involves balancing all inputs with the withdrawals. In practice, however, measuring the inputs and withdrawals may be quite complex.

The safe groundwater yield (Y_g) is equal to the watershed precipitation (P), less surface flow out of the watershed (Q_s), less evapotranspiration (E) plus the net groundwater inflow (Q_g), less the net change in surface storage (ΔS), less the net change in groundwater storage (ΔG).

Thus,

$$Y_g = P - Q_s - E + Q_g - \Delta S - \Delta G \qquad (3\text{-}2)$$

Only two terms in the above equation can be measured with reasonable accuracy, P and Q_s; the others must be estimated. Recharge of aquifiers in permafrost regions is much more limited than in other areas because permafrost may be an impermeable barrier. Hydrologists experienced in cold region work should be consulted when estimates must be accurate.

3.2.3 Other water sources

Snow, ice, and direct catchment of rainfall are potential water sources which may be considered for small or temporary establishments.

3.2.3.1 Snow and ice. In general, the natural quality of these sources is high but contamination of the ice or snow stockpile is a real hazard. Also, the cost of melting is significant and there are added costs for harvesting and storing equipment and melters. If significant quantities of waste heat are available (e.g. from a nearby power plant), this method may be more attractive.

Induced snow drifting may improve the feasibility of using snow as a source of water. However, unless the need is temporary and the population to be served is small, direct melting will not be practical. Large volumes of snow are required to obtain even small quantities of water and the cost of snow melting is high. It has been estimated that approximately one litre of "Arctic" diesel is required to produce 70 litres of water from snow [4]. In addition to fuel cost, labour for operating snow melters and snow harvest equipment must be considered.

Slaughter *et al*. [1] concluded that parallel snow fences spaced 50 to 100 meters apart would trap a maximum amount of snow. Fences should be erected so that they concentrate drifts near stream channels to assure a better runoff and easier collection. Fences between 1.5 and 3.6 metres high have been used in various configurations. Each installation should be designed to fit the local situation.

3.2.3.2 Seawater and brackish water. Desalinated seawater has been used for domestic supply but the associated problems are considerable. Intakes in the ocean or on the beach are subject to ice forces of phenomenal magnitude. Ice scour of beaches at all times during the year must be considered because of combinations of wind and sea ice. During the winter months, shore-fast ice and frozen beaches pose special problems. The largest drawback is that there are no economical (from an operating and management standpoint) methods to desalinate seawater on the scale necessary for a small community or camp.

Brackish water with total dissolved solids (TDS) of < 10 000 mg/L is occasionally the only source available. Such waters may be treated by reverse osmosis or distillation but significant problems must be anticipated at small installations.

3.2.3.3 Water reuse. In the absence of ample supplies of fresh water, water reuse may be considered. In Alaska, bath and laundry water are reclaimed and reused at several locations for toilet flushing and other non-potable purposes (see Section 11 for more details). Regeneration of potable waters is not yet state-of-the-art technology but it is logical to work toward that end in areas of extreme water shortage. Seawater contains approximately 35 times more dissolved solids than domestic sewage. The effluent from existing secondary or tertiary sewage treatment plants is basically free from suspended materials and should be more economical to treat than seawater [5].

3.3 Water Requirements

3.3.1 Water usage

The amount of water used by inhabitants of northern communities depends on several factors. Cultural background is particularly important since many cold climate communities are populated by Indians and Eskimos. Traditionally, native people have not had access to large quantities of water and as a result they tend to use water conservatively. However, as water becomes available, it is used more freely. In construction camps, workers may use large quantities of water but this, too, depends on the nature of the camp. Residents of temporary camps use less water than in base camp situations. Availability (or installation) of plumbing fixtures is another factor which influences use, perhaps more than any other factor.

The minimum amount of water considered adequate for drinking, cooking, bathing and laundry is 60 L per person per day. Even this may be difficult to achieve where piped delivery is not practical or possible. Current experience indicates that in communities without residential pressure systems which have "honeybag" waste systems water consumption is approximately 4 to 12 L/person/d.

Analysis of three years of data collected at Wainwright, Alaska, indicated that water use in homes rose from about 2 L/person/d in January 1974, to about 5.5 L/person/d in December of 1976 and the upward trend appears to be continuing. Wainwright, however, has a central facility which provides for bathing and laundry away from the home which was not included in these figures. In spite of these apparently low quantities for household use, significant health benefits have been observed in the village from improved water quality and sanitation facilities.

Table 3-1 presents water use factors for various types of communities in cold regions.

Water conservation. Even though these recommended quantities are recognized as adequate, many communities in Alaska and Canada consume large quantities of water which are essentially wasted. Table 3-2 gives examples of water use showing excessive quantities in many cases.

System designers must be alert to the possibilities for conserving water and potential reasons why systems sometimes encourage waste. Water and its treatment costs money, as do sewers and sewage treatment which must handle the hydraulic loads. Appendix B summarizes the various household water conservation fixtures, including toilet systems.

Bleeding. Users must be discouraged from allowing water to run to prevent freeze-up of service lines. This type of wastage is most common in the spring when frost penetration is greatest. To compound the problem, water sources are lowest in early spring. Subarctic cities seem to be more prone to this situation, probably because service lines in the

TABLE 3-1, RECOMMENDED WATER USAGE

Households	Litres/person/day Average	Normal Range
1. Self-haul from watering point	<10	5 - 25
2. Truck System		
a) non-pressure water tank, bucket toilet and central facilities	10	5 - 25
b) non-pressure water tank, bucket toilets, and no central facilities	25	10 - 50
c) non-pressure water tank, waste holding tank	40	20 - 70
d) pressure water system, waste holding tank and normal flush toilet*	90	40 - 250
3. Piped System** (gravity sewers)	225	100 - 400
4. Piped System (vacuum or pressure sewers)	145	60 - 250
5. Well and Septic Tank and Tilefield	160	80 - 250
Institutions (piped system)		
School: day student	10	2 - 18
boarder	200	100 - 400
Nursing Station or Hospital: per bed	100	
Hotels: per bed	100	
Restaurants, Bars: per customer	5	
Offices:	10	
Central Facilities:		
Showers (2 per person/week)	10	
Laundry (2 loads/family/week)	7	
Work Camps		
Base Camp	200	
Drilling pad	130	
Temporary, short duration camps	100	

* Conventional flush toilets not to be permitted with truck system in future.

** The figures for piped systems do not make allowances for the practice of letting fixtures remain open in cold weather to provide continuous flow in watermains to prevent freezing. Water use under that practice used only in older systems may be as high as several thousand litres per person per day.

TABLE 3-2. EXAMPLES OF ACTUAL WATER USE

City	Litres/ person/ day	Approx. number of people	Type of System
Minto, Ak.	190	180	Circulating water - gravity sewers
Anchorage, Ak.	890*	120 000	Conventional water and gravity sewers
Unalakleet, Ak.	300	400	same as Minto
Dot Lake, Ak.	190	50	Central heat - conventional water, individual sewer
Homer, Ak.	1630*		Conventional water and gravity sewers
Seward, Ak.	4500**		Conventional water and gravity sewers (winter)
	2300**		(summer)
Bethel, Ak.	270	1 200	Circulating water and gravity pressure sewer
Dillingham, Ak.	2300*		Conventional water and gravity sewer
Seldovia, Ak.	680*		same as Dillingham, Ak.
Kenai, Ak.	380		same as Dillingham, Ak.
Palmer, Ak.	760*		same as Dillingham, Ak.
Fairbanks, Ak.	650*	25 000	Circulating water and gravity sewer
Clinton Creek, Y.T.	1140*	381	Circulating water and gravity sewer
Dawson City, Y.T.	6400**	745	Circulating water and gravity sewer
Mayo, Y.T.	1700*	462	Circulating water and gravity sewer
Whitehorse, Y.T.	1680*	11 217	Circulating water and gravity sewer
Faro, Y.T.	1140*	--	Circulating water and gravity sewer
Inuvik, NWT (1976)	485-550	3 500	Circulating water and gravity sewer
Inuvik, NWT (1970)	20	1 300	Trucked water, honeybags
Resolute Bay, NWT	163		Circulating water
Resolute Bay, NWT (1970)	23	160	Trucked water, honeybags
Yellowknife, NWT	485	10 000	Piped water, gravity sewer
Yellowknife, NWT	90		Trucked water, sewage pumpout
Aklavik, NWT	63	600	Summer piped system
Fort McPherson, NWT	250	850	Piped portion of community
Edmonton, Alberta	236	500 000	Conventional, residential only

* some water wasting

** indicates leakage in old water pipes

Arctic are better designed for low temperatures and are usually heated or recirculated. Four remedies for this problem are to:

1) educate water users,
2) meter all customers (services),
3) provide inexpensive and quick methods of thawing frozen service lines,
4) construct service lines that are less apt to freeze.

Item 4) is the most important; keys to its accomplishment are:

a) bury lines below frost line until within the thaw bulb of the house,
b) insulate lines if there is a possibility of the surrounding ground freezing,
c) recirculate the water in service lines,
d) provide heat tapes on lines in frost zone,
e) add heat to water in distribution system.

Leakage. A lot of water is wasted because of leakage from old or broken service lines and mains and because of poorly maintained plumbing within buildings. Possible methods of minimizing losses of this kind are to:

1) maintain pressure in mains at the lowest pressure necessary (about 25 psi, 172.5 k Pa),
2) promptly repair all leaks in mains and service lines,
3) check system for leaks frequently by isolating sections and pressure testing,
4) educate users on the causes of each and train them to repair leaking fixtures such as faucets and toilets.

3.3.2 Demand factors

Factors used for computation of peak demand in small systems in cold regions will be somewhat higher than in temperate regions and for larger communities.

Maximum daily demand should be computed at 230% of the average daily demand. Maximum hourly demand should be computed at 450% of the annual average daily demand.

Figure 3-3 is presented for estimating hourly peak water demand in small cold climate communities.

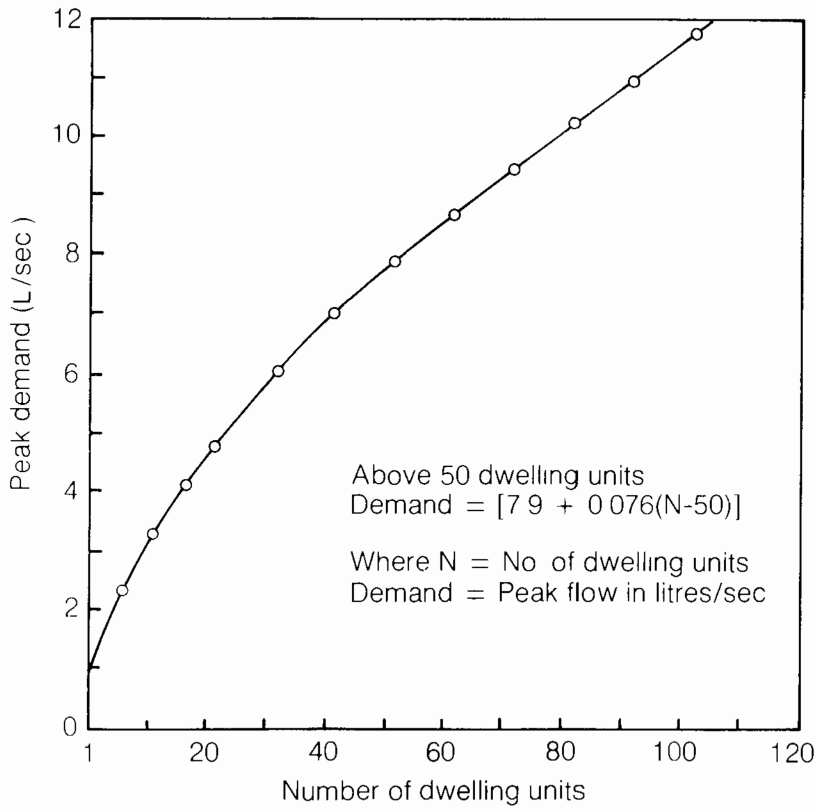


FIGURE 3-3. HOURLY PEAK WATER DEMAND IN SMALL COLD CLIMATE COMMUNITIES

3.3.3 Fire flows

In larger towns and cities water available for the fire flows should meet requirements of the National Board of Fire Underwriters (see Table 3-3). In smaller northern communities this is not feasible because of the distribution system such flows require. Because of the overall demand where only marginal sources of potable water exist, separate systems may be considered which would use untreated water such as seawater or river water in a normally dry fire system. This subject is covered in Section 12.

3.3.4 Water quality

Water quality is equal in importance to any aspect of public utility concern. Where the water source is concerned, however, quality need not be given highest priority since raw water can be treated to make it potable.

TABLE 3-3. FIRE FLOW, FIRE RESERVE AND HYDRANT SPACING RECOMMENDED BY THE NATIONAL BOARD OF FIRE UNDERWRITERS

Population	Fire Flow		Fire Reserve	Area per Hydrant, sq ft*	
	gpm*	mgd*	MG*	Engine Streams	Hydrant Streams
1 000	1 000	1.4	0.2	120 000	100 000
2 000	1 500	2.2	0.5	-------	90 000
4 000	2 000	2.9	1.0	110 000	85 000
6 000	2 500	3.6	1.5	-------	78 000
10 000	3 000	4.3	1.8	100 000	70 000
13 000	3 500	5.0	2.1	-------	-------
17 000	4 000	5.8	2.4	90 000	55 000
22 000	4 500	6.5	2.7	-------	-------
27 000	5 000	7.2	3.0	85 000	40 000***
40 000	6 000	8.6	3.6	80 000	-------
55 000	7 000	10.1	4.2	70 000	-------
75 000	8 000	11.5	4.8	60 000	-------
95 000	9 000	13.0	5.4	55 000	-------
120 000	10 000	14.4	6.0	48 000	-------
150 000	11 000	15.8	6.6	43 000	-------
200 000	12 000	17.3	7.2	40 000	-------

* Conversion factors: gpm x 5.450 = m^3/d
mgd x 4.381×10^{-2} = m^3/s
MG x 3785 = m^3
sq ft x 0.0929 = m^2

** For populations over 200,000 and local concentration of streams, see outline of National Board requirements.

*** For fire flows of 5000 gpm and over.

The concern for quality of a water source is based primarily on the ease with which the water may eventually be treated and the cost for the treatment required. Reliability in quality is of equal importance to reliability in quantity.

Groundwater quality. Water taken from above permafrost (suprapermafrost water) must be considered of questionable quality since contamination by pit privies and septic systems can easily occur. Subpermafrost waters are generally unpolluted but may contain high concentrations of iron (as high as 175 mg/L), magnesium and calcium as well as organics.

Iron and hardness below 7 mg/L and 100 mg/L, respectively, are reasonably easy to remove during treatment and do not detract from the value of the source. In the highly mineralized areas of Alaska, some groundwaters have been found to contain unacceptably high quantities of arsenic. Extremely high concentrations of nitrates have been observed in other groundwaters near Fairbanks, Alaska, and Nunivak Island.

Surface water quality Surface waters are more readily polluted by man; thus emphasis should be placed on bacteriological and biological quality of the water and watershed. It has been demonstrated that bacteria live for long periods in cold waters and pose a potential health problem for significant distances downstream from their entry point.

Water sources should be selected and the watershed protected in a manner acceptable in any climate. The U.S. Public Health Service [6] divides water sources into three categories: Group I water may be used as public water supplies without treatment; Group II water may be used after disinfection only; and Group III waters require complete conventional treatment including coagulation, sedimentation, filtration and disinfection. Because of the high probability of contamination of surface waters by wild and domestic animals harboring various tapeworms which cause hydatid disease in man, it is recommended that all surface waters be filtered prior to use in the public water supply.

Surface water sampled for quality during warm weather may indicate misleading values. Freeze-rejection of minerals and other impurities during ice formation causes the remaining liquid to be of significantly poorer quality.

Lake water quality improvement. It may be possible to improve the quality of water in a small saline pond or lake by pumping out the concentrated brines which remain under the ice near the end of the winter and allowing fresh spring runoff to replace it. Repeated one or more times, this method may permit the use of an initially unacceptable water body as a source of supply. The U.S. Public Health Service, in developing an improved water source for Barrow, Alaska, used this method with good results. Total dissolved solids concentration in the lagoon was about 7000 mg/L when ice cover was fully developed. The range of total dissolved solids in the lake is shown in Figure 3-4. In April 1976, 326 million litres of brine was pumped from beneath the ice, resulting in water of much higher quality.

3.4 Structures

Structures relating to water supplies range from a simple temporary intake on river ice to a complex dam on permafrost with a year-round intake and pumping station. Wells and their appurtenances are also considered as supply structures.

It is not the intent of this discussion to provide a guide for structural design of any facility but rather to point out features which may require special attention in cold climates. Designs should be prepared by engineers qualified to work in cold regions.

3.4.1 River intakes

Intake structures may be either temporary or permanent. Permanent structures are more desirable because they permit a certain freedom from attention at critical times such as during freeze-up and breakup. On the other hand, temporary structures may be less expensive and permit a degree of latitude of operation not afforded by permanent structures. Also, because temporary facilities may require attention during critical times of the year, they force the operator to become aware of existing or potential problems.

Depending upon the overall system design and source capabilities, intakes may only be required for a short period each year. If demands are such that they cannot be met by providing storage, then more elaborate intake works will be required.

Under some conditions a protected pump on the river shore or on the ice may suffice. This requires little design attention or continuing operator attention (see Figures 3-5, 3-6 and 3-7). The reverse is true of permanent intakes.

Numerous arrangements and configurations of river intakes have been designed with varying degrees of success. Figure 3-8 shows the piping schematic for a matched pair of intakes in the Great Bear River at Ft. Norman in the Northwest Territories. Such designs are continually evolving to make use of more sophisticated concepts and materials.

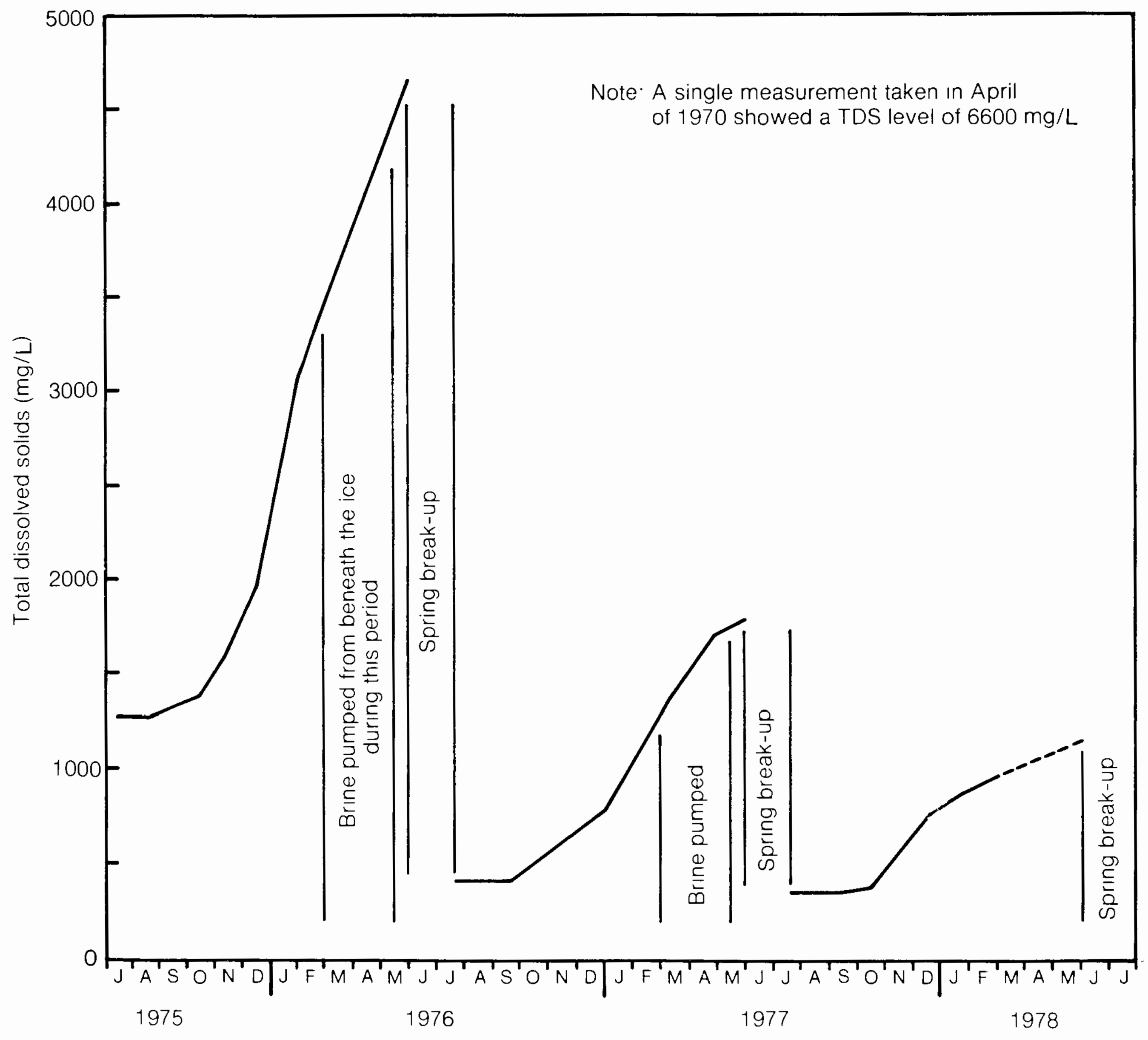


FIGURE 3-4. WATER QUALITY IN UPPER ISATKOAK LAGOON, BARROW, ALASKA, 1975-1978

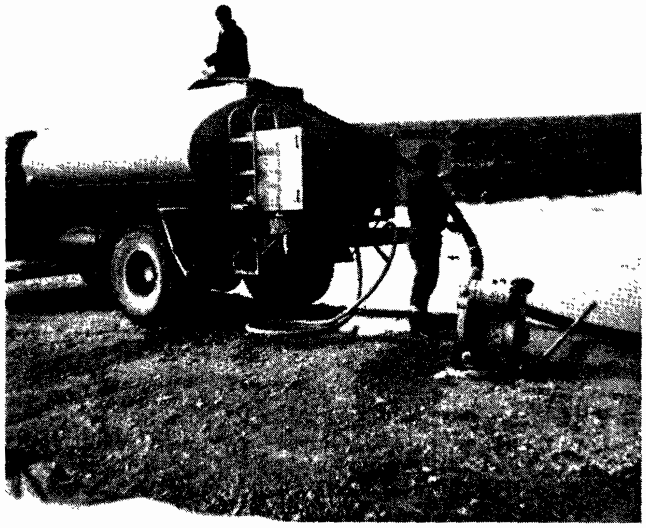


FIGURE 3-5. WATER TRUCK FILLING AT WATER LAKE IN CAMBRIDGE BAY, NWT

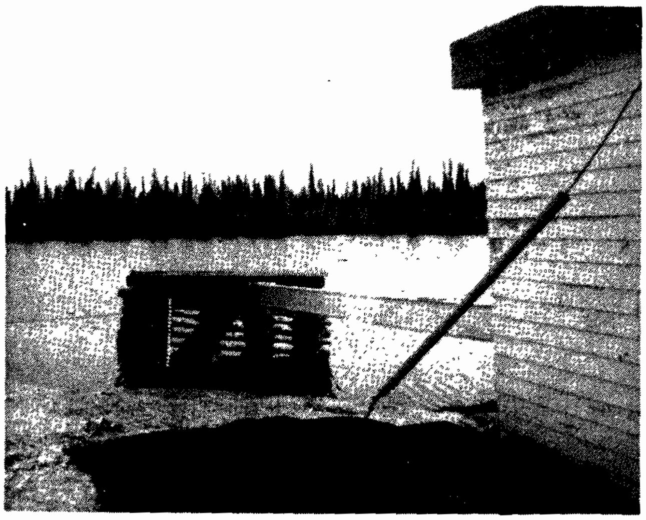


FIGURE 3-6. WATER INTAKE AT FORT McPHERSON, NWT

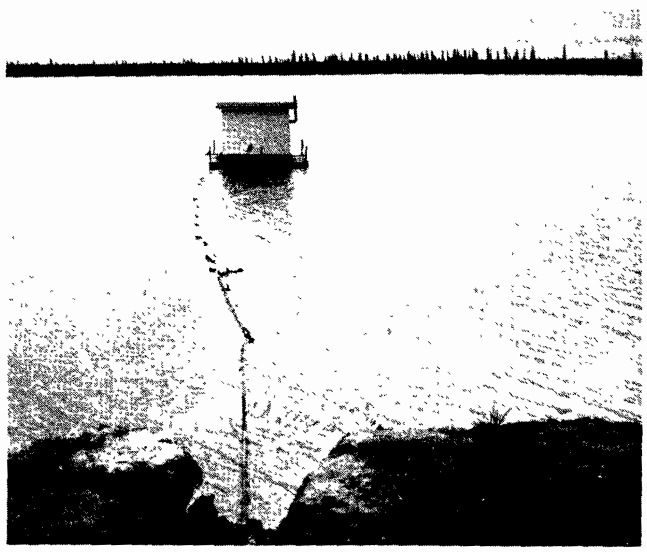
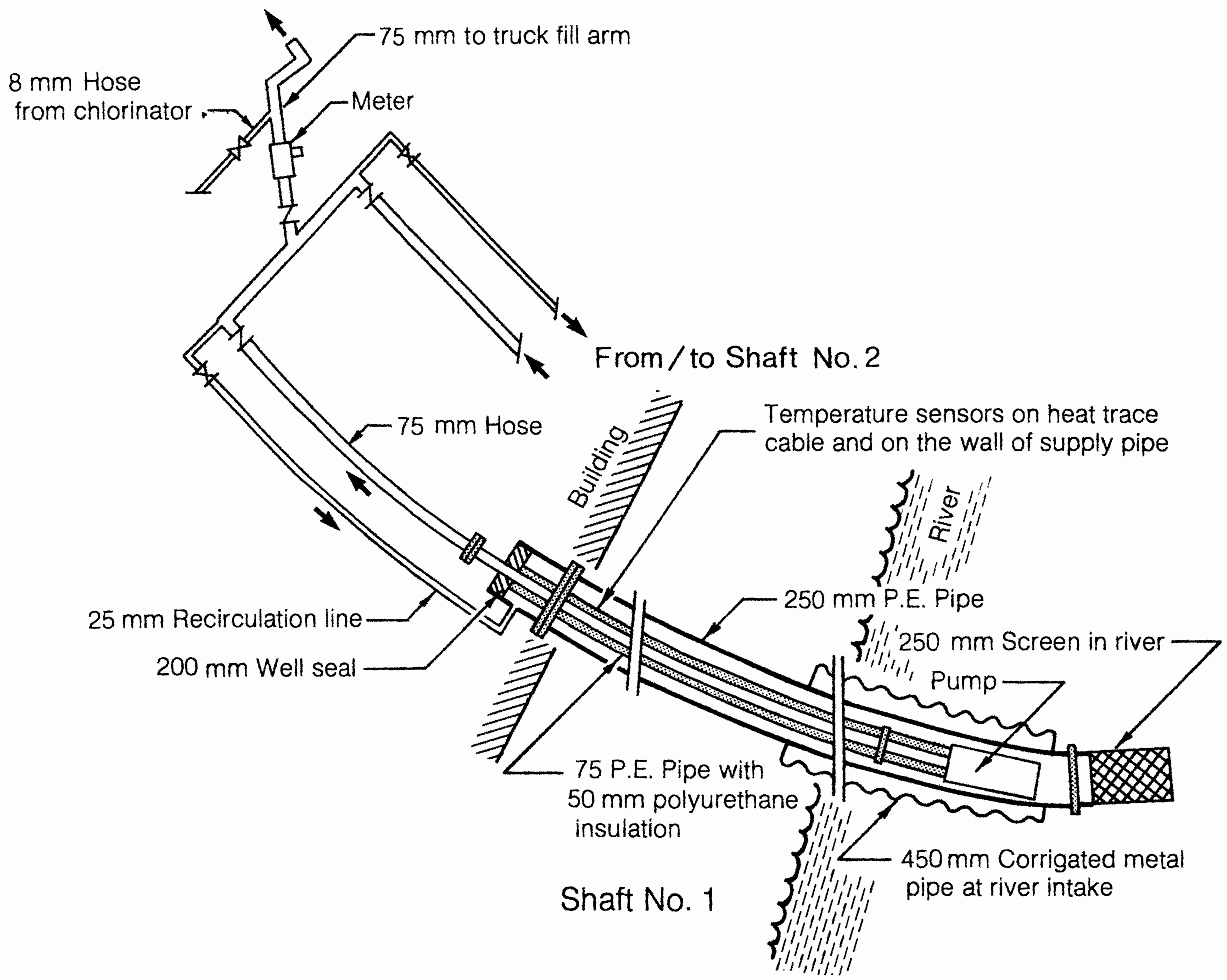


FIGURE 3-7. INTAKE HOUSE IN PEEL CHANNEL AT AKLAVIK, NWT


75 mm to truck fill arm
8 mm Hose
from chlorinator
Meter
From/to Shaft No. 2
75 mm Hose
Building
Temperature sensors on heat trace
cable and on the wall of supply pipe
River
250 mm P.E. Pipe
25 mm Recirculation line
250 mm Screen in river
200 mm Well seal
Pump
75 P.E. Pipe with
50 mm polyurethane
insulation
450 mm Corrigated metal
pipe at river intake
Shaft No. 1

Open water intakes in cold regions are jeopardized by flowing ice during freeze-up and breakup and must be given special attention.

Figures 3-9 and 3-10 show a water intake at Cambridge Bay in the Northwest Territories of Canada. Note that the intake line is installed to allow water to flow to the wet well by gravity so that even if the intake itself were damaged, water would remain available at the pump. Note also the construction details, such as insulation, wet well heater, heat trace for intake line and recirculation line from townsite.

Use of multiple intakes is a recommended approach which may enhance system reliability. An intake normally submerged in the summer may be high-and-dry late in the fall when streamflow has been reduced by freezeup. Further reason for multiple intakes is the option that provides for continuously circulating water to minimize ice cover and prevent freezing of the intake system.

Frazil ice is a phenomenon which occurs during freeze-up and creates problems for operation of river intakes in open water. Frazil ice occurs as ice forms in flowing water which is slightly colder than $0^{o}C$ (supercooled) and from which heat is continually being lost. Frazil ice adheres to and builds up on any submerged object it contacts, including itself. Thus intake screens, trash racks and the like may become choked by frazil ice in a matter of hours. Frazil formation can be prevented by locating the intake in a reach of river where surface ice forms before the water is supercooled, such as in a long, calm reach. Surface ice cover prevents rapid heat loss from the water and thus precludes frazil formation. Heating the intake works bar screens and the like to $0.1^{o}C$ will remove supercooling properties and prevent frazil ice accumulation.

3.4.2 Infiltration galleries

Infiltration galleries offer some advantages over conventional river or lake intakes. The most obvious is to remove the structure from the river and the hazards imposed by ice during freeze-up and breakup. Infiltration galleries may be placed in the thaw bulb of streams in permafrost areas and collect water even when the streams appear solidly frozen. Usually some flow of water will occur within the streambed itself, particularly when the bed material is relatively coarse.

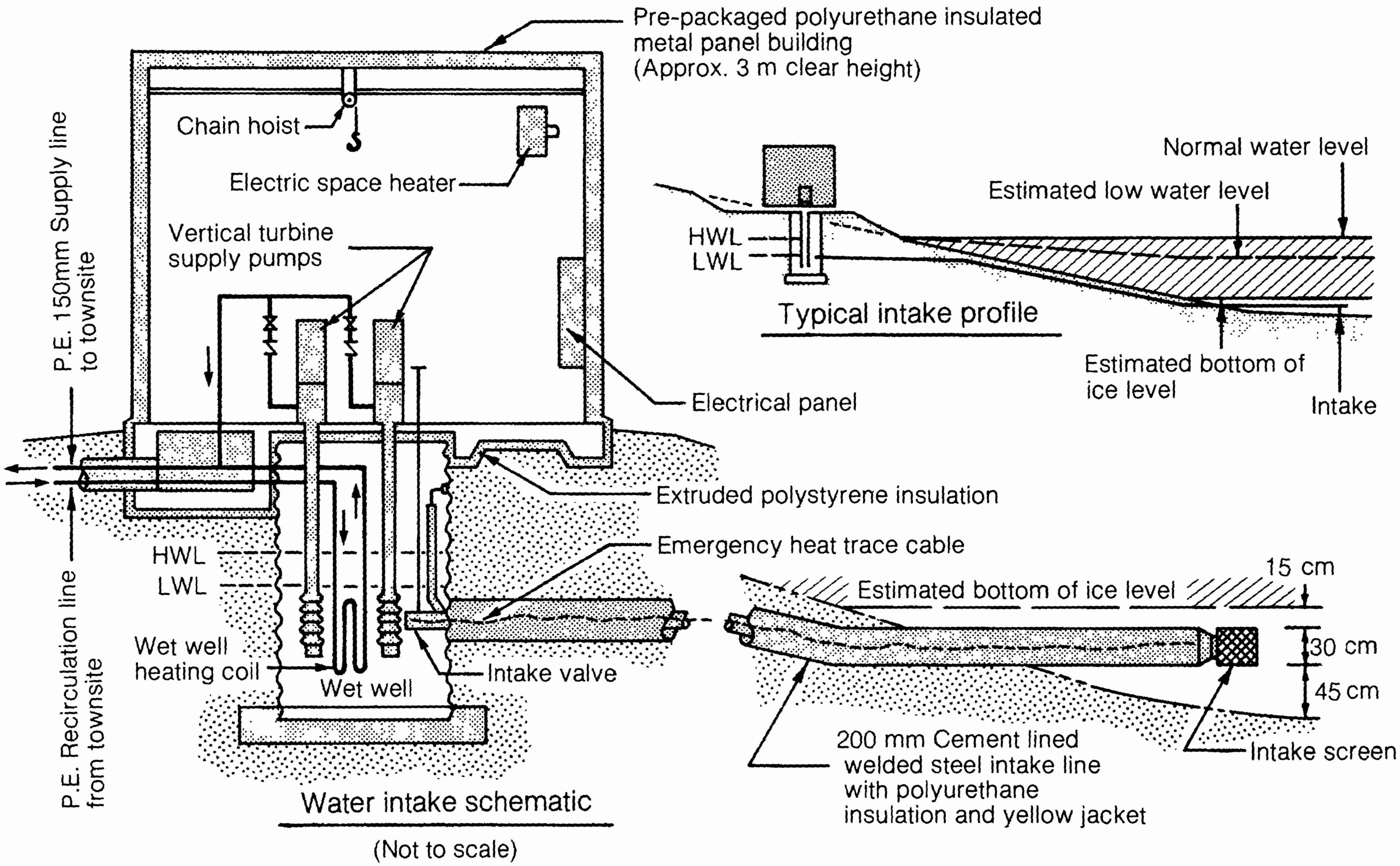


FIGURE 3-9. WATER INTAKE SCHEMATIC

FIGURE 3-10. WATER SUPPLY UTILIDOR AT COPPERMINE, NWT

A second benefit offered by the infiltration gallery is the filtration of the water by the materials surrounding the collectors. This may be a very significant advantage in streams which carry a load of suspended material such as silt or glacial rock flour.

Infiltration galleries may be constructed parallel to the water course, across the water course, vertically, or radially. Schematics of such systems are shown in Figure 3-11.

Galleries must be protected against freezing, especially in permafrost areas. Some sort of heating system is usually installed during construction. Both electric and steam heating systems have been successfully used. Usually steam lines are placed on the upper surface of the lateral and a second steam line is installed 0.4 to 0.6 metres above the lateral.

Insulation with snow is another way to reduce frost penetration However, to be effective, the area should receive no traffic in order to preserve the uncompacted snow cover [7].

Periodic gallery cleaning may be necessary to remove silt and other sediments which enter the laterals and sumps. The use of modern filter fabrics may reduce this requirement and improve overall system performance.

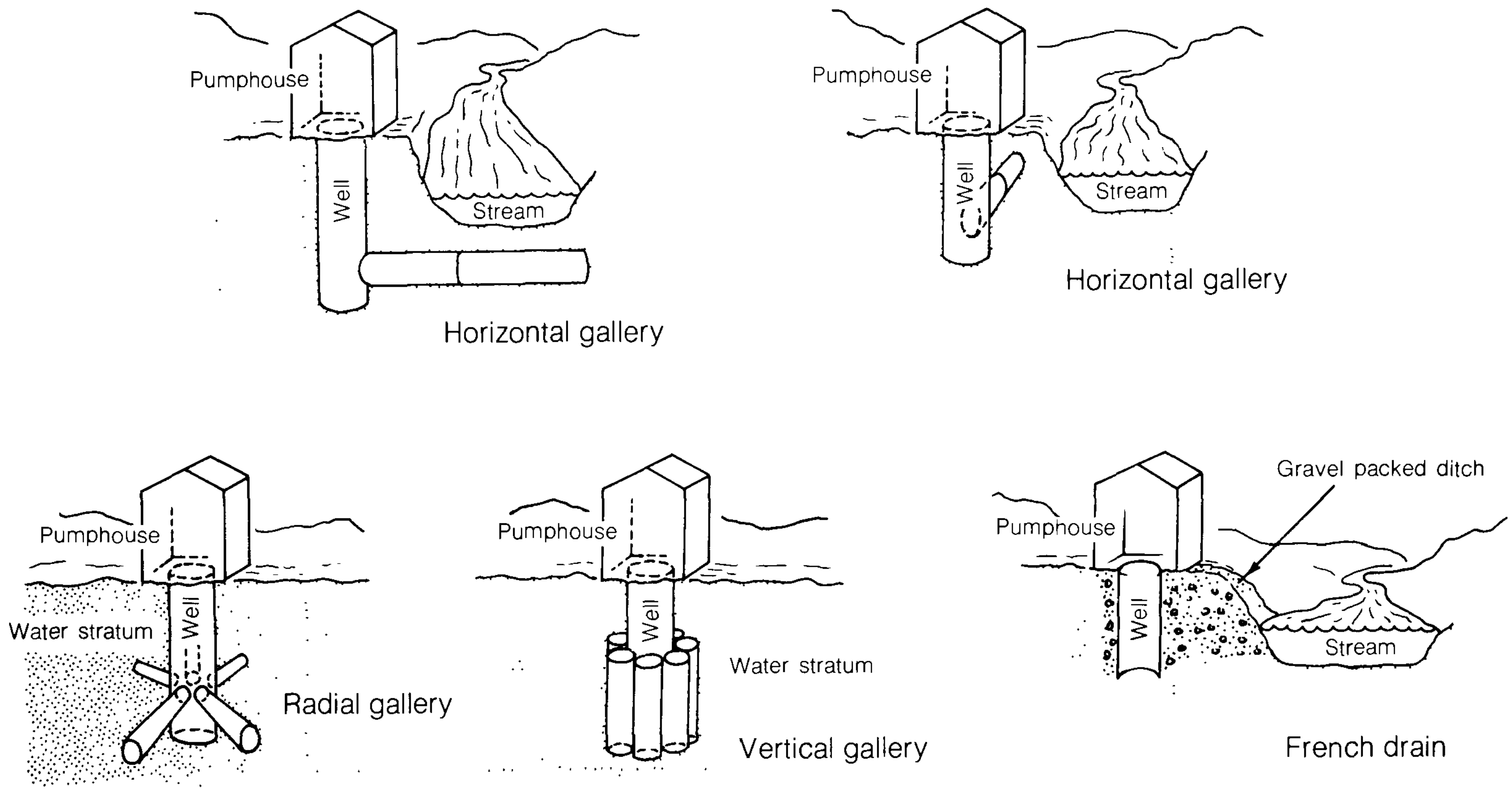


FIGURE 3-11. INFILTRATION GALLERIES

Springs can be developed by installing horizontal infiltration galleries in the aquifer. This is a generally approved method since it reduces the possibility of water contamination at the point of collection.

3.4.3 Wells

A producing well is most successfully located through detailed examination of geologic conditons: kinds and permeabilities of soils and rocks; position of layers; character of cracks, fissures and other large openings; and a study of performance records of other wells in the area [8]. Especially in arctic regions, professional hydrogeologists familiar with permafrost should be consulted during the preliminary stages when considering groundwater as water supply source.

In all cases, wells must be located a safe distance from potential sources of pollution. Local health departments usually have specific requirements but in the absence of other guides, wells should be at least 60 m from the nearest source of pollution.

3.4.3.1 Well drilling. There are several opinions on the best method for drilling water wells. Locations, accessibility, size of well required and other such factors will influence the methods used. The U.S. Public Health Service, Indian Health Service, Office of Environmental Health believes that because of equipment transportability, cable tool drilling is superior in remote areas. "Jetting" of smaller wells has the advantage of relatively low cost and the machinery is easier to move into remote areas. Cable tool systems require less water for the drilling operation than the jetting method, although most water used in drilling can be reused.

Jetting combines hydraulic action and thawing, relying upon the volume of water rather than high pressure to "drill" the well. A stream of water is directed down into the ground, gradually thawing the soil which is washed away in the water. Water may be reused repeatedly by recirculating through a settling basin to remove cuttings. Jetting is best suited to frozen soils which are primarily sand, silt, clay, or a combination of these. The system is not effective in regions where there are large rocks or layers of rock to be penetrated.

Cable tool drilling uses the weight of a "string" of drilling tools to penetrate through all varieties of soil and rock. Progress may be from 1.5 m to more than 30 m per day, depending upon geologic conditions. Tools are lifted, dropped and turned regularly; this pulverizes the soil or rock and allows it to be suspended and carried away by a minimal amount of water and a bailer. In hard formations, no casing is required until the well is completed. However, in sand, silt or clay (or organic) soils the string of tools is operated inside the well casing. The casing is usually driven into the ground and then the well drilled inside. This procedure is repeated in a leap-frog manner until a water-bearing stratum is penetrated.

Rotary drilling machinery may also be used in all types of geological formations, but involves considerable expense for equipment, and reasonable degree of operational experience and skill. Whereas jetting and cable tool drilling equipment may be "broken down" for transport in light aircraft, rotary drills are not as small nor as easily moved to remote locations. Rotary drills are, in general, much faster than other means of drilling. As with cable tool drilling, a small amount of water is used with the rotary drill. A special Bentonite "drilling mud" pumped down through the drill stem and out through ports in the drill bit and subsequently to the surface carries away the cuttings. The drilling mud coats the sides of the hole and protects it from scouring action of the water. Drilling mud is used over and over during the drilling operation after the cuttings have been removed.

In some instances it may be necessary to heat the drilling fluid during the operation, such as when drilling through frozen soil under winter conditions. The heated fluid prevents the mud from freezing in the permafrost and aids in thawing as the drill penetrates.

Air rotary drilling is a variation of rotary drilling which employs pneumatic rather than hydraulic action to carry cuttings away from the drill.

3.4.3.2 Well seals. Sanitary well seals on top of well casings will prevent contamination by surface sources and still permit easy removal of the pump when necessary. If pumps and pipes to the building can be installed below the seasonal frost line, a single pipe from the well will suffice. However, if the well is installed in permafrost or pipes cannot be installed below seasonal frost, some method will be required to prevent freezing of the well. One such system is illustrated in Figure 3-12. The use of Bentonite grout instead of cement provides an adequate seal and reduces the possibility of frost heave damage to the well casing.

3.4.4 Pumping stations

Pumphouses can provide shelter for pumping equipment controls, boilers, treatment equipment and maintenance personnel who must operate and service the facility. Structural design will depend on the requirements of each location and must be considered individually. Equipment housed within the shelter will also depend on the individual system and may vary from a simple pump to a complex system with boilers for heat addition, standby power, alarm systems to alert operators of malfunction and the like. Any system must provide the degree of redundancy and safeguards required by the nature of the operation and location. Figure 3-13 shows the pumphouse at Rankin Inlet, Northwest Territories.

More elaborate pumphouses will include redundant pumps, standby power sources and alarm systems to alert the operator in the event of failure. Voltage control devices are recommended to protect electrical equipment where power is of questionable consistency or dependability (see Figure 3-14).

All pumphouses should be designed with moisture-proof floors since water will be on the floors frequently. Pumphouses in cold regions must be large enough to accommodate additional equipment such as heaters and their controls. Oversizing the original pumphouse at an installation should be considered carefully in relation to design life and the accuracy of demand predictions.

Heat addition at the source is usually desirable since the water will be very cold, often approaching $0^{\circ}C$. Protection from freezing, then, is the overriding reason for heating water at the source, although there are also difficulties associated with treatment of very cold waters. Enough heat must be added to at least compensate for heat lost in transmission. It is generally accepted that water in transmission lines should

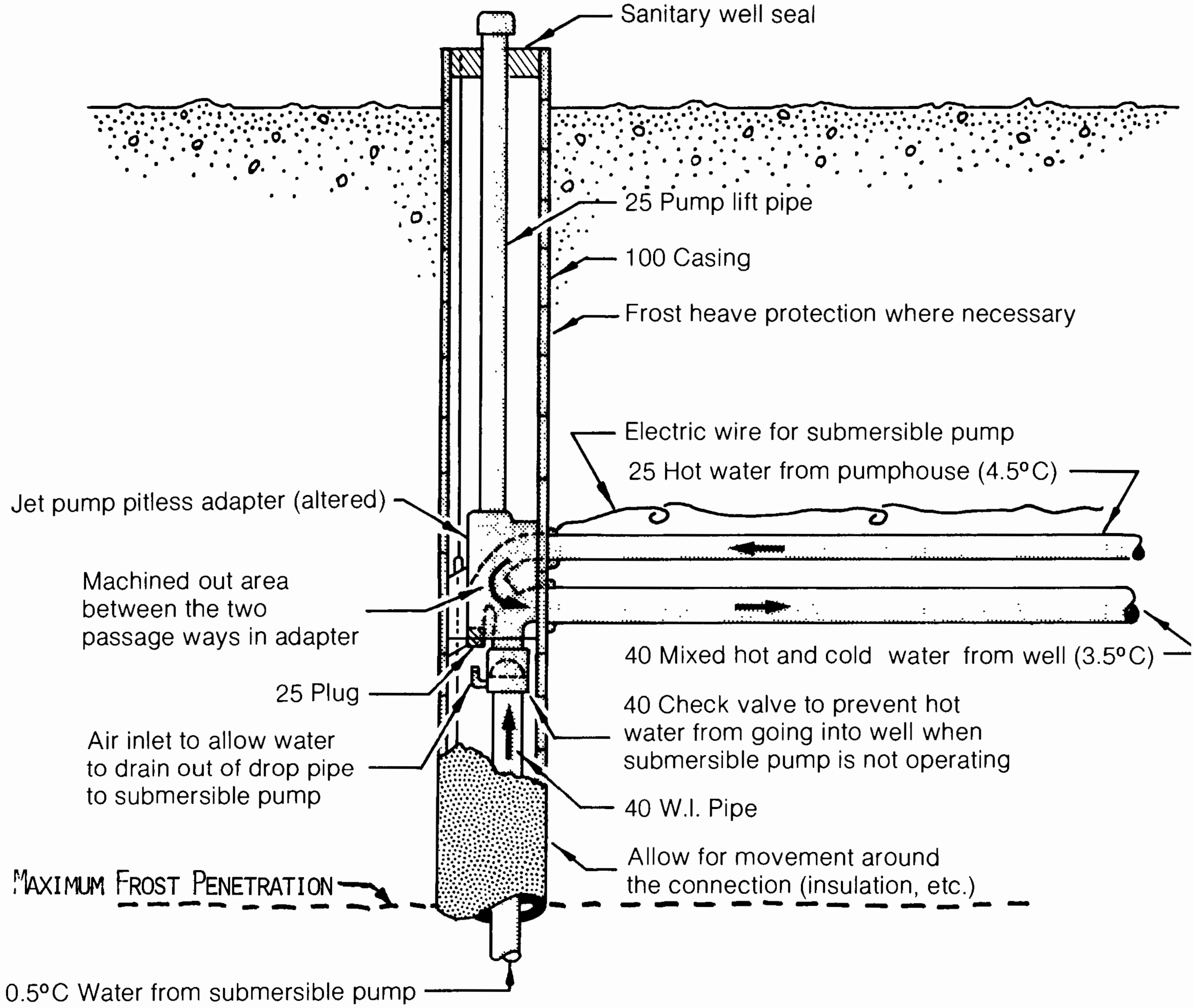


FIGURE 3-12. WELL SEAL

FIGURE 3-13. PUMPHOUSE AT WILLIAMSON LAKE AT RANKIN INLET, NWT

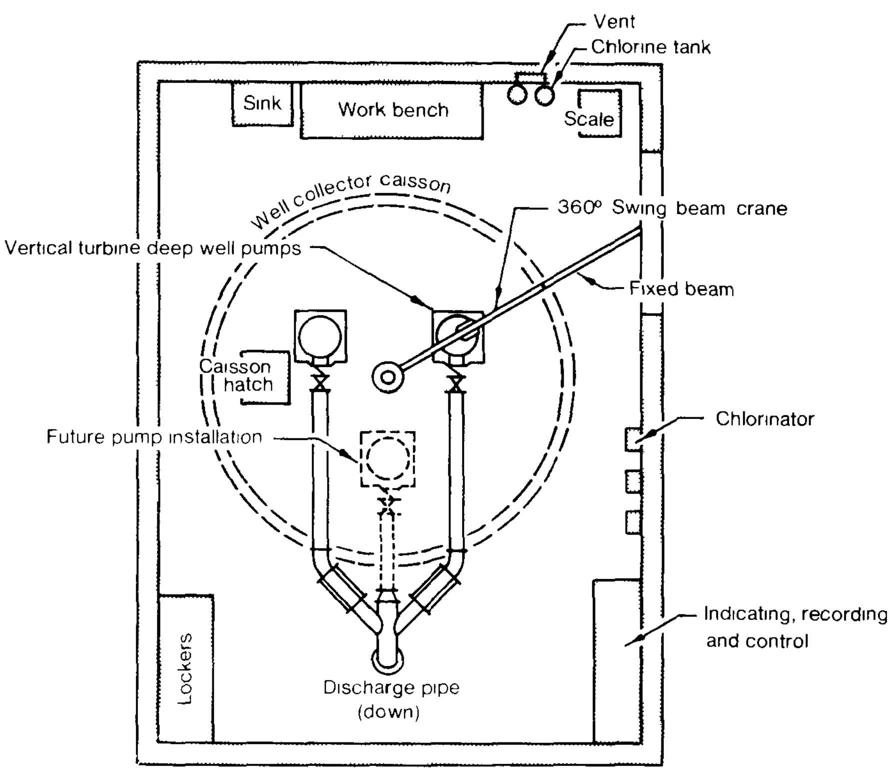


FIGURE 3-14. PUMP STATION

be at least 4°C to provide an adequate margin for heat loss in the event of a pump failure.

3.4.5 Transmission lines

Pipelines carrying water from the intake and pumphouse to the storage reservoir may be either buried or laid above-ground, depending upon local conditions. In general, buried lines are preferred to reduce maintenance and heat loss. Surface or elevated lines must have additional insulation and should be protected from climatic and physical abuse which is likely to occur. All pipelines should be provided with some form of heat tracing or thawing method. More detailed design information is covered in Sections 6 and 15.

Pumps and transmission lines should be provided with drains, preferably automatic, to evacuate the water in case of power loss or other long-term failure, and thus prevent rupture due to freezing. These essential provisions may be as simple as the elimination of check valves and providing positive gradient.

3.5 References

1. Slaughter, C.W., Mellor, M., Sellmann, P.V., Brown, J., and Brown, L. "Accumulating Snow to Augment the Fresh Water Supply at Barrow, Alaska". U.S. Army, Cold Regions Research and Engineering Laboratory. Special Report 217, Hanover, New Hampshire, January, 1975.

2. McFadden T., and C. Collins, "Case Study of a Water Supply for Coastal Villages Surrounded by Salt Water", Cold Regions Specialty Conference, 17-19 May, 1978, Anchorage, Alaska, American Society of Civil Engineers, New York, N.Y., 1978.

3. Smith, M.W. and C.T. Hwang, "Thermal Disturbance due to Channel Shifting, Mackenzie Delta, N.W.T, Canada" In: North American Contribution to Permafrost Second International Conference, 13-28 July, 1973, Yakutsk, U.S.S.R., National Academy of Science, Washington, D.C., pp. 51-60, 1973.

4. Alter, A.J. "Water Supply in Cold Regions". Cold Regions Science and Engineering Monograph III-CS2. U.S. Army, Cold Regions Research and Engineering Laboratory. Hanover, New Hampshire, January, 1969.

5. Reed, S.C. "Water Supply in Arctic Regions". New England Waterworks Association. Vol. 84 (4), December, 1970.

6. U.S. DHEW. Public Health Service. "Manual for Evaluating Public Water Supplies", PHS Pub. No. 1820, Washington, D.C., January, 1969.

7. Feulner, A.J. "Galleries and Their Use for Development of Shallow Ground Water Supplies with Special Reference to Alaska". U.S. Geological Survey Water Supply Paper 1809-E, Washington, D.C., January, 1964.

8. Longwell, C.R. and Flint R.F. Physical Geology. John Wiley & Sons, New York, 1955.

3.6 Bibliography

Alter, A.J. "Arctic Environmental Health Problems". CRC Critical Reviews in Environmental Control, Vol. 2, pp. 459-515. January, 1972.

Babbitt, H.E., Doland, J. James and Cleasby, John L. Water Supply Engineering. McGraw-Hill, 1962.

Campbell, Michael D. Water Well Technology. McGraw-Hill, New York, 1973.

Dickens, H.B. "Water Supply and Sewage Disposal in Permafrost Areas of Northern Canada". Polar Record, Vol. 9, p. 421, 1959.

Eaton, E.R. "Thawing of Wells in Frozen Ground by Electrical Means". Water and Sewage Works, Vol. III (8), August, 1964.

Foulds, D.M. and Wigle T.E., "Frazile-the Invisible Strangler". Journal AWWA, Vol. 69, No. 4, p. 196, April, 1977.

Gordon, R.C. "Winter Survival of Fecal Indicator Bacteria in a Subarctic Alaskan River". U.S. Environmental Protection Agency Report EPA-R2-72-013, Washington, D.C., 1972.

Heinke, G.W. "Sanitation for Small Northern Communities: Some Problems and Goals". Canadian Journal of Public Health, Vol. 62, 1971.

Hostrup, Lyons and Assoc. "Study of the Mechanical Engineering Features of Polar Water Supply". U.S. Naval Civil Engineering Research Lab. Contract No. y 27491. August, 1953.

Karr, W.V. "Groundwater, Methods of Extraction and Construction". International Underground Water Institute. 1969.

McKee, Jack Edward and Wolf, Harold W., "Water Quality Criteria". The Resources Agency of California. Publication #3-A, Sacramento, 1963.

Page W.B., Hubbs G.L., Eaton E.R., "Report on Procedure for Jetting Wells". Arctic Health Research Centre, Fairbanks, Alaska, May, 1958.

Rice, E.F. and Alter A.J., "Water Supply in the North". The Northern Engineer. Vol. 6 (2), 1974.

U.S. Arctic Health Research Centre, "Technical Information on Water Supply Management for North Slope Activities". Report No. 106, Fairbanks, Alaska, 1970.

U.S. Department of the Navy, Naval Facilities Engineering Command. "Cold Regions Engineering Design Manual", NAVFAC DM-9. Alexandria, Va., March, 1975.

SECTION 4

WATER TREATMENT

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4 WATER TREATMENT

4.1 General

The objectives of water treatment in cold regions are identical to those in other areas - to provide high quality potable water to improve and sustain health and eliminate the spread of waterborne disease.

Under most conditions the treatment methods used in cold regions are the same as those in temperate climates. However, temperature has a significant effect on many processes in water and wastewater treatment, sometimes requiring adjustment in design and operation.

Water is susceptible to a change of state at temperatures of $0^{o}C$ or less unless properly protected. When means of replenishing lost heat fail, freezing may occur even when pipes and tanks have been insulated. For this reason and because treatment is simplified when water is relatively warm ($> 5^{o}C$), it is common practice in cold regions to add heat to water prior to or as a part of the treatment process.

Cold climate conditions require that special attention be given to certain aspects of treatment plants and processes. Although these considerations sometimes seem trivial, failure to attend to them may cause serious difficulty in achieving desired objectives.

Quality standards have been established for drinking water in the United States and Canada. These standards are presented only as a guide since provincial or state standards may be more restrictive.

4.2 Process Design

Standard water treatment processes may need to be modified when they are applied to cold waters. An alternative to process modification is the option of adding heat as a pretreatment operation; sometimes both methods are used together.

Water treatment involves chemical, physical and biological processes which are, to a greater or lesser extent, temperature sensitive. "Cold water" is the term used to describe water in the temperature range of $0^{o}C$ to about $5^{o}C$. Exact definition of the range is not intended nor is it required since changes are continuous with temperature.

4.2.1 Heat addition

Heat addition is often practiced to protect the distribution system. When heat is added prior to treatment, other benefits accrue. Also, as an alternative to modifying unit process designs to compensate for low temperature, the designer may choose to add heat to the water as a preliminary treatment step. The annual temperature variation for surface waters in cold regions varies from 0°C to about 20°C. By adding heat during the period when the water is cold, other treatment processes may be used essentially unmodified. Higher sedimentation and filtration rates and reduced mixing times result, and overall plant requirements for space and energy are reduced. Moreover, pumping requirements for warm water are lower than for cold water.

4.2.1.1 Corrosion control. Cold water can absorb more oxygen than warm water. Figure 4-1 shows the variation of oxygen saturation with temperature. As water is warmed, oxygen is released. This oxygen causes iron and steel pipes, pumps and tanks to rust. By controlling the region in which oxygen is released, corrosion within the treatment plant and the distribution system may be reduced.

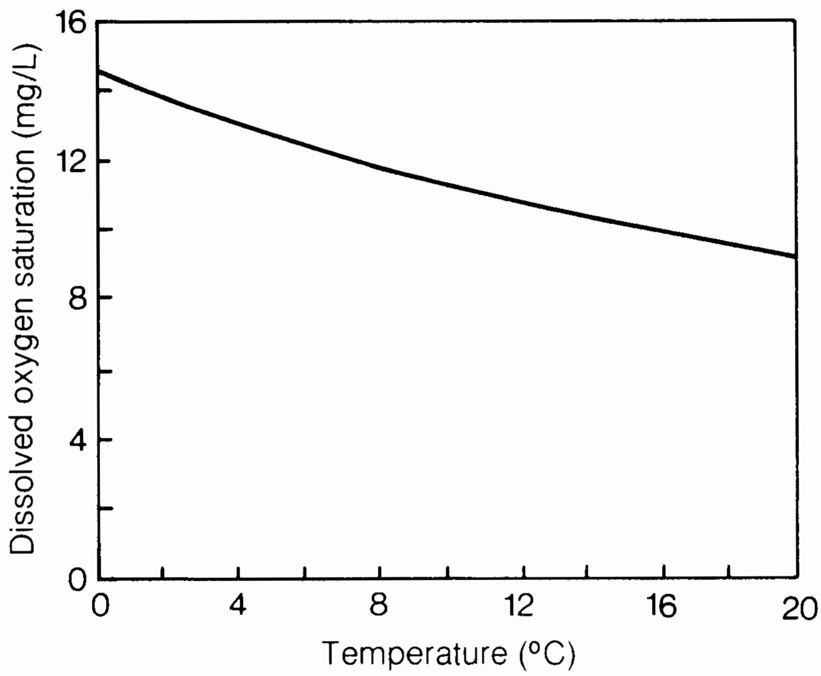

FIGURE 4-1. DISSOLVED OXYGEN SATURATION VARIATION WITH TEMPERATURE.

4.2.1.2 Standardization. Virtually all "package" type treatment systems are designed for use with water warmer than about 5°C. If incoming water is expected to be colder, heat must be added for the system to perform properly at design rates. This allows the use of standard design in areas of varying water temperature.

4.2.1.3 Method of heating. Several methods of heating water may be used for equally satisfactory results. It should be remembered that purity of drinking water is extremely important and any possibility of contamination must be avoided.

Direct fired boiler. This system uses a direct-fired oil, gas or coal furnace operated so that the water is maintained below boiling, usually at about 90°C. Three basic types of boilers are 1) water tube, 2) fire tube, and 3) cast iron water jacket. The boiler must be operated in a manner which prevents cooling exhaust gases below the dew point. Cold water may reduce exhaust gas temperature significantly and if condensation occurs corrosion will reduce boiler and chimney life. Thermal efficiency is optimized when the boiler is operated at the lowest temperature possible without causing condensation of exhaust gases.

Liquid-liquid heat exchangers. This system employs a closed vessel containing a series of tubes. An inlet and an outlet manifold are provided for both the jacket and the tube bundle. Usually the hot liquid is circulated through the jacket and the liquid to be heated is circulated through the tubes.

The source of heat for this system may be a building or city central heating system or the cooling water from an engine, or any other suitable source. Antifreeze may be used in the hot fluid but caution must be exercised because of the possibility of tube leak and cross-connection.

Blending. Occasionally a source of hot water is available which can be blended with cold water to achieve the desired temperature. Such a source may be condenser water from a steam system. Fairbanks, Alaska, successfully employed this system of warming cold well water. In Whitehorse, Yukon Territory, geothermal water is added to raw water and provides a very substantial saving.

4.2.2 Coagulation and flocculation

Coagulation is a chemical process involving the destablization of colloids. It is slightly temperature-sensitive in the range from 0°C to 30°C. Flocculation is the aggregation of destabilized colloidal particles to a size adequate for subsequent settling by gentle mixing of the fluid in which the colloids are contained. The inter-particle contacts necessary for flocculation are influenced by fluid viscosity. Figure 4-2 shows viscosity is inversely related to temperature.

4.2.2.1 Mixing. Mixing is an important function in water treatment since it is required for flocculation and the dissolving of solids in liquids. Mixing is strongly dependent on temperature because of changes in the viscosity of the liquid. Figure 4-3 can be used to make the necessary adjustments in design criteria for temperature-induced viscosity changes. It is plotted with 20°C as the base level. The power input for mechanical flocculation is directly dependent on fluid viscosity, as defined by:

$$P = G^2 V \mu \tag{4-1}$$

where: P = power input (kW),
G^2 = velocity gradient (m/s/m),
V = tank volume (m^3),
μ = absolute fluid viscosity (Pa/s).

To maintain the same velocity gradient in the tank as the liquid temperature decreases, it is necessary to adjust the 20°C power requirement by the multiplier from Figure 4-3. This relationship will be valid for any type of mechanical mixing.

Detention time required for mixing is determined separately. It is influenced by the time required for desired reactions to occur and is often arbitrarily based on successful performance of similar units. Recommended detention times for flocculation of water range from 15 to 30 minutes. Increasing this detention time will compensate for lower water temperatures. The multipliers from Figure 4-3 can also be used for this purpose. Multiple basins in series are the most effective way to increase detention time, provided some basins can be bypassed during warm weather.

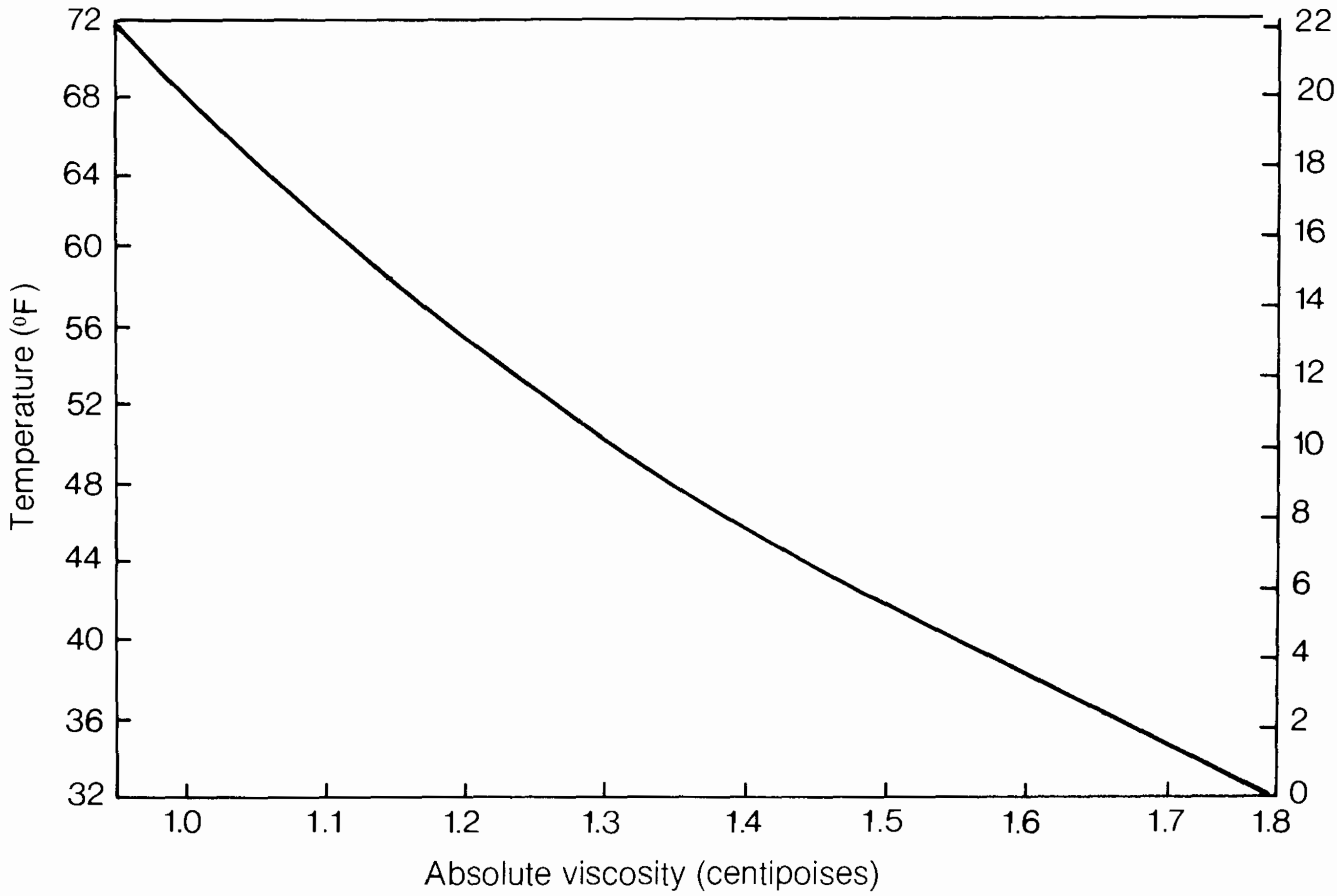

FIGURE 4-2. VISCOSITY OF WATER AT ATMOSPHERIC PRESSURE

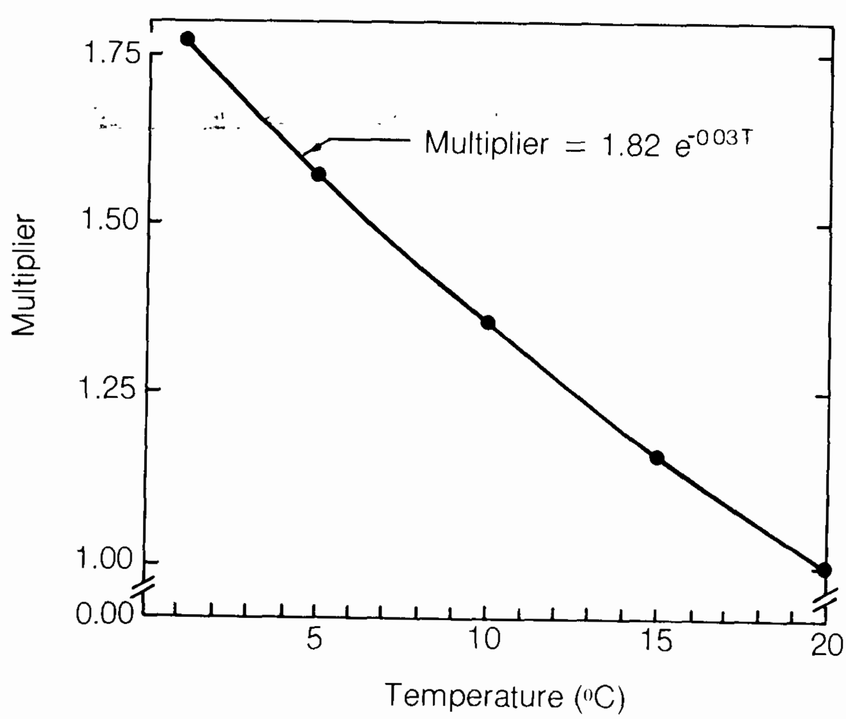

FIGURE 4-3. VISCOSITY EFFECTS VERSUS TEMPERATURE

One alternative to extended mixing time is the use of higher chemical dosage. Another is to adjust pH to the optimum for the temperature of the water being treated. Optimum pH varies inversely with water temperature. It is advisable to evaluate each alternative since one may be more economical.

4.2.3 Sedimentation

Settling of particulate materials is retarded by increased viscosity in cold waters. The settling velocity of particles is proportional to the temperature as shown in Figure 4-4. Increased clarifier size is recommended where cold water is to be treated.

Upflow clarifiers. Upflow and sludge blanket clarifiers are not as sensitive to low temperature as conventional clarifiers. However, temperature variations may cause thermal currents which can easily break through the sludge blanket and ruin efficiency. Sludge blanket and upflow clarifiers should be operated at nearly constant temperatures. Table 4-1 presents some recommended loading rates for upflow clarifiers which employ tube modules.

4.2.4 Filtration

Filtration is affected by low water temperature to the extent that head losses through the filter are proportional to viscosity. The relative head loss changes about 3.5% per degree Celsius temperature change. Normal sand filter loading rates are about 5 $m^3/m^2{\cdot}h$ and mixed media filter loadings are about 12 $m^3/m^2{\cdot}h$. Therefore, multi-media filter beds would provide more efficient use of space in cold climate facilities. The multiplier values from Figure 4-3 should be used to reduce filtration efficiency. For example, if the initial design head loss is 1 m at 20°C it will be about 1.5 m at 5°C.

Backwashing of filters is also affected. Power for pumping will vary as shown on Figure 4-2. Adjustments for filtration and backwashing are based on viscosity changes. However, the minimum upflow velocities or wash rates to fluidize and clean filter media will be reduced because of increased fluid density. For example, if it takes a velocity of 0.09 cm/s to fluidize a sand bed at 20°C it will only require 0.06 cm/s at 5°C.

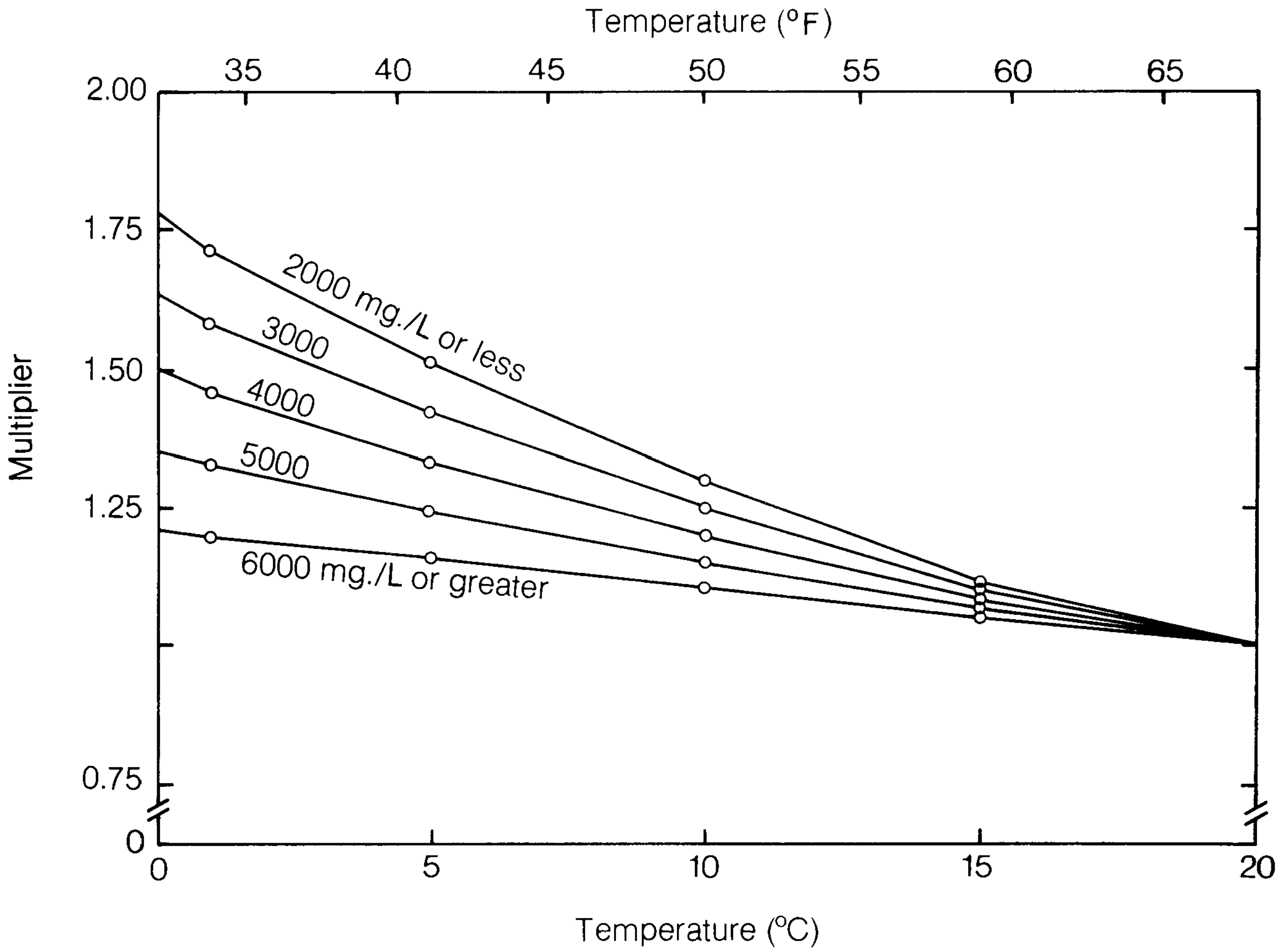

FIGURE 4-4. SETTLING DETENTION TIME VERSUS TEMPERATURE

TABLE 4-1. UPFLOW CLARIFIER LOADING RATES

Overflow rate based on total clarifier area and temp. less than 4°C.		Overflow rate based on total clarifier area and temp. greater than 10°C.	
m^3/m^2 h	gpm/ft^2	m^3/m^2 h	gpm/ft^2
3.7	1.5	4.9	2.0
4.9	2.0	6.1	2.5
Overflow rate based on area of clarifier covered with tubes. Temperature less than 4°C.		Overflow rate based on area of clarifier covered with tubes. Temperature greater than 10°C.	
m^3/m^2 h	gpm/ft^2	m^3/m^2 h	gpm/ft^2
6.1	2.5	4.9	2.0
8.6	2.5	7.3	3.0

4.2.5 Adsorption

Adsorption is an exothermic process and in the range of 0°C to 20°C is essentially unaffected by temperature change [1,2].

4.2.6 Disinfection

Disinfection is the process of destroying or inactivating disease-causing organisms in the water. Traditionally, disinfection has been directed toward reduction of bacteria and is probably not as effective in destroying either viruses or cysts.

4.2.6.1 Chlorine. Chlorine has been almost universally used as a disinfectant for potable waters throughout this century. The greatest advantages are the ability to maintain and measure residuals, low cost and economy of use. Also, the availability of chlorine as Cl_2 gas, calcium hypochlorite $Ca(OCl)_2$ and sodium hypochlorite (NaOCl) make it possible to safely handle the disinfectant under a variety of conditions. Logistics and operator qualifications should guide the designer in selecting the chlorine source.

Solubility of chlorine is theoretically a factor in cold water. However, chlorine is virtually never dosed at rates which are insoluble in water in the normal range of temperatures.

In recent years there has been significant concern over the byproducts created by using chlorine as a disinfectant in waters containing organic compounds. It has been discovered that some organic compounds form carcinogenic substances when exposed to chlorine in water. As a result there is a growing trend away from pre-chlorination in the production of potable water.

Chlorine disinfection is hindered by cold water. Exposure time must be increased as water temperature decreases. Contact time of at least one hour is recommended and residuals must be maintained throughout the contact period to achieve the desired bacteriacidal effects.

4.2.6.2 Halogens. Aside from chlorine, two other members of the halogen group have been used as potable water disinfectants. These elements are iodine and bromine. Both substances have been tentatively approved but their use has been primarily supplemental to chlorine in swimming pools with only occasional use as potable water disinfectants.

Costs for iodine and bromine cannot compete with gaseous chlorine (about 25 to 1); however, iodine may be competitive with some forms of hypochlorite.

Iodine has the advantage over chlorine of producing minimal tastes and odours in the presence of phenols. Also, iodine can be stored in non-metallic containers for extended periods without appreciable loss or deterioration.

4.2.6.3 Ozone. Next to elemental fluorine, ozone is the strongest oxidizer known and as such it is an excellent disinfectant. Ozone also has other possible uses which are discussed in Section 4.2.13.

Ozone is only slightly temperature sensitive so no appreciable modification of standard technique is required. However, ozonation equipment is expensive to install and operate. Where cost is less important than logistic consideration, ozone has the advantage of being generated from air using electricity and is unaffected by resupply problems in remote areas.

4.2.7 Fluoridation

Fluoridation of potable water in cold climates requires a higher dosage because per capita consumption of drinking water tends to be somewhat less than in temperate regions. Normally, fluoride concentration should be about 1.4 mg/L in cold regions. Table 4-2 lists the recommended ranges of fluoride in drinking water at various annual average air temperatures.

TABLE 4-2. FLUORIDATION REQUIREMENTS

Annual average of maximum daily air temperature* °C	Recommended control limits Fluoride concentrations in mg/L		
	Lower	Optimum	Upper
12 and below	0.9	1.4	2.4
12.1 to 14.6	0.8	1.1	2.2
14.7 to 17.6	0.8	1.0	2.0
17.7 to 21.4	0.7	0.9	1.8
21.5 to 26.6	0.7	0.8	1.6
26.7 to 32.5	0.6	0.7	1.4

* Based on temperature data for at least five years.

4.2.8 Water softening

Water softening is often required in cold climates where groundwater frequently contains high concentrations of calcium and/or magnesium hardness. Two methods of softening are well developed: ion exchange and chemical precipitation.

4.2.8.1 Ion exchange. Ion exchange water softening is affected by low water temperature to the extent that it is essentially a filter-type system and flow is viscosity dependent.

Waters derived from subpermafrost aquifers tend to be slightly deficient in oxygen and as a result may contain relatively large amounts of soluble forms of iron. Iron can foul zeolite and greensand ion exchange resins and must be removed prior to softening. (See Section 4.2.9).

4.2.8.2 Chemical precipitation. Lime-soda softening is frequently used where water to be treated is turbid and requires clarification. This process is affected by low water temperature since it involves mixing, flocculation, sedimentation, filtration and sludge handling.

4.2.9 Iron removal

Iron is of considerable concern in waters in cold climate areas. Iron is one of the most abundant elements in nature and its presence in varying amounts is to be expected. It may exist in any of nine valence states but Fe^{+2} and Fe^{+3} are most important in water. In addition to elemental iron, organic iron complexes present problems.

Limiting iron in water supplies is more for aesthetic purposes than for health reasons. Canadian Drinking Water Standards and Objectives and the U.S. National Secondary Standards for drinking water limit iron to 0.3 mg/L.

High iron concentrations in cold climate waters may be explained as follows. Groundwaters and waters beneath the ice in ponds and shallow lakes are deficient in dissolved oxygen. As the water dissolves iron it is oxidized to $FeOH^+$, which is a highly soluble form. In surface waters where there is sufficient dissolved oxygen, much less soluble $Fe(OH)_3$ and Fe_2O_3 are formed.

Treatment of waters containing iron requires oxidation, which may be accomplished by aeration or by chemical oxidation with chlorine or ozone. Simple aeration is not effective for removing iron/organic complexes.

Low temperatures restrict the aeration process. Although oxygen is more soluble at low temperatures, overall gas transfer is lower. This is explained on the basis of viscosity, gas/liquid contact etc. Furthermore, the type of aeration system influences gas transfer rates. Compressed air systems are more efficient than mechanical surface-type aerators. Oxygen transfer coefficients have been evaluated over the temperature range from 3°C to 35°C with the following results:

- for compressed air system = $1.024^{(T_\Theta - T_2)}$
- for mechanical aerators = $1.016^{(T_\Theta - T_2)}$

Coarse bubble diffusers tend to be more maintenance-free than other types of aerators. Aeration can be accomplished by cascade or "waterfall" systems, but these tend to be associated with humidity problems in the treatment plant.

Aeration tanks should have a width to depth ratio of 2 to 1 or greater to promote good mixing. Detention time will be on the order of 10 to 30 minutes and the air volume range required will be 0.05 to 1.25 m^3 per m^3 water treated.

4.2.10 <u>Colour removal</u>

Objectionable colour concentrations are frequently found in water originating in tundra regions where organics are leached from decaying vegetable matter. Colour may be reduced or removed by chemical oxidation with chlorine or ozone and with carbon adsorption.

4.2.11 <u>Organics removal</u>

Organic materials in water, much like colour, are removed to a limited extent by coagulation and sedimentation. More complete removal requires carbon adsorption or ozone treatment.

Activated carbon is effective for removal of organics but when granular carbon is used, there is a strong potential for enhancing bacterial growth in the carbon bed. Organics removed from the water become food for micororganisms which may eventually be washed through the carbon bed and into the product water. Post disinfection is required in this situation.

Joint use of ozone and carbon adsorption has been found extremely effective in organics removal and for treating iron-organic complexes.

Ozone destroys microorganisms and breaks down many organics. The remaining organics are absorbed on the carbon beds.

4.2.12 Desalination

In coastal areas of the Arctic and in some areas where groundwater sources are highly mineralized, desalination may be required. Several desalination methods are available including distillation, reverse osmosis (RO) and freeze treatment.

4.2.12.1 Distillation. Distillation is the best known, most highly developed means of removing dissolved materials concentrations from water. Cold water increases the operational costs of distillation slightly. The relatively high skill requirement for operators makes this an undesirable process in remote areas. Small stills (about 20 m^3/h) require about 1 kg of diesel fuel for 175 kg product.

4.2.12.2 Reverse osmosis. Reverse osmosis (RO) uses mechanical energy to drive water through a semipermeable membrane. By proper membrane selection water may be produced which is quite acceptable for potable purposes. RO is temperature sensitive with the best results obtained when water temperatures are in the range of 20°C to 30°C.

The cost of RO is relatively high due to equipment operation and maintenance requirements. Small RO units are available in sizes from 3.5 m^3/day to 3500 m^3/day. These units require about 2.4 kWh of power for each cubic metre of water treated. The cost/benefit ratio for RO desalination is improved by the following factors:

1) higher water temperatures,
2) industrial/commercial water users,
3) sewers for brine disposal.

Reduction of the cost/benefit ratio is caused by the following:

1) high land costs,
2) high electrical power costs,
3) high population density per dwelling unit,
4) high interest costs.

Actual costs for RO in the United States ranged from 11 cents per cubic metre of water for a town of 63,000 people to 55 cents per cubic metre for a town of 1250 people.

RO treatment systems must be protected from freezing at all times. Membranes which have been frozen are unreliable even if freezing has occurred during shipping prior to installation.

4.2.12.3 Freezing. Treatment by freezing is a system which may be practical in cold regions where the cold may be used as a resource. This method is based upon the fact that as water freezes, impurities are slowly "refined" or "salted out" and the ice contains only pure water. Three types of freezing processes have been used successfully in pilot projects.

The reservoir process involves freezing a large volume of water. When ice containing the desired volume of water has been formed, the brine below the ice is withdrawn. When the ice is melted, purified water is the product.

Layer freezing involves a more complex system of freezing brackish water in successive sheets. The first water melted off in warm weather is wasted because it contains most of the impurities.

Spray freezing involves spraying brackish water through a modified lawn sprinkler to form a cone of ice. Pure water is frozen most quickly and brine drains away continuously throughout the winter. In a pilot scale test in Saskatchewan, chloride content was reduced from 2000 mg/L to 500 mg/L for 75% of the brackish water sprayed [3]. Estimated total costs for the process were about 22 cents per cubic metre of product.

4.2.13 Ozonation

Ozone as a disinfectant was briefly covered in Section 4.2.6.3. However, European experience with ozone in water treatment for many years has shown numerous benefits in addition to disinfection.

Iron and manganese are effectively removed by oxidation with ozone followed by separation. Applied early in the treatment chain, ozone rapidly oxidizes iron and manganese and aids in flocculation.

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* 1977 U.S. dollars.

Organics oxidation by ozone is accomplished by ozone addition in the middle of the overall process. Followed by granular activated carbon, this is very effective in removing organics and has none of the side effects of taste and odour associated with chlorination.

Ozone systems are expensive to build. Costs for a system producing less than 450 kg/d (O_3) are approximately $2200 per kg of daily ozone production. Operational cost, including amortization over 20 years, ranges from 1/2 cent per cubic metre to 1 cent per cubic metre of water treated.

4.3 Plant Design

There are several aspects of water treatment plant design in cold regions which are important. Nearly all functions of water treatment must be housed for process protection as well as for ease of maintenance and operation of equipment. Certain unit processes require heated shelter, while others require shelter only. Generally, processes which include equipment such as pumps and exposed piping must be housed and heated to prevent damage from freezing. Water temperature, not air temperature, determines process efficiency.

4.3.1 Buildings

Combining different functions under one roof rather than in a group of smaller buildings reduces surface area and heating requirements. Piping and electrical runs may be shorter and less expensive initially and possibly easier to maintain. Possible expansion in the future should be considered in selecting the single building concept. The floor plan of cold region systems can be critical to building efficiency. Designers should place areas which require stable heat in the building interior, and store rooms and other less vital functions against outer walls. In this manner, heat lost from the interior is used to heat other space before escaping outdoors. Building shape can be optimized to reduce surface area and oriented to take advantage of sunshine.

Placement of some functions below ground and banking buildings with earth on outside walls will reduce energy requirements (See Figure 4-5).

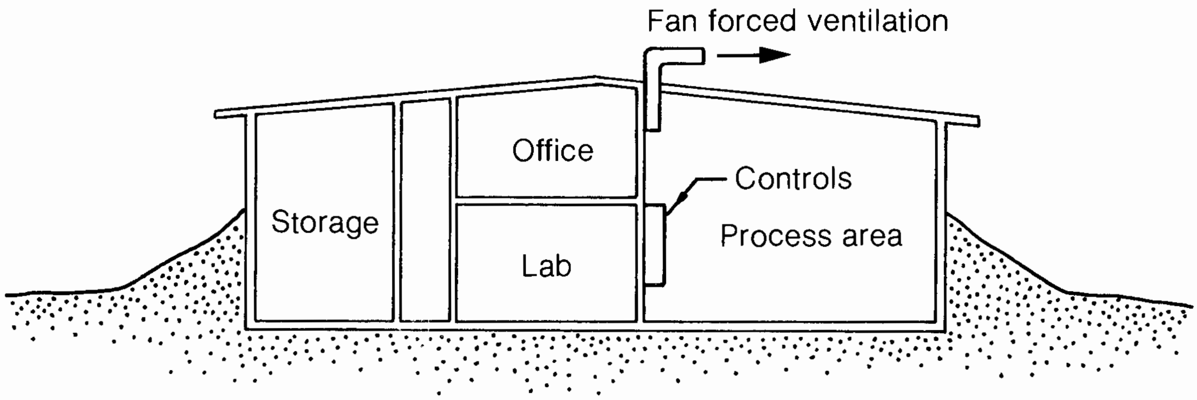

FIGURE 4-5. BUILDING PARTIALLY INSULATED WITH EARTH BANKS

Vapour barriers are very important in cold climates and more so in buildings where moist air is prevalent such as in treatment plants. Poor vapour barriers will permit moisture to penetrate into wall and roof insulation and reduce its effectiveness.

4.3.2 Ventilation

Ventilation is important both for human health and comfort and building economy. Moist indoor air in process areas must be expelled to prevent condensation and related problems. Air may be reused from one type of space to another to economize on the amount of warm-up required. For example, air may be moved from office space to lab space before exhaust, or from office to process areas. If dehumidification equipment is installed, process space air might be reused in either office or lab space.

An alternative to this direct reuse of air is to extract heat from warm, moist exhaust air to preheat incoming fresh air. Several fairly efficient devices are available to perform this function.

Continuous ventilation may not be necessary in all spaces. When offices and labs are not occupied it is unnecessary to force ventilate them and waste heat.

4.3.3 Lighting

Adequate lighting is important both inside and outside treatment plants; in cold northern climates it is particularly essential because of reduced wintertime daylight. Controls for lighting circuits should be designed so that minimum light is provided in unoccupied areas with supplementary lights available as needed. Unless relatively small lighting circuits are provided, appreciable power may be lost to a function not actually needed.

4.3.4 Controls

Process controls are sensitive devices which may be adversely affected by low temperature or high humidity. Plant design should provide controls on interior walls or in special cabinets away from the influence of moisture and temperature. Ventilation should be provided to reduce the possibility of damage by atmospheric changes.

4.3.5 Standby equipment

In cold regions equipment is subjected to rigorous conditions. As a result, equipment failure may be more frequent. Providing redundant equipment may increase system reliability.

It is recommended that the designer not place total reliance on one item if that reliance could as easily be placed on two smaller items. For example, rather than one large pump, two or three smaller ones will generally be more desirable. This also permits periodic maintenance without suspending operation entirely.

4.3.6 Miscellaneous considerations

4.3.6.1 Drainage. Whenever possible, plants should be designed and built so that they can be drained by gravity if necessary. This is particularly true in remote areas and at smaller installations.

4.3.6.2 Auxiliary power. Auxiliary power supply should be provided to support minimum operation of the treatment plant and distribution system.

4.3.6.3 Space/process trade-offs. Under some circumstances the designer may wish to evaluate the overall benefits of energy-intensive processes which are space-efficient. For example, pressure filters or pre-coat filters which require pumping may have overall advantages compared to standard or mixed media gravity filters. Or in another case a centrifuge may be preferable to a standard clarifier.

In cold climates these trade-offs must be evaluated carefully because heating requirements are significant. Where plant expansion is contemplated, these considerations may be particularly valuable by allowing addition of capacity within existing space.

4.3.6.4 Replacement parts. Plant management should maintain a stock of replacement parts for equipment subject to failure or wear. This is particularly important in remote areas where much time may be lost in shipment of parts from sources of supply.

4.4 References

1. Magsood, R. and Benedek, A., "The Feasibility of the Physical-Chemical Treatment of Sewage at Low Temperatures", IN Symp. on Wastewater Treatment in Cold Climates, Saskatoon, Sask., Aug. 22-24, 1973, E. Davis, ed., Environmental Protection Service, Environment Canada, Report No. EPS 3-WP-74-3, pp. 523-548, Ottawa, 1974.

2. Magsood, R. and Benedek, A., "Low-temperature Organic Removal and Denitrification in Activated carbon Columns", Jour. Water Poll. Control Fed., 49(10):2107.

3. Spyker, J.W. and Husband W.H.W, "Desalination of Brackish Water by Spray Freezing", Saskatchewan Research Council. EDC-73-CIV3, 1973.

4.5 Bibliography

Alter, Amos, J. "Water Supply in Cold Regions". U.S. Army Cold Regions Research and Engineering Laboratory, Monograph III-C52, January 1969.

Twort, A.C., Hoather R.C., Law F.M., Water Supply, second ed., American Elsevier Publishing Co., Inc., 1974.

Wallis, Craig, Staff, Charles H. and Melnick, Joseph L., "The Hazards of Incorporating Charcoal Filters into Domestic Water Systems". Water Research, Vol 8, pp. 111-113, 1974.

Weber, Walter J. Jr. Physiochemical Processes for Water Quality Control. John Wiley & Sons, Inc., 1972.

SECTION 5

WATER STORAGE

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5. WATER STORAGE

5.1 Purposes and Capacity Requirements

The total water storage requirement is the sum of flow equalization, emergency and fire requirements. The reliability of the water source and the community size, i.e., equipment and expertise available, will influence the storage requirements. Typically, these will be two days total water demand plus the fire requirements and any seasonal requirements.

Most piped and trucked water delivery systems will require some storage capacity to meet daily and hourly water demand fluctuations. This storage is called "buffer" or "equalization" capacity. Piped systems in small communities typically have a peak hourly consumption of 4.5 times the average daily consumption (see Section 4). The storage requirement for buffer capacity is generally one day's consumption. Also, emergency storage of at least one day's water requirement should be provided. Several days' supply may be necessary when the community is served by a long pipeline. For trucked systems, storage of two days' consumption within the community is desirable to breach any supply interruptions, and to act as buffer capacity where a piped supply line from the source is used.

Storage capacity is also required to act as a buffer and to breach temporary supply failures where limited-yield wells or constant-flow treatment plants are used.

Fire protection requirements for both piped and trucked systems are outlined in Section 12. These requirements should be used to calculate the storage capacity needed.

Water supply systems in some remote northern communities are operational only on a seasonal basis. Where a continuous water supply cannot be obtained, is too expensive, or is impractical to maintain, enough water must be stored to supply the demand during periods of supply failure. For example, where a temporary water intake system is utilized, short-term storage is required to supply the demand when the intake is inoperative during river or lake freeze-up and break-up. Complete winter storage has been utilized at locations where all water sources cease, freezeup, or are inaccessible during the winter. A water supply pipeline from an inaccessible or distant water source may be used in the summer to fill a winter storage reservoir or tank. In these instances, the duration of the expected source interruption and the design rate of consumption will determine the storage capacity required. Local records must be consulted.

5.2 Tanks

5.2.1 General

Special cold regions design considerations and problem areas include: icing conditions; insulation; heat requirements; foundation design (particularly in frost-susceptible soil); the difficulty and high cost of carrying out maintenance in remote areas; and other cold climate construction and operation and maintenance (O&M) considerations such as transportation, labour, logistics, and weather (see Section 2). Tanks in cold regions must be insulated and heat added to prevent ice formation in the tank.

Common storage tank construction materials are wood, steel and concrete. Small individual tanks of aluminum, plastic and fibreglass have also been used.

Wood tanks are particularly useful because they do not have to be insulated. They are relatively light and the small pieces can be easily shipped into remote areas. They can be erected by local people without expensive, special equipment. Wood tanks can leak by sweating. With very careful erection and regular maintenance, such as tightening of bands, leakage can be reduced; however, this is not always easily accomplished in northern utility systems. Any leakage during the winter will result in icing on the outer surface. This ice buildup is a nuisance and can result in damage to the tank and foundation. Unlined tanks should be operated with as little water level fluctuation as practical since the wood shrinks when it drys out, producing cracks. Unlined wood tanks must be allowed to sweat; therefore, they must not be painted or coated. Leakage problems can be overcome by installing a flexible waterproof liner inside the tank. The liner material must be rugged enough to withstand shipping and installation handling, and may require low temperature specifications (see section 5.3.5). Wherever possible, the liner should be prefabricated, with the necessary openings reinforced, and in one piece, to reduce the amount of field work and allow complete replacement. It is imperative to prevent ice formation within the tank because this will damage the liner and punctures are difficult to locate. This is often impractical and is a major disadvantag of membrane liners. Where greater thermal resistance than the wood itself is required, near-hydrophobic insulation may be placed on the inside wall of the tank and covered with a liner (Figure 5-1).

Steel tanks can be either bolted or welded. Small tanks of less than 200 m^3 could be barged complete but larger ones must be constructed on-site. Bolted tanks ar quickly erected; however, any damage to the plates during shipping will make alignment difficult and leaks may occur. Leakage at the joints may occuur due to misalignment, poor erection or foundation movement. The insulation and coating must consider such movements and leakage. Welding is the preferred method of construction, particularly for large tanks (i.e., greater than 2000 m^3). However, qualified welders and vacuum and radiographic equipment to check the welds are necessary.

Special low-temperature, high-impact steels, such as ASTM A-516 or CSA G40.8, are advisable where the tank may remain empty during the winter and reach the lowest ambient temperature. The designer must assess the risk of this situation. Because of the high cost of special steels, conventional steel has been generally used for insulated water storage tanks. Welded steel tanks have been insulated with polystyrene or polyurethane boards and with sprayed-on polyurethane. Figure 5-2 illustrates a welded steel tank with board insulation and metal cladding.

Steel tanks must have an anti-corrosion lining such as an epoxy paint system. The minimum temperature conditions required during the installation and curing are significant to construction scheduling. Failure to achieve this and follow manufacturer's instructions are major causes of premature lining failures. The cost of sandblasting and liner installation is very high in remote locations; therefore, the liner system should be selected for the best ovaerall economics, not just the initial cost. Alternatives such as membrane liners or electrical corrosion protection systems such as anodes or impressed current may be considered.

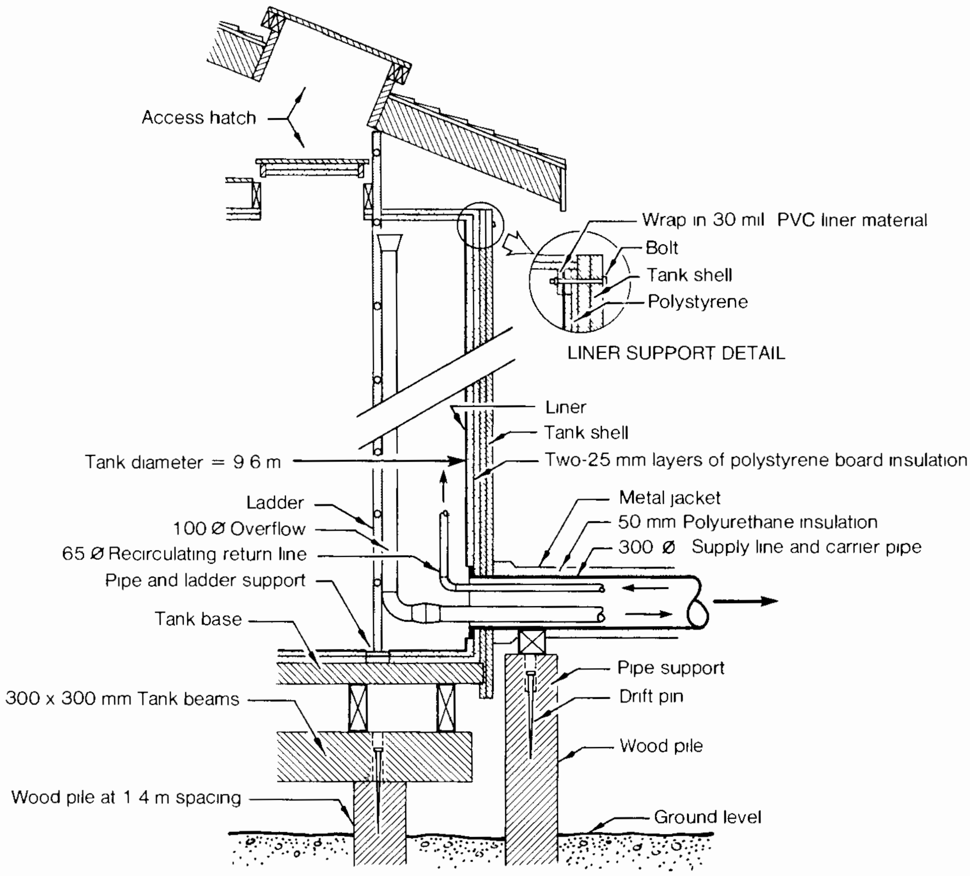

FIGURE 5-1. WOOD TANK WITH INSULATION AND LINER ON INSIDE (on pile foundation)

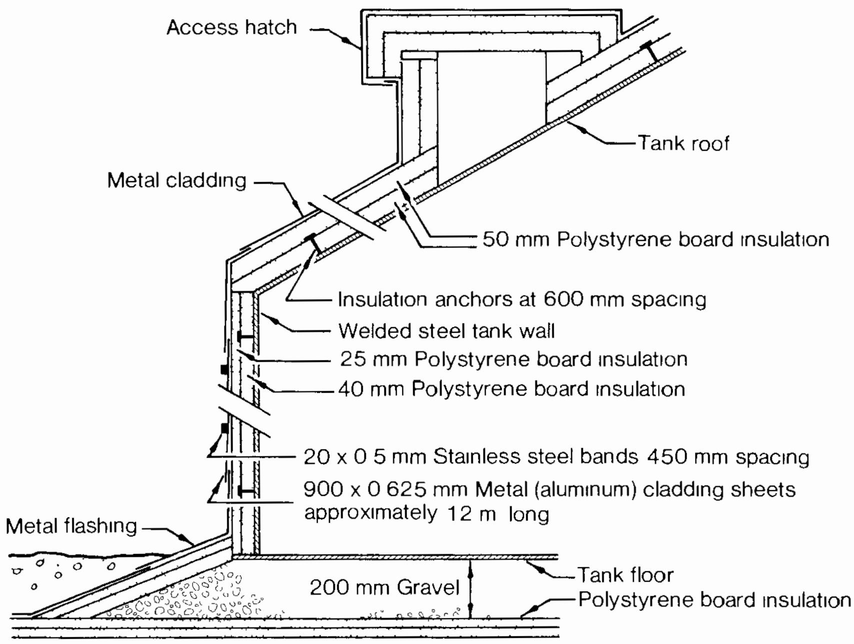

FIGURE 5-2. STEEL TANK WITH BOARD INSULATION AND METAL CLADDING

Concrete tanks have been used where adequate aggregate is available and the foundation is rock or where soils permit slab construction. They should be covered with earth where practical to reduce heat loss and insulated if necessary (Figure 5-3).

5.2.2 Insulation

Insulation may be earth cover, wood, fibreglass batt, polyurethane or extruded polystyrene boards. The typical 75-mm walls of wood tanks provide some insulation value, but the thermal resistance of concrete and steel is negligible. The thermal inertia of soil dampens out the extreme air and ground surface termperatures, while fibreglass, polyurethane and polystyrene provide thermal resistance to reduce heat loss. Only moisture resistant insulation should be installed in contact with storage tanks which are inaccessible or below ground, since moisture from leaks, condensation, rain or groundwater can drastically reduce the insulating value.

Tanks of any material can be enclosed within a building shell. Such an exterior frame and shell may be constructed against the tank or a walkway may be provided between the tank and the exterior wall (Figure 5-4). The wind protection and air gap will reduce heat losses and this can be further reduced by insulating the enclosure. Where access to the insulation is provided, such as by a walkway, fibreglass batt insulation can be used (Figure 5-4).

Near-hydrophobic plastic foam insulations are readily available and commonly used. Polyurethane may be foamed on-site, reducing the shipping costs; however, field costs may be higher. Polyurethane boards may be made up, but the foam is more commonly sprayed directly onto the storage tank surface (Figure 5-5). To ensure a good bond to a metal surface loose scale and paint flakes should be removed, the surface should be solvent-cleaned if it is oily and a compatible primer applied. Foamed-in-place insulations are particularly useful for insulating curved surfaces or places that are difficult to reach. Spraying must not be carried out in the presence of water, rain, fog, condensation, wind velocities greater than 5 km/h, when the tank surface temperature is below 10°C, or when the air temperature is below 2°C without special techniques and heating

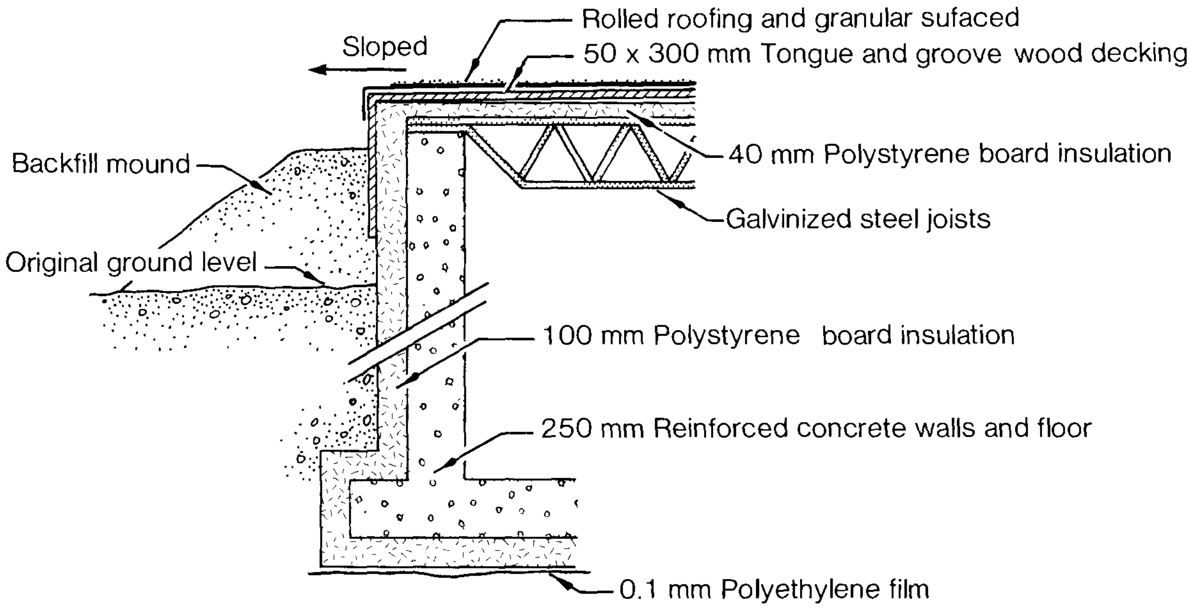

FIGURE 5-3. INSULATED BURIED CONCRETE TANK

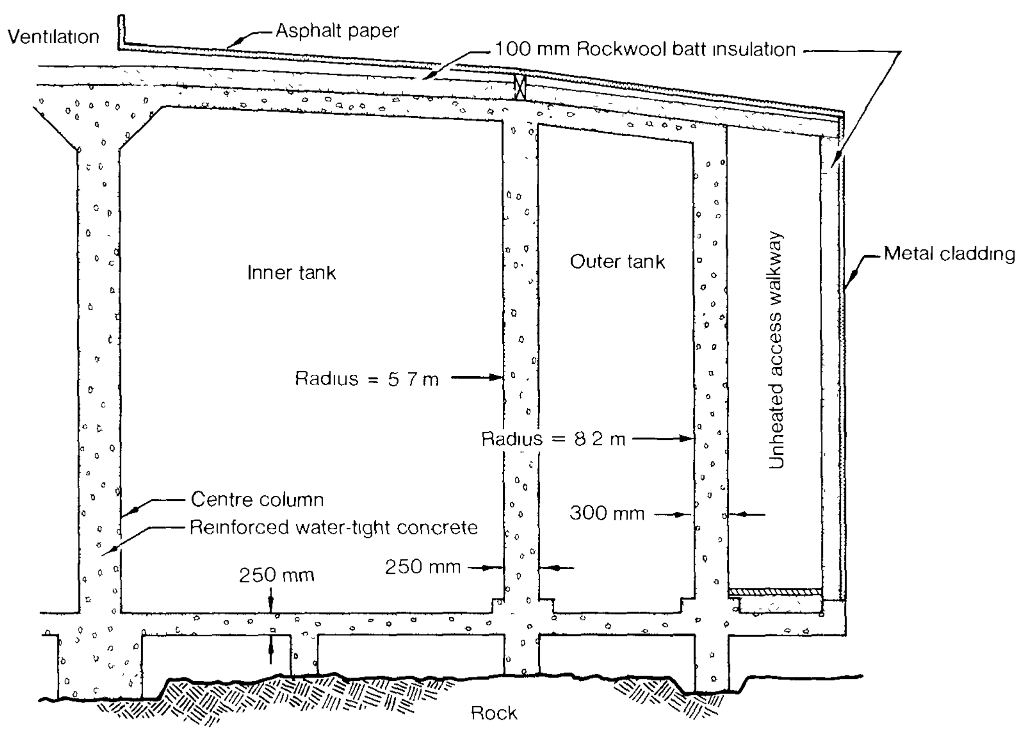

FIGURE 5-4. ABOVE-GROUND CONCRETE TANK, GREENLAND

FIGURE 5-5. STEEL TANK WITH 75-mm SPRAYED ON POLYURETHANE INSULATION, BARROW, ALASKA

equipment. Quality must be controlled during and after foaming. A high degree of skill is required in application to ensure a smooth surface. Polyurethane foam must be protected from vandalism, weather and from ultraviolet light (sunlight). This can be done with low-temperature elastomers or other coatings compatible with polyurethane which are sprayed onto the insulation, usually in two or three coats, with the first coat applied within one day of foam application. The walls can be further protected by sheet metal cladding.

Extruded expanded polystyrene or polyurethane boards can be glued and strapped (typically with 40 mm x 0.5 mm stainless steel banding 450 mm on centre) to the outside of tank. Large tanks will require clips. The boards should generally be less than 75 mm thick to allow installation on the curved tank surfaces. Two layers are preferable so that by staggering these, the joints can be covered. The insulation must be protected from weather, and vandalism. This is commonly done with metal cladding. Embossed, corrugated or ribbed (i.e., not smooth) surfaces will not show bends or deformities incurred during construction or operation.

Near-hydrophobic insulation boards can also be used to insulate the walls of below ground level concrete tanks. High density foams with compressive strengths up to 700 kPa can be placed under a tank, if desired (Figure 5-3). These higher density foams also absorb less moisture.

Ice is a relatively poor insulator, 1/60th that of polystyrene; therefore, an ice growth on an insulated tank wall does not appreciably reduce heat losses. However, ice is 20 times a better insulator than steel and an ice layer will reduce heat loss better than an exposed surface.

5.2.3 Design

Ice in water storage tanks can cause serious damage. A floating ice sheet may destroy ladders, structural supports, pipes and similar interior appurtenances as it rides up and down in the tank due to fluctuations in water level. If these are attached to the tank wall, failure can result. Ice formed on the tank walls can suddenly collapse, e.g., when the walls warm up during warm weather, and cause failure or puncture holes in the bottom of the tank. Therefore, water storage tanks must be designed to prevent the growth of ice in the tank under all foreseeable circumstances, including unusual operating conditions, and they should be completely drainable. Because of their vulnerability to ice damage, interior appurtenances should be installed with caution.

While it is usually easy to keep the stored water warm, particular attention must be paid to the air space above the free water surface. The air in one Alaskan tank was 2.5°C below the water temperature, but this will vary with the geometry, insulation and outside temperatures [1].

Since water is most dense at 4°C, surface icing can be prevented by operating the tank at a temperature greater than 4°C. Continuous or intermittent circulation within the tank will also help to prevent density stratification and surface or wall icing. The return line of a recirculating water distribution system is often discharged into the storage tank. This provides circulation and temperature control within the tank, and a large heat reservoir for the system.

Where practical, breather vents should be located on the interior of the tank, venting into an attached pumphouse or building rather than to the outside where ambient temperatures are low. This will prevent the vent from icing up due to condensation and will reduce heat loss. The vacuum created by a blocked vent when the water level is lowered can cause the tank to collapse.

Overflow piping should be designed so that a trickle flow does not ice up and eventually block the pipe. It should be insulated and heat traced if located outside the tank or perhaps run inside the tank (Figure 5-1).

Instrumentation should include a non-contact water level elevation (head) indicator, such as a pressure transducer, since ice would damage floats. Temperature monitoring at various levels for control and alarms should be installed.

Seasonal storage, e.g., where complete winter storage is required, can cause water quality changes, such as reduced oxygen. Chlorine residuals will also decrease with time, though less with colder waters [2]. Because of the effects of long-term storage on water quality, treatment should occur after storage.

Elevated tanks can provide the necessary pressures in the distribution system; however, they can be a maintenance problem in cold weather. The large surface area and high winds increase heat loss, and the standpipes must be freeze-protected. The foundation must be carefully designed. In small communities a pneumatic system or constant pressure pumps fed from a surface storage tank are generally more practical.

Freezing of a storage tank will not usually occur all at once. Layers of ice are formed over several hours or days. Periodic drawdowns cause such layers or plugs to become hung up and separated by air gaps. If this occurs, precautions must be taken to prevent the piston action of a falling ice layer. Thawing of an ice layer should be carried out from the top. The method and sequence of thawing a particular tank must be designed into it and specified in operational procedure manuals. Extra equipment required must be supplied at the time of construction.

5.2.4 Thermal considerations

The thermal characteristics of alternative designs should be considered, although in many cases the size, shape and location are specified by other constraints. Elevated tanks expose the greatest surface area and must contend with low air temperatures and high winds. Tanks at the ground surface will lose less heat and the common vertical cylinder shape is very near optimum, since heat loss to the ground is less than to the air. Whenever practical, tanks should be buried or covered with soil to reduce the effect of low air temperatures.

All exposed surfaces should be insulated. This is particularly important for steel tanks since the heat loss through exposed steel, where the only resistance is air film, will be at least 50 times that of a tank surface insulated with 50 mm of polystyrene. Thermal breaks or penetrations such as a ladder attached to the tank exterior must be avoided or reduced. The risers for elevated tanks must also be insulated.

Exposure of inflow, outflow and circulation piping should be minimized, perhaps by using a common carrier (e.g., pipe in a pipe). A common carrier also reduces the number of connections into the tank, which is of importance for lined tanks.

The exterior surface could be painted a dark colour to absorb as much incident radiant heat as possible during the long dark winters.

The economic thickness of insulation can be determined by comparing the initial capital cost for increased insulation thickness to the accompanying reduced heat loss, and lower annual energy cost and heating capacity requirements (see Section 15). Other considerations such as a required maximum rate of heat loss or temperature drop over a specified period may require greater than this minimum thickness. Thermal calculations are also necessary to size heating systems to heat water and to replace heat losses. For storage tanks, piping and other utility system components, the required capacity is based on supplying the maximum rate of heat loss, whereas the total energy consumption is based on the annual heat loss. The heating of water in storage tanks by the practical application of alternative energy sources, such as wind and low temperature waste heat from electrical generation, should be considered (see Section 14).

Heat loss can be reduced only slightly by operating the tank near freezing since it is the temperature difference that determines heat loss. For example, if the ambient temperature is -20°C then there will be a 12% reduction in heat loss for a tank operated at 2°C compared to at 5°C. The lower the ambient temperature, the less are the savings by reducing the tank temperature. There are, however, energy benefits to operating near freezing where the mean air temperatures are not much below freezing, and where this eliminates or reduces the need to preheat raw water supplies.

Operation at over 4°C will prevent density stratification and surface freezing, but operating at over 10°C is usually unnecessary and can result in vent icing problems. The large mass of water reduces the potential for freezing and damage from failures, such as prolonged stopages of heat input. In any case, the tank should be completely drainable.

Small storage tanks may be located within a building. Some innovative examples of this are the Kemi, Finland, multi-story city hall which incorporates an elevated storage tank, and the British Petroleum camp near Prudhoe Bay and several new schools in Alaska where the swimming pool doubles as water storage for fire protection.

5.2.5 Foundation

Foundation considerations are similar to those for other northern buildings, with the added concern of the high weight of water-filled storage tanks. In non-permafrost areas, normal foundation precautions should be considered, including those for frost heaving. In permafrost areas, active or passive design measures can be used. Active measures include pre-thawing, excavation and replacement, and designing for settlement. Passive measures include those that separate the tank from the ground and those that maintain the permafrost. An example of the former is the use of piles. The heavy loads require close spacing of piles and a design analysis which considers the creep of frozen ground, particularly in "warm" permafrost areas. Examples of the latter are artificial refrigeration, thermal piles, and air ducts (with or without fans).

5.2.6 Costs

Table 5-1 shows typical costs for water storage tanks in cold regions.

5.3 Earth Reservoirs

5.3.1 General

Water impoundments for domestic [3] and industrial water supply [4] and dams for hydro power generation [5] have been successfully constructed in the North. Special design considerations are required in permafrost areas, particularly in high ice content soils [6]. Construction problems may include lack of specific soils required for embankment construction, excavation and placement of frozen soils, and other northern construction problems such as logistics and weather (see Section 2).

The effective reservoir volume can be reduced substantially by ice cover which can at times be 2 m thick. The most critical years will be those with low snowfall. Ice thickness can be reduced to a limited extent by using snow fences to create snow drifts, thereby insulating the surface. Deep reservoirs can be used to minimize surface area and thus reduce the volume of frozen water.

5.3.2 Water quality

The quality of the water is influenced by the soils and vegetation that it comes into contact with. Leaching from bog soils and oxygen depletion during long periods of ice cover will necessitate water treatment for colour, pH, taste and odour prior to use. These effects should be considered in preparing the bottom of the reservoir before flooding [7]. Water quality is also affected by ice growth. Thermal stratification may influence the location of intakes. It is normally desirable to dyke the edges to prevent unwanted runoff from entering the reservoir. Signs, in appropriate languages, and fences are necessary to deter access to reservoirs by animals and unauthorized personnel.

TABLE 5-1. WATER STORAGE TANK COSTS

LOCATION	SIZE	DESCRIPTION			COST (YEAR)
		Tank	Foundation	Insulation	
Ft. McPherson, NWT	450 m^3	Wood	Piles	5 cm polystyrene	$166 000 (1975)
Resolute Bay, NWT	450 m^3	Bolted Steel	Insulated Pad	5 cm polystyrene	$190 000 (1976)
Inuvik, NWT	2250 m^3	Welded Steel	Piles	6.2 cm polystyrene	$750 000 (1976) (estimated)
Savoonga, Ak.	380 m^3	Welded Steel	Pad	7.5 cm polyurethane	$106 000* (1977)
Shismaref, Ak.	1140 m^3	Welded Steel	Pad	7.5 cm polyurethane	$176 000* (1977)
Unalakleet, Ak.	3780 m^3	Welded Steel	Pad	7.5 cm polyurethane	$308 000* (1977)
Twin Hill, Ak.	230 m^3	Welded Steel	Pad	7.5 cm polyurethane	$ 78 000* (1977)
Stebbins, Ak.	1900 m^3	Welded Steel	Pad	7.5 cm polyurethane	$212 000* (1977)
Grayling, Ak.	230 m^3	Welded Steel	Pad	7.5 cm polyurethane	$ 80 000* (1977)

* Does not include foundation. Foundation costs in Alaska were $65 000 for a gravel pad or $170 000 for piling with a floor system.

5.3.3 Dams

Dams may be constructed to raise the level of an existing lake or create a reservoir on a stream or river. Overtopping is not permissible; therefore, overflow structures must be provided. Runoff at spring breakup from northern watersheds tends to be very short and violent, thereby increasing the size and complexity of the spillway. Floating ice and wave action must be considered in large reservoirs. The force of ice bonded to dam structures can be significant when it is raised or lowered with the fluctuating water level.

5.3.4 Diked impoundments

Dugout type, generally cut and fill, earth reservoirs may be periodically filled by pumping or by siphoning water from a nearby source. This eliminates expensive overflow structures and simplifies inflow and intake requirements. The low head reduces seepage and embankment stability design problems; however, the effective reservoir volume is reduced by ice growth. Groundwater seepage into a reservoir can be a problem, and must be considered in the geotechnical investigation, even in permafrost areas, since sub-permafrost or intra-permafrost groundwater may be encountered. Impervious membranes have been used successfully in the central and eastern Arctic where the native soils are generally permeable sands and gravels with some silt [3].

To reduce or eliminate excavation of frozen soils, a reservoir may be constructed by impounding embankments. The higher head will increase the importance of seepage control and embankment stability.

The design of a dugout and diked impoundment for a wastewater lagoon is similar to a water supply reservoir.

5.3.5 Impervious liners

Many techniques and types of natural and synthetic linings have been used to reduce or prevent seepage from water reservoirs and wastewater ponds [8]. In cold regions where impervious soils are not readily available, the thin film synthetic liners have been popular, although spray-on liners, including polyurethane, have been used to seal petroleum product storage tank areas [9].

Impervious liners may be used within the embankment only, or to seal the entire reservoir (Figure 5-6). Folds may be left in the liner to allow for settlement; however, large differential settlements such as in high ice-content soils should be avoided or designed with caution. Groundwater or the thawing of permafrost under the reservoir may create hydrostatic uplift pressures or icing conditions. These can be relieved by underdrains, well points or pressure relief valves. The liner must be adequately protected from ice action to prevent punctures during installation and operation (Figure 5-7).

The liner material must be approved for the application, for example, potable water, must be suitable for low temperatures and freeze-thaw conditions, and durable enough for shipping and installation [3,10]. The ease of field seaming and repairing punctures is also important in selecting a liner system. There are numerous liner materials available but few are suitable for the rigorous installation and operating conditions associated with cold regions. Thin plastic films (4, 8 and 10 mil polyethylene and PVC) have failed at heat-sealed joints. Exposed portions were punctured by the gravel base and ripped by falling ice as the water level lowered. If adequately bedded and covered, weak films as thin as 10 mil can perform satisfactorily but even the most suitable material must be installed properly and with care. Membranes of high puncture strength and elasticity will require less intensive bedding preparation and installation restrictions than more fragile ones. Successfully used liner materials include hypalon synthetic rubber, chlorinated polyethylene (CPE), and Dupont 3110 elasticized polyolefin.

Manufacturers and suppliers must be made aware of the anticipated installation and operating conditions. New materials or requirements should be laboratory tested under extreme conditions such as those outlined by Foster et al [3].

5.3.6 Foundations and thermal considerations in permafrost areas

Impounded bodies of water disturb the natural ground thermal regime. In permafrost areas, a permanent thaw bulb is created beneath water bodies that do not freeze to the bottom. In ice-rich soils this thawing may cause structural and seepage problems for the reservoir and

FIGURE 5-6. INSTALLATION OF AN IMPERVIOUS LINER IN A WATER RESERVOIR, ESKIMO POINT, NWT

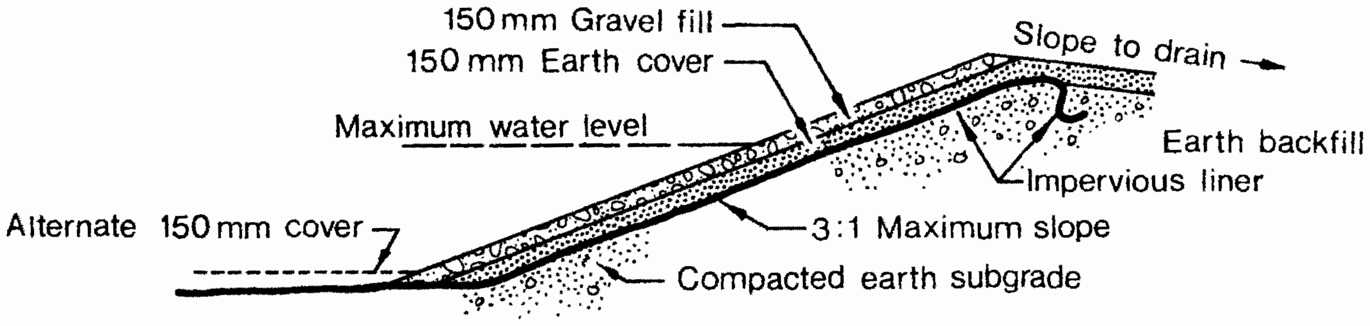

FIGURE 5-7. LINER INSTALLATION AND ANCHORAGE EMBANKMENTS

the containing embankments or dam. The structural problems are essentially two-fold. Firstly, the thaw-consolidation of underlying ice-rich soils creates differential settlement, and secondly, excess pore-water pressure generated in fine-grained soils as the thaw front advances can cause failure.

Foundations and thermal consideration provide the main design problems. The main construction problems are availability of soils and excavation and placement of frozen soils.

The thermal regime and, in particular, the thaw boundaries can be estimated by two and three-dimensional analysis and the settlement calculated from the soil and temperature conditions [6]. The most sensitive area with regard to stability is under or adjacent to the toe of the upstream slope. Some differential movement may be tolerated in low head dams as long as the overall stability and seepage control are adequate.

Seepage reduction or elimination is important in the thermal design as well as the functional design. In the former case, sensible heat transport by seepage will result in embankment temperatures only slightly lower than that of the reservoir water [5]. This will promote deep thawing under the embankment with its associated problems. Icing will occur at the toe of seeping embankments.

Passive foundation designs are based on preventing the embankment from thawing. Thawing under the reservoir is inevitable and would be impractical to arrest. In very cold regions with a shallow active layer, the permafrost may rise in the embankment resulting in a natural impervious frozen core [11]. In warmer regions, hydrophobic insulation and/or cooling may be necessary to maintain a frozen core and foundation. Vertical air ducts with natural draft or blowers to induce winter air circulation and refrigeration have been used in dam construction. These measures have high capital and operating costs, but may be necessary for high embankments on thawing ice-rich soils.

Active designs allow thawing but any resulting settlement or instability is considered. Such "thawed" designs are necessary in the discontinuous permafrost zone. Measures to decrease the total thaw or rate of thawing may be required. Settlement can be reduced by natural or artificial pre-thawing or excavation of the high ice content near-surface organic and soil layers. These expensive measures may be limited to the embankment foundation and selected areas. Where differential settlement is expected, self-healing semi-impervious embankment material, such as sand, should be used, although this allows seepage which will promote thawing. Maintenance approaching rebuilding may be required in the first few years [12].

5.4 References

1. Cohen, J.B. and Benson, B.E. "Arctic Water Storage", Journal American Water Works Association, 60(3):291-297, 1968.

2. Nehlsen, W.R. and Traffalis, J.J. "Persistance of Chlorine Residuals in Stored Ice and Water", U.S. Naval Civil Engineering Research and Engineering Laboratory, Port Hueneme, California, Technical Note N-206, 1954.

3. Foster, R.R., Parent, T.J. and Sorokowski, R.A. "The Eskimo Point Water Supply Program", In: Utilities Delivery in Arctic Regions, Environment Canada, Environmental Protection Service, Report No. EPS 3-WP-77-1, Ottawa, Ontario, 1977.

4. Rice E.F. and Simoni O.W. "The Hess Creek Dam", In: Proceedings, Permafrost International Conference, Lafayette, Indiana, 1963, National Academy of Science, Washington, D.C. pp. 436-439, 1966.

5. Brown, W.G. and Johnston, G.H. "Dykes in Permafrost: Predicting Thaw and Settlement", Canadian Geotechnical Journal, 7(4):365-371, 1970.

6. National Research Council of Canada, "Permafrost Engineering Manual - 1 Design and Construction", National Research Council of Canada, Ottawa, in preparation.

7. Smith, D.W. and Justice, S.R. "Effects of Reservoir Clearing on Water Quality in the Arctic and Subarctic", Institute of Water Resources, University of Alaska, Fairbanks, Alaska, IWR-58, 1975.

8. Middlebrooks, E., Perman, C.D. and Dunn, I.S. "Wastewater Stabilization Pond Liners", U.S. Army, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, In preparation.

9. EBA Engineering Consultants Ltd. "A Study of Spray-on Liners for Petroleum Product Storage Areas in the North", Environmental Impact Control Directorate, Environmental Protection Service, Environment Canada, Report No. EPS 4-EC-77-2, Ottawa, Ontario, 1977.

10. Thornton, D.E. and Blackall, P. "Field Evaluation of Plastic Film Liners for Petroleum Storage Areas in the Mackenzie Delta". Environmental Conservation Directorate, Environmental Protection Service, Environment Canada, Report No. EPS 3-EC-76-13, Ottawa, 1976.

11. Fulwider, C.W. "Thermal Regime of an Arctic Earthfill Dam", In: North American Contribution PERMAFROST Second International Conference, 13-28 July, 1973, Yakutsk, U.S.S.R., National Academy of Science, Washington, D.C. p. 662-628, 1973.

12. Cameron, J.J. "Waste Impounding Embankments in Permafrost REgions: The Sewage Lagon Embankment, Inuvik, N.W.T.", In: Some Problems of Solid and Liquid Waste Disposal in the Northern Environment, Slupsky J.W. (ed), Environmental Protection Service, Environment Canada, Edmonton, Alberta, EPS-4-NW-76-2, pp. 141-230, 1976.

5.5 Bibliography

Alter, A.J. and Cohen, J.B. "Cold Region Water Storage Practice", Public Works Magazine, October, 1969.

Branch, J.R. "Evaluated Water Tank Freeze-up: A Freeze-up Experience", Journal American Water Works Association, 60(3):291-297, 1967.

Shoblon, G. and Oliver, R.H. "An Evaluation of Foamed Polyurethane for Containment Dike Liners". A report prepared for the Technical Committee on Petroleum Dyking in the North, G. Shoblom and R.H. Oliver, Cominco Ltd., Trail, British Columbia, 1976.

Eaton, E.R. "Floating Plastic Reservoir Covers in the Arctic", Solar Energy, 8(4):116, 1964.

Foster, R.R. "Arctic Water Supply", Water and Pollution Control, 3(3):24-28, 33, March, 1975.

Larson, L.A. "Cold-weather Operation of Elevated Tanks", Journal of American Water Works Association, 68(1):17-18, 1976.

Toman, G.J. "Elevated Water Storage Tank Freeze-ups: Correction of Freeze-ups", Journal American Water Works Association, 59(2):166-168, February, 1967.

Wormald, L.W. "Water Storage Tank Failure Due to Freezing and Pressurization", American Water Works Association Journal, 64(3):173-175, March, 1972.

SECTION 6

WATER DISTRIBUTION

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6 WATER DISTRIBUTION

6.1 Introduction

Throughout this section the various methods of distributing water from source to user will be discussed in the following categories:

General: a general discussion on why or when the particular system is applicable and suitable to a given northern situation.

Objectives: the objectives that should be achieved when designing the particular system for northern conditions.

Existing Systems: descriptions of systems that have or have not worked.

Water distribution is carried out in three main ways. These are self-haul, community-wide haul (trucked water or ice) and piped systems. The system which should be used in any given situation depends on a number of factors:

- governmental policy,
- population,
- geographic and physical site location conditions,
- economic base of community,
- health standards,
- available technical skills,
- ability and willingness of community to operate and maintain the facilities.

Given the factors involved for a particular northern community, a detailed economic analysis must be carried out to determine which is the most appropriate system for that community.

In the Northwest Territories, general terms of refrence [1] have been prepared for use in carrying out the economic analysis.

6.2 General Assumptions and Design Considerations

Average residential consumption of water in areas serviced by a trucked water delivery and sewage collection systems is generally 95 l/ person/day for a four person household with conventional plumbing. Water conservation fixtures (e.g., low water use toilets) can reduce consumption and should be a necessary part of future building design for most northern communities.

Present consumption in houses without plumbing is less than 20 L/person/day. However, concurrent with the gradual improvement of housing in the North will be a gradual increase in per person consumption of water. Residential areas serviced by a piped water delivery system and trucked sewage collection system will have an average water demand of 140 L/person/day immediately. Communities totally serviced by a piped water distribution and sewage collection system will have an average water demand of 450 L/person/day, including industrial uses. The average residential water demand will be 270 L/person/day.

For communities with a poor road system it is not practical to design water and sewage trucks to carry greater than 4550 litres per load.

Building water and sewage tanks should be sized for a minimum of five and seven days capacity, respectively.

Community population projections are available from the appropriate government departments: in the Northwest Territories and the Yukon, the Department of Local Government; and in Alaska, the Department of Community and Regional Affairs. These projections should be utilized in planning community systems.

Fire protection requirements for system designs incorporating full fire protection capability or otherwise are noted in Section 12.

6.3 Self-Haul Systems

The self-haul system has limited application and a number of drawbacks which often make it undesirable for water distribution.

In northern Canada this mode is practiced mainly in small unincorporated settlements of 50 people or less where no mechanization yet exists, e.g., the people obtain their water from a nearby lake or river and haul it to their house.

As the community grows, the increased population density often results in sewage contamination of the drinking water source and the need to provide central water points where people can pick up safe chlorinated water. These watering points are usually only installed when the community doesn't have the necessary infrastructure, i.e., roads, holding tanks for water in houses with exterior fill points, sewage pump-out tanks, etc., to accept a trucked water and sewage system.

The trucked water system is preferred where possible over a central pick-up watering point. The reasons for this are:

- more positive means of supplying housing units on regular basis with clean safe water,
- allows increased water usage and thus better hygiene,
- housing units with pressure systems can eventually be hooked onto piped systems with minimum problems,
- unsupervised watering points tend to be vandalized and become both unsanitary and quickly nonoperational.

6.3.1 Watering point design

Watering points (see Figure 6-1) are usually operated in conjunction with some other form of water distribution or supply system. They are often located in older parts of a community where the houses are not equipped for a trucked or piped system. In Alaska they are constructed as an interim solution to provide safe drinking water until distribution of some sort is feasible.

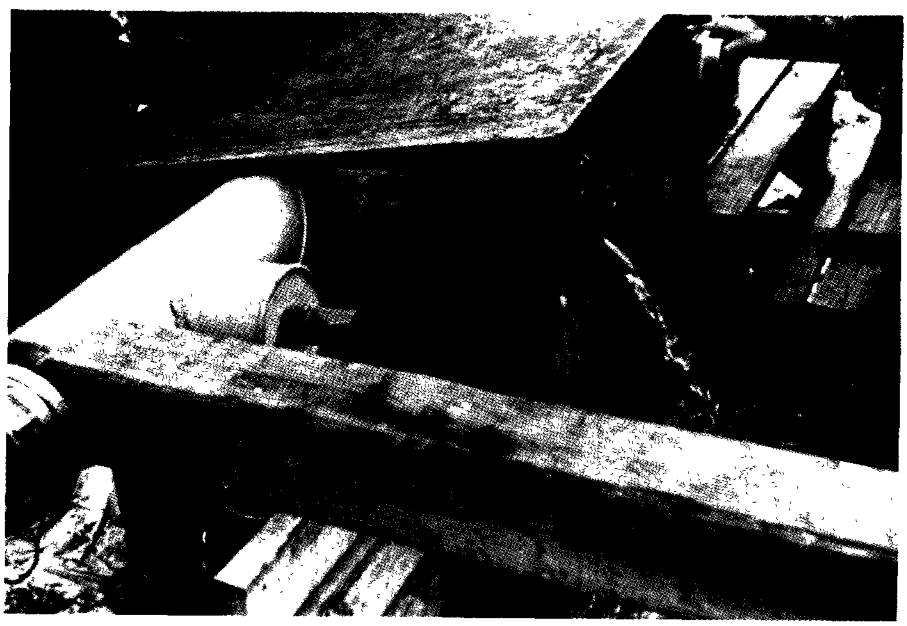

FIGURE 6-1. SELF-HAUL WATERING POINT (Greenland)

The failure rate of the self-haul watering point is very great. Almost six out of 10 are nonoperational after one year. This is mainly due to vandalism, freeze-ups, poor design, and lack of supervision and management. Because of these problems the water points are usually abandoned and not repaired.

Objectives of the ideal self-haul watering point are:

- maximum cleanliness and sanitation in getting water to the container,
- minimum maintenance,
- material design to minimize vandalism.

6.3.2 Types of systems

6.3.3.1 Exterior unsupervised. This is a small heated building containing a water tank, water piping and valves. The user either pulls a chain from outside the building or pushes an electrical button activating a solenoid valve which releases water through a spout into his container. When he releases the button the valve closes and the remaining water in the line drains out the spout. A similar mechanical spring-loaded lever can also be used. A suitable splash base of gravel and rocks or slotted boards is required below the spout. A hanger for the water container is also normally provided. The exterior of the building must be made as vandal-proof as possible. Native logs or heavy duty siding is preferable to normal "metal type" siding. Concrete block would also be ideal if feasible for the location. The entrance door is kept locked and only the maintenance man should have access.

The tank could be filled by truck from the outside, and again access to the inside would be prohibited. A light outside would indicate that the tank is full. Failure to stop filling when the light oomes on would result in the tank overflowing outside through a vent pipe. Usually two lights are used in oase one burns out, which is also an indication for the maintenance man to replace it. Similar on-line systems in conjunction with water distribution mains are also used.

6.3.3.2 Interior watering points must be supervised. Otherwise, the door to building will be left open, and the system will either freeze up or be vandalized.

6.3.3.3 Central facilities are discussed in detail in Section 11.

6.3.4.4 Containers. The type of container recommeded is a 20 L enclosed plastic "camper" type water container to minimize contamination. What is used in practise is anything that will hold water, usually an open water pail.

6.4 Community-Wide Haul Systems

Community-wide haul systems are those systems which transport water from a water or ice source or watering point to a fill point at the individual houses. This is usually accomplished using a tracked, towed or wheeled vehicle.

The "truck" or vehicle-delivery system is used in all or portions of most communities in northern Canada where the population ranges from 50 to 1500. Generally, it becomes more economic to pipe water when the population reaches a range between 600 and 1,000 people, depending on the location and conditions. At this point a dual system of both trucked and piped water continues until the existing areas are put on piped service. In Alaska the truck-haul system has been found expensive to operate and maintain. Piped delivery systems and/or central pick-up is preferred in most cases. However; circumstances in each community must be considered on an individual basis. No subsidy is offered for operation of water delivery systems in Alaska.

In a nonpiped community, the water loading point for the vehicles is usually a prefabricated building on the shore of a lake or river, or beside a well. Vehicle system costs can be reduced at some communities by construction of a water supply pipeline from a distant water source.

6.4.1 Water loading point design

Objectives for the design of the water loading point are:

- maximum cleanliness and sanitation,
- minimum spillage and subsequent freezing and ice buildup around the water point,
- efficient truck entry and exit routes taking into consideration prevailing winds and snow drifting,
- minimum maintenance requirements.

There are four types of systems used:

- overhead pipe loading,
- hose nozzle fill,
- bottom loading,
- interior building fill point.

6.4.1.1 Overhead pipe filling system. Figures 6-2 and 6-3 show typical overhead systems. Included in such a system would be an exterior key start switch for the water pump. Often the water delivery is done by a private contractor, and only the contractor is given the key. All water pumped out is registered on a meter inside the building. Access to the inside of the building is limited to maintenance personnel.

The loading arm drains in two directions after each filling. From the high point it drains back to the heated building and from the spout into the truck. Thus freezing is prevented when the fill point is not in use.

A swivel type elbow allows the loading arm to swing away if hit by a vehicle. This often happens in the winter when the snow and ice builds up so that the top of the truck is close to touching the fill pipe

A major problem with this type of fill design is that, invariably, the key gets turned off when the truck tank is overflowing. This leads to ice buildup on the ground which makes it hard for the truck to park and often is the cause of the building siding being damaged by the vehicle. Guard rails should be used to protect the building, and the water fill pipe should be located such that the downspout is far enough away from the building and high enough off the ground to compensate for seasonal snow and ice buildup. To prevent splashing during filling and to compensate for the seasonal variation in height, flexible low temperature rubber hose should be connected to the bottom of the downspout, as shown in Figure 6-3.

6.4.1.2 Hose nozzle filling system (Figure 6-4). In an effort to prevent spillage and ice buildup, a fill point using a gas tank fill hose nozzle has been used. The truck drives by a wooden platform, a small door in the loading point building is opened, and a hose nozzle is

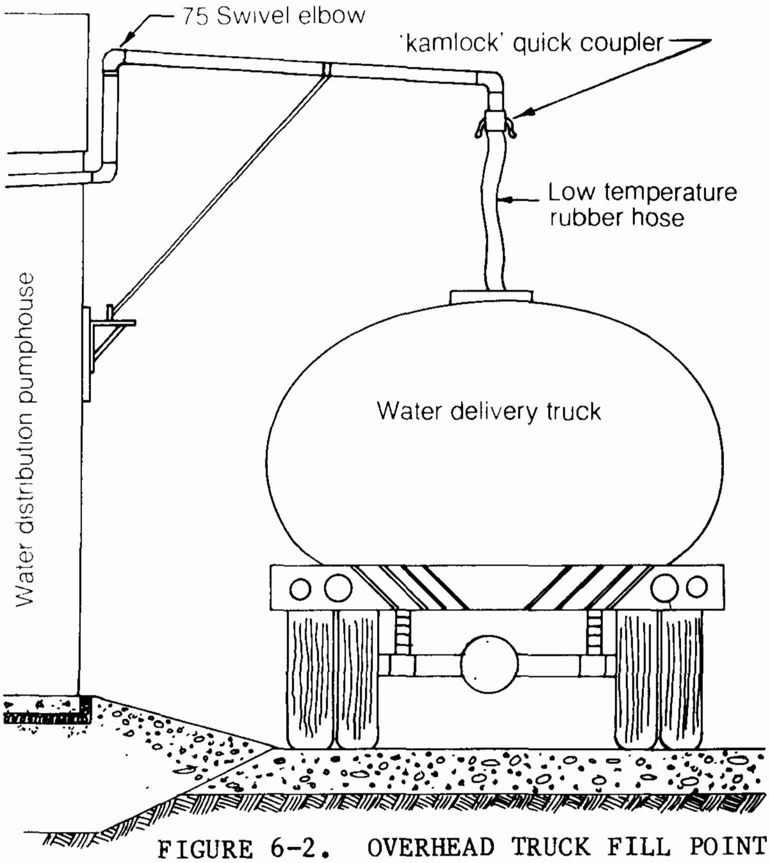

FIGURE 6-2. OVERHEAD TRUCK FILL POINT

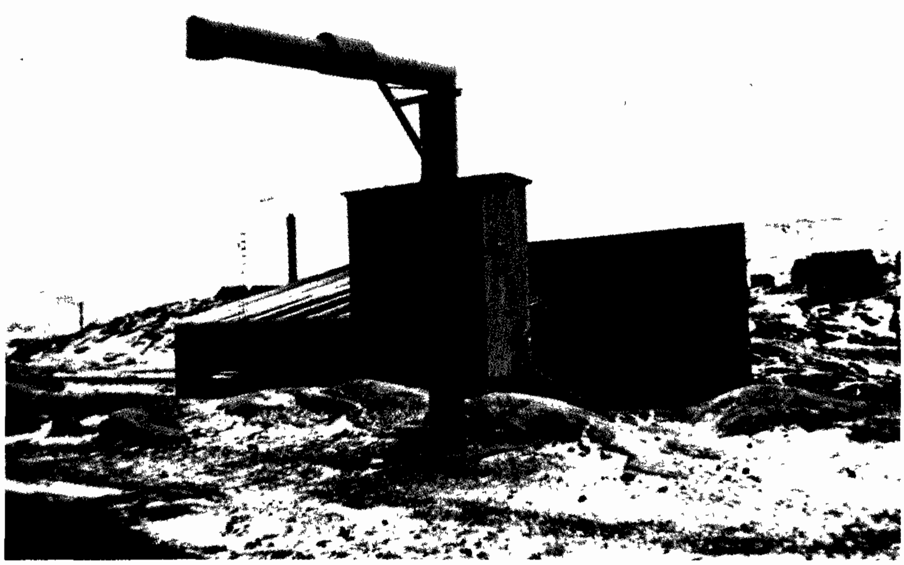

FIGURE 6-3. WATER TRUCK FILL POINT (Greenland)

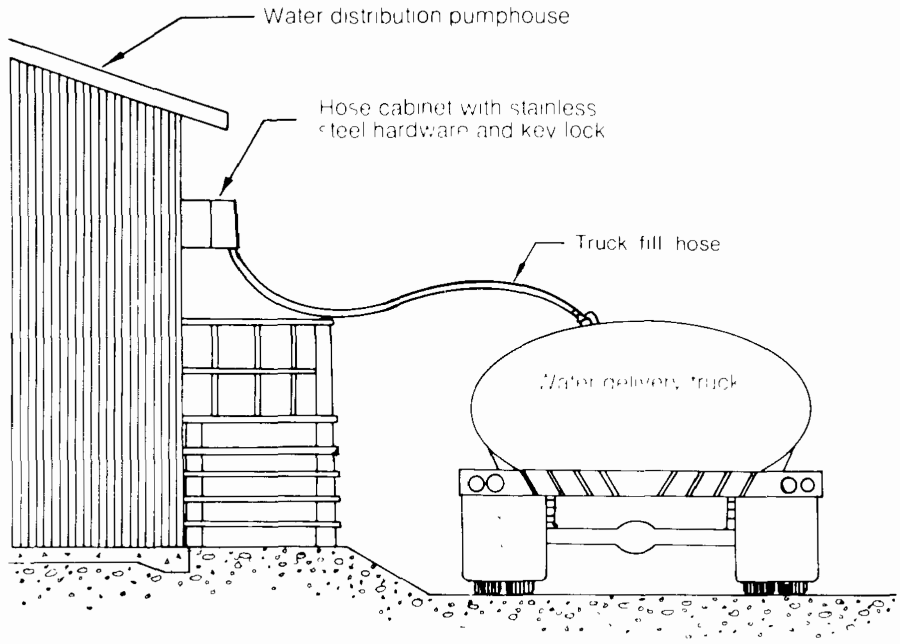

FIGURE 6-4. WATER TRUCK FILL POINT WITH HOSE NOZZLE FILL

pulled out through roller guides. A platform is provided such that the driver can take out the hose nozzle, put it in the top of the truck, and then turn on the key start. The nozzle is designed to turn off under back pressure. However, more often than not it is thrown in the open top hatch of the truck locked in the open position. When the driver sees the tank is full he turns the key off and puts the hose back in the cabinet. The hose is such that it is long enough to reach the truck but not long enough that it could touch the ground.

While this design does not totally eliminate water spillage because of misuse, it has greatly reduced the amount of spillage compared to the overhead fill pipe. There is some spillage when the driver pulls the hose out of the tank and puts it back in the building.

6.4.1.3 <u>Bottom filling system</u> (Figure 6-5). The third type of system utilizes an aircraft refueling technique. A bottom liquid loading device as shown in Figure 6-5 is provided and the truck is filled through the water source suction inlet at the back of the tank.

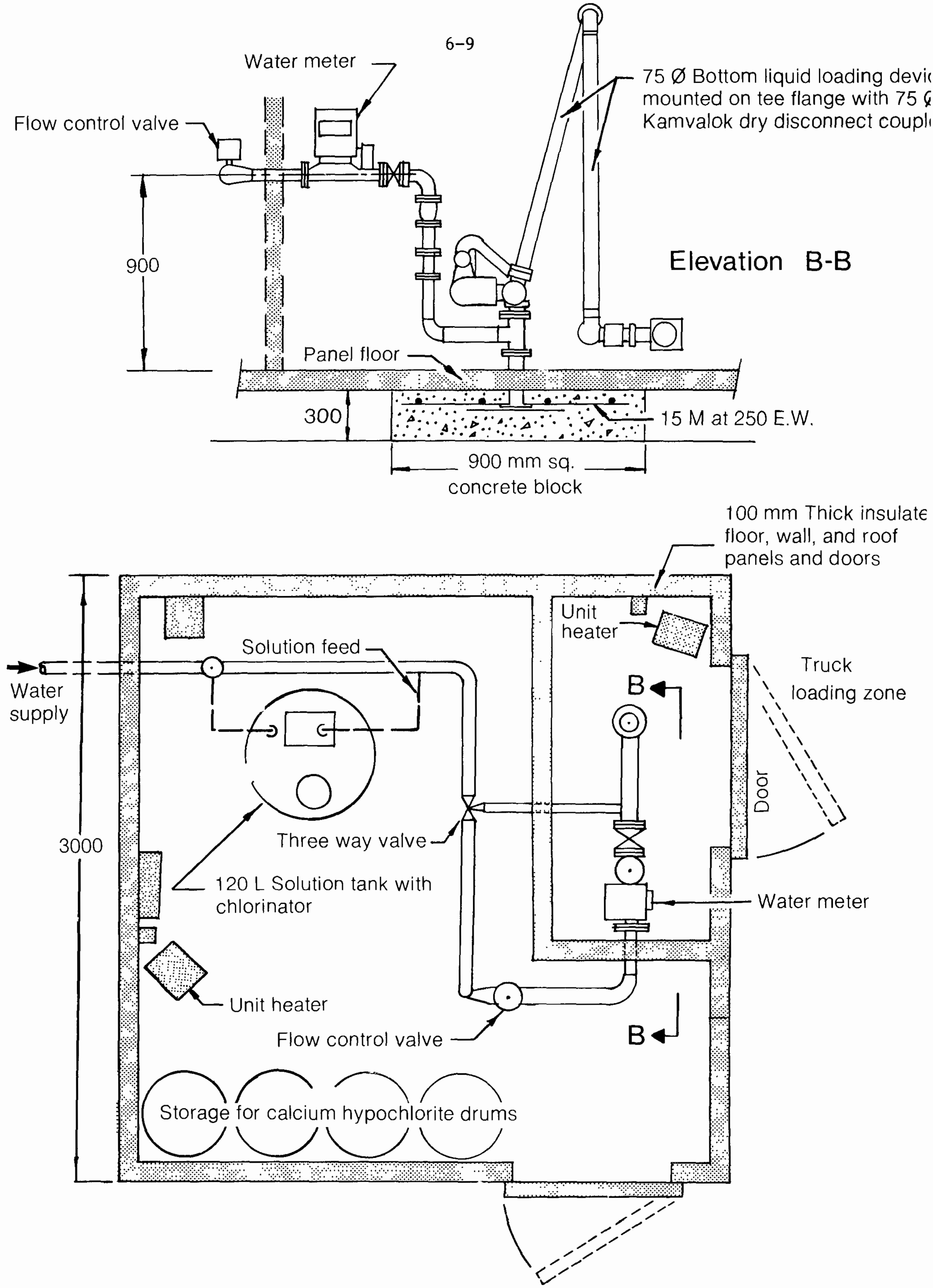

FIGURE 6-5. BOTTOM FILL POINT

Again, the filling point is separately housed with access for maintenance.

To prevent overfilling the truck a batch meter is provided that can be set by the truck driver for the tank capacity of the truck. The bottom loader is swung out, connected to the back of the truck via a quick connect coupling, the volume desired punched in on the batch meter, and the pump turned on using key start. The meter shuts off the pump when the preset amount is reached, the loader arm is disconnected and swung back into the compartment, and the door is shut. The quick connect coupling between the loading arm and the truck is spring loaded so that it closes on disconnection and only a small amount of water is spilled.

6.4.1.4 Interior fill points. These consist of watering points similar to the overhead type except that the fill point is inside the water truck garage. This is usually only used when the community size is small, 200 - 300 population, and the loading frequency is only once or twice per day.

All new truck filling points in northern Canada are designed to provide a minimum loading rate of 450 L per minute with a desireable rate of 700 L per minute. The basis for the minimum filling rate is two-fold. Firstly and most important fire trucks in an emergency must be refilled as quickly as possible. The Fire Marshal has set a minimum rate of 450 L per minute or 10 minutes to fill a 4500 L tank. The second reason is economic, i.e., the quicker the fill rate, the less chance the operator will sit in the cab and forget about the truck filling, and the shorter the turn around time.

The truck filling points should be well-lighted because in many areas there is total darkness in the winter and the truck's parking position is critical no matter what the filling system.

The truck should be able to drive past the loading point where at all possible. Backing up requires more time and often results in minor accidents which damage a building or support structure. Snow removal is also easier. The road should be built up higher than the surrounding tundra and in line with the prevailing winds, to keep snow from building up in front of the loading point.

Where piped systems are available in a community the water truck usually obtains water from the firehall or other suitable building that has piped water service and appropriate connections for filling the truck. Often the water truck and the fire truck are stored in the same building and the filling point is inside the garage.

6.4.2 Vehicle sizing and design

Water and sewage pump-out trucks are designed so that the holding tanks and filling or suction mechanism can be housed on a standard truck chassis. This is also true of sewage pump-out vehicles.

The costs for wheeled and tracked water delivery vehicles in 1976 dollars are:

4450 L insulated tank unit	\$16 000
Cab and chassis, wheeled vehicle	10 000
Total Capital Cost	\$26 000
Tracked vehicle	\$26 000
2225 L tank unit	16 000
Total Capital Cost	\$42 000

Use of tracked vehicles is discouraged as much as possible because of their:

- high initial cost,
- high annual maintenance costs and difficulty in obtaining parts,
- short life expectancy,
- lower payload,
- slower speed and longer travel time from water source to houses and back to water source.

Tracked vehicles are only recommended for those communities where there are no roads or where it is impossible to get to the water source in anything other than a tracked vehicle. An example of this would be a source of water close to the community with road access only in the summer. In this situation a pipeline from the source becomes very attractive because of the high cost of operating the slow tracked vehicles.

There are very few communities in northern Canada that still use a tracked water vehicle. It has been found that in normal snow and winter conditions a wheeled vehicle can adequately do the job. In areas where very heavy snow and snow drifting conditions are experienced, wheeled vehicles with four-wheel drive and large floatation tires are being utilized with success (see Figure 6-6).

6.4.2.1 Truck and tank sizes. Larger tanks reduce the number of trips to the water source. However, they are heavier and require larger vehicles. Often, the condition of the roads in the community and to the water source, access to buildings and other local conditions will dictate the practical maximum size of tanks and vehicles. In very small communities, truck tank units of 2225 L capacity are usually adequate. However, 4550 L units are now being ordered even for these communities since the cost difference between the two is small. Where roads and community infrastructure are still rudimentary (no mechanics, etc.), 2225 L water trailer units are being purchased rather than wheeled or tracked vehicles with the tank assembly mounted on the chassis. These units are in all aspects the same as those mounted on truck chassis, except that they are towed by a farm tractor or other suitable vehicle (see Figure 6-7).

The number of vehicles required depends primarily upon the total community consumption, distance to the water source, the vehicle characteristics and the efficiency of operation. Equations to estimate the requirements and costs are presented in Appendix D. For typical operations with little or no distance to the source and a water consumption rate of 90 L/person/day, one 4550-L water truck can service a population of approximately 250. If consumption was only 10 L/person/day, it could service 1000 persons. If the source was 3.25 km away, the number of persons served would be 160 and 850, respectively.

In the Northwest Territories, the truck tank capacities to date have largely been sized and directly influenced by the low water consumption due to a lack of plumbing. Public housing provided only rudimentary domestic plumbing systems: a small water holding tank (approximately 450 L), a sink and direct drain pipe to the outside, and a honey bucket. With this arrangement water consumption is usually about

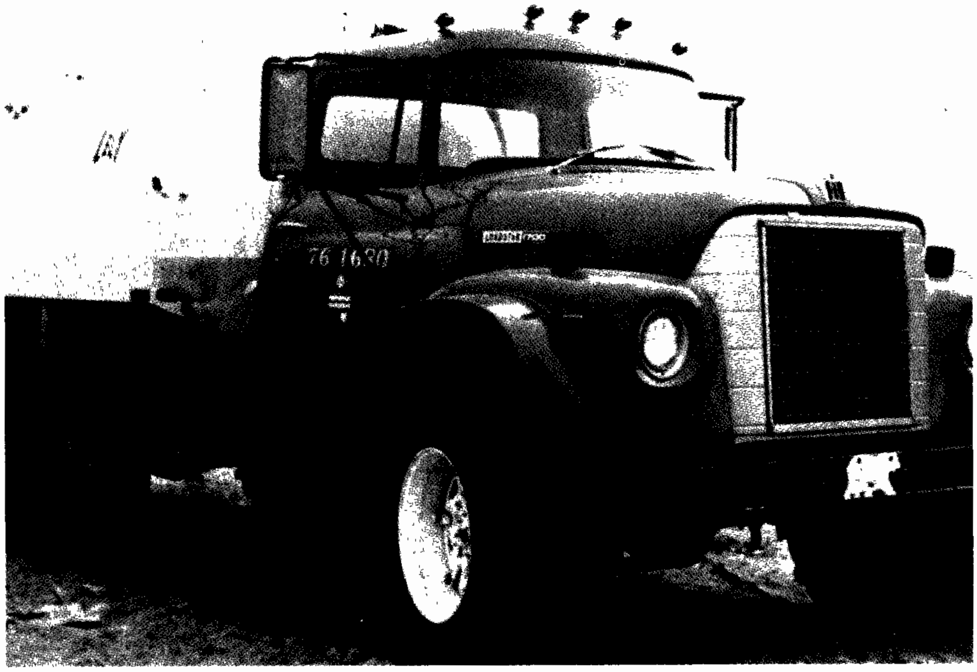

FIGURE 6-6. TRUCK WITH FLOTATION TIRES FOR TRACTION IN SNOW

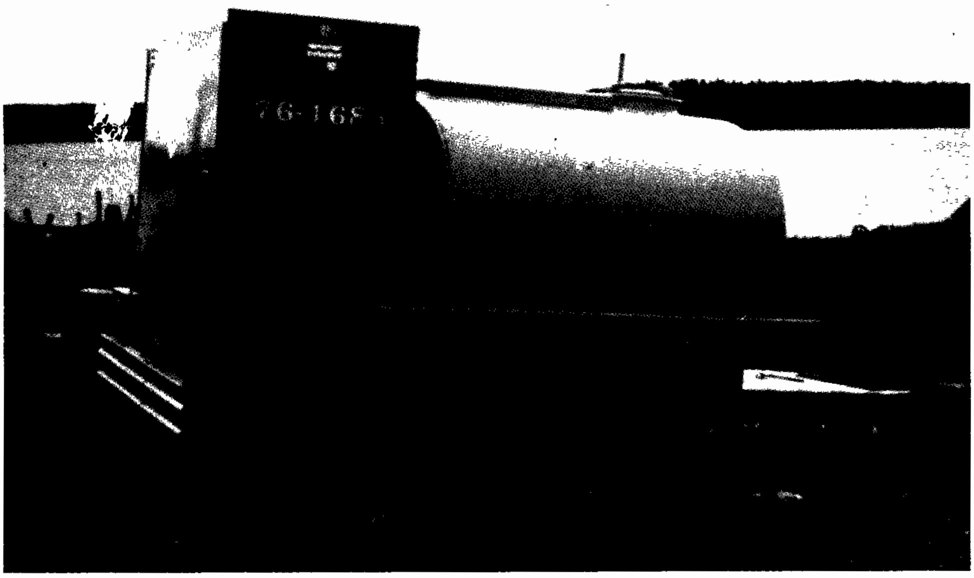

FIGURE 6-7. 2225-LITRE WATER TRAILER

10 - 20 L/person/day. The public housing in the NWT now provides full plumbing, pressurized systems with 1140 L water holding tanks, and 1140 L sewage pump-out tanks. In these houses it is expected that water consumption will reach 95 L/person/day, as is experienced in four-person homes with full conventional plumbing on trucked systems in Yellowknife, NWT. Water conservation measures can reduce this demand.

Since truck system costs are directly proportional to the consumption, they will become more expensive to operate as the residential and non-residential water demand increases with higher populations and/or higher standards of housing and plumbing. At some point, it will become more economical to install a piped supply line and/or distribution system since these costs are less sensitive to the capacity requirements. A complete evaluation of any given system can be made using the rationale and equations given in Appendix F.

6.4.2.2 Vehicle design. Over the years water delivery vehicles and sewage pump-out vehicles have continually been modified and improved to meet the needs of northern conditions.

Truck tanks for northern use must be insulated and all working systems protected from freezing (see Figure 6-8).

Vehicle specifications which reflect the state of trucked delivery design at this time can be obtained form the Department of Public Works, Government of the N.W.T., Yellowknife, N.W.T., Canada, and the U.S. Indian Helath Service, OEH, Box 7-741, Anchorage, Alaska 99510.

The sewage pump-out vehicle uses a pressure vessel and vacuum pump system to evacuate holding tanks. The inherent maintenance problems associated with fluid passing through a pump are thus eliminated.

A prototype using this concept is being developed and tested by private industry for water delivery. For water vehicles using the pressure vacuum system the action is the reverse of a sewage vehicle, i.e., the tank is pressurized to force the liquid out. Such a system has a high flow rate and may have sufficient water flow and pressure to meet the unerwriter's requirements for fire trucks as well as water delivery vehicles. Advantages of this system include elimination of the problems of pump maintenance and freezing. In addition, such a water delivery vehicle can be easily converted to a sewage pump-out truck.

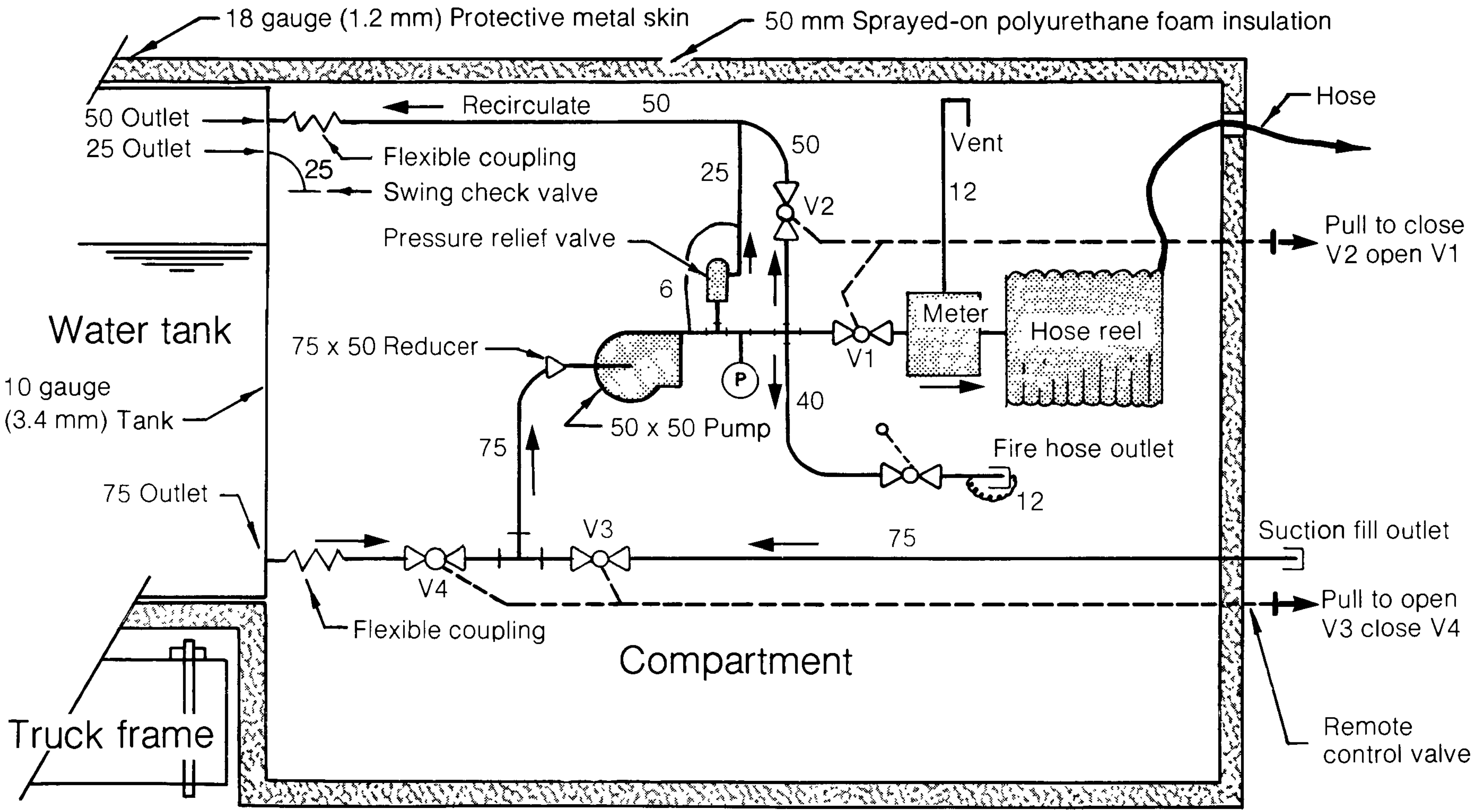

FIGURE 6-8. WATER DELIVERY TRUCK TANK BODY PIPING AND EQUIPMENT DIAGRAM

6.4.3 Ice haul

Ice as a water source and community ice haul as a means of water distribution is carried out only where no other normal water source is available. For example, in arctic Canada only one community, Grise Fiord, still uses ice as a winter water source via icebergs locked in the sea. In Alaska there are still a few communities, such as Barrow, that use ice to supplement the normal water supply.

In numerous other communities ice is used as a winter water source because of individual choice and preference. That is, some local people in certain communities prefer the taste of water obtained from ice to that of the delivered chlorinated water which is obtained from usually small lakes. The taste of water from such lakes is affected by lack of oxygen after prolonged ice and snow cover in the winter and presence of organics. Ice obtained in this case is usually on an individual basis and not supported or organized by the community.

The inherent high degree of labour and handling involved in harvesting ice increases the possibility of contamination. Any system of ice harvesting should minimize labour involvement as well as possible sources of contamination in all phases of the operation, including harvesting, storage and distribution.

When ice is harvested from icebergs, as is the case in Grise Fiord, Canada, the distance from the shore to the bergs could be as much as 8 km. Tracked vehicles are required to traverse the sea ice and pressure ridges (see Figure 6-9).

Tracked vehicles with flat bed open boxes are used to harvest and distribute ice in winter. In the summer the box is removed and a water tank with a pumping attachment is fitted to the tracked vehicle.

The ice is cut with chain saws or axes. Electric chain saws powered from the tracked vehicles are recommended to avoid contamination. This operation is usually done by two men.

The ice is brought back and, if not distributed immediately, is stored in an unheated parking garage to prevent contamination. The ice delivered to each household is placed in the water holding tank to melt.

FIGURE 6-9. TRACKED VEHICLE USED FOR ICE HAUL
(Grise Fiord, N.W.T)

Grise Fiord has a population of 94 and the annual operating cost of harvesting ice is $36 000. Because of the high cost and severe water restrictions in winter, plus the possible health hazard due to contamination, such systems are replaced as soon as economic alternatives are developed.

6.5 Piped Systems

As discussed earlier, piping systems are used because they are the most efficient, safe and economical means of distributing potable water given a population of usually greater than 1000 people. Alaska, however, has piped systems in communities considerably smaller than 1000 population. The point at which piping systems become more economical than trucked systems must be determined for each individual community with its unique characteristics (see Reference [1]).

The systems outlined below describe the basic operation and antifreeze mechanisms. Backup mechanisms will be discussed under a separate heading.

Northern piping systems should be designed to:

- minimize energy input for operation,
- be simple to operate and maintain,

- be protected against mechanical damage, vandalism and severe climatic conditions,
- have a prime antifreeze mechanism with at least one backup mechanism, if not two,
- be drainable,
- have a minimum 40-year design life,
- provide easy isolation of sections and service lines at any time of the year,
- minimize on-site labour and,
- allow maximum use of the short construction season.

6.5.1 Above or below-ground

Whether the piping system is placed above or below-ground will depend on the particular site conditions of a given location. Generally, below-ground systems are preferred where at all possible. The criteria for selection of above or below-ground systems are presented in Section 2.

Piping systems are described later in this section do not differ in operation whether the system is above or below-ground. Only appurtenances of the system vary.

Above-ground systems have been used where ground conditions and thaw do not permit the use of a buried system with any degree of success. However, with the advent of more efficient insulating material, these conditions are becoming less significant factors in choosing between above and below-ground systems. Above-ground systems are becoming economical only where ground conditions are very rocky.

In areas where there is no permafrost, pipes can be buried below seasonal frost penetration. However, this may be impractical or very expensive due to deep frost or excavation through rock. An analysis should be carried out to determine whether a shallow buried, insulated pipe would be more economical and less of a maintenance problem than a deep buried pipe.

6.5.2 Types of systems

6.5.2.1 Single-pipe recirculation. The single-pipe recirculation system, whether above or below ground, is recommended as the best piping system for arctic conditions. This system consists of one or more uninterrupted loops originating at a recirculating facility and returning to that facility without any branch loops.

A well-planned recirculating system minimizes the length of piping required which, in turn, minimizes energy losses. Recirculation eliminates dead ends and any possibility of stagnant water or freezing.

The system also allows positive simple control of water distribution. Flow and temperature indicators on the return lines at the central facility are all that is required. Under constant pumping the pretempering requirement is controlled by the supply and return temperatures. Normally water is pumped out at between 4-7°C and returns at between 1-4°C, depending on local preference. In Greenland, temperatures are held at 1°C, and down to 0.1°C return with electric heat tracing and better sensing devices. However, this leaves a very low margin of safety for repairs and is not recommended.

The obvious disadvantage is that, as the length of the loop increases, the loss of service increases in case of a shutdown due to a problem anywhere along the line. In practice this usually is not a problem as the loop is extened annually to meet the normal growth rate of the community, and at the completion of each phase, temporary short loop links are installed to complete the loop that given year. The following year these links are abandoned, valved off and the pipe left empty. In the case of an emergency these abandoned links can be opened up to reroute the flow of water and possible isolate the break. This problem is also easily overcome on a short-term basis by bleeding at appropriate points, especially when combined "mini service-centre manholes" are used.

The single-pipe recirculation system is usually designed to supply water in the normal "return" line as well as the supply line under fire conditions. For this reason the return line does not decrease drastically in size. A typical pipe size would be 250 mm out and 200 mm return for a design community population of 2000 population.

The recirculating facility could be located at the point of treatment or in a separate pretempering pumping facility, or a combinatio of the two. Figure 6-10 illustrates an ideal town layout for this system. The pretempering/recirculating and/or treatment facility is preferably centrally located and the community is divided into a number of single-looped sections. By planning community growth in a dense circular pattern maximum efficiency can be made of this method of servicing. The worst situation would be a long strung-out community with the facility at one end. This usually ends up increasing pumping requirements and duplication of lines.

As noted in Figure 6-10, back-of-lot mains are preferred if possible. In arctic communities under 3000 in population there are very few, if any, paved roads. Snow accumulation and drifting is often severe

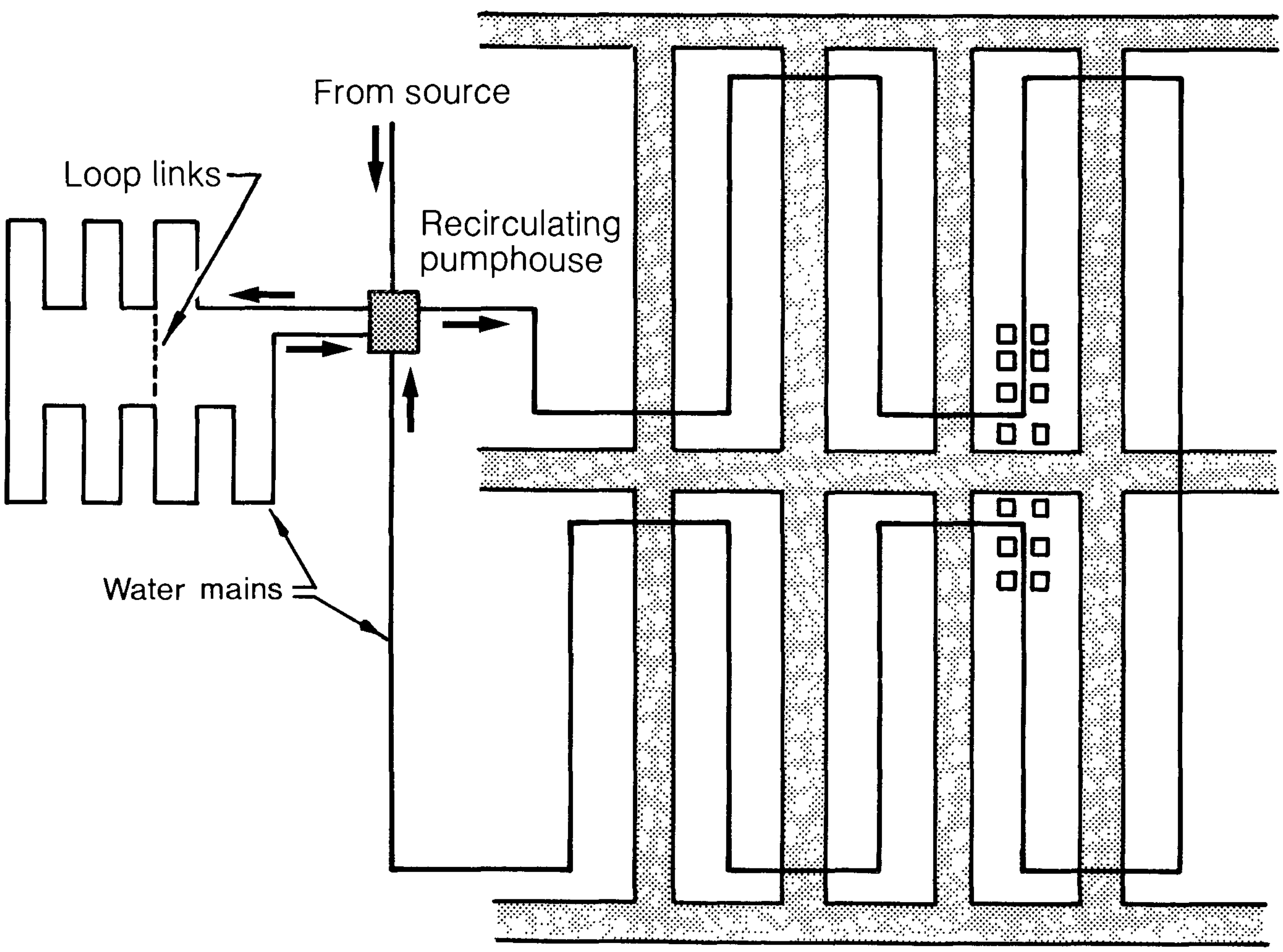

FIGURE 6-10. LAYOUT AND LOCATION OF MAINS FOR SINGLE-PIPE RECIRCULATION

and roads are cleared with a dozer. If the mains are placed in the street (unpaved gravel roads), the manholes are subject to physical damage. If the lines are shallow buried they are also subject to colder ambient temperatures because snow clearing reduces insulation.

Placing the mains at the rear lot line not only avoids these problems but reduces service line connections and permits service lines of equal length on both sides of the main. With mains in the road allowance, usually to one side, plus the normal 8 m requirement between the front of the house and the road right-of-way, average service line length would be 15 m on one side and 23 m on the other. The cost per hook-up would be between $5000 to $7500 for the lot owner. With the mains at the rear lot line, where houses can be placed as close as 3 m from the lot line, an average service line length would be 6 m in either direction at a cost per hook-up of approximately $2000. There is a significant saving to the lot owner in this method of servicing which encourages development of piped services.

"Back yards" are not used to a great extent in northern communities. If houses are placed in a planned fashion similar to southern temperate communities, the large area between the rear of the houses could become wasted space. Depending on community attitudes, this may be one more reason for placing mains at the rear lot line and the houses as close to it as possible according to fire regulations. (For more information see Section 2.)

A further advantage of mains located along the rear lot line is that the manholes containing water line valves and hydrants, freeze protection controls, etc., can be elevated in cylindrical shape approximately 3 feet above grade. This results in easier access during the winter as the immediate area around the elevated manhole is blown clear of snow by local winds.

6.5.2.2 Water wasting - conventional systems. In this type of system the water line network is layed out conventionally. To ensure flow at dead ends, loops, and service lines water is bled off to sewers at a number of areas.

Disadvantages of this system are the inevitably high water consumption and possibly high energy input. Consumption could go as high as 4500 L/person/day (see Section 3).

This system should not be used where there is a limited water source, where water requires expensive treatment, or where pretempering of water is necessary as well as wasting. Possible use would be where a relatively warm inexhaustible water source exists, allowing low initial capital system cost through minimum pipe line lengths and pipe insulation.

A further drawback of the system is that sewage with highly diluted characteristics and large volumes becomes expensive to treat. The City of Whitehorse, Yukon Territory, has such a water wasting system with its incumbent sewage treatment problem. Whitehorse has the advantage of being able to tap relatively warm groundwater, which reduces operational costs.

6.5.2.3 <u>Single pipe - no recirculation</u>. This system is employed to a great extent in Greenland and requires for its success complete coordination with town planning. High volume users, such as large apartment blocks or fish processing plants are strategically located at the ends of main lines to ensure a continual flow in the line without requiring a return loop (see Figure 6-11).

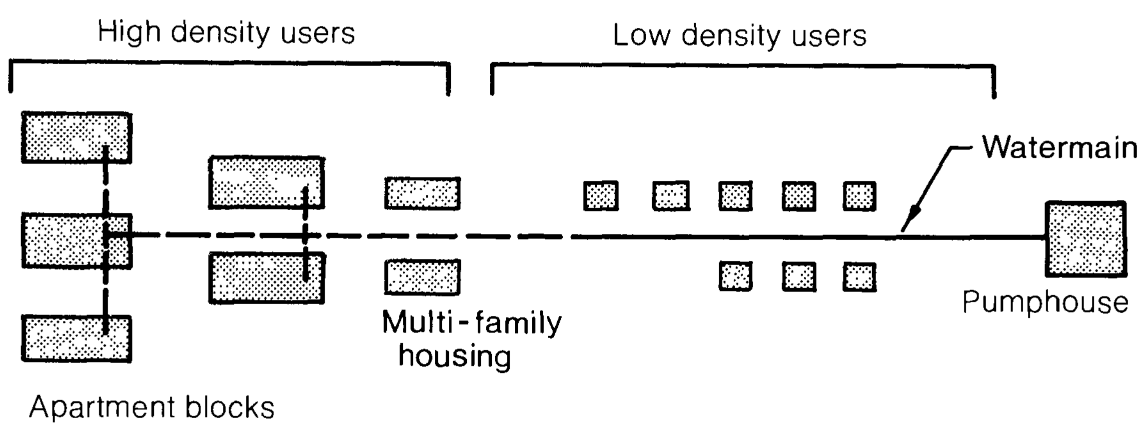

FIGURE 6-11. SINGLE-PIPE SYSTEM WITHOUT RECIRCULATION

In Greenland, apartment blocks accommodating up to 1500 people in one building are used for this purpose. In Canada, small community sizes and the standard of housing make it impossible to implement this type of system.

6.5.2.4 Dual pipe system. In this type of system a large supply line and a small return line are placed side by side either in a utilidor or in a packaged preinsulated pipe sysem (see Figure 6-12).

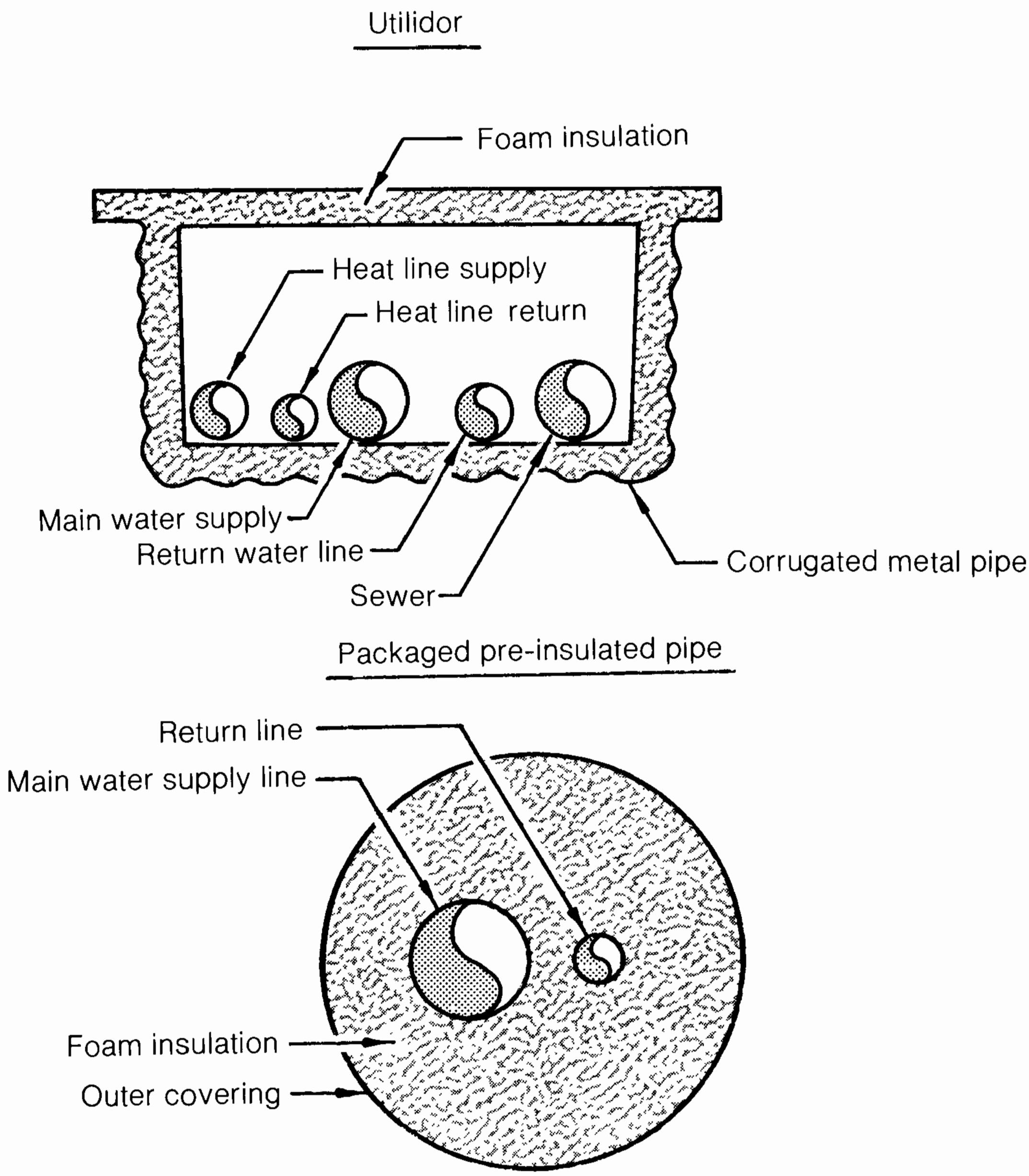

FIGURE 6-12. TYPICAL UTILIDOR AND PACKAGED PREINSULATED PIPE

This system permits lines to be laid out in the normal manner. The main is connected to the return line at the end of the line to ensure circulation.

Service lines are taken off the main and return via the return line to ensure circulation through the service connection by the pressure differential between the two mains.

Heating of the mains can be provided either by pretempering the main supply water or by utilizing separate heating lines.

Control mechanisms for this type of system tend to be elaborate because varying consumption in different locations results in stationary water in certain areas at certain times. Thermostatically controlled solenoid valves are required on "short circuit" branches between two lines at regular intervals to overcome this problem (see Figure 6-13).

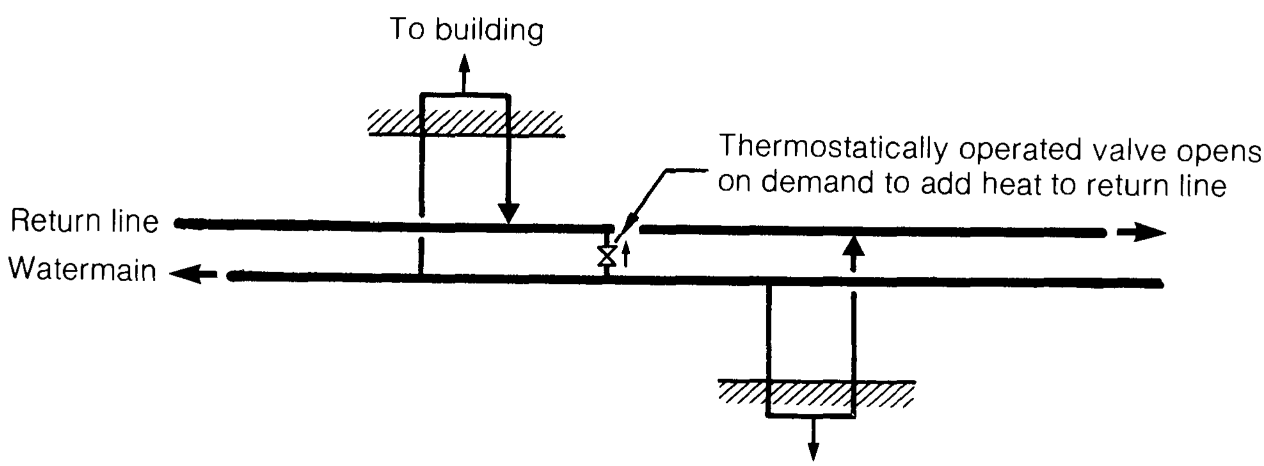

FIGURE 6-13. DUAL PIPE SYSTEM

Even with these or similar control devices it is difficult to ensure 100% movement of water at all times.

Other disadvantages of this system include:

- The greater number of lines used increases initial capital cost and energy consumption is high due to the greater surface area.
- The greater number of lines also increases the risk of line breaks. However, ultimate flexibility is allowed in isolating line breaks and keeping everything serviced.

While this system is not recommended as a main system it does have application as a sub-system to the single-pipe recirculation system or in long pipelines where there are no take off branches, such as supply lines from source to community, etc. The dual pipe system is often used as a sub-system of a single-pipe recirculation system to service existing houses in small areas that are difficult to service from the main loop or where it is impractical to extend the main loop (see Figure 6-14).

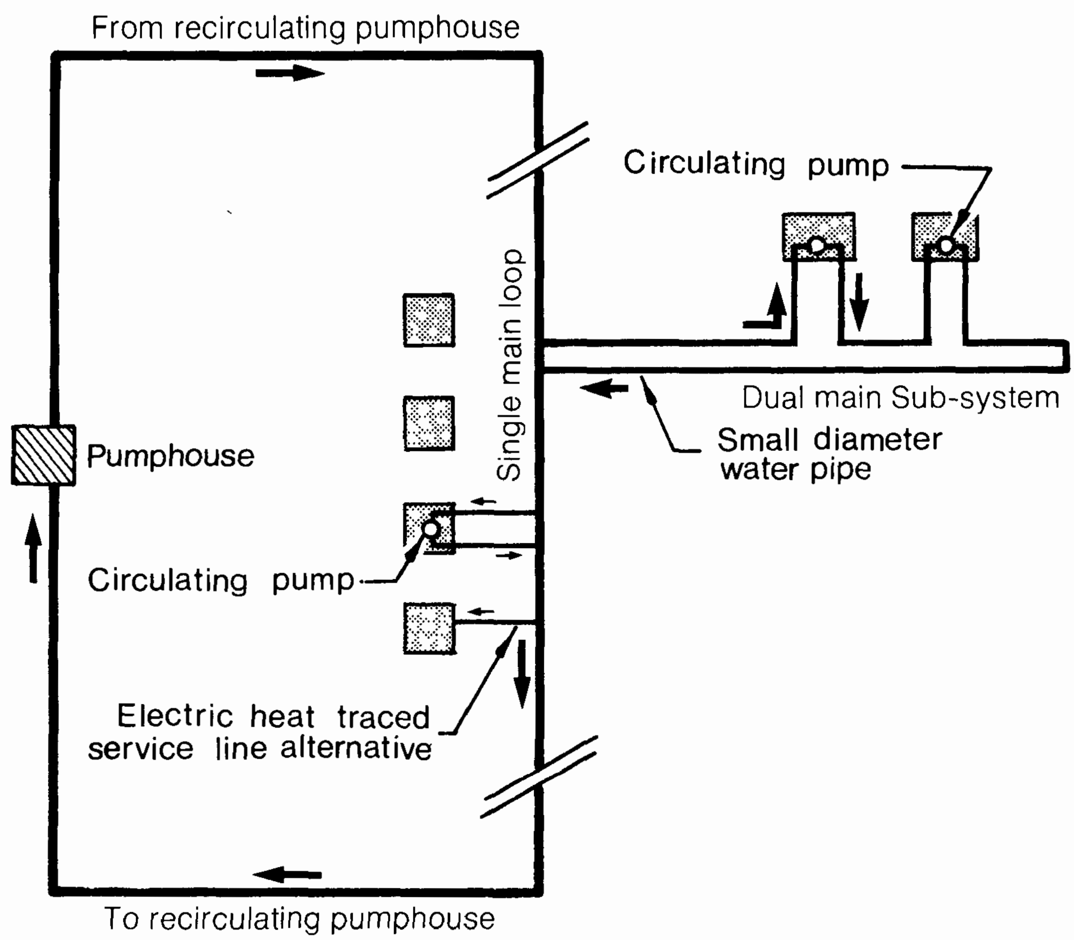

FIGURE 6-14. DUAL MAIN SUB-SYSTEM

The sub-system in effect becomes an elongated service line servicing a number of houses. The unit at the end of the line will have a circulation pump between the two lines to ensure that pretempering water from the main loop is circulated through the line.

6.5.3 Other methods

Other methods either still in the development stages or less frequently used are as follows:

6.5.3.1 Small-diameter water distribution lines can be a more cost-effective method of delivery for both small and large communities.

Small-diameter lines mean pipes of diameters from 50 mm to 152 mm. If full fire flow and hydrants were used the lines would range from 152 mm to 305 mm in diameter. The mode of circulation or main freeze protection mechanism would be any one of the types previously described.

Small-diameter mains require more emphasis to be placed on fire protection through building structure, building materials, etc. and the use of sprinklers and hose cabinets in lieu of exterior hydrants.

One advantage of such a system is in the net energy savings. Less surface area means less heat loss. There is also greater movement of water in the pipes, making the system more reliable. The pipes can be placed near or directly under houses due to lower capital cost, practically eliminating service line problems.

Small-diameter piping systems are used extensively in Greenland (see Figure 6-15), including the capital Godthab with a population of 12 000, and in Alaska, where 50 mm to 102 mm have been used by the U.S. Public Health Service. In Greenland, in lieu of factory insulated pipe, small diameter water mains and sewer lines are insulated and wrapped on-site.

6.5.3.2 Intermittent or batch water supply has been proposed for small communities as the most cost-effective method of distributing water [2,3]. Under this system, small diameter lines would go into and out of each house in a series of continuous loops. Water would be distributed at only certain times or on certain specified days. The lines would be preheated, water distributed say for eight hours every Monday, Wednesday and Friday, and then the lines would be blown out with air. The latter, however, is not a very reliable method of dewatering lines.

In houses with existing 1136-L holding tanks, it would be the homeowner's responsibility to open and close a valve on the water line to fill his holding tank. Utilizing the existing storage capability in the house in this manner is very attractive, especially for those communities

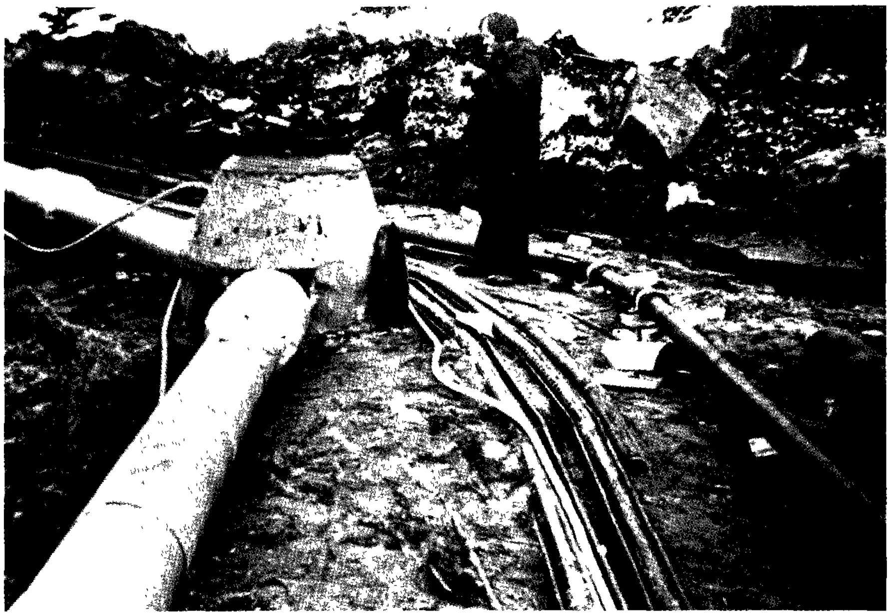

FIGURE 6-15. SMALL-DIAMETER WATER MAINS

where water use is restricted by the lack of a continuous source, where expensive storage reservoirs had to be built. In such communities it is expensive to truck water; yet if fully-piped systems were used, increased water consumption would either deplete the community's water source or very large reservoirs would have to be constructed.

6.5.3.3 Summer line systems are useful in many communities where permanent lines are not economically feasible. Local topography and conditions, plus economics and convenience, may make uninsulated summer lines desireable.

Such lines often take advantage of sources of water that allow flow by gravity to the community. In other cases they are used in conjunction with pumping systems. Eliminating the need for trucked water for up to four months and using inexpensive above-ground lines reduces overall costs. The summer lines can also be used to fill reservoirs for winter use.

There are many different forms of summer lines but since they are not unique to cold regions no further detail on this topic will be given in this manual.

6.5.3.4 Lines with "flushing hydrants" are used to prevent sewer lines from freezing up where relatively few hook-ups are on the end of a long line. A small amount of water (5 to 10 L/min) is bled into an end-of-line sewer manhole. The bled water is syphoned into the sewer line in predetermined batches, as shown in Figure 6-16, at regular intervals determined by the flow of water and volume held in the manhole before the syphon action takes place.

6.6 Service Lines

Service lines are usually incorporated as part of a service bundle or utilidette. The common service bundle package used in arctic Canada is as shown in Figure 6-12.

Double recirculation lines are recommended in all cases. However, single-line systems with electric heat trace to prevent freezing have been and are still being used by lot owners. The single-line system uses a great deal of electric energy which, in isolated communities, costs as much as $0.25/kWh. For this reason its use should be carefully evaluated. Service lines entering the house must be isolated and/or protected against movement.

Main elements of the service line are described below.

6.6.1 Method of circulation

The two most common methods are a pump inside the housing unit and pitorifice circulation. Pitorifices must have a 0.61 m/s velocity in the mains to operate properly. However, they cannot be used for service line circulation if the lines are longer than 25 metres. Beyond this length, a small circulation pump must be added in the house. Observed head losses across pitorifices are given below. These measurements were made in 1975 in the Kotzebue system to determine the head loss in the main line loops due to the presence of the pitorifice fittings.

Loop	Length (m)	Number of Services	Head Loss/Service (pair of pitorifices)
KEA loop	12 300	110	0.31 kPa/pair (3.3 cm/pair)
uptown loop	11 055	80	0.32 kPa/pair (3.3 cm/pair)
centre loop	8 250	93	0.34 kPa/pair (3.6 cm/pair)

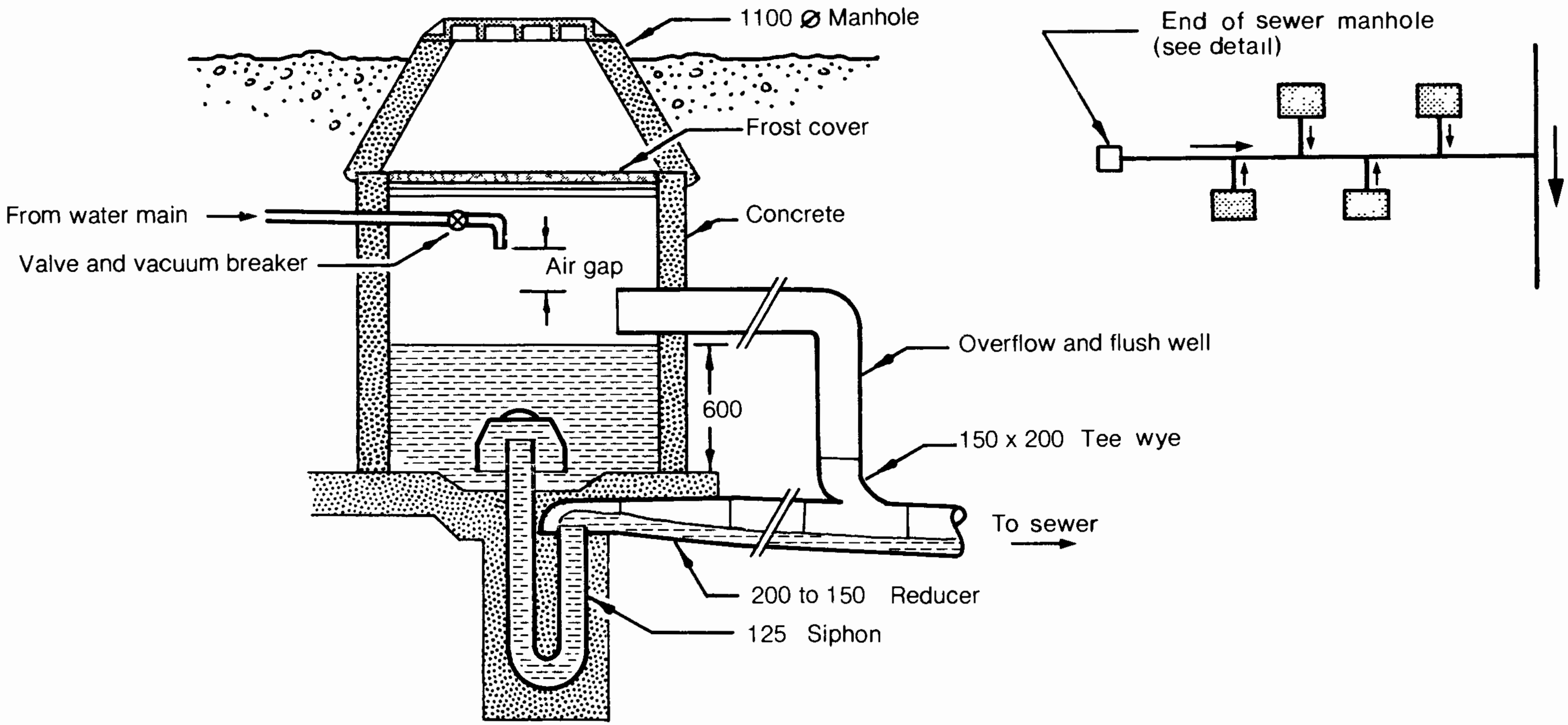

FIGURE 6-16. FLUSHING MANHOLE SYSTEM

The measurement of head loss is valid for a 101.6 mm main line flow of 6.75-7.5 L/s and 5 cm-1.9 cm pitorifices. A conservative design loss of 6 cm per pair could be used.

The head losses in the pumphouse plumbing on each system must also be calculated. These losses are substantial on most systems.

The main back-up freeze protection is an electric heat trace thermostatically controlled from the housing unit, with high and low temperature limits. If copper pipe is used as a carrier a metal band across the two pipes at the mains can provide electric resistance thawing from within the house as a second back-up system (see Figure 6-17 for details).

Another method is to insert a small-diameter probe into the frozen pipe from the house and force hot water through it. (See Appendix F).

6.6.2 Materials

The standard service bundle includes a preinsulated 101.6 mm diameter sewer line (65 mm water lines and a 18 mm conduit for pulling in heat trace cable). The overall diameter is approximately 300 mm with a 41 mil yellow jacket placed on the outside. If the service bundle is exposed or used as an above-ground service, a metal outer jacket is also recommended.

Details of above and below-ground service box take-offs are shown in Figures 6-18, 6-19 and 6-20. Note details concerning service valves and operating stems. These are a must in order to isolate a service without digging it up and damaging the insulated hook-up box. Other special precautions are taken, such as packing the valve box assembly with low-temperature nonhardening grease to prevent water from freezing around the mechanism and making it inoperable in winter. The top of the valve box assembly is terminated about 10 cm below grade to prevent damage by playing children, snowmobiles, etc.

6.6.3 Dual servicing

When adjacent housing units have a common owner, such as in public housing, common services are often used as shown in Figure 6-21. The water lines are so arranged that the supply goes into one house through the circulating pump, out the return line to the main. In other words, a small water loop connects two houses using the same service bundle.

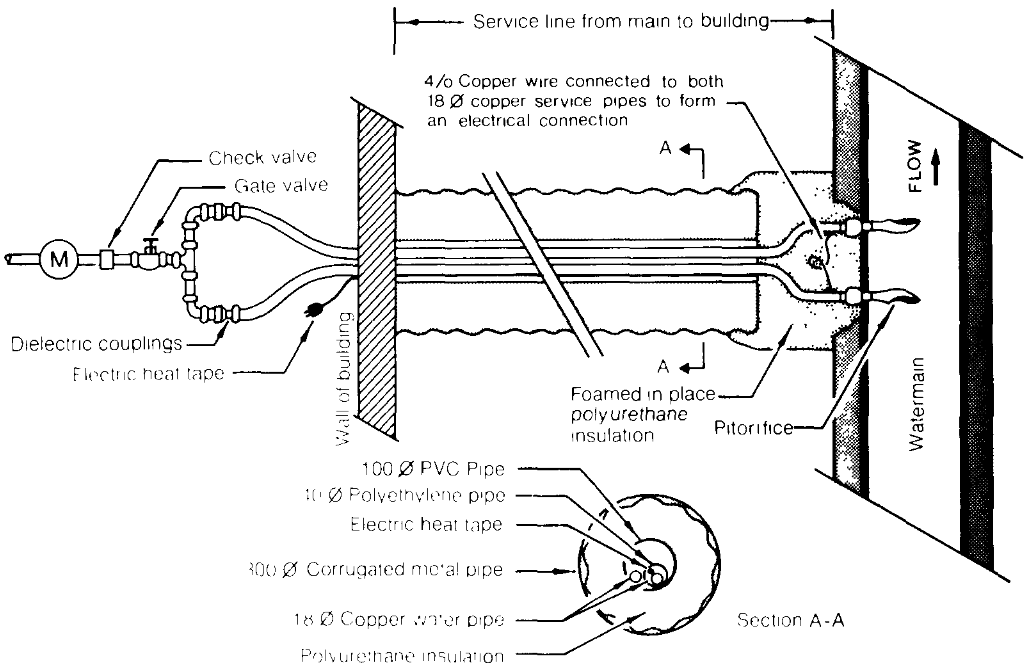

FIGURE 6-17. WATER SERVICE LINE

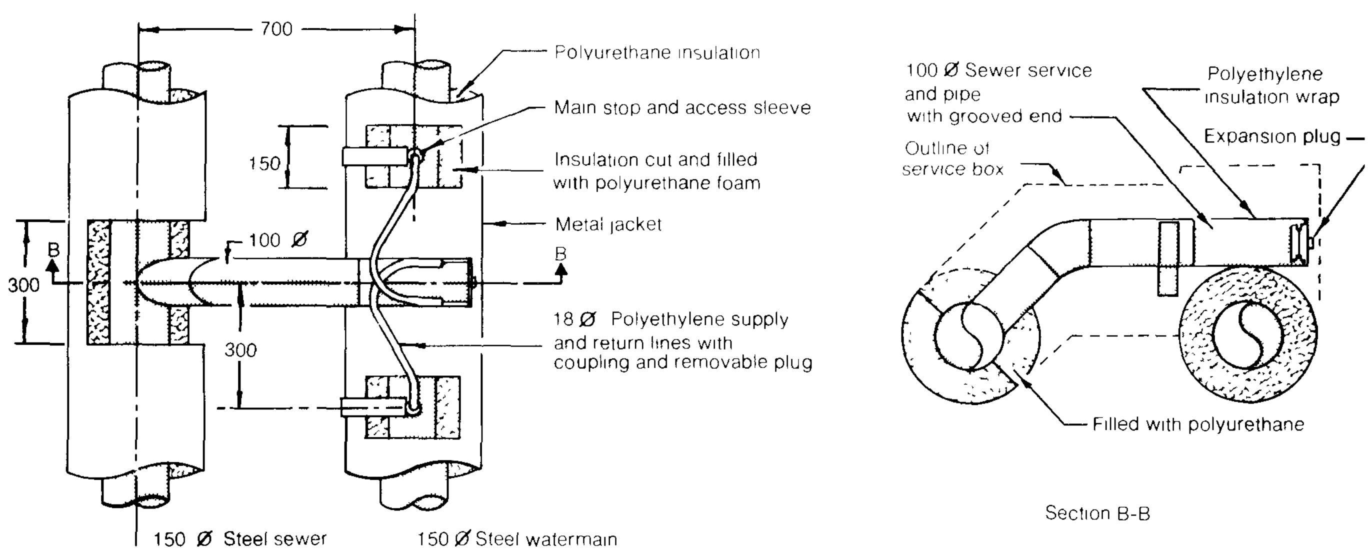

FIGURE 6-18. ABOVE-GROUND SERVICE LINE

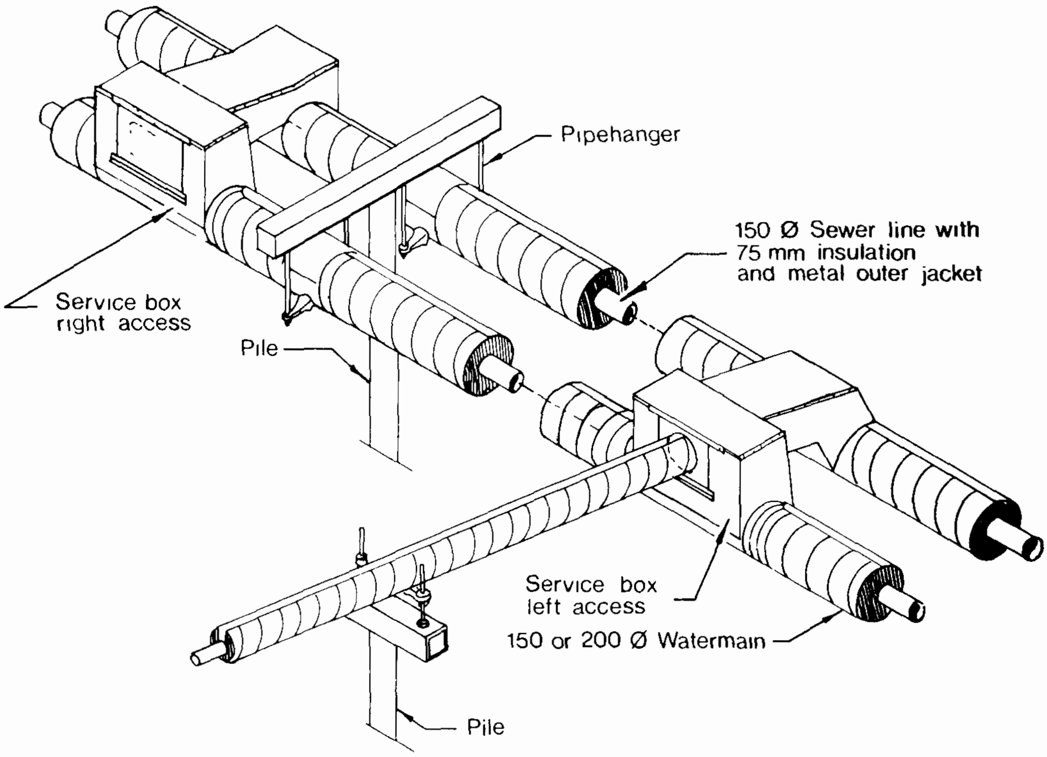

FIGURE 6-19. ABOVE-GROUND SERVICE LINE TAKE OFFS

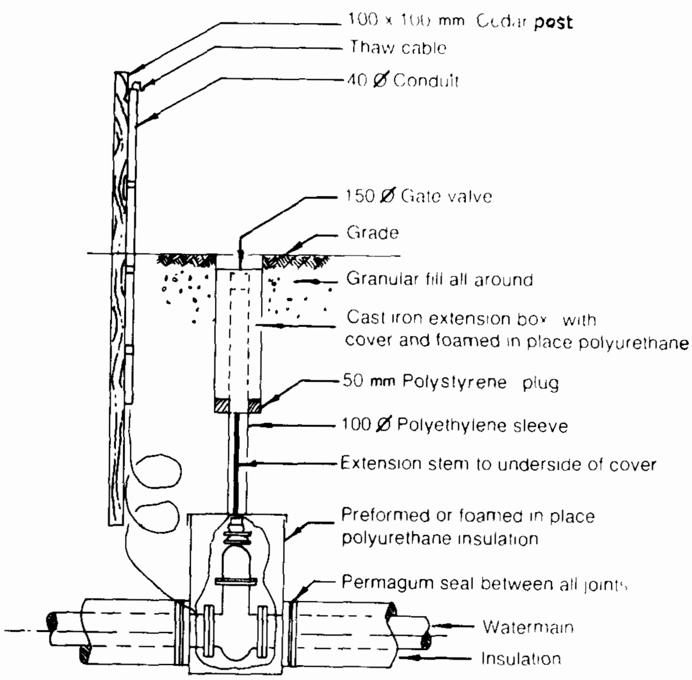

FIGURE 6-20. UNDERGROUND VALVE AND BOX

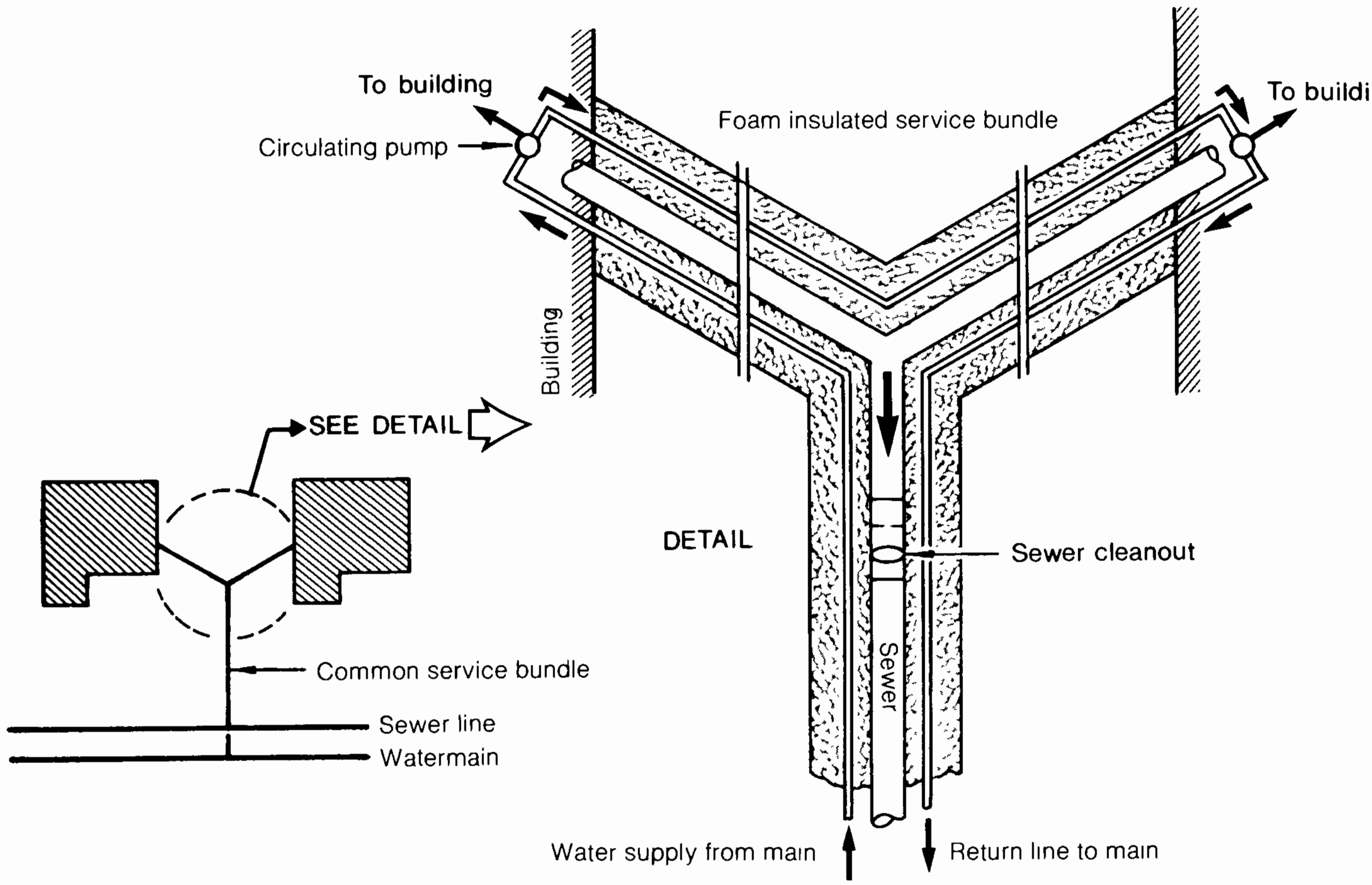

FIGURE 6-21. DUAL SERVICING

This cuts the capital installation cost of the service line to each house by approximately 1/3, and increases the reliability due to greater consumption and dual circulation pumps on the one loop.

6.7 Materials of Construction

Described below are the most common materials used for piped water distribution in northern regions. The materials are broken into two categories. Category 1 materials are considered the best materials for northern use. Category 2 materials should be used only if design conditions allow their use in a safe dependable manner.

6.7.1 Category 1 materials

6.7.1.1 Copper is mainly used in service lines because it can be thawed using electric resistance. Type K only is recommended.

6.7.1.2 Ductile iron pipe can take shock loadings and has some flexibility. Corrosion resistance is low and lining should be used as with cast iron. It is very durable and fairly heavy. Its use is recommended through rocky areas and/or where sand or gravel bedding materials are not available. It is the best of the steel or cast iron pipes but relatively expensive (about $11.50/m for 10 cm). (C = 125).

Ductile iron with tyton or victaulic joints is also used where bridge strength is required. This occurs when spanning piles above-ground or where there is a possibility of isolated settlement below-ground. Ductile iron also can be thawed using electrical resistance.

6.7.1.3 Steel pipe. The description for ductile iron also applies to steel, except it is less corrosion resistant, somewhat lighter and more flexible. The flexibility is hard on linings. Flexible epoxy linings are being developed which should be more durable. Continuously welded steel pipe is also used (especially in above-ground systems) to obtain maximum spans between piles. It can be thawed using electrical resistance. Expansion and contraction, including necessary thrust anchors, must be taken into consideration.

Steel pipe can be connected using a method called "zap lock". In this method two pipes of the same size with the ends bevelled to fit into one another are hydraulically rammed one inside the other in the field. A layer of epoxy cement is applied prior to the ramming process. The resulting overlap of approximately 35 cm gives a joint that is stronger than the pipe. This method is a good alternative to continuously-welded steel pipe and can be carried out quickly in the field at cold temperatures.

6.7.1.4 Plastic pipe is just coming into its own. It is light (5.0 m section of 10 cm diameter weighs about 12.8 kg), flexible, and has a smooth interior (C = 150). Bedding is not as critical but still must be done properly. It is easy to install but a little more expensive than metal pipes. It has a higher coefficient of contraction and expansion than the other materials and this must be taken into account at joints. The recommended type for northern regions is high molecular weight polyethelene.

High density polyethelene (PE) is very flexible and impact resistant. It cannot be threaded. PE is used widely for service lines and main lines. Butt-fused PE pipe is used extensively in Canada for water distribution and sewage collection lines. The pipe is insulated with urethane and the outer pipe is also PE (the outer pipe joints are heat shrink couplings). It is claimed that it can freeze solid and be thawed using a heat trace line without rupturing or breaking [4].

Other materials are used where bridge strength is required. Precautions must be taken if laid above-ground to account for large expansion and contraction.

Pipe take-offs from fixed joints such as pumping stations must be supported in case of ground settlement, which would cause unacceptable stress on the pipe joint (see Figure 6-22).

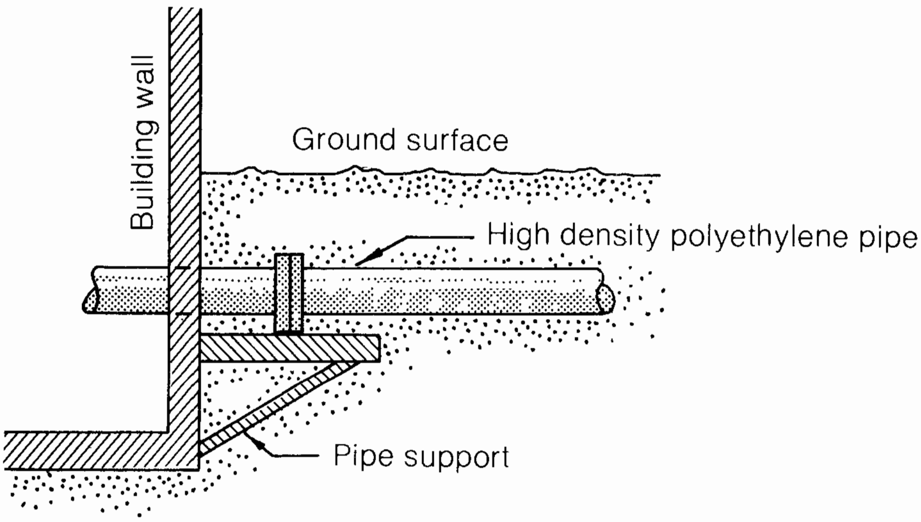

FIGURE 6-22. SUPPORTED PIPE TAKE-OFF

6.7.2 Category 2 materials

6.7.2.1 Cast iron is probably the oldest (in use in Germany since 1455
It is relatively corrosion resistant if cement-lined and tar-coated, and).
providing the lining is not damaged before or during installation (damage occurs easily). Unlined pipe should not be used. It is heavy and hard to handle, but durable (6.1 m section of 10 cm diameter weighs 225 kg).

6.7.2.2 Asbestos-cement pipe is being used extensively in temperate climates. It must be carefully bedded or uneven loading will break it. It is extremely corrosion resistant. It is relatively light (a 4 m section of 10 cm diameter weighs about 30 kg), easy to install and is nonmetallic. It is not costly (about $6.00/m for 10 cm diameter). It has a smooth interior (C = 140) and retains it longer than the metal pipes.

Asbestos-cement pipe should never be used for northern work in buried conditions in soil subject to settlement or frost heave.

6.7.2.3 Plastic pipe. Polyvinyl chloride (PVC) pipe is the most common type used in water mains. Type I is stronger; Type II is more impact resistant but not rated for as high pressures. In cold climates a Type I/Type II is used to gain part of the benefits of both. It can be threaded and has the same cross-section dimensions as steel.

PVC pipe is manufactured in two basic types. First are the SDR classes which have constant pressure ratings for all sizes throughout each class. SDR is an abbreviation for sidewall diameter ratio. SDR 26 pipe, which is rated for 1103 kPa, is widely used for water mains. Second are Schedules 40, 80 and 120, which roughly correspond to iron pipe sizes and have more uniform wall thicknesses for different sizes within each schedule. This sizing procedure results in small-diameter pipes having much higher pressure ratings than larger pipes in the same class.

Both of these general types are designed for pressure applications and are used mainly for water systems. PVC pipe, designed specifically for sewer use, has, in the past, been thin-walled and breakable. For this reason, considerable quantities of the SDR 26 pressure-rated pipe have been used for sewer lines in recent years. Non-pressure rated pipe with thicker walls is now being manufactured under the ASTM designation shown below for PVC sewer pipe and has proven very satisfactory. PVC pipe is covered by the latest revisions of the following ASTM standard specifications:

PVC pipe and fittings (SDR classes) - D-2241
PVC pipe and fittings (Schedules 40, 80 and 120) - D-1785
PVC sewer pipe and fittings - D-3034

The design and installation practices recommended by the PVC pipe manufacturer should be complied with. Many manufacturers have compiled very good booklets covering PVC pipe and are quite willing to provide these to actual or potential customers.

PVC pipe is not recommended for single-pipe buried installations in permafrost.

Acrylonite-butadiene-stryrene (ABS) has high impact strength and flexibility but has low mechanical strength (half that of PVC). It does not become brittle at cold temperatures. ABS is being used primarily for non-pressure drainage, waste and vent (DWV) work.

ABS has also been used by the U.S. Indian Health Service for sewer mains, service lines and drain field installations. This pipe is not as readily available as PVC in some sizes. In general, ABS pipe has a higher impact strength than PVC in the more common types but it requires a thicker wall to be equivalent to PVC in pressure rating. Ratings and nomenclature for different types of ABS pipe are basically the same as those for PVC. ASTM standard specifications covering ABS pipe are as follows:

ABS pipe and fittings (SDR classes) - D-2282
ABS pipe and fittings (Schedules 40, 80 and 120) - D-1527
ABS sewer pipe and fittings - D - 2751

Design information is available from manufacturers and should be followed closely. Again, ABS is not recommended for single-pipe buried installations in permafrost.

6.7.3 Other types of pipe used

Regular or prestressed, reinforced concrete pipe is used, usually for larger transmission lines.

Wood stave piping is good in cold regions because of its insulation value. It is expensive and corrosion-free (except for the wire). C = 140 and does not change with age. It is also able to withstand freeze-thaw cycles without breaking.

6.7.4 Miscellaneous fittings

Joints - bell and spigot (rubber o-ring), mechanical joint, dresser couplings, solvent welding, threaded, etc.

Service lines are nearly all copper now but polyethelene is being used more and more. The copper has the advantage of being electrically thawable, but PE is considerably cheaper, easier to install, and can withstand freeze-thaw.

Dresser or other type repair clamps should always be kept on hand for all pipe sizes in the distribution system to repair leaks.

Valves should be AWWA approved types, rated for the pressure under which they will have to work [5].

There are four basic groups of valves: globe, rotary (butterfly, plug, etc.), slide (gate) and swing (check valves). Plug and ball type valves are older; gate valves are most widely used now. All valves that need frequent adjustment or operation should be furnished with a valve box to the surface.

6.7.5 Insulation

Pipes of the materials noted above, when used in individual piping systems, are normally insulated with high-density urethane foam under factory conditions and covered with a 40-mil high-density polyethelene jacket or steel, depending on the exposure of the material when used. The factory-insulated pipes are shipped to the job site complete with preformed half shells of urethane for the joints. Heat shrink sleeves, or polyken tape is used to complete the joint in the field where high-density polyethelene is used as an outer jacket. For pipes insulated and covered with a steel jacket, a special metal jointing section is used.

Except for appurtenances using urethane, insulation is not normally done in situ because of the high cost and high labour requirement. There is also a lack of end-product quality.

6.8 Appurtenances

6.8.1 Hydrants

6.8.1.1 Above-ground. Above-ground hydrant housings must be tailor made to fit the particular design. They are generally of the siamese building wall hydrant type.

Figure 6-23 shows a typical above-ground hydrant with its individually-designed insulated housing. The distance from the main is

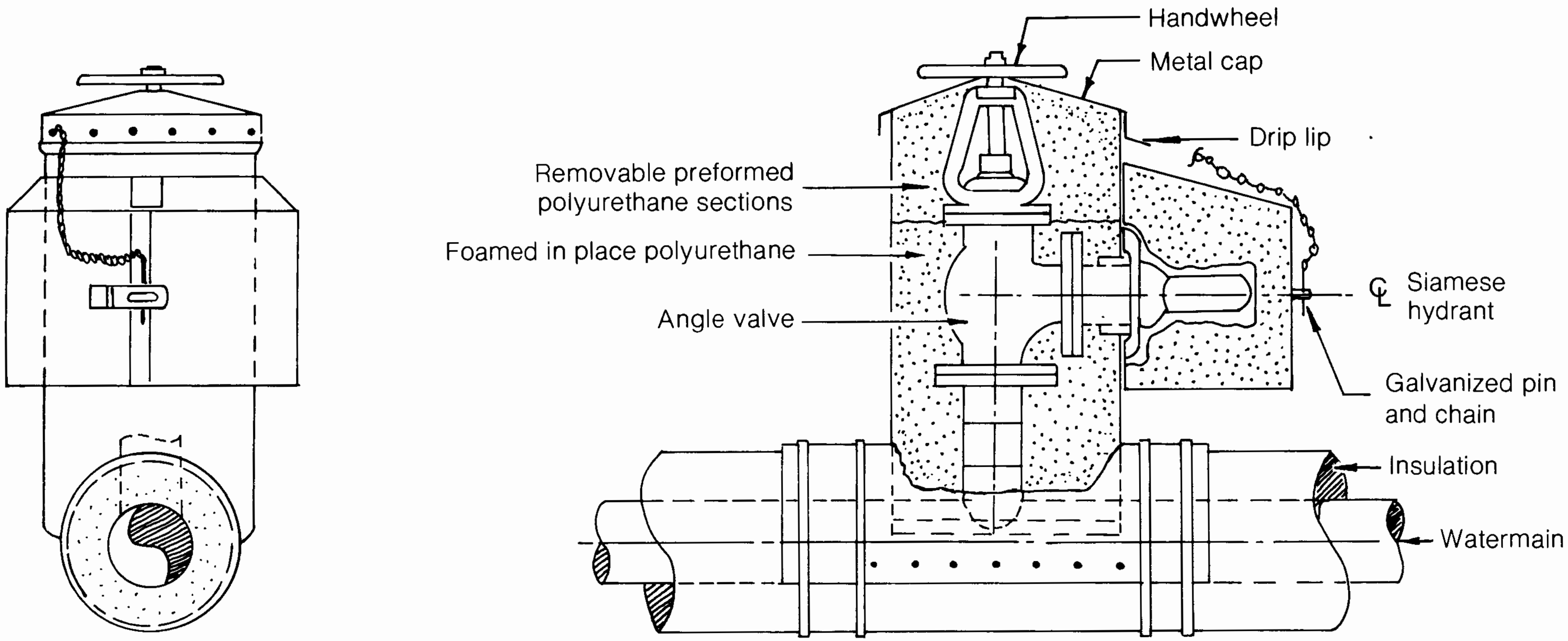

FIGURE 6-23. ABOVE-GROUND HYDRANT

kept as short as possible so that heat conduction from the water flowing through the main keeps the water in the hydrant from freezing. The hydrant housing is painted fluorescent yellow.

6.8.1.2 Below-ground. A typical below-ground hydrant installation is shown in Figure 6-24. The hydrant is normally on-line to minimize possibility of freezing, with a frost-isolating gasket between the bottom of the hydrant barrel and the tee into the main. The hydrant barrel is insulated with 7.62 cm preformed polyurethane and placed inside a 50 cm diameter polyethelene series 45 pipe sleeve. The cavity between the sleeve and the insulated barrel is filled with an oil and wax mixture to prevent damage to the hydrant due to frost heave.

Isolating valves are normally put on either side of tee into the main to allow for hydrant replacement or repair.

An appropriate mixture of propylene glycol and water of a grade acceptable for potable water systems is pumped into the empty hydrant to prevent the hydrant from freezing. After use, the hydrant must be pumped out and recharged, since permafrost conditions may prevent self-draining.

6.8.2 Valves

Above and below-ground valves are basically the same, with the exception of the valve box and operating stem details. Typical details for such installations are shown in Figures 6-19 and 6-20.

Again, foamed-in-place polyurethane insulation is used with a series 45 polyethelene sleeve over the operating stem filler, similar to hydrants. Valves generally used for buried installations or where the valve is completely insulated are nonrising stem-gate valves. In other situations, such as in manholes, any appropriate valve can be used.

6.8.3 Metering

Standard meters are used to monitor flow in the distribution system, including magnetic flow meters, in-line gear meters, and orifice pressure differential recording graph meters.

Both the supply and return lines must be metered in circulating systems with one or more loops. The difference gives the daily consumption. Under fire conditions, a reverse flow meter or bypass is required on the return line.

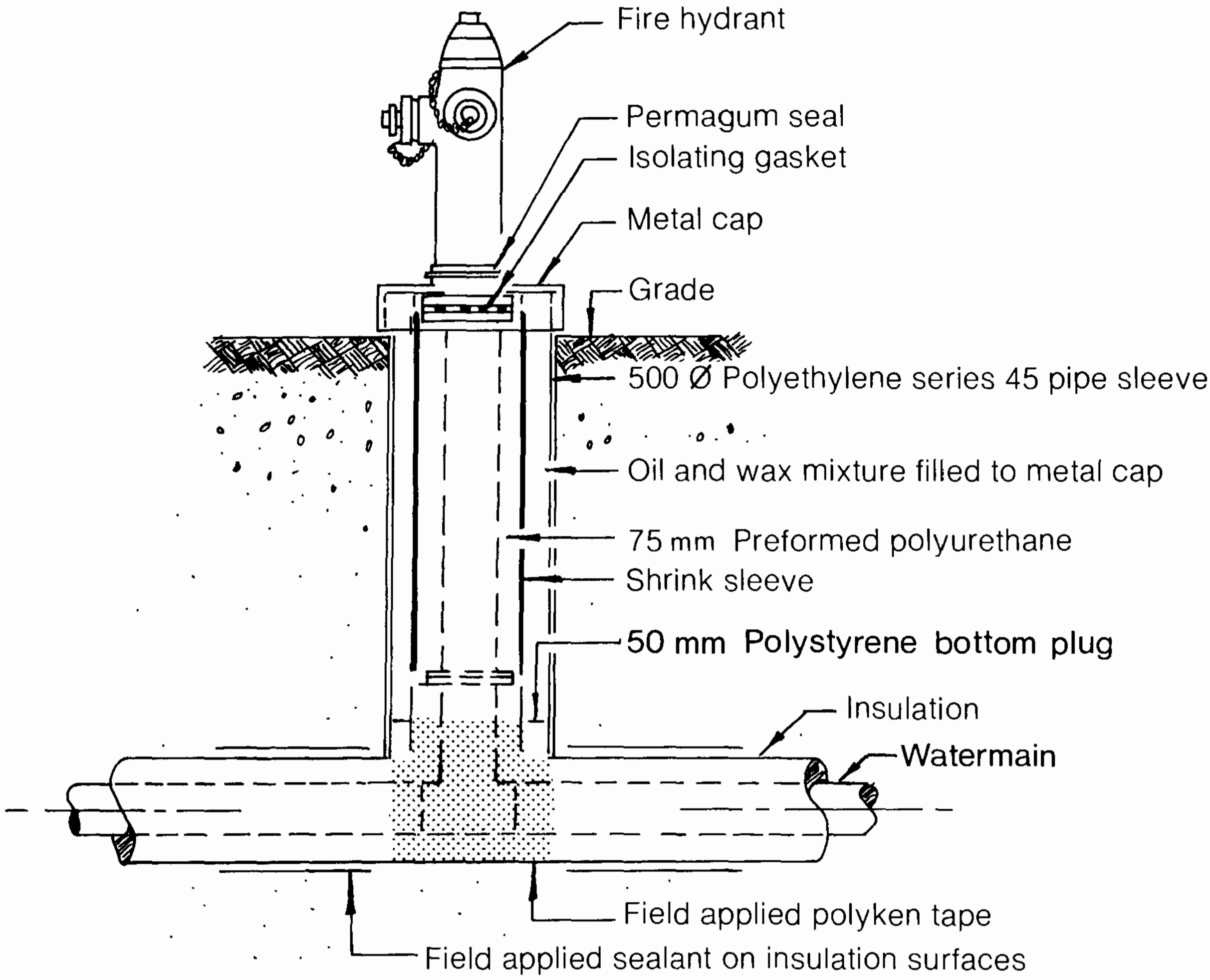

FIGURE 6-24. BELOW-GROUND HYDRANT

Most northern communities are relatively small. This means the fire flows are as much as 10 to 15 times greater than the average flow. In this case an orifice plate meter which is satisfactory for fire flows will give unsatisfactory results under normal conditions. If it gives a satisfactory graph under normal conditions then the orifice plate is such that it restricts flows during a fire situation. Both magnetic flow meters and gear-driven meters are very expensive for large diameter pipes. In most instances, the large diameter supply pipe flow is diverted through a small pipe through one of the latter two meters, and then back to the larger supply size pipe. During fires the meters are completely bypassed and flow is directed through the large supply lines.

6.8.4 Manholes

Manholes for both water and sewer requirements have been constructed of a number of materials. Common types are:

- concrete,
- corrugated metal, and
- welded steel.

All of these have varying means of insulation.

The main problems in the past with manholes were that they were too small, leaked excessively, or were subject to damage. One alternative which evolved in the Northwest Territories is the manhole shown in Figure 6-25, known as the "mini service-centre manhole".

The manhole shown in Figure 6-25 is a comprehensive one showing both water and sewer lines as well as a hydrant, but the same basic design is used for any situation. The interior layout and size are designed to fit the requirements.

The basic concept is that all necessary day-to-day maintenance of the distribution mains can be carried out in a climate controlled environment. This includes maintenance of water line valves, hydrants, heat trace power point, and sewer cleanouts.

Some of the features of such a manhole for northern work are:

Hydrants - Standard hydrants can be used and operated in the normal manner.

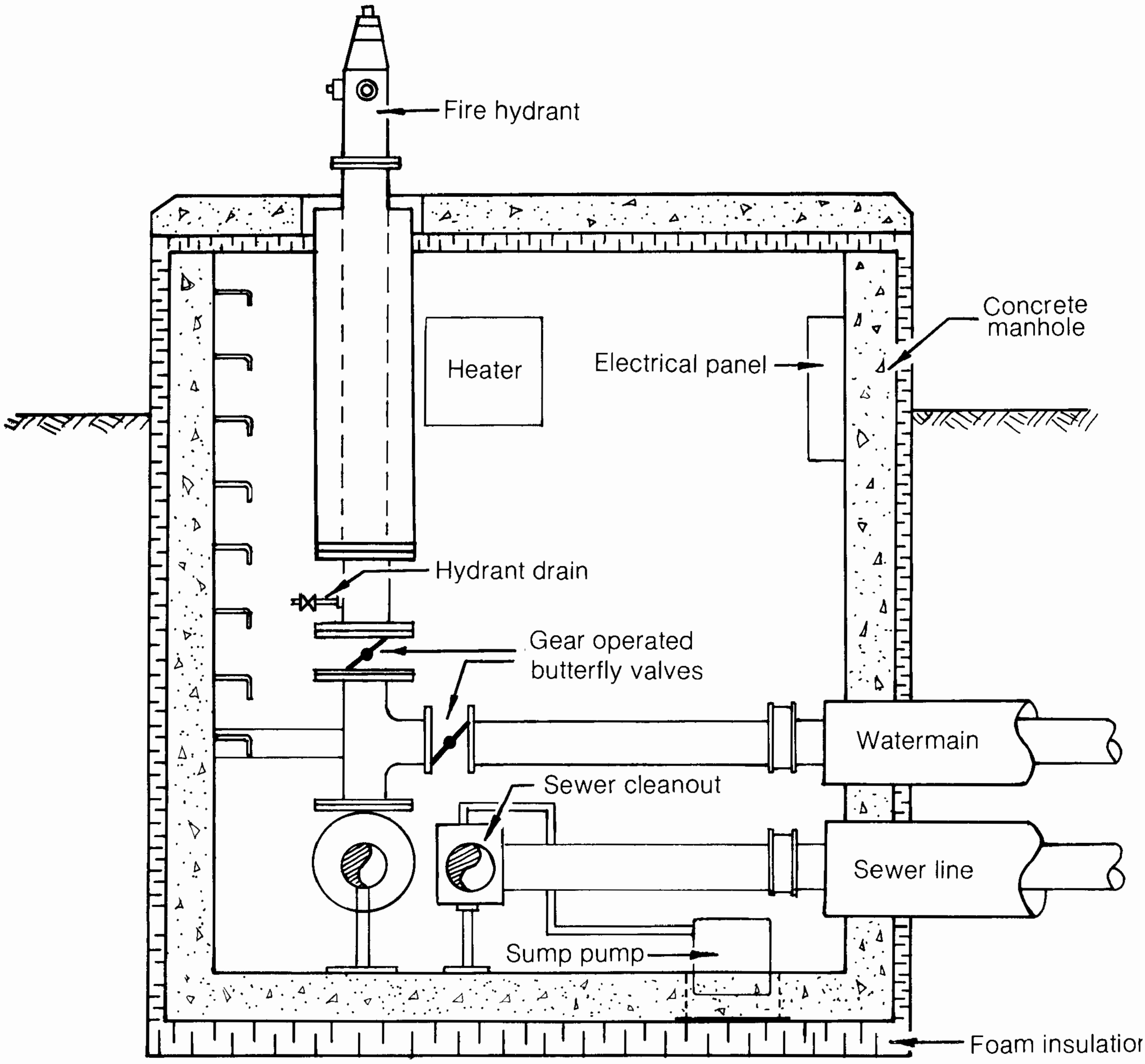

FIGURE 6-25. MINI SERVICE-CENTRE MANHOLE

- One isolating valve plus valve boxes and operating stem extension are eliminated, reducing installation cost.
- Replacement is easier; no digging is required.
- Relatively fool proof compared to glycol filled hydrants.

Main valves - These are placed in manholes giving easy access for operation or replacement and eliminating valve boxes.

Manhole Structure
- The manholes are well insulated for energy conservation
- They are large: minimum size 1.2 m^2 depending on interior fittings.
- All exposed surfaces are metal or concrete: relatively vandal-proof and maintenance-free.

Power Point/ heat trace
- Heat trace lines and control points are terminated in the manholes. Replacement heat trace lines can be pulled in from one manhole to the next.
- A thermostatically controlled electric heater keeps the temperature above freezing.
- There is an electric plug for lights and small power tools.

Sump pump - The sump pump is located in a prefabricated steel sump pit set in the concrete base. The pump comes on automatically if water from a used hydrant or groundwater enters the hydrant and pumps through a back flow preventor into the closed sewer line.

Sewer cleanout - Closed sewer cleanouts are provided in the manhole; covers have rubber gaskets so excess pressure can be detected.

6.8.5 Alarms and safeguards

Alarms and safeguards are a very important part of any system. Flow alarms are a necessity in any circulation line to warn of stopped circulation.

Low heat alarms are needed to warn of impending freeze-ups. Flow meters are especially important to adjust flow in the return circulation loop.

The alarms should be wired to the operator's house and be loud enough at the pumphouse to wake someone and get them there to check out the trouble. Alarms must be tested at least weekly to be sure they are operational. A central control panel should be provided either in the operator's house or the pumphouse.

6.9 Backup Freeze Protection Mechanisms

The main backup freeze protection mechanisms are:

- heat trace systems,
- thaw wire electrical resistance systems,
- steam or hot water thawing.

6.9.1 Heat trace systems

This is the standard back-up system used in most piped water distribution systems. While it is effective, both the initial capital cost and operating cost for this type of insurance are substantial. The cost of installing heat trace systems is approximately $30/m of line, including material and labour for the overall system.

Constant monitoring must be carried out on such electrical systems if they are to perform as intended. If the controlling thermostats are not working properly or the sensing bulbs are in the wrong location, either too much electric energy will be expended at great cost or it will fail to do the job when required.

Easy replacement of heat trace lines should be a standard feature of any system. The heat trace normally used is the constant watt per foot type placed in a conduit or channel next to the pipe with or without heat contact cement. Common wattages used are 2.5 watts per foot for service lines and 4 watts per foot for main lines. This method of placement of heat trace lines is relatively less efficient on plastic pipes. In Greenland and Northern Scandanavia the heat trace is placed inside plastic pipes.

Care must be taken to ensure the conduits are sealed. Otherwise they will allow groundwater to enter the electrical system and manholes.

6.9.2 Thaw wire electric resistance systems

This system can only be incorporated on piping materials that will pass an electric current, such as copper and steel. A current is induced into sections of the pipe through strategically-placed thaw wires by a portable electric generating unit. The resistance and resulting heat thaws out the pipe.

The initial capital cost for this backup thaw system is low. It is only used if the pipe is already frozen, as opposed to heat trace systems which add heat before freezing takes place.

6.9.3 Steam or hot water thawing

This system uses a source of steam, such as a portable steam jenny, or hot water introduced under pressure into the frozen pipe via a suitable hose or tube to thaw out the pipe. This system can be used on many types of materials. It is not recommended for use on plastic pipes which could melt or be damaged if the procedure used is improper.

An example of the difference in the cost of heat tracing systems versus steam thawing was noted in Norman Wells, N.W.T., where a portable steam jenny was purchased in lieu of an electric heat trace system for the welded steel pipe system. The difference in initial capital cost for approximately 1800 m of mains was $95 000. This difference will increase as more mains are installed because the steam jenney can be used for other purposes.

The great difference in cost encourages careful consideration of the alternatives to a heat trace system.

While heat trace systems appear to be the trend in back-up thawing for single-loop recirculation systems, better prefabricated insulated pipe packages, and simple control and alarm systems warrant re-evaluation of the justifications for a heat trace system.

For thawing small service lines a power pump, a hot water reservoir and small probe tube as described in Appendix F has proved most successful and superior to other methods. Helpful tips, tables and guidelines for thawing frozen water lines are also given in Appendix F.

6.9.4 Freeze damage prevention

The reduction of damage to water distribution pipes when freezing occurs has been discussed by McFadden [6]. The use of a diaphram at the last point to freeze in each section of pipe was recommended as a good technique to reduce damage. The location of the proper point can be selected and somewhat controlled by careful analysis of the system and careful placement of additional insulation.

6.10 References

1. Government of the Northwest Territories, Department of Local Government, "General Terms of References for an Engineering Pre-design Report on Community Water and Sanitation Systems", Yellowknife, August 1977.

2. James, William and Ralph Suk, "Least Cost Design for Water Distribution for Arctic Communities", McMaster University Hamilton, Ontario, May 1977.

3. James, William and Ralph Suk, "Design Examples: Least Cost Water Distribution Systems for Pangnirtung and Broughton Island, N.W.T.", McMaster University, Hamilton, Otario, May 1977.

4. O'Brien, E. and A. Whyman, "Insulated and Heat Traced Polyethylene Piping Systems - A Unique Approach for Remote Cold Regions", In: Utilities Delivery in Arctic Regions, Environmental Protection Service, Environment Canada, Report No. EPS 3-WP-77-1, Ottawa, 1977.

5. Edwards, J. "Valves, Pipes and Fittings", Pollution November 1971.

6. McFadden, T., "Freeze Damage Prevention in Utility Distribution Lines In: Utilities Delivery in Arctic Regions, Environmental Protection", Service, Environment Canada, Report No. EPS 3-WP-77-1, Ottawa 1977.

6.11 Bibliography

Alter, A.J., "Water Supply in Cold Regions", Cold Regions Research and Engineering Laboratory, Monograph III-C5a, Hanover, New Hampshire, 1969.

Bohlander, T.W., "Electrical Method for Thawing Frozen Pipes", AWWA Journal, May 1963.

Buck, C., "Variable Speed Pumping has Many Advantages", Johnson Drillers Journal, May-June 1976.

Canada Department of Indian Affairs, "Handbook of Water Utilities, Sewers and Heating Networks Designed for Settlements in Permafrost Regions", Translated from Russian by V. Poppe, 1970.

Carlson R. and J. Butler, "Alaska Water Resources Research Needs for the 70's", Institute of Water Resources, Univ. of Alaska, Report #IWR-39, Fairbanks, 1973.

Cheremisinoff, N. and R. Niles, "A Survey of Fluid Flow Measurement Techniques and Fundamentals", Water and Sewage Works, December 1975.

Crum, J.A., "Environmental Aspects of Native Village Habitat Improvement in Alaska", Standford Eng. Econ. Planning Report, EEP-46, 1971.

Dawson, R.N. and J.W. Slupsky, "Pipeline Research - Water and Sewer Lines in Permafrost Regions", Canadian Division of Public Health Engr., Manuscript Report No. NR-68-8, 1968.

Easton, E.R., "Reservoir Liners for Use in Arctic Water Supplies", Arctic Health Research Centre, Fairbanks, Alaska, 1961.

Gamble, D. and C. Janssen, "Evaluating Alternative Levels of Water and Sanitation Service for Communities in the N.W. Territories", Canadian Journal of Civil Engineering, Vol. 1, No. 1, 1974.

Gardeen, J., "How to Fathom Liquid Level Sensing", Water and Wastes, May 1976.

Gaymon, G.L., "Regional Sediment Yield Analysis of Alaska Streams", Journal of the Hydraulics Div., ASCE, January, 1974.

Gordon, R., "Batch Disinfection of Treated Wastewater With Chlorine at Less than 1°C", U.S. Environmental Protection Agency, Report # 660/2-73-0, Fairbanks, Alaska, September, 1973.

Government of the Northwest Territories, Department of Public Works, Equipment Specification No. 601, Municipal Water Delivery Truck Hydraulic Drive, Yellowknife, NWT.

Grainge, J.W., "Arctic Heated Pipe Water and Waste Water Systems", Water Research, Vol. 3, Pergamon Press, 1969.

James, William, and A.R. Vieirn-Ribeiro, "Arctic Hydrology Project, Baffin Island Field Program 1971 and 1972", McMaster University, May 1977.

James, F., "Buried Pipe Systems in Canada's Arctic", The Northern Engineer, Fall, 1976.

Kill, D., "Cost Comparisons and Practical Applications of Air Lift Pumping", Johnson Drillers Journal, September-October, 1974.

Page, W.B., "Report on Tests Conducted to Design Pitorifices and to Measure Heat Losses from House Service Pipes at Washington State College", Pullman, Washington, April, 1953.

Poss, R.J., "Distribution System Problems", AWWA Journal, Vol. 52, No. 2, February, 1960.

Reiff, F., "Hydropneumatic Pressure Systems", U.S. Indian Health Service, Anchorage, Alaska, 1967.

Ryan, W.L., "Design and Construction of Practical Sanitation Facilities for Small Alaskan Communities", Paper included in 2nd International Permafrost Conference Proceedings, National Academy of Science, Washington, D.C., 1973.

Ryan, W.L., "Methods of Pipeline Construction in Arctic Areas", U.S. Indian Health Service, Anchorage, Alaska, September 30, 1971.

Ryan, W. and J. Grainge, "Sanitary Engineering in Russia", AWWA Journal, June, 1975.

Sanger, F.J., "Water Supply, Sewage Disposal and Drainage in Cold Regions", U.S. Army Cold Regions Engineering and Research Laboratory, Hanover, New Hampshire, 1964.

Simonen, E., "An Evaluation of Municipal Services in the Mackenzie River Delta Communities", Univ. of Toronto, Masters Thesis with G. Heinke, Toronto, Ontario, October, 1970.

Smith, D.W., ed., Proceedings Symposium on Utilities Delivery in Arctic Regions, March 1976, Environmental Protection Service, Environment Canada, Report No. EPS 3-WP-77-1, January 1977.

U.S. Department of Health, Education and Welfare, Division of Indian Health, "Design Criteria for Indian Health Sanitation Facilities", Anchorage, Alaska, 1972.

U.S. Environmental Protection Agency, "Manual of Individual Water Supply Systems", Publication #24, Washington, D.C., 1962.

Watson, et al., "Performance of a Warm-oil Pipeline Buried in Permafrost", Proceedings of 2nd Int. Permafrost Conference, Yakutsk, USSR, 1973.

SECTION 7

WASTEWATER COLLECTION

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7. WASTEWATER COLLECTION

Wastewater collection systems collect wastewater from users and transport it to the sewage treatment facility or disposal point. The sources of wastewater and types of collection systems and design parameters are presented in this section. As presented in Section 2, the main types of collection systems are individual bucket haul, vehicle-haul with house storage, and piped. Table 7-1 summarizes the characteristics of wastewater collection systems.

7.1 Sources of Wastewater

The main sources of wastewater are domestic and industrial. In the case of domestic waste, 100 percent of the water in northern areas ends up as wastewater because there is very little lawn and garden watering or car washing. This also applies for industrial or commercial wastes unless local experience or actual measurements indicate otherwise. An exception would be the case of a cold storage-fish processing operation or a cannery where a significant portion of the water may be used for cleaning floors and equipment and is discharged directly to the ocean. A contrary example would be the case where salt water was used for cleaning and discharged to the collection system. Infiltration and inflow allowances must be made for buried lines in high groundwater situations or where water wasting is practiced. These problems should be corrected before sewers and sewage treatment plants are designed. Inflow and infiltration studies should be performed so the decision can be made to either correct the problems or design a plant to treat the dilute waste.

7.1.1 Domestic waste

Water use rates typical to cold regions were presented in Section 3 and sewage design flows with peaking factors are presented in Section 9. The values presented show that sewage flows can vary considerably. They are lower in volume, and higher in strength, for camps and facilities with low water use plumbing fixtures. Where water is wasted during the winter to keep service lines from freezing, wastewater volume can be extremely high and of very low strength. There is no substitute for actually monitoring sewage flows, or at least water use rates, before sewer or sewage treatment design is undertaken.

TABLE 7-1. CHARACTERISTICS OF WASTEWATER COLLECTION SYSTEMS

TYPE	SOIL CONDITIONS	TOPOGRAPHY	ECONOMICS	OTHER
Gravity	Non frost susceptible or Slightly frost susceptible with gravel backfilling material.	Gently sloping to prevent deep cuts and lift station.	Initial construction costs high but operational costs low unless must go above ground or use lift stations.	Low Maintenance. High health and convenience improvements. Must hold grades. Flushing of low use lines may be necessary. Large diameter pipes necessary.
Vacuum	Most useful for frost susceptible or bedrock conditions, but can be used with any soil conditions.	Level or gently sloping.	Initial construction cost moderately high Operational costs moderate	"Traps" every 100 metres. Low water use. High health and convenience improvements. Must have central holding tank for each 30 to 50 services with additional pumps to pump waste to treatment facilities. Can separate gray and black water. Uses small pipes. No exfiltration.
Pressure	Most useful for frost susceptible or bedrock conditions, but can be used with any soil conditions	Level, gently sloping or hilly	Initial construction costs moderate. Operational costs moderately high.	Low water use if low water use fixtures are installed. High health and convenience improvements. No central facility necessary - units are in individual buildings. Number of services not limited. No infiltration. Uses small pipes.
Vehicle-Haul	Year-round roads must be available.	Level, gently sloping or hilly.	Initial construction costs low. Operational costs very high.	Low water use and moderate health and convenience improvements. Operational costs must be subsidized.
Individual-Haul	Used with any soil conditions but boardwalks are necessary in extremely swampy conditions.	Level, gently sloping or hilly.	Initial construction cost and operational costs very low.	Low usage by inhabitants and thus low health and convenience improvements.

7.1.2 Industrial waste

Industrial waste output is usually seasonal in cold regions. Canneries and cold storage wastes occur during the summer fishing season only. Reindeer slaughtering and packing plant wastes have a high strength and flow, but usually only last for a couple months during the fall. The amount and strength of industrial wastes produced must be estimated using information from temperate areas for similar facilities, unless the facility can provide the information for their operation. The kind and size of the solids present in an industrial waste may be a factor in waste collection system design. Screening or comminuting may be necessary before discharge to the sewer system.

7.1.3 Public uses

Nearly all communities will have schools and hospitals or health clinics. Estimates of wastewater flows must be obtained for schools, considering the number of students, the number of teachers living in quarters, the type of facilities provided (i.e., swimming pool, flush valve toilets or regular gravity flush toilets, urinals, shower facilities), boarding student dorms, etc. With hospitals or clinics, the number of beds and, again, the type of facilities provided should be determined. It may also be necessary to consider incineration or other special treatment of wastes that are dangerous to health. Another public use waste would be that from laundromats. These wastes are not much different from those from similar facilities in more temperate climates. See Section 3 for estimating water use to be expected at public facilities. The strength of the wastewater is a function of the type of water distribution system.

7.1.4 Water treatment plant wastes

Wastes from water treatment plants must be estimated if they cannot be measured. The highest flows, which would be from filter backwashing, are usually known. They can be very sporadic (not usually continuous) and may require a holding tank for flow equalization before discharge to the collection system. Filter backwashing flows are low in BOD but create a high chemical and hydraulic loading. Consider the effect of the chemicals on the collection line materials. They can be of high pH and/or very corrosive. Consider electrolysis problems when wastes are from a salt water distillation unit. This can usually be reduced by correct grounding and non-conduction fittings in piping systems. When plastic pipe is used corrosion and electrolysis are usually not problems.

7.2 Individual Bucket Systems

With a collection system relying on the individual users to bring their wastes to a disposal point, the important considerations are the types of containers in which the waste is transported and the facilities at the point of discharge.

7.2.1 Hauling containers

Containers used by individuals for transporting wastes will vary from conventional oil drums to honeybucket pails. They should be cleanable so they can be washed or steam-cleaned and disinfected for reuse (see Section 13). The containers should be covered so the contents don't splash out in the owner's house or throughout the community as they are transported. The containers should be sized for the way they will be transported. In many communities with no roads the children or women will empty the honeybuckets. Larger containers can usually be used in the winter because they can be carried on sleds. The summer is the critical time because the swampy conditions around many coastal communities will mean hauling by hand. In this case, the pail or bucket should probably not be larger than 10 litres, which would weigh about 10 kg when full. If roads are present and individual vehicles can be used year-round, larger containers may be desirable. In many smaller villages, 20-litre containers are readily available because gasoline and white gas are purchased in them. They are used for everything from hauling water to patching holes in the roof. In larger communities, individuals use pickups or trucks to transport oil drums filled with honeybucket wastes to a disposal site. Individual honeybuckets in the house are emptied into the oil drum which sits outside the house. Sometimes the oil drum is emptied and returned to be refilled but usually, unless cleaning facilities are available at the disposal site, the drum is discarded with the waste.

7.2.2 Disposal point

The disposal point must be designed to accommodate a wide variety of container sizes and be convenient for people; otherwise the wastes may not be deposited according to facility design. The disposal point could be a landfill site, a facultative lagoon or pond, a waste disposal "bunker", or a discharge point on the side of a building such as a watering point or central facility (see Section 13) where the waste is then transported to a treatment facility by pipes.

Where honeybucket wastes are dumped at a landfill site they should be covered daily to prevent children, dogs, and birds from getting into them.

If the wastes are deposited in a lagoon or pond the dumping point should be designed to prevent erosion of the lagoon dykes and yet allow for easy access so the waste doesn't end up all over the dykes instead of in the lagoon. A platform with a hole out over the water is satisfactory. A major problem with lagoon disposal is the plastic bags which are often used as liners in honeybuckets. They are not biodegradable and should not be deposited in the lagoon. It will be necessary to empty their contents into the lagoon and then deposit the bags at a landfill or burn them.

Waste disposal pits are constructed by cribbing a hole in the ground, similar to a cesspool and covering it with a platform containing a disposal hole covered with a fly-tight, hinged lid (Figure 7-1). When the old pit is full the platform is removed and the bunker is covered with the material excavated from the new pit. Most of the liquid portion of the honeybucket wastes will seep out when the surrounding ground is thawed. As with privies, waste pits are not a desirable form of waste disposal if the soil is frozen fine grained silts or when there is a high groundwater table. More modern methods such as sewage treatment plants or lagoons are desirable, but the pits at least reduce the serious health problem of having the honeybucket wastes dumped over a river bank or around the houses.

The most satisfactory disposal for honeybucket wastes would be at a central facility or watering point where the wastes are a small part

FIGURE 7-1. WASTE DISPOSAL PIT

of the total waste load to the facility. The treatment would be accomplished by one of the methods discussed in Section 9. A fly-tight closeable box, which is convenient to use, should be provided on the outside of the building. It must be vandal proof and capable of being thoroughly washed down and cleaned daily. Above all, it must be aesthetically acceptable and easy to use; otherwise, it will not be used.

Disposal points must be centrally located to all dwellings or their chances of being used regularly are small. The distance that individuals will haul wastes varies with many factors. Two of the more important considerations are training and education of the users, and the ground conditions over which the wastes must be hauled. Experience indicates that the number of individuals that utilize a disposal point starts dropping off considerably when the distance exceeds 200 metres. Also, the people tend to haul longer distances in the winter because in most communities, it is easier to get around and snowmobiles can be used. An extensive education program is invaluable in promoting the use of a disposal point with individuals hauling their own waste.

The type of waste dumped at a disposal point could be an important consideration in treatment plant design even though the quantity (by comparison to the facility wastes) may be small. The waste quite often contains a high concentration of deodorizers such as formaldehyde and phenols, which could affect biological treatment processes. It also may contain plastic bags and other solid wastes and will be very high in BOD (up to 1000 mg/L) and low in hydraulic loading.

7.3 Vehicle-Haul with House Storage Tanks

Community-haul sewage collection deals with the collection of wastewater from each dwelling and its transportation by a community or contractor-operated tracked or wheeled vehicle to a treatment and/or disposal facility.

7.3.1 Facilities at pick-up point

The facilities at the individual user's dwelling or building can vary from simply emptying a honeybucket (as discussed under individual-haul above) into a tank on a truck (Figure 7-2), to a holding tank within the building from which the wastes are pumped into the collection truck.

If the facilities in the building consist only of honeybuckets, the same considerations listed under individual-haul would apply. However, most modern vehicle-haul systems consist of a sewage holding tank located on or beneath the floor of the house into which the household wastes from sinks, lavatories, and toilets drain by gravity. The tanks are then emptied into the collection vehicle (Figure 7-3) by pumping.

The efficiency and operational costs of this type of collection system are dependent partly on the sizing of the holding tanks. For most circumstances, tanks should be around 1000 litres, but at least 400 litres larger than the water storage tank provided [1,4]. In Canada, household tanks as large as 4500 litres have been used and it is common practice to make the sewage holding tank up to twice as large as the water storage tank. The size of the collection vehicle and reliability of the service should be considered in sizing wastewater storage tanks. It is also important to provide the structural support in the house required to carry this additional load. The tank must be constructed with a large manhole with removable cover so it can be cleaned and flushed out at least yearly. It must be well insulated, kept within the

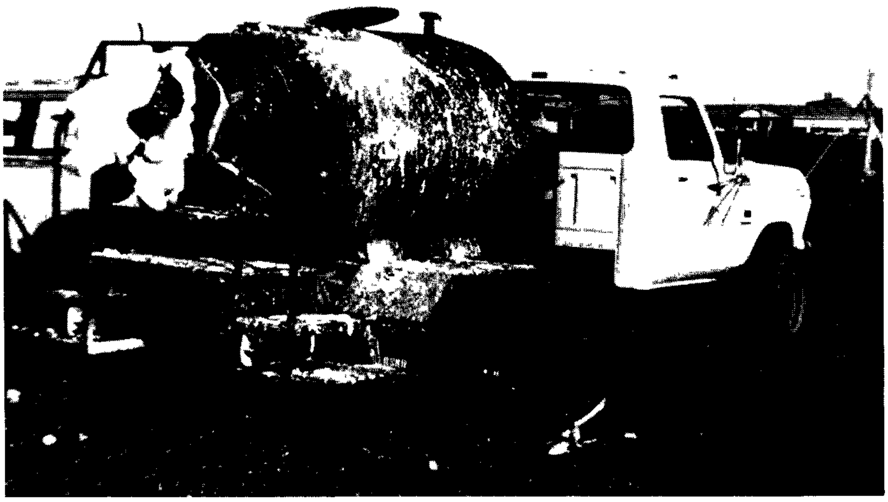


FIGURE 7-2. TRUCK FOR COLLECTING HONEYBUCKET WASTES
- BARROW, ALASKA

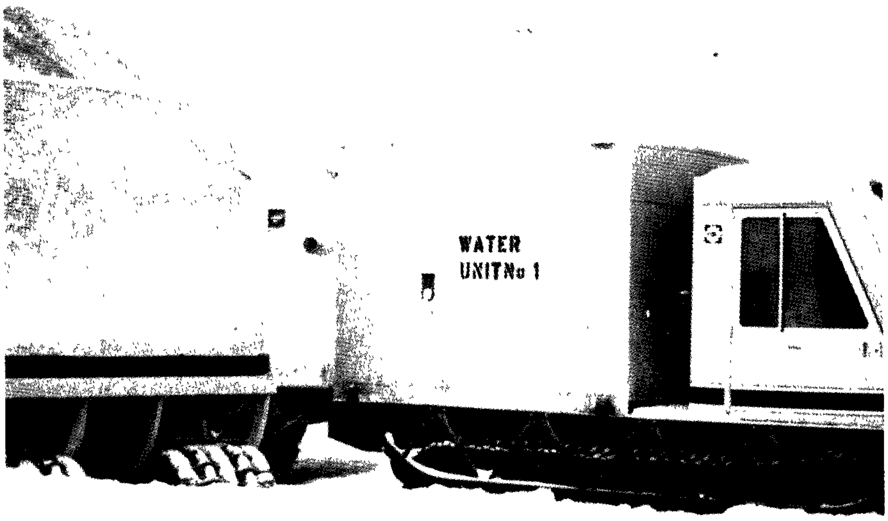


FIGURE 7-3. TRACKED SEWAGE PICK-UP VEHICLE
- ARCTIC VILLAGE, ALASKA

heated portion of the building and/or heat must be added using heating coils or circulating hot water to prevent any ice formation. In some instances, the holding tanks have been buried in the ground beside or beneath the houses (Figure 7-4). In permafrost areas this is not satisfactory and it is even necessary to add heat in areas where the tank is buried in the active layer. The tanks must be placed so they are emptied from the outside of the house.

The hose connections should be of the quick-disconnect type and be a different size than that of the water delivery hose, to eliminate the possibility of a cross-connection. The pumpout connection at the building must be sloped to drain back into the tank after pumping so sewage does not drain outside the house or stand in the line and freeze. The tanks must be vented into the attic or outside to allow for air escape or supply as the tank is filled and emptied. The same considerations should apply to this vent as are discussed at the end of this section under building plumbing.

With any haul system, low water use plumbing fixtures (Figure 7-5) are necessary to reduce water usage.

7.3.2 Hauling vehicles

The type of vehicle used depends upon the conditions at the site. Tracked vehicles should be avoided if at all possible because of the much higher capital, operating and maintenance costs, and slower speed compared to rubber-tired vehicles. Typical costs of the vehicles themselves are presented in Section 6 and Appendix D. Instead of tracked vehicles, four-wheel drive trucks with floatation tires can be used where snow drifting and poor roads are prevalent. Where there are no roads tracked vehicles may be necessary.

Vehicle-haul systems have higher O&M and replacement costs than piped systems, and the vehicles have a short useful life (see Section 2.6.2).

The vehicle must be equipped with a tank, pump and hoses to contain and extract the wastewater (sample specifications are shown in the Appendix E). For collecting honeybucket wastes, the most practical tank is a half-round or round shape with a large manhole with a hinged lid on the back in the flat cover (see Figure 7-2). The flat top

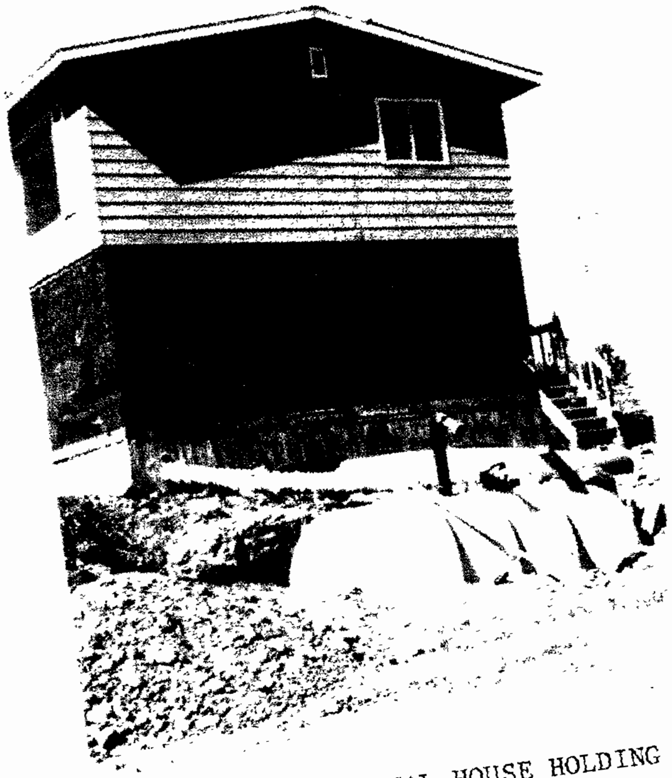


FIGURE 7-4. INDIVIDUAL HOUSE HOLDING TANK

FIGURE 7-5. LOW WATER USE, FOOT PEDAL OPERATED TOILET

allows for a lower emptying point. Steps are provided on the side so the honeybuckets can be carried up and emptied into the tank. The trucks should be kept as small and maneuverable as practical to get around to the houses. Presently, tanks of 1000 to 5000 litres are used in small communities. The tank should be capable of being dumped at the disposal site unless the contents are to be pumped into a sewage treatment plant. At the rear, a large valved outlet pipe of at least 200 cm (8 inches) in diameter is provided which can be opened to empty the tank. A small heater may be needed to keep the short pipe and valve from freezing. The truck exhaust can also be routed to keep this valve warm and eliminate the need for a heater. A full opening, non-rising stem gate valve has proven best for this application as it must be capable of passing solids such as plastic bags.

The tanks on vehicles to be used with a pumpout system may have to be insulated or enclosed in heated units on the backs of the vehicles (see Figure 7-3). These units will include the tank, pump, piping, and connection hose. The size of tank needed will depend primarily on the distance to the disposal site and the sizes of the tanks in the houses [1]. Larger tanks will reduce operating costs, particularly when the disposal site is distant. Size and weight of the vehicle, and thus the tank will be limited to the layout of the community and the condition of the roads. The truck must maneuver close enough to the houses to pump out the tanks in a reasonably short time.

The number of trucks needed in a given community will depend mainly on the number of buildings to be serviced and volume of wastewater to be collected [1,4]. Two methods of emptying the house tanks are being used. With one, a pressure tank is used on the vehicle. The tank is held under a vacuum using a small compressor and a three-way valve. The contents of the house tank are withdrawn into the truck tank under vacuum. At the disposal point the valve is turned to pressurize the tank, forcing the wastewater out (see schematic in Figure 7-6). The advantages to this method are that a compressor is used instead of a pump, and there are no pipes containing sewage. which could freeze. The other method is similar except that sewage pumps are

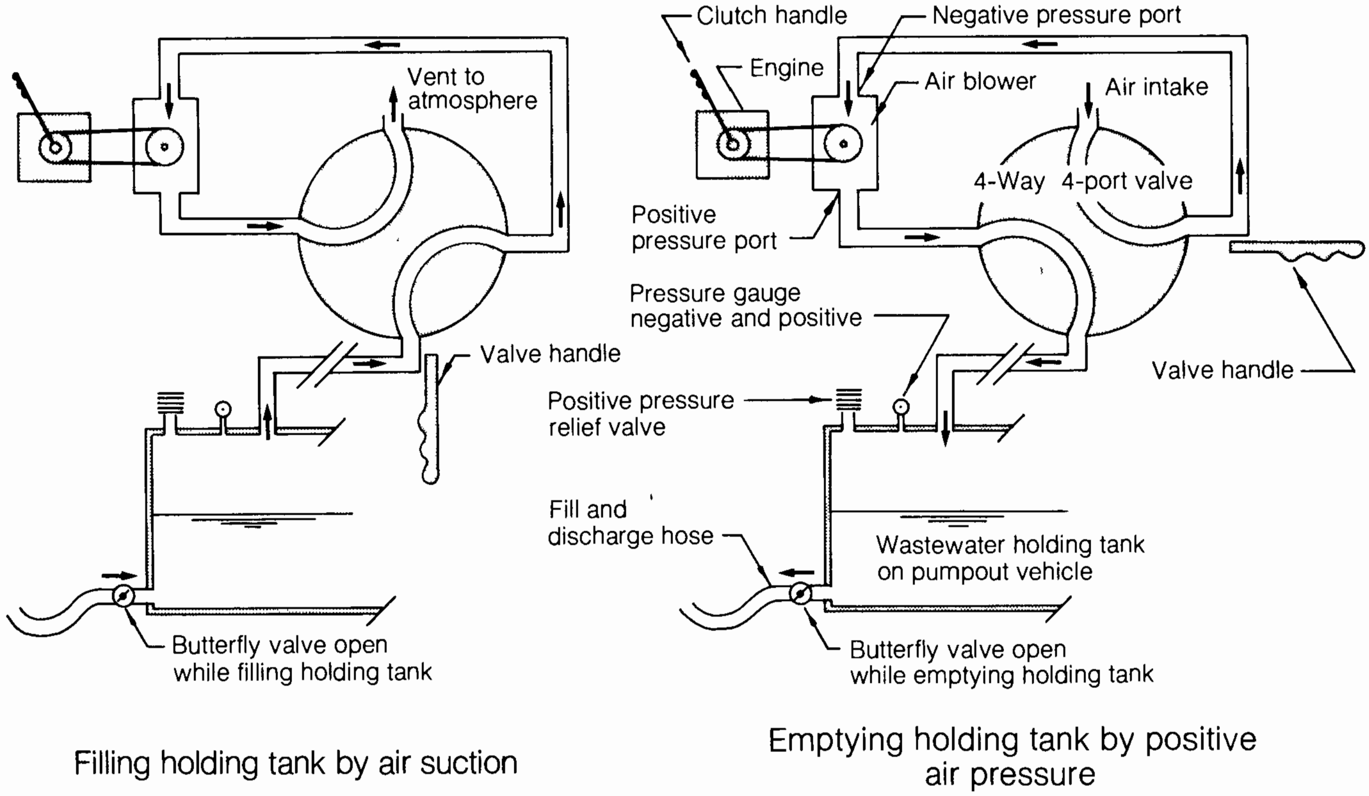


FIGURE 7-6. FILLING AND EMPTYING PROCEDURE FOR HOLDING TANK PUMPOUT TRUCKS

used instead of a compressor and the vehicle tank does not have to be pressure rated. The suction hose must be long enough to extend from the house to the most convenient parking place for the truck. It should be at least 7.5 cm in diameter and kept on a reel so it can be rolled up inside the heated compartment on the truck. It must also be rugged enough that it can be dragged behind the truck between houses, and be flexible at low temperatures.

7.3.3 Disposal site

The disposal point should be in a heated building with a "drive through" design to make the unloading time as short as possible. The building should also provide heated storage for the vehicles while not in use or when they're down for repairs. Where the disposal point is at a landfill or lagoon, a ramp or splash pad or something similar should be provided to prevent erosion and still allow the vehicle to deposit the wastes well within the lagoon or landfill. The same problems with plastic bags will be present as were discussed under individual-haul.

The building in which the vehicles are stored and/or emptied should also be equipped with water for flushing and cleaning the tanks. Extreme care should be taken to prevent any cross-connections.

7.4 Piped Collection Systems

There are several variations of piped sewage collection systems. Normally, a conventional gravity system has the lowest life-cycle cost and should be used whenever feasible. However, the layout of the site and/or the soil conditions may make a vacuum or pressure sewage collection system necessary. An additional advantage of a gravity system is that a freezeup seldom causes pipes to break. The freezeup is gradual and in layers, in contrast to pressure lines which are full when freezing takes place.

7.4.1 Design considerations

When soil conditions do not allow burying collection lines (as discussed in Sections 2 and 8), they must be placed on or above the surface of the ground. In most locations, the topography and building layout would dictate above-ground lines on pilings (or gravel berms) to hold the grades necessary for gravity sewage flow. Above-ground lines are undesirable because of transportation hinderance (see Figure 7-7), high heat losses, blocked drainage, vandalism, and the cluttered look they create within the community (see Section 8). It may be preferable to use a pressure or vacuum system so that the lines can be placed on the ground surface (see Figure 7-8), to minimize the above problems.

Sewage collection lines may be placed in utilidors (see Section 8) with other utilities, depending on the local circumstances. Utilidors cost between \$600 and \$1700 per metre to construct, depending on the utilities included and the roads to be crossed (see Section 8). Buried pipelines cost (per pipe) between \$100 and \$300 per metre to install, depending on the excavation conditions. Above-ground pipeline costs depend on the foundation required. If they can be layed directly on the ground surface they cost \$50 to \$100 per metre, but if they have to be placed on pilings the costs could run as high as \$250 per metre. Assuming the same design, heat losses, and thus O&M costs, of above-ground facilities are nearly three times as high as for the same line placed below-ground because of the greater temperature differential between the inside and outside of the line. Section 2 includes a more in-depth discussion of the advantages and disadvantages of above or below ground facilities.

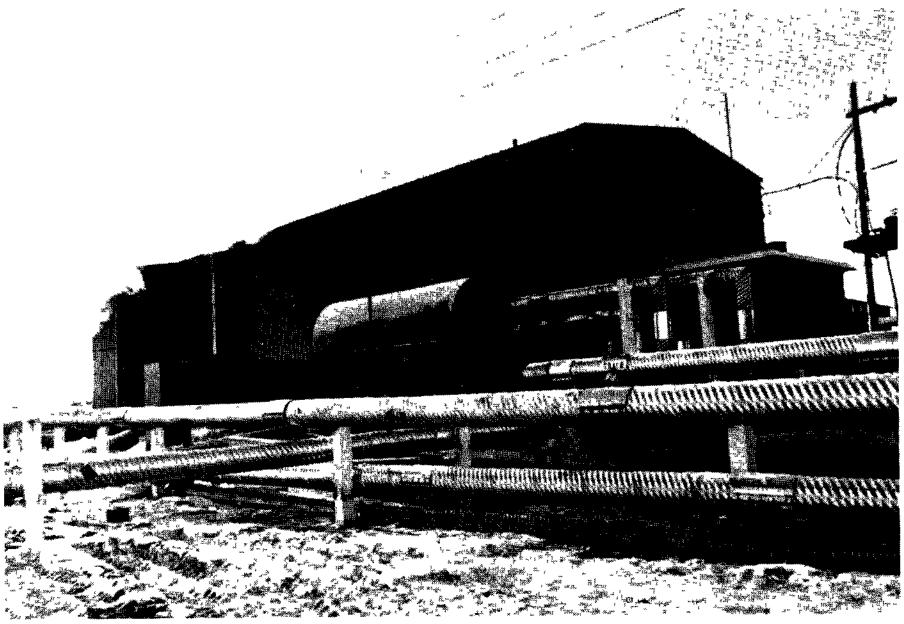


FIGURE 7-7. SEWAGE COLLECTION LINES ON PILING - BETHEL, ALASKA

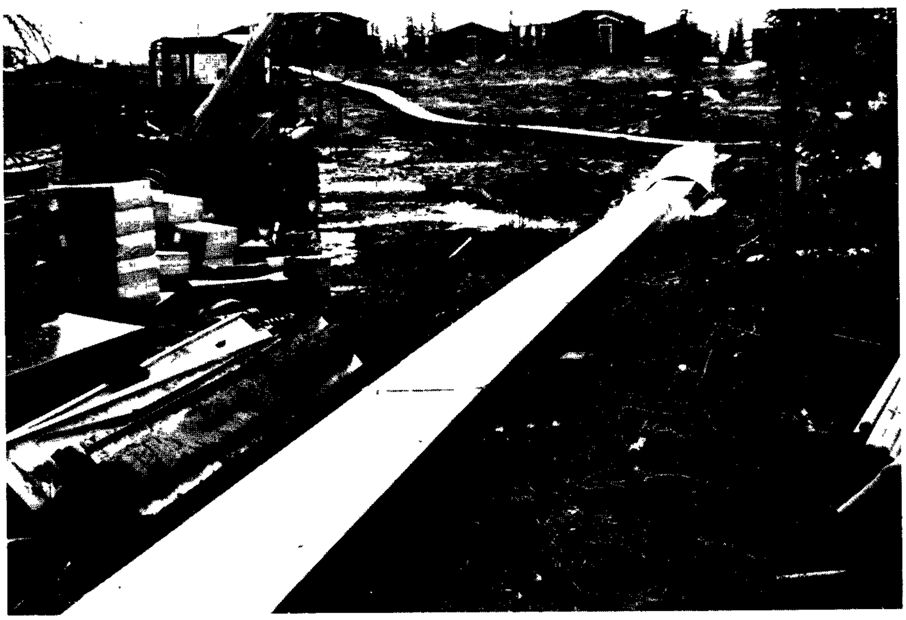


FIGURE 7-8. SMALL (0.4 m x 0.5 m) UTILIDOR LAID DIRECTLY ON THE TUNDRA SURFACE CARRYING WATER, SEWER AND GLYCOL LINES - NOORVIK, ALASKA

Sewage temperatures are also an important design consideration. In camps or communities where the individual buildings have hot water heaters, sewage temperatures usually range between 10 and 15°C. Where hot water heaters are not used and any hot water must be obtained by heating water on a cook stove, sewage temperatures range from 4 to 10°C. A greater percentage of this heat will be lost between the users and the point of treatment with a gravity system than with a pressure or vacuum system. The sewage is longer in transit and there is air circulation above the sewage in the pipes because they are not flowing full. It is often necessary to dump warm water at the ends of little-used laterals in a gravity system to eliminate freezing problems caused by the lines slowly icing up. Also, a greater percentage of the heat will be lost if the lines are above ground. Sewage heat losses will not vary considerably from summer to winter with buried lines, but there can be a considerable variance in above-ground lines. (This is discussed in detail in Section 8.) Thus, the worst condition is to have gravity sewage collection lines placed above-ground.

7.4.2 Conventional gravity collection lines

If lines can be buried and the layout of the site is sloping a gravity sewage collection system will have lower O&M costs than other types of systems. Initial construction costs will usually be lower unless there is considerable rock to excavate. Costs for rock excavation range between \$50 and \$75/m^3 in the N.W.T. (1977).

The most important design consideration with gravity sewers is the minimum grades necessary to ensure adequate velocities in the pipelines. The following minimums should be used with stable ground conditions (not frost-susceptible):

a) Main collection lines

Nominal Pipe Size (inches)	Minimum Slope (percent)
6	0.6
8	0.5
10	0.4
12	0.3

14	0.22
15	0.17

b) Building service lines

4 or 6	1.0

If soil stability is unsure (i.e., a small amount of settling or heaving is likely), use a minimum slope of one percent for all collection lines and backfill with non-frost susceptible sand or gravel at least 30 cm at the bottom and sides of the pipe (Figure 7-9). The 4-inch service lines should be placed the same way with a two percent minimum slope. Higher slopes than those above should be used if possible because the longer the sewage is in the collection system, the more heat it will lose. In small communities minimum sewage collection line sizes could be 6 inches instead of the normal 8 inches.

Lines should be placed deep enough to prevent damage from surface loadings and the possibility of future expansion should be considered. A minimum of 0.7 metres of bury is usually recommended but less could be allowed in communities with no roads or vehicles. Other depth of bury considerations are given in Section 15.

Storm water should not be included in sewers in cold regions. It can be cold, lowering wastewater temperature, it overloads treatment facilities hydraulically, and it usually contains sand and grit which deposits in collection lines. Insulated pipe should always be used unless lines can be buried well below the active layer and not in permafrost.

In addition to the steeper slopes listed above, provisions should be made to readjust the slope of a line if it traverses an area where movement is likely. With lines on piling this has been done by placing blocks between the piling and the pipeline, acting as shims. They can be removed or added to readjust the slope. If the lines are in a utilidor they can be suspended from the utilidor roof with adjustable turnbuckles or placed on adjustable yokes or supports.

Manholes require protection from frost heaving or jacking forces by use of plastic film to break the soils bond to the manhole (see Figure 7-10). They should also be insulated with a minimum of three inches of styrofoam or urethane around the outside. The insulation reduces heat

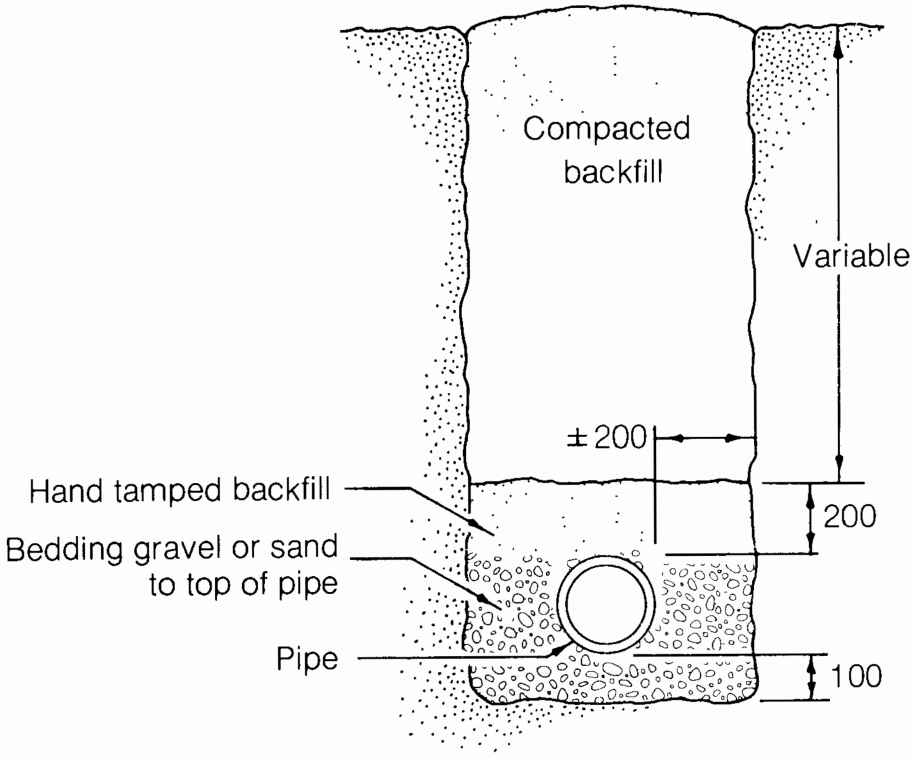


FIGURE 7-9. TYPICAL SEWER AND WATER BEDDING DETAILS

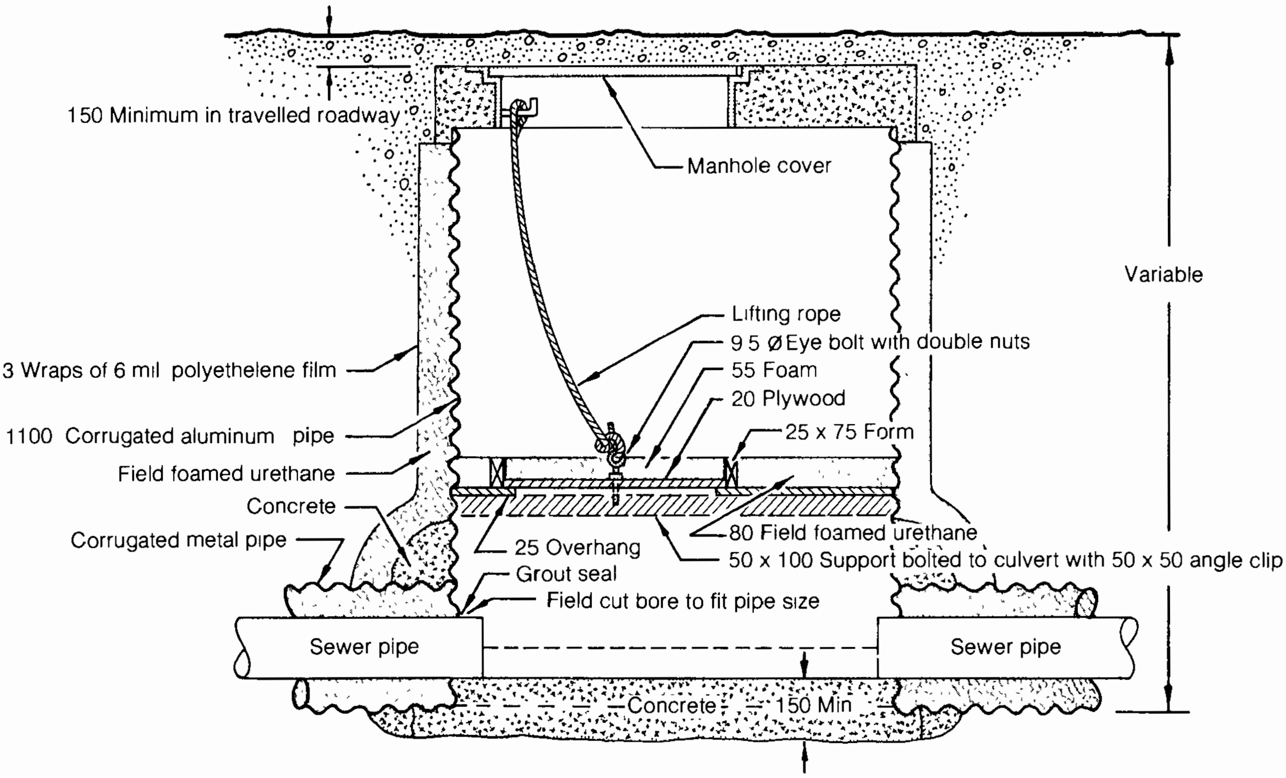


FIGURE 7-10. SEWER SYSTEM MANHOLE

losses and provides an additional safety factor against soil bonding and frost jacking. An insulated frost cover to further reduce heat losses should be provided inside. Manholes must have a firm foundation to prevent settlement. This could mean pilings under the manhole or, at least, over excavation and backfill with gravel. The invert should be poured over insulation to reduce heat loss downward which could thaw unstable permafrost and cause settlement.

Conventional pre-cast concrete manholes are very expensive to ship and install in remote northern areas. Bolted corrugated aluminum manholes can be used in nontraffic situations. They can be nested during shipment and air freighted in small planes. Manholes should be placed every 90 m or at any changes in grade or alignment. To reduce heat losses, 107-cm diameter manholes are used as a minimum in arctic areas. Also, solid manhole covers without holes should be used so that surface water does not enter the manhole. The lids should be locked down to prevent the deposit of rocks and garbage in the manholes. Gravity sewer lines should be thoroughly flushed out each summer, ideally when the fire hydrants are being cleaned and flushed.

Cleanouts, as they are known in temperate climates, should be used with caution. They are susceptible to frost jacking and hard to protect (see an example in Figure 7-11). In place of a cleanout on a sewage collection line it is better to use a conventional manhole.

A special manhole has been developed in the N.W.T. that contains hydrants and valves for the water line and an air tight cleanout on the inlet and outlet sewer lines for rodding and flushing. (See Section 6). One must be sure not to create a cross-connection with a manhole containing water line appurtenances.

As mentioned earlier self-flushing siphons may be required at the end of long, little used laterals. They can be set to dump a given quantity of warm water at different intervals. The slug of warm water traveling down the sewer lines will eliminate any glaciering which may have built up because of slow trickles of water from normal use. The flushing also scours solids which may have been deposited because of low flows. They should not be used unless absolutely necessary as they waste water and create an additional O&M cost. It is better to lay out the

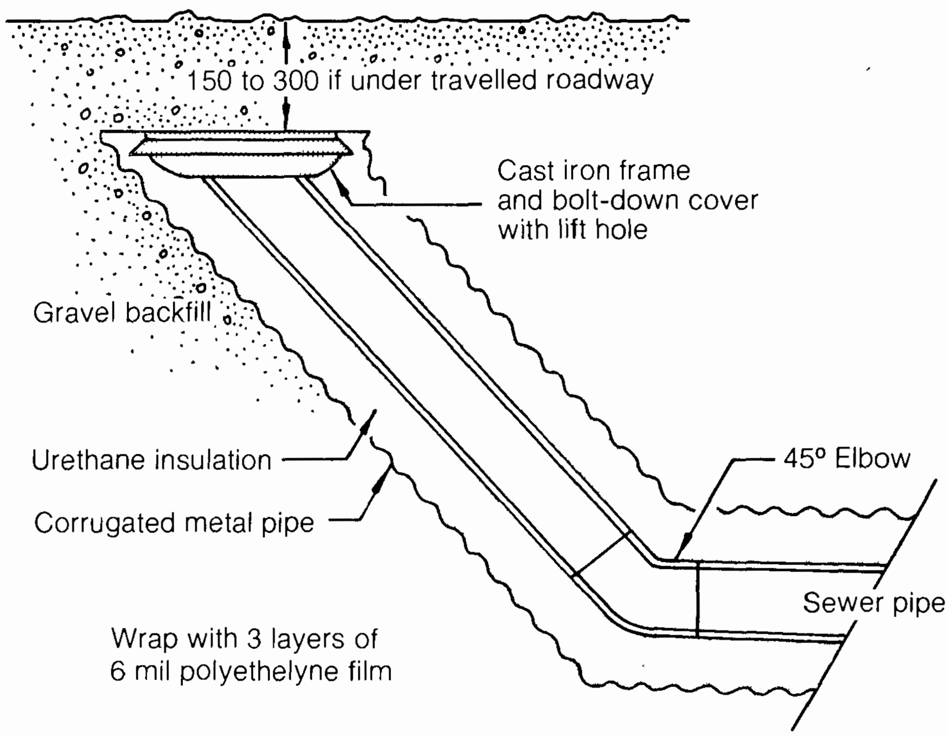


FIGURE 7-11. SEWER CLEANOUT DETAILS

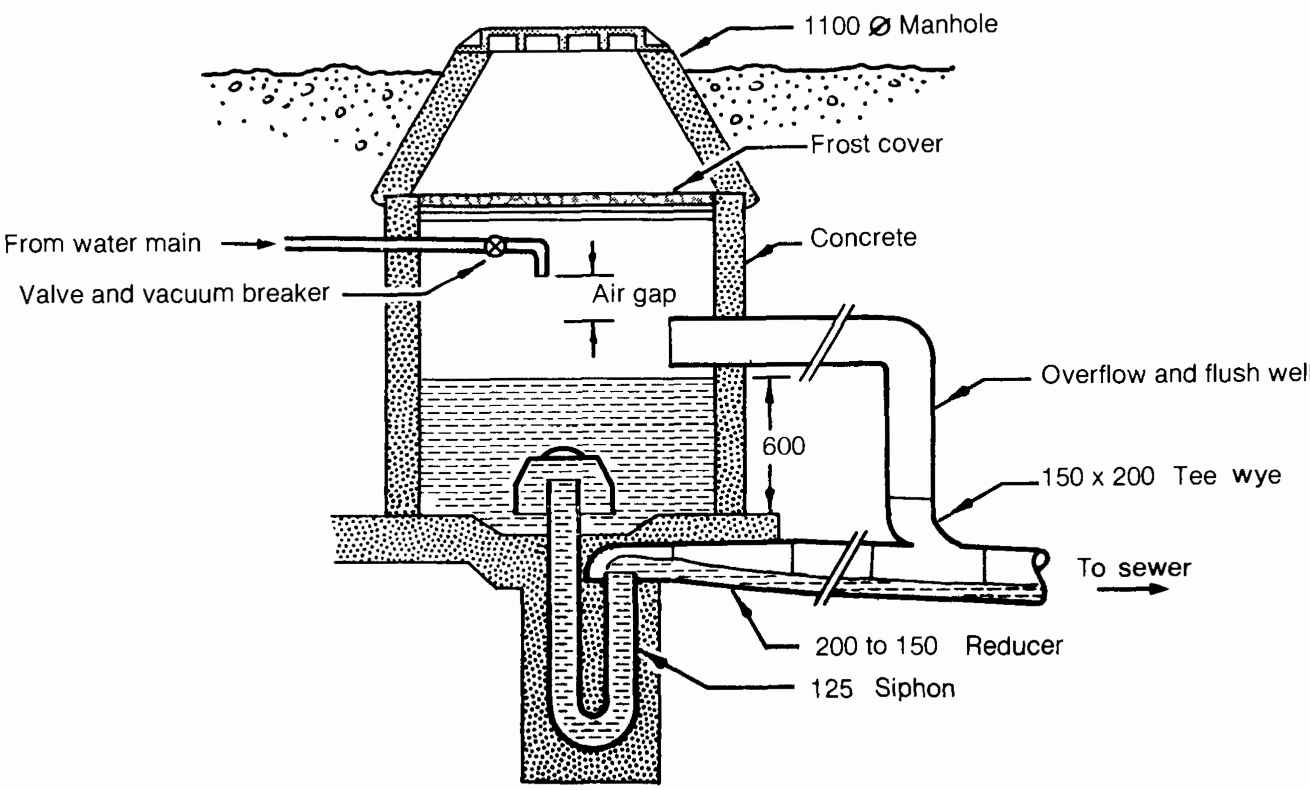


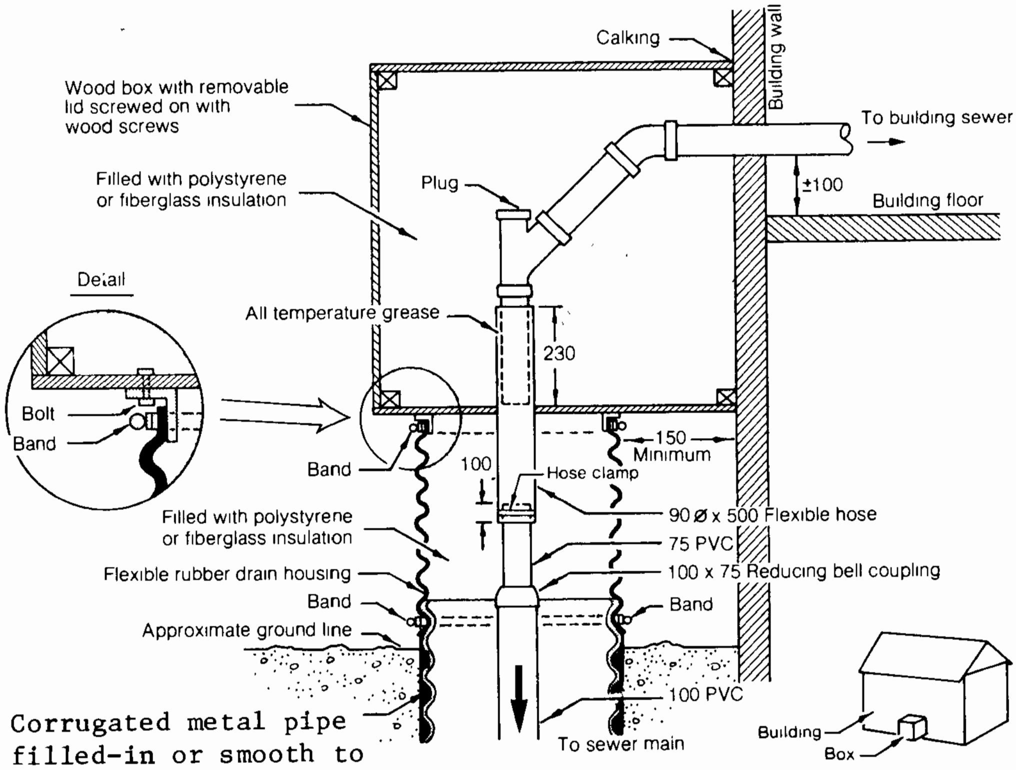
FIGURE 7-12. SINGLE LINE SIPHON

sewer system so there is at least one large user near the end of each lateral to eliminate the need for flushing. They can be constructed in a building or in a manhole as shown in Figure 7-12. Again, care must be taken not to create a cross-connection between the water and sewer systems.

Figures 7-13 and 7-14 show typical service line connections to a building for a cold region gravity sewage collection system. They should slope at least one to two percent to the collection main, depending on soil stability. Of the two examples shown, the method of going through wall is preferable to going through the floor. The former will allow for more movement of the house without damage to the sewer service line and also permits all house plumbing to be kept above the house floor (this will be discussed later).

The preferred method for thawing sewage collection lines is to push a small diameter plastic line through the frozen line while circulating warm water. A complete discussion of thawing lines is contained in Appendix F.

Sewage lift stations will be discussed later in this section. They can be an important part of a gravity system.



Corrugated metal pipe filled-in or smooth to reduce frost jacking

FIGURE 7-13. HOUSE SEWER WALL CONNECTION

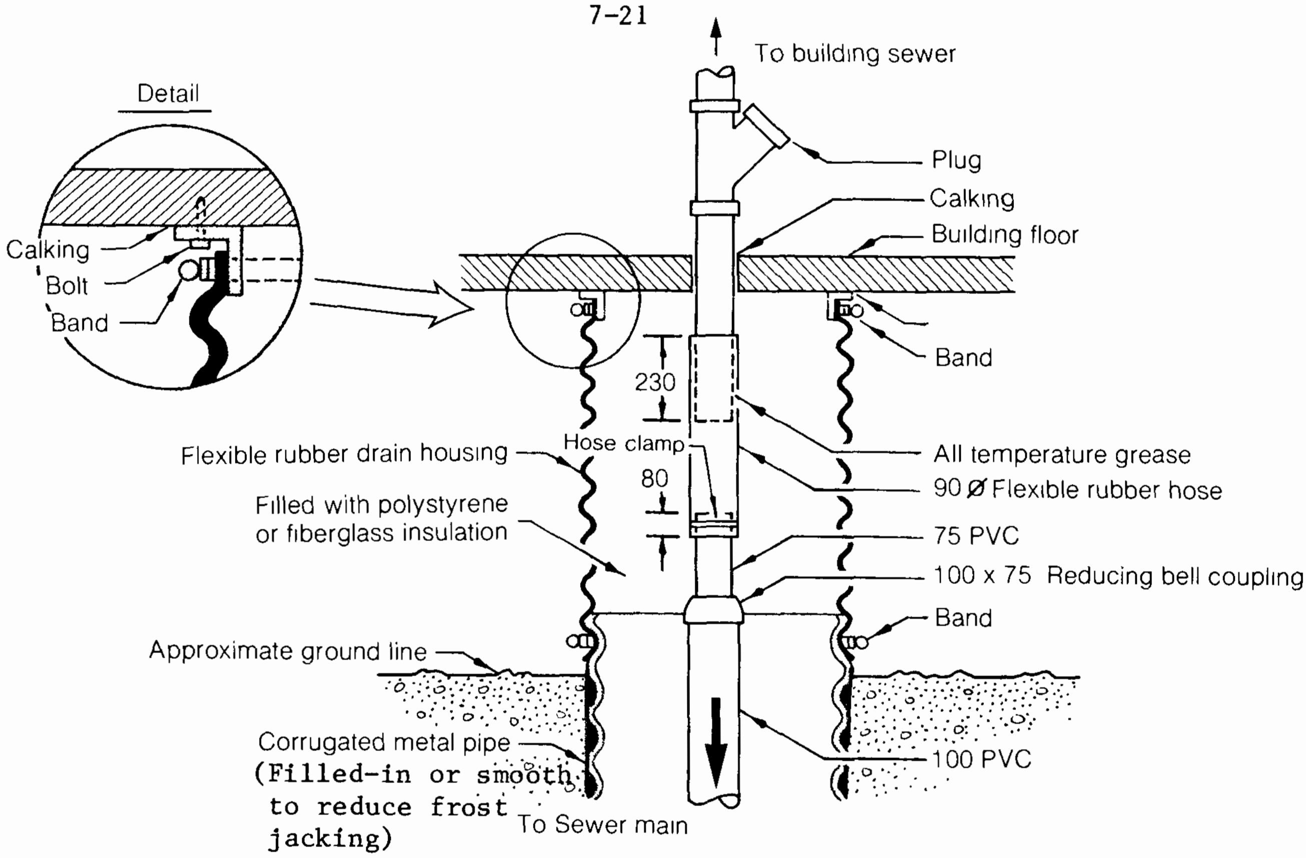


FIGURE 7-14. HOUSE SEWER FLOOR CONNECTION

7.4.3 Pressure sewage collection systems

If soil conditions and community layout make a gravity collection system not practical a pressure or vacuum system may be considered. Pressure sewage collection systems usually have sections that operate under gravity, and vice-versa. A small pump-grinder unit in or near each building provides the motive force for the pressure system (see Figures 7-15 and 7-16). The largest advantage is that it is not necessary to maintain grades. Pipelines or utilidors do not have to be on piling or up off the ground. They can be at the surface or buried and small movements due to frost heave or thawing will not affect operation. There can be no problems with infiltration of groundwater because the lines are under pressure; however, a leak in the sewer line, if not repaired, could contaminate other lines within a utilidor. Construction costs would probably be lower than either a gravity or vacuum system, but O&M costs would be greater than for a gravity system because of the pump-grinder units in each building. Smaller collection lines can also be used with a pressure system and normal elevation differences throughout a community will not affect operation. Pressure collection lines can be

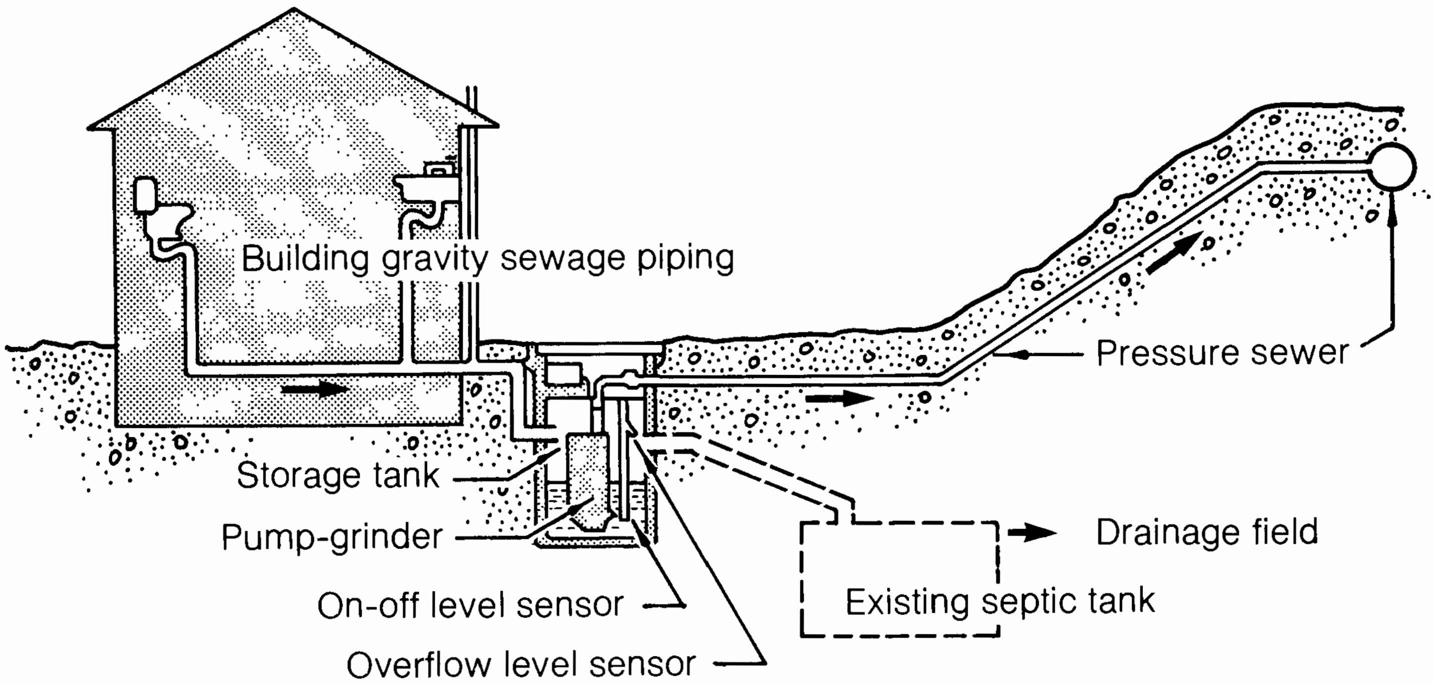


FIGURE 7-15. TYPICAL PRESSURE SEWER INSTALLATION

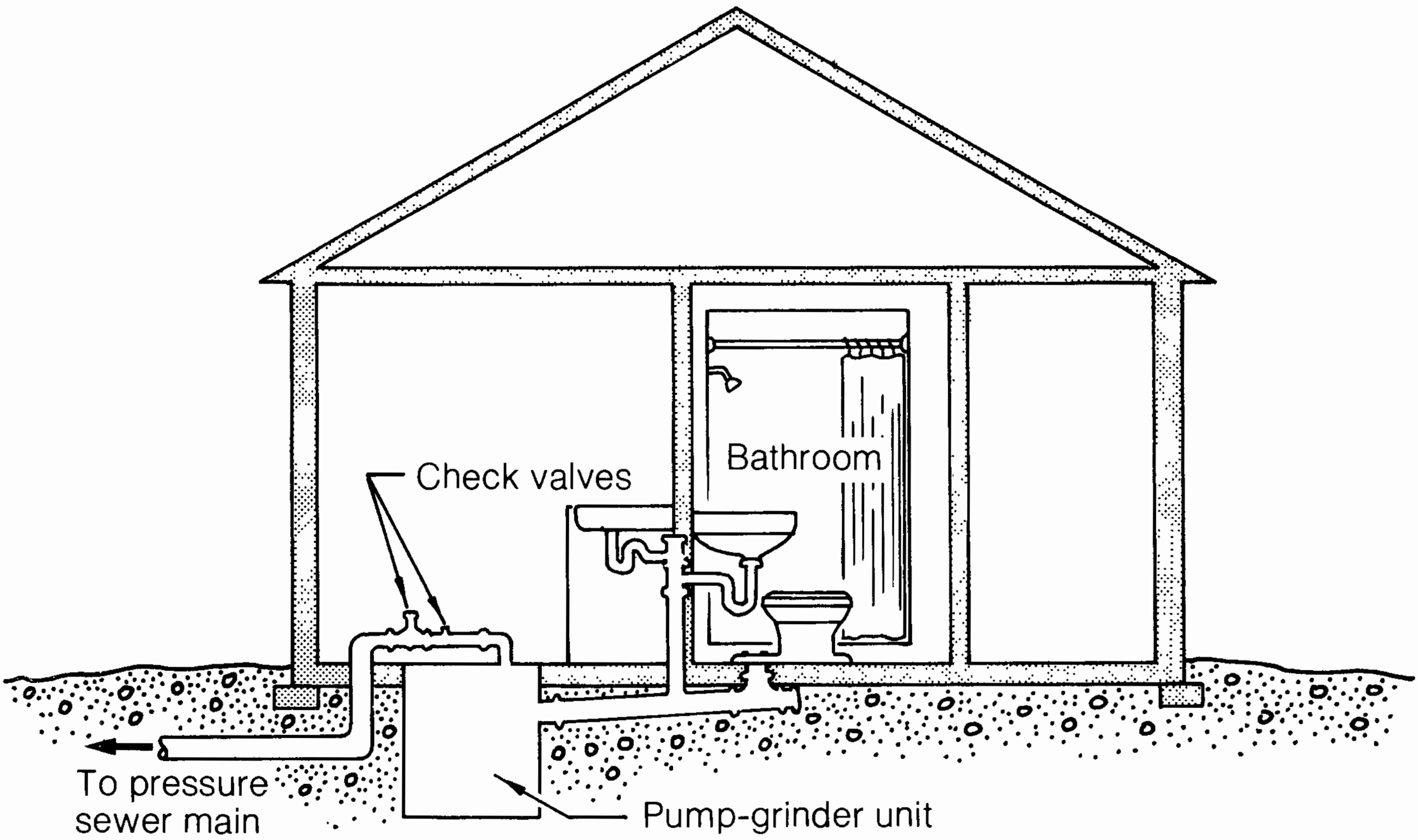


FIGURE 7-16. TYPICAL PUMP-GRINDER INSTALLATION

sized to handle any number of connections. Another advantage, in a remote community, is that, with the pump-grinder unit in each building, the O&M costs for the majority of the sewage collection system will be paid by the building owners as they pay for the electricity and maintenance of their pump. This essentially eliminates billing and collection of operational costs from users and if a unit fails because of lack of O&M, only one user suffers.

The collection lines must be sized to maintain a minimum of one metre per second scour velocity. The minimum size collection line is 1-1/4 inch, which would be the size for one unit. If more houses are added than were originally planned for, velocities will increase down the line. The effect of this velocity increase is an increase in head loss which, within reason, is not a problem because the individual pump-grinder units have a very flat pumping rate vs head curve. Pressures should be held below 275 kPa (40 psi) in the layout, and the lines should be slightly undersized (higher velocity) rather than oversized if the correct size (for one metre per second) is not available. In the design of a pressure system, an assumption that 33 percent of the pumps will be operating at once is recommended for sizing pipes. The collection lines should be constructed to drain to low points if the system has to be shut down during the winter. In low flow conditions where heat losses may be extreme (such as at night in the winter in an above-ground situation) or where the minimum scouring velocity (one metre/second) cannot be met, the pressure collection lines should be looped back to a water source so warm water can occasionally be pumped through the lines. Air relief valves should be installed at major high points in the line.

The pump-grinder units can be situated in each building or several buildings could drain into one unit by gravity (like the system in Bethel, Alaska [2]). The units should be designed to pump against the design head in the main plus a 40 percent overload (with 33 percent of them operating at once). Each unit should have complete duplication of controls, sump pumps, and pumps or compressor, for standby. The extra unit would take over if the primary unit is inoperable and, at the same time, set off a warning device (audible and visual) to alert the operator that repairs are required. Standby power should be available in case of a power outage for units serving several buildings. The pumping units should be well insulated and installed on a stable foundation if they are placed outside or in the ground. As with manholes they must be protected from frost jacking forces. Double check valves should be provided on inlet and outlet to prevent backflow. This is especially important for pneumatic type pump stations, discussed later. Also, weighted check valves have proven more satisfactory than spring loaded valves.

The pump-grinder units designed to serve individual buildings are equipped with positive displacement pumps which have a nearly constant pumping rate over a wide range of heads (Figure 7-17). The grinder unit reduces all foreign objects to 6.5 mm size before they go into the pump. The unit must be able to handle items flushed down the toilets such as rock, wash rags, utensils, etc. Positive displacement pumps also require a lower power input to purge the system of air pockets which could form. The units must be small and light enough that they can be easily removed from the sump and repaired while the standby unit continues to operate.

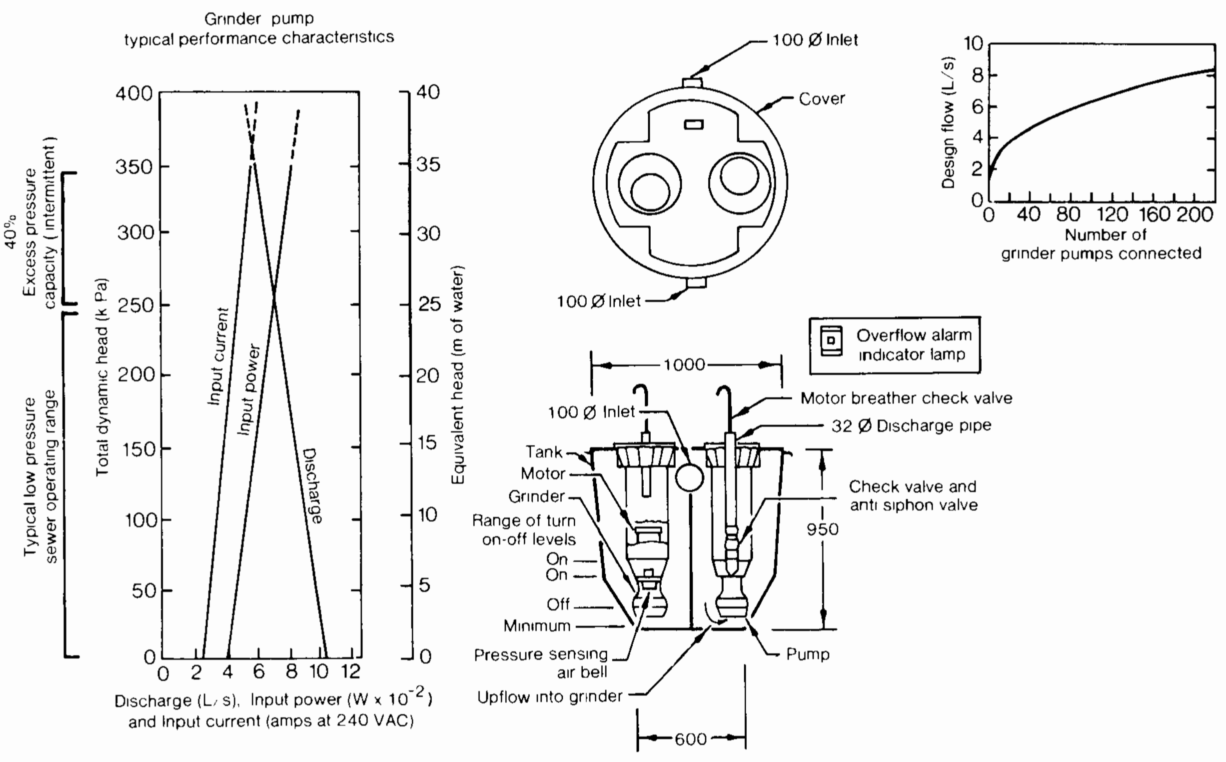


FIGURE 7-17. PUMP-GRINDER CHARACTERISTICS (adapted from Environment/One Corp. Ltd.)

With a 750-watt (1 hp) pump-grinder unit and a water use rate of 190 L per person/day (50 gpcd), the pump would operate only about three times per person per day with each operating period lasting about one minute. Thus, a five-person family would use about 0.5 kWh a day. At 25¢/kWh, this would only amount to about $3.75 per month per family for electricity.

The sump or tank from which the pump draws must be designed so that it is cleaned by scouring as the pump operates. The outlet check valves should be located in a horizontal run to prevent solids from settling out in them when the pump isn't running. Pressure sensors should be used to control pumps and alarms because rags and grease tend to foul float switches. The sump should be sized (450 to 570 litres) to provide several houses with storage in case of a temporary power outage or other problem. It is recommended that they be constructed of fiberglass or plastic for protection from corrosion.

Low water use fixtures should be used with pressure systems whenever possible (see Figure 7-5).

The pump-grinder units and any compressors, pumps, etc. in larger lift stations should be supplied with low voltage protection and a relay that will stop the motors in case of a major voltage fluctuation. This device would also protect the motor under a locked rotor condition.

The pressure system can also be modified by using conventional submersible sewage pumps in holding tanks at each building. The tanks are similar to septic tanks where the solids settle, biodegrade anaerobically, and are pumped out by truck occasionally. The submersible pump pumps the relatively clear effluent into the pressure sewer lines to a treatment facility. Some of the advantages of this type of operation are:

a) Problems with the grinder on the pump plugging up are eliminated.
b) There are no solids to settle in the collection lines.
c) The treatment facility is not as complicated as for conventional sewage.

7.4.4 Vacuum sewage collection systems

As with pressure systems, a vacuum sewage collection system is sensible only if soil conditions and community layout make a gravity collection system not feasible. The vacuum sewer system is detailed in Figure 7-18. Toilet wastes, with a small amount of water, are transported in the pipes by the differential pressure between the atmosphere (air admitted to the system with the flushing action) and a partial vacuum in the pipe created by a central vacuum pump. The flow conditions are slug-type, but the friction in the pipe breaks down the water slug. To reform the slug flow, transport pockets are required at intervals of about 70 to 100 m [3,5]. Vacuum systems are not limited to holding grades, but are limited to 4.5 to 6 metres in elevation differences because they are operated at 56 to 70 kPa (8 to 10 psi) vacuum. The vacuum toilets (Figure 7-19) only require 1.2 litres of water to flush and the collection lines are small (2"). The requirement for transport pockets (traps) is a disadvantage of the vacuum system. The traps will have liquid standing in them for extended periods of time so they must be inside a heated utilidor or be well insulated. They should also be provided with drains. Vacuum systems are limited to 30 to 50 services on a given collection line.

Leakage out of the sewage collection lines is essentially eliminated, and there is little possibility of sewage contaminating a water line in a utilidor. The need for house vents and P-traps, with the freezing problems that accompany them, is also eliminated.

Vacuum systems can also be used to collect sewage in large apartment buildings.

The vacuum system was developed in Sweden. Manufacturers and/or distributors [6,7] in the U.S. and Canada should be contacted to obtain the latest design standards as improvements are being incorporated continuously.

The collection line sizes will depend on the number of fixtures on a line and the estimated number which will be operating simultaneously. Usually 2 to 2-1/2 inch lines are used with the traps dipping at least one and one-half pipe diameters. Tests have shown that head losses increase about 3.37 kPa (one inch of mercury) for each 300 m of collection line velocities of 4.5 m/s or less. Because the lines carry a

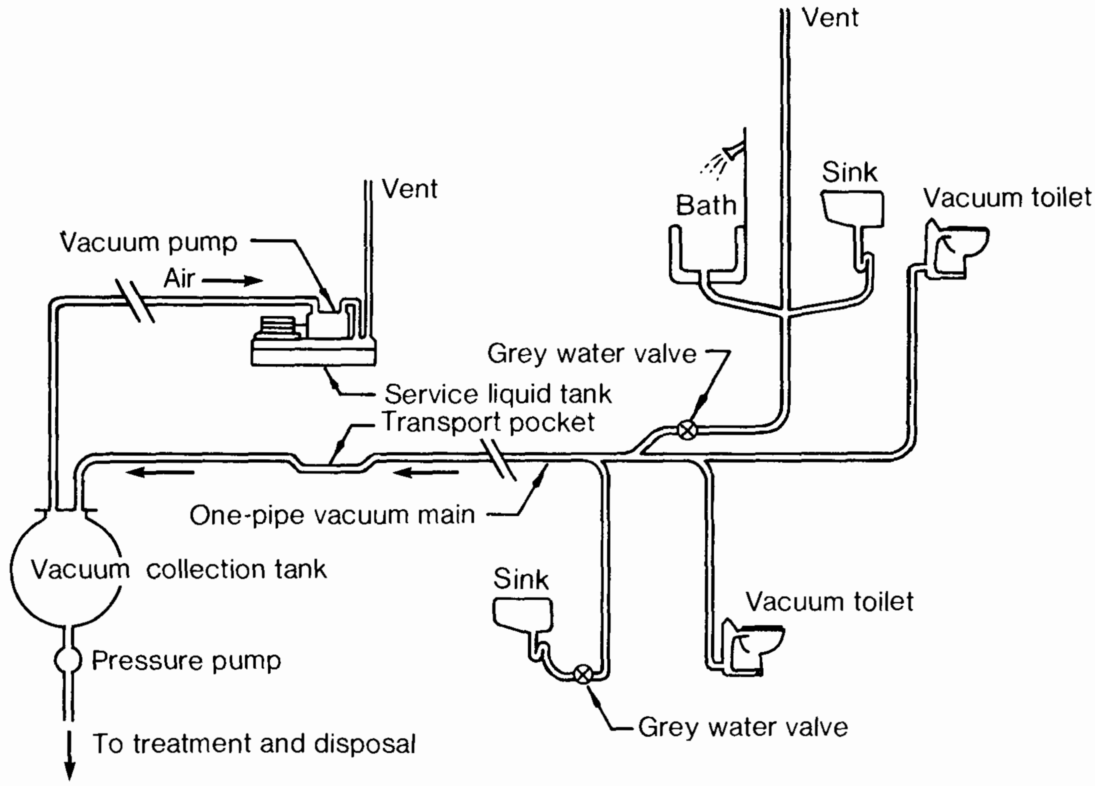


FIGURE 7-18. ONE-PIPE VACUUM SYSTEM SCHEMATIC

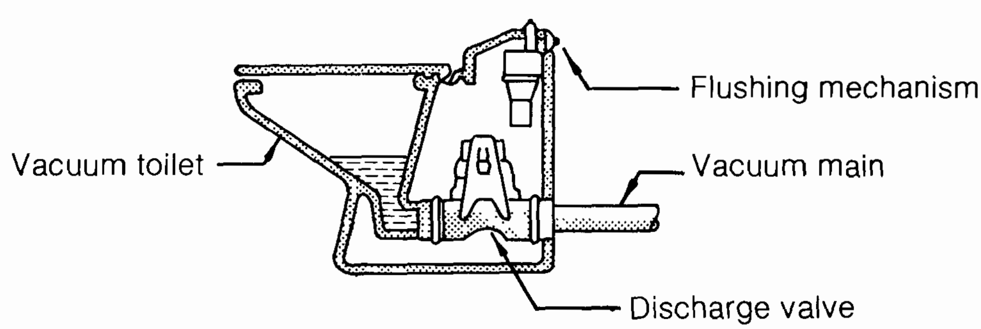


FIGURE 7-19. VACUUM TOILET

combination of air and water, head losses are nearly impossible to compute. However, when going uphill, the increase in head loss is only about 20 percent of the actual elevation increase. Most fixtures will not flush if there is less than 41 to 48 kPa (6 to 7 psi) vacuum in the collection lines. Thus, if several are flushing simultaneously and the vacuum drops to 41 to 48 kPa, additional fixtures will not flush until the vacuum builds back up. Grey water (sink, shower and tub wastes) can be separated from black water (toilet wastes) for treatment purposes or water reuse, by having the toilets on a different collection line than the grey water fixtures. In low use lines where it is not desirable to have sewage stand in the traps for extended periods, an automatic or timed valve can be installed to bleed air into the end of the line and keep the wastewater moving. Full opening ball valves should be installed approximately every 60 m so that sections of the lines can be isolated to check for leaks or plugs.

A collection tank is located at the end of the collection lines. The tank is held under a vacuum at all times by liquid-ring vacuum pumps which must be sized to evacuate the air and liquid admitted to the system by the users with a safety factor of two. In Noorvik, Alaska, the design figures used were six flushes per person per day for the toilets and 115 litres per person per day for sinks and showers [3]. For 50 houses, pumps were selected which were capable of evacuating 1.8 m^3/ minute at a vacuum of 53 kPa (16" of mercury). The collected wastes are then pumped out of the tank to the treatment facility using conventional centrifugal pumps. They must be designed to pump with a negative suction head equal to the maximum vacuum under which the tank must operate. The collection tank is sized similar to the pressure tank in a hydro-pneumati system. One-half of the tank capacity is used for liquid storage and thec other half is space (vacuum) serving as a buffer for the vacuum pumps. Several alarms should be included in the tank to give warning of high levels of sewage in the holding tanks, low incoming sewage temperature, and low vacuum in the system.

The plumbing fixtures in the building are the third important part of a vacuum system. Grey water valves (Figure 7-20) collect water from the showers, tubs, sinks, and lavatories. These individual fixtures

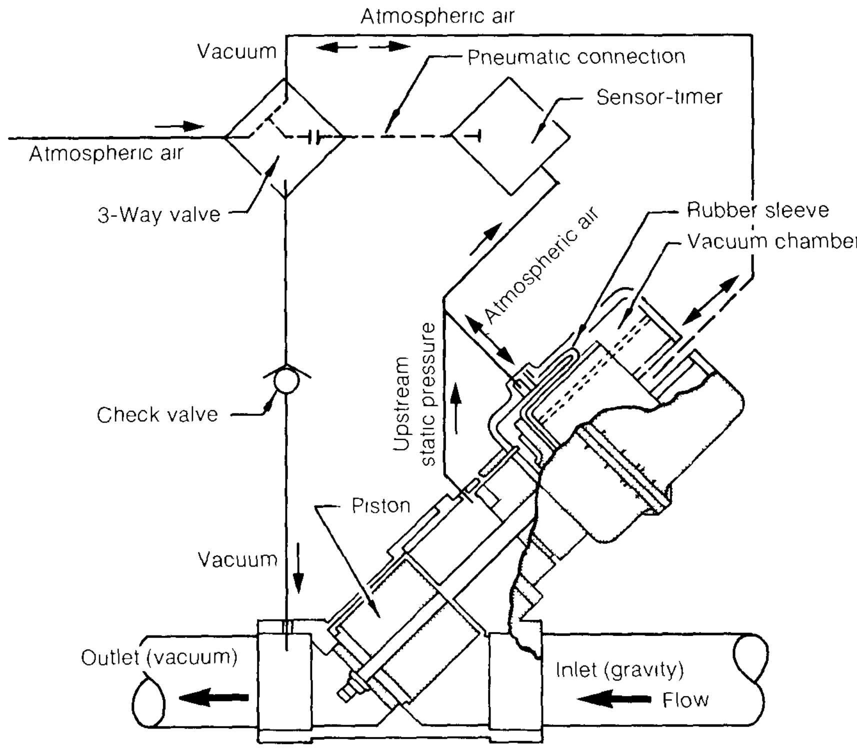


FIGURE 7-20. GREY WATER VALVE

are conventional but the addition of water use restricting devices is recommended. The grey water valve is activated by pressure from water upstream in the fixture drain line through a small pressure-operated diaphragm. This diaphragm is mounted in a tee just upstream from the valve. As grey water drains from the fixture, it hits the closed valve and backs up against the diaphragm, activating it and allowing the vacuum in the collection main line to open the valve. The length of time the valve is open is controlled by a timer. The cycle will continue until no more grey water flows into the line and the fixture is empty. The grey water valves allow equal parts of air and liquid to enter the system (e.g., 115 litres of waste and 115 litres of air per person per day in Noorvik).

Vacuum toilets resemble conventional flush valve toilets (see Figure 7-19). They are activated by push buttons which expose the waste in the bowl to the vacuum in the main. The button activaces the discharge valve and a water valve at the same time. The water valve allows about 1.2 litres of water from the water system to enter the toilet bowl for cleaning purposes. The discharge valve closes shortly before the water valve, allowing a small quantity of water to remain in the toilet. The toilet discharge valve allows 100 parts of air per one part of liquid into the system or 120 litres of air per flush. The fixtures have been relatively trouble free at Noorvik, Alaska, for the three years that system has been in operation [3].

7.4.5 Other collection systems

Other collection systems have been investigated, such as the possibility of using oil or antifreeze solutions to transport the sewage. However, none of them have proven feasible for a community or camp collection system.

7.4.6 Piped collection system materials

(See Appendix A).

7.4.7 Pressure and alignment testing of sewer lines

Pressure sewer lines should be tested as any pressure water line would be. If using water or liquid, use 1-1/2 times the working pressures with an allowable loss of 10 litres in 24 hours. If using air, use 1-1/2 times the working pressure with an allowable loss of 103 kPa in 24 hours. Great care must be exercised when using compressed air because of the possibility of explosion. Air testing must be used at below freezing temperatures.

Standard tests are satisfactory for air testing gravity sewer lines. An exfiltration test for water-tightness should be used where gravity sewer lines are above the watertable. The test should be made between manholes by blocking the lower manhole to a depth one metre over the top of the valve. The leakage should be measured by checking the drop over a period of two hours minimum. The maximum allowable infiltration or exfiltration, including manholes, should not exceed 190 litres per 24 hours per 300 metres of sewer per 25 mm of pipe diameter for each isolated section tested.

The alignment and grade of the completed sewer main or one under construction can best be checked by lamping the line. This operation is performed by simply shining a light through the line from a manhole and observing the alignment. Horizontal and vertical curves in sewer mains are not recommended but are permitted under most codes.

7.5 Lift Stations

Sewage lift stations are used mainly with gravity collection systems but could be used with pressure sewage collection systems, and even vacuum systems (to pump the waste from the collection tank to the treatment facility).

7.5.1 Types

Table 7-2 presents the advantages and disadvantages of each type of lift station.

7.5.2 Cold regions adaptations

The following modifications should be made to conventional lift stations in cold regions.

The outside of the station should be insulated with at least 8 cm of urethane or styrofoam with an outer protective covering to protect the insulation from moisture. Insulation should be placed underneath the station to prevent settling due to the thaw of frozen ground. Visqueen (plastic) or some other bond breaker should always be used to reduce frost jacking in the active layer. If thawing and settling under the station is anticipated, pile foundations extending well into the permafrost are recommended. All stations must be attached to concrete slabs to provide sufficient weight to overcome the buoyancy of the station itself if it were completely submerged in water. Pressure coupling (flexible) type connections are recommended at the inlet and outlet of the stations to prevent differential movement from breaking the lines.

A lift station should never be installed in the ground without immediately placing the heater and dehumidifier into operation. Condensation from cold surrounding ground could corrode the controls and electrical connections.

Alarms are an absolute necessity in any lift station. All critical components, such as pumps and compressors, should be duplicated in each station. The controls should allow the operator to specify operation of a pump or compressor, with the identical standby unit taking over if one or the other does not start. An alarm (both visual from the surface and audible) would then warn the operator that one unit is malfunctioning. The alarms can also be set for the temperature and water level in the station (to warn of a sump pump malfunction). These alarms

TABLE 7-2. TYPES OF LIFT STATIONS

	TYPE	ADVANTAGES	DISADVANTAGES
1.	Submersible	Low initial cost; low maintenance requirements; does not require installation of appurtenances such as heaters, dehumidifiers, sump pump, etc.; station can easily be expanded and increased in capacity; available for wide range of capacities. Little of the structure is above ground so heat losses are greatly reduced.	Difficult to make field repair of pump, requires specialized lifting equipment to remove pump.
2.	Dry Well	Pumping equipment located away from wet well; low cost per gallon capacity; good reliability; high efficiency; desirable for large installations; easily maintained.	High initial costs; requires larger construction site.
3.	Wet Well	Low initial cost; high efficiency; wide range of capacity available	Requires explosion proof electrical motors and connections; difficult to maintain pump.
4.	Suction Lift	Good reliability; available for wide range of capacity.	Suction lift limited to 4.5 metres; decrease in priming efficiency as pump ages.
5.	Pneumatic Ejector	For low capacity (40 gpm or 150 L/minute) low head, for short distances; generally nonclogging, 380 L/minute (100 gpm) maximum usually.	Somewhat more complex than other types of stations; high maintenances; low efficiency.

should be tied back into a central alarm panel in the pumphouse or operator's house, and can be connected to the operator's and/or the fire or police department's phone. Standby electrical power should be provided for each major lift station.

Inlet screens must be provided to remove items that would clog pumps or check valves. Each lift station should be checked by the operator and the inlet screen cleaned daily. Submersible types or those without a heated dry well in which to work should be housed in a heated surface structure with the electrical controls and alarms. All entrance manholes must extend above the ground surface sufficiently to be above any flooding or snow drifts. Also, manhole entrances or building entrances must be kept locked. All pumps or motors should be supplied with running time meters for measuring flow rates; conventional water meters do not work properly with sewage. Corrosion protection should be provided for the metal shell in each station. Sacrificial and corrosion protection systems do not work well when the ground surrounding the anode or lift station is frozen.

7.5.3 Force mains

Force mains are pressure lines into which the pumps in the lift station discharge. They should be designed to have scour velocities during pumping (2-1/2 to 3 ft/sec or 7.5 to 9 m/s) and to drain between pumping cycles. If this is not possible the line must be placed in a heated utilidor or heat traced in some way. Another option would be to time the pumping cycle so the sewage stays in the line for a calculated period, and to size the holding tank at the lift station to hold at least the volume of the force main. The mains should be pressure tested and they should meet all the criteria of pressure water transmission pipelines (see Section 3). If they empty into a manhole, the entrance should be at least 0.7 m above the exit line.

7.6 Building plumbing

Service lines and their connections to the buildings were discussed earlier. The special plumbing needed with vacuum sewers was covered in the section dealing with vacuum collection systems.

The use of floor-mounted, rear-flushing toilets keeps all waste plumbing lines in the walls of the building and out of the floors (10 cm above the floors). These toilets are readily available. Wall-mounted, rear-flushing units are not recommended unless the wall is reinforced because the wall supports the entire weight of the toilet and the user. The floor-mounted, rear-flushing units must be carefully installed; over -torquing the flange bolts will crack the base. Examples of floor-mounted, rear-flushing toilets are the "Yorkville" by American Standard or the "Orlando" by Eljer. Tubs should be placed upon blocks so the entire trap and drain is 10 cm above the floor. This allows the tub to drain into the toilet discharge line in the wall. All fixtures should be placed on inside walls which are warm on both sides. If possible, the sink should be placed on the opposite side of the bathroom plumbing wall to reduce the length of drain lines. All fixtures and lines should be installed so that they can be drained or otherwise protected from freezing. Drainable p-traps should be used and the user should be aware that antifreeze solution should be added to his toilet if there is a danger of freezing. Stop and waste valves should be provided at all low points in house water supply lines. Home owners must be trained to maintain the facilities after they are installed. They need to know how to order parts, how to repair leaky faucets and toilets, and what not to flush down toilets.

House vents frequently frost over in cold weather. They should be constructed of low conductivity material and should increase in size as they go into the unheated attic. One and one-half inch vents should be increased to 3" and 3" to 4" and insulated in extreme circumstances.

7.7 Typical Construction Costs

Table 7-3 gives estimates of 1977 unit construction costs.

7.8 References

1. Gamble, D.J. and Janssen, C.T.L., "Evaluating Alternative Levels of Water and Sanitation Service for Communities in the Northwest Territories", Canadian Journal of Civil Engineering, Vol. 1, No. 1, 1974.

TABLE 7-3. UNIT CONSTRUCTION COSTS (1977)

Item	Cost in Place*	Remarks
Buried Utilidors	\$400 to \$1,200/m	Does not include excavation. Depends on how many lines are included. Depends on backfill material.
On-surface	\$200 to \$300/m	Depends on lines included
Above-surface	\$600 to \$1,700/m	Costs depend on foundation (piling, etc.). Depend on lines included.
Buried Pipeline	\$90 to \$300/m	Does not include excavation Depends on Backfill material.
Rock excavation	\$50 to \$75/m^3	
Permafrost excavation	\$40 to \$80/m^3	Depends on water content and time of year excavated.
Normal Excavation	\$20 to \$30/m^3	
On-surface Pipeline	\$60 to \$100/m	
Above-surface Pipeline	\$120 to \$300/m	Depends on foundation (piling, etc.).
Sewage grinder pump and sump	\$3,200	Two pumps in sump.
Manholes	\$1,500 to \$2,000	Does not include excavation
Lift stations	\$18,000	Depends on size, does not include excavation
Tracked hauling vehicle (2250 l)	\$45,000	With tank, etc.
Truck hauling vehicle (4500 l)	\$25,000	With tank, etc.
Vacuum toilet fixtures (plumbing)	\$2,600	In existing house.

Table 7-3. (CONT'D)

Item	Cost in Place	Remarks
Refuse packer unit on 1-1/2 ton truck	$30 000	
Low water use toilet	$2200	In existing house.
Plumbing a house	$2100	Toilet, sink and lavatory. Includes fixtures.
Waste disposal bunker (cribs)	$800	Includes excavation. 5' deep x 6' x 6'
House holding tanks	$3500	Water and waste

* All costs vary with transportation (see Section 2). Those costs given are representative for mid-arctic conditions.

2. Ryan, W.L. and Rogness, D.R., "Pressure Sewage Collection Systems in the Arctic", Proceedings of Symposium on Utilities Delivery in Arctic Regions, Report no. EPS 3-WP-77-1, Environmental Protection Service, Environment Canada, Ottawa, 1977.

3. Rogness, D.R. and Ryan, W.L., "Vacuum Sewage Collection in the Arctic: Norvik, Alaska - A Case Study", Proceedings of Symposium on Utilities Delivery in Arctic Regions, Report no. EPS 3-WP-77-1 Environmental Protection Service, Environment Canada, Ottawa, 1977.

4. Cadorio, P.M. and Heinke, G.W., "Draft Manual for Trucking Operations for Municipal Services in Communities of the N.W.T.", Publication of Dept. of Civil Eng., Univ. of Toronto, Oct. 1972.

5. Averill, D.W. and Heinke, G.W., "Vacuum Sewer System", Indian and Northern Affairs Pub. No. QS-1546-000-EE-A, Information Canada, Sept. 1974. Also available from Dept. of Civil Engineering, University of Toronto.

6. Colt Industries, Beloit, Wisconsin 53511, U.S.A.

7. Vacusan Systems Ltd., #12, 6115-4th St., S.E., Calgary, Alberta, T2H 2H9.

7.9 Bibliography

Alter, A.J., "Sewerage and Sewage Disposal in Cold Regions", U.S. Army Cold Regions Research and Engineering Laboratory M3-C56, October 1969. 106 p., AD-698452.

Environment Canada. Environmental Protection Service, Proceedings of Symposium on Utilities Delivery in Arctic Regions, Report No. EPS 3-WP-77-1, Environmental Protection Serivce, Environment Canada, 1977.

Gamble, D.J. and Janssen, C.T.L., "Estimating the Cost of Garbage Collection for Settlements in Northern Regions", Northern Engineer, Winter 1974-75.

Gamble, D.J., "Wabasca-Desmarais Water and Sanitation Feasibility Study", prepared for the Northern Development Group, Alberta Executive Council, 1974.

SECTION 8

UTILIDORS

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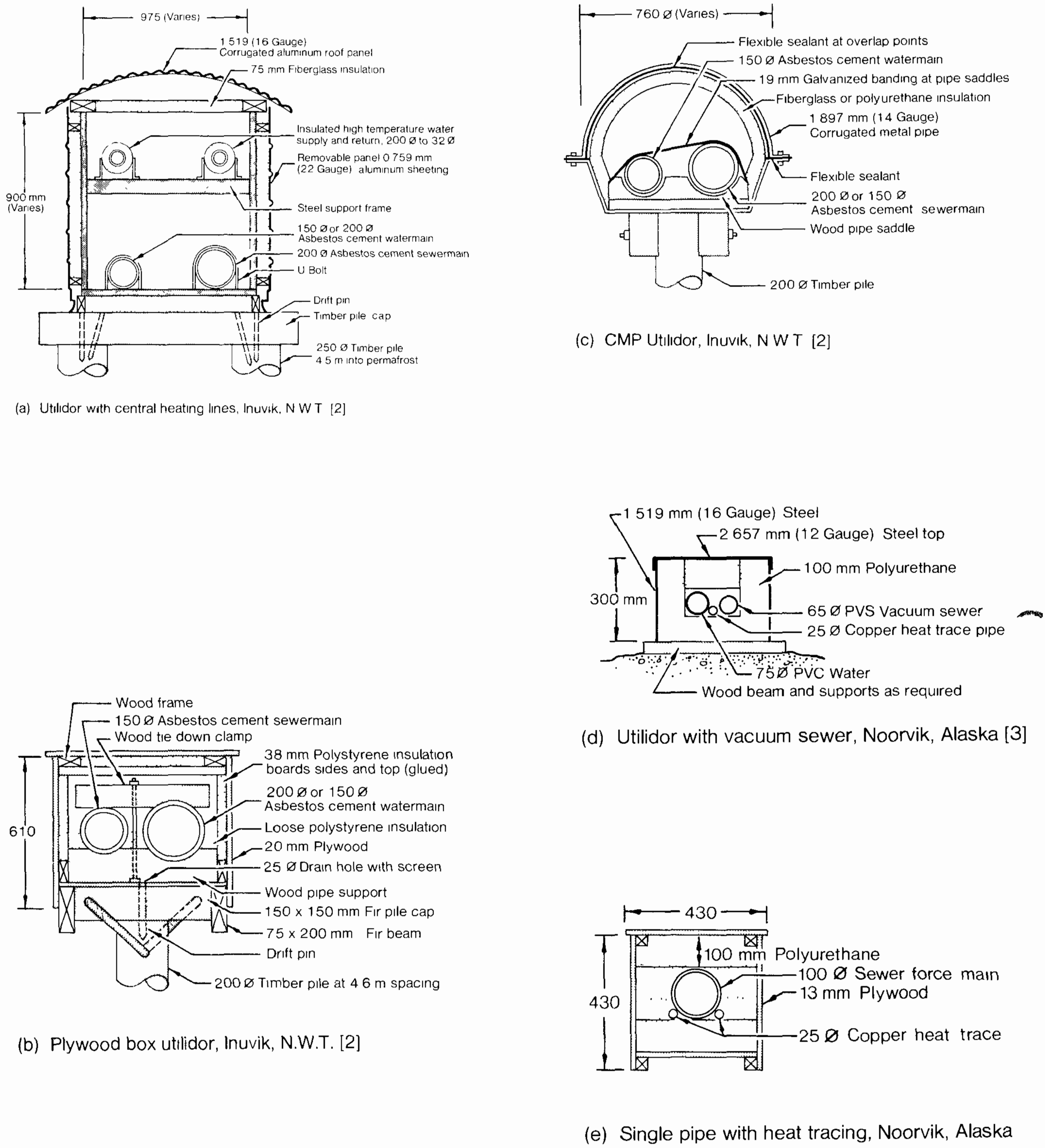
8 UTILIDORS

8.1 Introduction

Utilidors are conduits that enclose utility piping which, in addition to water and sewer pipes, may include central heating, fuel oil, natural gas, electrical and telephone conduits. Utilidors may be located above, below, or at ground level and have been used in stable and unstable seasonal frost and permafrost soils as well as in snow [1]. They may be large enough to provide access for maintenance purposes or for use as a walkway, or they may be compact with no air spaces. Single pipes or separate pipes on a common pile are not utilidors. The size, shape, and materials used depend upon the number and types of pipes, local conditions and requirements, and economics.

Utilidors have been constructed in many northern locations [1]. Perhaps the best-known examples of above-ground utilidors are in Inuvik, NWT [2,11,12]. Utilidors have also been extensively used below-ground in high density areas and in permafrost areas in Russia [8,13]. Examples of various utilidors that have been constructed in cold regions are illustrated in Figure 8-1.

Utilidors are not water distribution or sewage collection systems in themselves. They are commonly used in cold regions to consolidate piping, and perhaps other utilities, particularly where central heating pipes are used and for above-ground systems. Also of significance are physical protection of pipes and insulation, and thermal considerations. As with other cold regions piping, they must be insulated to reduce heat loss but often the insulation is located on the utilidor exterior casing rather than on the individual pipes. Other freeze-protection measures, such as recirculation to maintain a flow in water pipes, may also be necessary. Most utilidors have some mutually beneficial heat transfer between the enclosed pipes. If central heating pipes are included, heat loss from these can be sufficient to replace utilidor heat losses and prevent freezing, but with this arrangement temperature control within the utilidor is difficult. This can lead to inefficiency and undesirably high temperatures in water pipes. Freeze-protection alone is not sufficient justification for the use of



(a) Utilidor with central heating lines, Inuvik, N W T [2]

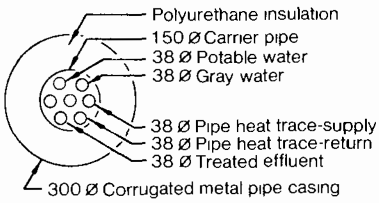
(c) CMP Utilidor, Inuvik, N W T [2]

(d) Utilidor with vacuum sewer, Noorvik, Alaska [3]

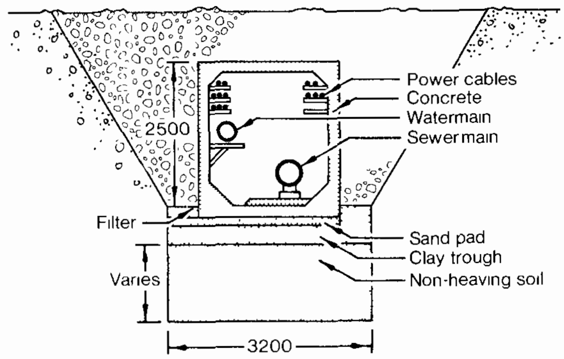
(b) Plywood box utilidor, Inuvik, N.W.T. [2]

(e) Single pipe with heat tracing, Noorvik, Alaska

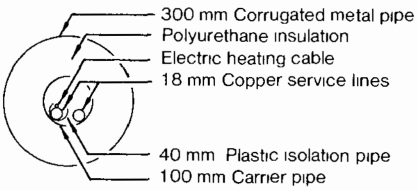
FIGURE 8-1. VARIOUS UTILIDORS INSTALLED IN COLD REGIONS



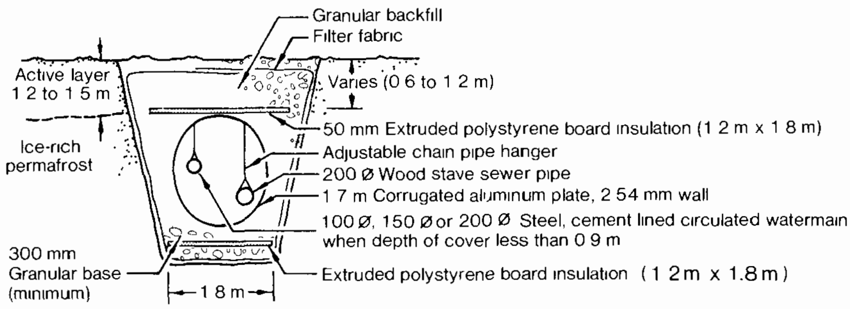
(f) Utilidor with many small pipes, Wainwright, Alaska [4]



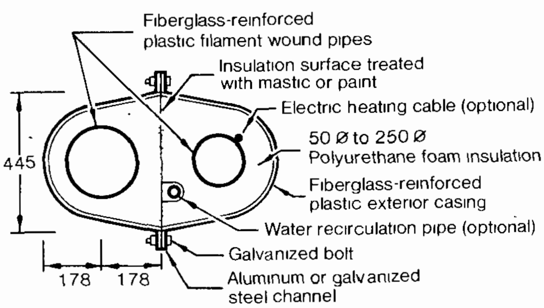
(i) Buried accessible utilidor, Mirryl, U.S.S.R [8]



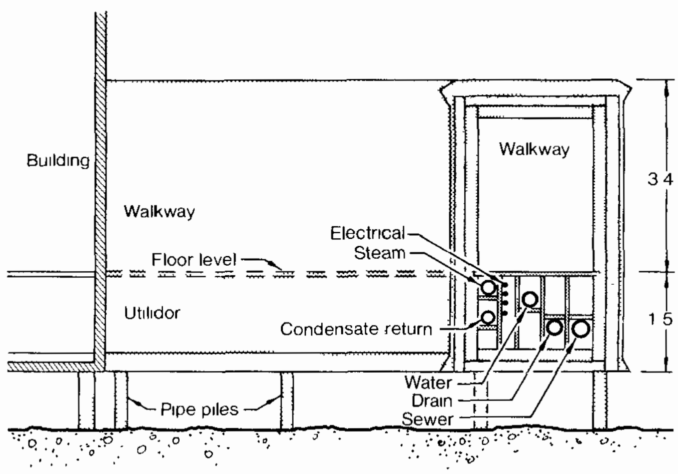
(g) Service connection [5]



(j) Buried accessible utilidor, Nome, Alaska [9]



(h) Prefabricated utilidor [6,7]



(k) Walkway utilidor, Cape Lisburne, Alaska [1]

FIGURE 8-1. (CONTINUED)

utilidors since individually insulated pipes could be used. Utilidors, or utility tunnels designed for public passage are very expensive, and are generally not justified for piping alone. However, where they are required for passage or transportation, there can be overall economic benefits by locating utility conduits within them.

In North America, utilidors are most commonly constructed above-ground in permafrost areas. Although below-ground utilities are preferred, above-ground construction may be necessary where there is ice-rich permafrost, expensive excavation, or a lack of equipment for the installation and maintenance of underground utilities. Temporary pipes or piping that requires access may also be located above-ground.

Utilidors have disadvantages. Their applicability for a particular location should be carefully assessed before implementation. Individually insulated pipes, in a common trench or supported by a common pile (see Figure 6-18) may be a more appropriate and economical alternative [10].

8.2 Design Considerations

Inclusion of conduits such as electrical power, natural gas, and telephone cables, along with water and sewer lines in utilidors can be cost-effective and aesthetic. This practice is generally recommended wherever practical. The addition of central heating lines may require significant changes in utilidor design and operation. The use of central heat generation and distribution is a more complex economic decision. Walkways are sometimes constructed between buildings in construction camps or military facilities or in high traffic and severe snow drifting conditions. In these situations placing utility lines within them should be considered. In some cases surface utilidors have been designed for use as sidewalks.

These common functions of utilidors are often the primary benefit and reason for their use. Some of the problems encountered when other utilities besides water and sewer pipes are included in the utilidor are:

a) jurisdiction problems in installation and maintenance;

b) coordination between various utility agencies during planning and construction;

c) differences in routing or other conflicting design criteria for various utilities or utilidor uses;

d) difficulty or restrictions in expansion or changes to utilities;

e) piping and utilidor design problems, particularly at intersections and bends;

f) compatibility of materials; and

g) larger size, and perhaps special materials, which increase the costs of utilidor construction and above-ground road crossings.

In some situations, such as at industrial camps, military bases or in planned communities, these problems may be overcome with overall cost savings and aesthetic benefits.

8.2.1 Utilidors with central heating lines

The decision to use utilidors to carry central heating lines is secondary to the benefits of central heating. These benefits include the elimination of less efficient individual building furnaces and a significant cause of fires, central fuel storage, and the possible use of waste heat (see Section 14). These pipes often require access, particularly for steam and condensate return lines. If they are buried, utilidors are necessary for access. Separate pipes can be used for above-ground systems and may be more economical, but consolidating piping within a utilidor may be more aesthetic.

When only central heating lines are considered, utilidors or individually insulated pipes can be used (see Figures 14-8, 14-9 and 14-11). When central heating and water and sewer lines are installed in a utilidor, the former can give off enough heat to prevent freezing temperatures within the utilidor. This may eliminate or reduce the need to loop and recirculate the water mains, although circulation is always desirable in cold regions. Because the utilidor exterior is insulated, conventional, uninsulated water and sewer piping and appurtenances are usually used. For economical operation the central heating lines are usually insulated. In some cases it may be necessary to remove some insulation from around the heating pipes to provide enough heat during the coldest ambient temperatures. The utilidor in Figure 8-1(a) commonly has 0.25 m of insulation removed every 10 m.

Problems occur because the heat source is constant and must operate for all or most of the year. Therefore, when the ambient temperature is warmer, the interior temperature of the utilidor will increase and undesirably high water temperatures can occur when there is little or no flow in the water pipes (see example 15-5). Users have found it necessary to bleed considerable volumes of water to obtain cool water [11]. For this reason it is desirable to insulate the water pipes [10].

The heating of a large air space in the utilidor is less efficient than the direct heating of water and its recirculation to prevent freezing. This inefficiency is more significant for above-ground and large utilidors. In some situations it will be more efficient to design and operate the heating and the water and sewer systems independently. If a utilidor is used the benefits will be aesthetic for above-ground utilities, accessibility for below-ground utilities, and structural support for the pipes.

Thermal stratification can cause freezing of lower pipes in large open utilidors when the average temperature is adequate. Vertical air flow barriers may be necessary to prevent air currents along inclined utilidors [11]. Thermal shielding of pipes and poor temperature distribution within a utilidor are shown in Figure 8-2 [14].

Utilidors for central heat distribution pipes and other utilities are expensive. Their large size increases the material and construction costs, particularly for above-ground systems and road-crossings. Central heating is only economical in relatively high density developments, not single-family housing areas. With adequate planning these utilidors can form the backbone of large community systems, with non-heated utilidors servicing adjacent lower density areas.

Central heating systems must provide continuity of service and they should be looped so that areas can be isolated for maintenance or

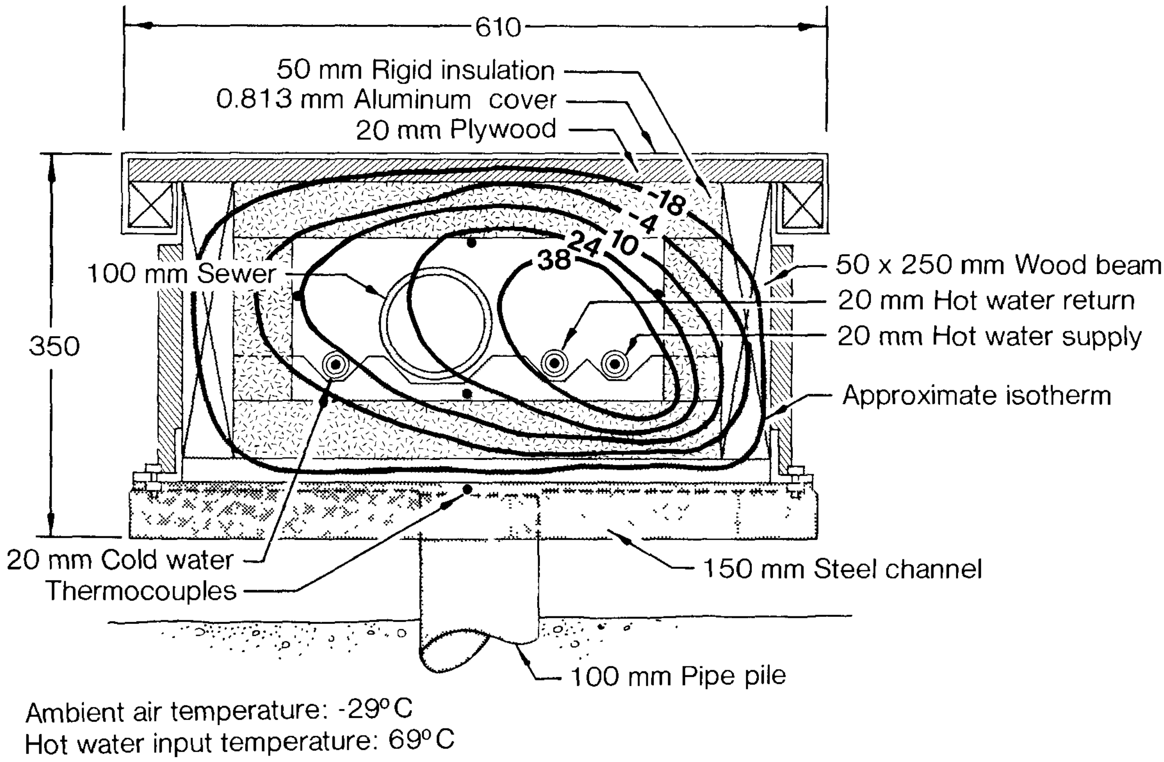


FIGURE 8-2. TEMPERATURE VARIATION IN A UTILIDOR WITH CENTRAL HOT WATER DISTRIBUTION, FAIRBANKS, ALASKA [14]

repairs. Long-range planning is necessary to incorporate future expansion and to allow efficient staging without the need for temporary or unused lines to complete loops.

8.2.2 Utilidors with pipe heat tracing

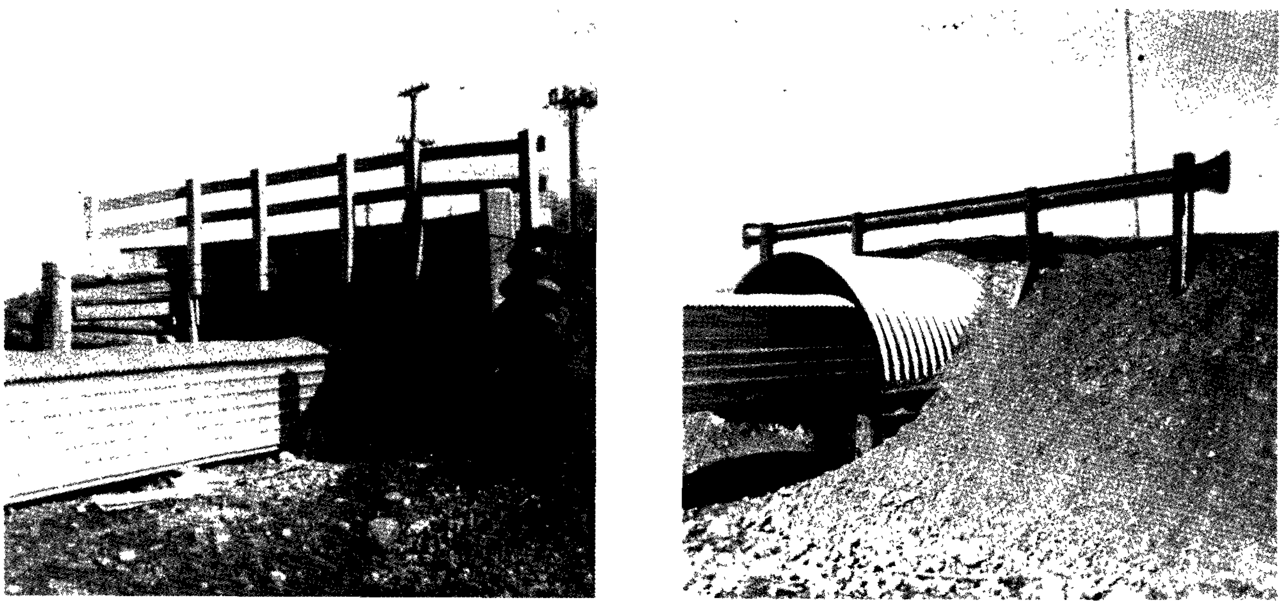
Utilidors with the pipe heat tracing are designed specifically to supply the amount of heat necessary to prevent freezing of the pipes in the utilidor. Low temperature, 80°C to 98°C, glycol solutions or other non-freezing fluids, and small-diameter bare pipes are commonly used (see Section 15.4.3). They can be used to heat utilidors or thaw out frozen pipes. Many of the inefficiencies and problems with central heating lines do not apply.

8.2.3 Above-ground utilidors

Below-ground utilities are usually preferred, but local conditions, operating requirements and economics can make above-ground utilities and utilidors attractive. Factors to be considered when choosing between above or below-ground utilities are detailed in

Section 2. It should be noted that above-ground utilities were often necessary in the past because the types of insulations in common use required dry conditions and accessibility. For the same reason, buried accessible utilidors were used. The development and availability of near-hydrophobic rigid plastic foam insulations, such as polyurethane and extruded polystyrene, has made buried systems feasible and more attractive in many situations.

Above-ground utilidors should be as compact and as close to the ground as practical to reduce the obstruction to traffic. Low utilidors also reduce the elevation of buildings necessary for gravity sewer drainage. Utilidors with central heating lines are often large and require expensive wood or corrugated metal arch structures at road crossings (Figure 8-3). Vacuum or pressure sewer systems may be attractive in undulating areas since the utilidor can follow the ground surface or can be buried at a constant depth. These systems use smaller-diameter pipes than gravity systems. When small-diameter water and sewer pipes are used, the utilidor size can be reduced (see Figure 7-8).



(a) Wood

(b) Corrugated Metal Arch

FIGURE 8-3. ROAD CROSSINGS FOR A UTILIDOR WITH CENTRAL HEATING LINES INUVIK, NWT

Above-ground utilidors are located within rights-of-way behind building lots where both physical and legal access are provided. Buildings should be located near the utilidor to reduce the length of service lines. A minimum of 3 m between building and utilidor is often specified for fire protection. The street layout must consider the looping of water mains for recirculation, the expense of road-crossings and vaults, and the high cost per metre, which are characteristics of above-ground utilidors. An example of good planning is illustrated in Figure 2-14.

Utilidors have been routed through the crawl space in buildings to provide thermal and physical protection for the pipes, eliminate the service connection utilidettes which are the most freeze-susceptible portion of cold regions utility systems, and reduce the length of utilidor and right-of-way required. Problems with this layout can include the provision for access to piping and the danger of fires which could jeopardize the community utility system. Fire and smoke can travel along utilidors to other buildings. Fire resistant materials and fire cutoff walls have been used to minimize this danger.

People often walk on utilidors, but because the travelled surface and utilidor will require increased maintenance this is often discouraged by design and legislation. In some locations, they have been designed as sidewalks, but this is often impractical because of the routing requirements for the utilidors and their elevation.

8.2.4 Below-ground utilidors

Although buried utilidors, usually of concrete, have been constructed in unstable soils in many large communities in northern Russia, they have had limited application in the cold regions of North America and in Antarctica [1]. Few buried utilidors have been constructed without the inclusion of central heating lines and perhaps other conduits besides water and sewer pipes. A notable exception to all of these generalities is the corrugated metal pipe utilidor for water and, sewer lines in Nome Alaska (Figures 8-1(j) and 8-4). The primary advantages of buried utilidors are access for maintenance and repairs, the consolidation of utilities in a single structure and trench, and thermal

FIGURE 8-4. BURIED UTILIDOR UNDER CONSTRUCTION, NOME, ALASKA

considerations which may include freeze-protection and ventilation to reduce the thawing of permafrost. In some cases, individual pipes or utilidors without an air space (for example Figures 8-1(h) and 14-11) may be appropriate and more economical.

Below-ground utilidors are subject to ground movements from frost-heaving or thaw-settlement and groundwater infiltration, and this has caused failures in ice-rich permafrost. To prevent progressive thawing of permafrost, open utilidors with natural ventilation have been used in Russia. Vents are opened during the winter to maintain sub-freezing temperatures within the utilidor and refreeze the foundation soils that were thawed the previous summer. Other foundation designs that can be used in permafrost areas include the provision of supports, refrigeration, insulation, and improving the foundation soils within the expected thaw zone (see Section 15.6.1). Groundwater, melt-water and water from pipe breaks must be considered in both unstable and stable soils. In the spring, flooding can occur in buried utilidors which have an air space. Provisions to allow drainage of the utilidor must be made; watertight utilidors are desirable and usually required. Diversions or cutoff walls in the trench may be necessary in permafrost areas to prevent detrimental groundwater flow along the trench.

8.3 Components and Materials

Utilidors that are well designed and constructed with high quality materials have a longer useful life, cost less to operate and provide more reliable service. Utilidors which have performed best were constructed with metal exterior casing, used closed-cell insulation, were structurally sound and had a solid foundation [2]. The basic components of a utilidor are:

a) foundation,
b) frame,
c) exterior casing,
d) insulation, and
e) piping.

8.3.1 Foundation

Foundation considerations and design will be different for utilidors that are below-ground, at ground level or elevated. Each requires site investigations and designs that will accommodate, reduce or eliminate the effects of frost-heaving, settlement and surface and subsurface drainage.

Above-ground utilidors must be supported to provide grades for gravity sewers and to allow the draining of pipes and the utilidor. Pipes must be adequately anchored to resist hydraulic and thermal expansion stresses.

Where ground movements are within acceptable limits, utilidors can be installed directly on the ground, or on a berm, earth mounds, sleepers or posts.

In unstable areas utilidors are commonly supported on piles which are adequately embedded into the permafrost (see Section 15.6.3). The piles are dry augered if possible because thawing the permafrost with steam or hot water increases the freeze-back period and frost-heaving. Because of the light weight of utilidors, the vertical loads on the piles are relatively small and frost-heaving will usually be the most significant design consideration for embedding piles. Lateral forces may be significant on some permafrost slopes, and lateral thermal expansion and hydraulic stresses must be considered at bends. Various types of piles have been used to support above-ground piping. The selection depends upon the availability of local materials, the length of pile required and economics. Piles used in Inuvik, NWT, are usually rough timber poles and are embedded 4 to 6 m. At Norman Wells, NWT, frost-heaving is severe and 100-mm diameter steel pipe is driven 12 m and grouted to the fractured shale bedrock. Piles may cost from $200 to over $750 each and may account for 10 to 20% of the total cost of above-ground utilidors. Small utilidors are usually placed on a single pile, but large utilidors may require double piling for stability. The utilidor structure must be adequately anchored to the pile foundation. Pile caps are often used to allow for poor alignment.

Buried utilidors in stable soils have conventional design considerations which include surface loads. Frost-heave must be considered for shallow-buried utilidors, and in ice-rich permafrost soils, thawing must be prevented or considered in the design (see Section 15.6.1).

8.3.2 Frame

The supporting frame must keep the above-ground utilidors rigid in spanning piles or other supporting structures. The utilidor dead loads, live loads including people, and stability must be considered in the structural design. In some instances steel has been used, but wooden beams are more common. Solid utilidors may utilize the pipe, insulation and shell for beam strength (Figure 8-1(g,h)). An economic analysis would indicate the best spacing of piles versus increasing the beam strength of the utilidor frame. Utilidors supported by wooden beams in Inuvik, NWT, usually span 4.5 m. Steel beams or pipe can be used to span up to 7.5 m, which is generally the practical limit without special designs.

Buried utilidors must also have some beam strength to hold pipe grades and span local poor bedding or foundation soils. Beam strength is usually incorporated into the exterior casing.

8.3.3 Exterior Casing

The primary function of the exterior casing is usually to hold the insulation in place and to protect the pipes from the weather and physical damage. When the exterior casing is an integral part of the structural strength and rigidity it is usually metal or fibreglass with polyurethane insulation bonded to it.

The outer shell of above-ground utilidors should be designed for easy removal to provide access to piping. This is particularly important at appurtenances, but is desirable along the complete utilidor. The joints in the sections must be designed to seal against rain, snow or air infiltration. Drain holes located in the bottom should be provided periodically to allow drainage in case of a pipe break.

Materials that have been used for the exterior casing include corrugated and sheet metal, plywood or wooden beams, and fiberglass reinforced plastic. Concrete has also been used for surface or buried utilidors. Although wooden box utilidors have the lowest capital cost, they have a low life expectancy and the highest maintenance costs due to painting requirements and physical damage. Wood is easy to work with and the utilidor, vaults and service connections can be easily constructed on-site even in cold weather. Wooden utilidors are sometimes covered with a thin metal sheet or asphalt paper. Metal utilidors may be difficult to fabricate and install, particularly at bends, junctions and appurtenances. They are rugged and have a longer life expectancy, and require less maintenance than wooden exterior casing utilidors.

Below-ground utilidors require a rigid exterior casing that is watertight and provides the structural strength required by the utilidor.

8.3.4 Insulation

Insulation is probably the most critical component in all cold regions piping systems, including utilidors. Water can enter the utilidor at joints or from breaks in the pipes, and it is impractical to keep the insulation dry. Insulations that absorb moisture lose their insulating value, particularly when the moisture freezes; therefore, asbestos fibre, rock wool, glass fibre, wood, sawdust, peat moss and similar materials are undesirable and must not be used in inaccessible utilidors. Polyurethane, and expanded and extruded polystyrene are the most common insulations used. Ground or bead polystyrene and foamed-in-place polyurethane can be used to fill the voids in utilidors. The former provides access to pipes for repair and removal. Fire resistant insulations are preferred since they reduce the spread of fire along utilidors.

Thermal characteristics of various insulations are given in Appendix C and Section 15.7.2.

8.3.5 Piping

Leaks from pipes and joints in utilidors may cause water and icing damage to the utilidor, and there is also a danger of contamination and cross-connections. Most public health codes do not allow the proximity of water and sewer pipes. Wavers or adoption of new codes will be necessary before utilidors can be used. In the Northwest Territories, water and sewer pipes are allowed in a common trench or utilidor if pressure-rated pipes and joints are used and all pipes are tested for zero leakage. Open sewers are not allowed and sewer cleanouts must be capped.

Most types of pipe materials have been used in utilidors. Each has advantages and disadvantages. Rigid pipes with welded or equivalent joints may not require as much support or hydraulic thrust blocking at bends, hydrants and intersections, but the design must allow for thermal expansion.

8.3.6 Cross-section design

The cross-section design and piping arrangement will depend upon the access required and type, size and number of pipes to be included in the utilidor. Other considerations may include standard sizes of materials, for example 4 feet x 8 feet plywood sheets, and the routing of piping. The utilidor size is often dictated by the maximum dimensions of pipe appurtenances, repair clamps and joints, and the spacing of pipes that is necessary at deflections and intersections.

Pipes with smooth joints may be placed closer together and a smaller cross-section may be used. Installation, repairs and maintenance requirements must also be considered.

8.3.7 Prefabricated utilidors

Most utilidors are prefabricated to some extent, but all require some field construction. The primary advantage of prefabrication is the reduction in field-erection time. This reduces labour costs and facilitates installation within the short construction season, but prefabricated utilidors generally have high material costs. High quality control and special designs are possible in shop fabrication. Prefabricated utilidors commonly combine the functions of the basic utilidor components. The pipes, rigid insulation and exterior casing provide beam strength, rigidity, and thermal and physical protection.

One type of prefabricated utilidor consists of a carrier pipe, polyurethane foam insulation, and a bonded exterior casing of sheet or corrugated metal, glass fiber reinforced plastic or plastic, depending on the strength requirements (see Figures 8-1(f)(g), A-1 and A-2). This system is commonly used for small-diameter pipes and service connections to buildings. A completely prefabricated glass fibre reinforced plastic two-pipe utilidor system is illustrated in Figure 8-1(h). It is longitudinally segmented and has staggered joints to allow removal of individual pipes.

Appurtenances such as hydrants, cleanouts, and bends are prefabricated modules that are inserted into the system where required [16].

8.4 Appurtenances

Some appurtenances for piping systems and utilidors must be specially designed or adapted. This applies particularly for above-ground utilidors, where special hydrants, valves, cleanouts and bends may be necessary.

8.4.1 Above-ground hydrants

"In-line" hydrants located directly on a tee in the water main are recommended. They may be installed without additional freeze protection if the barrel is short enough that heat from the water main will prevent the valve from freezing. Leakage through the valve must be prevented since the freezing of water may damage the hydrant and make thawing necessary before use. Building-type fire hydrant outlets and butterfly valves have been used because of their small size and light weight. One design is illustrated in Figure 8-5.

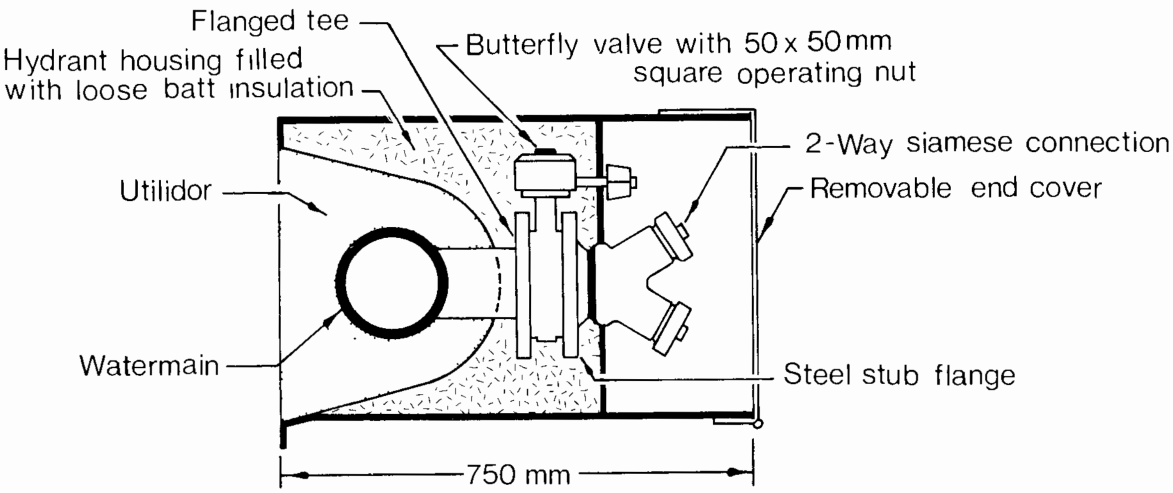


FIGURE 8-5. ABOVE-GROUND UTILIDOR HYDRANT

The hydrant enclosure must be rugged, well insulated, and appropriately marked and painted. Access to the hydrants must be quick and easy but it must also discourage vandalism.

8.4.2 Sewer access

For above-ground sewers, and water and sewer pipes within a utilidor, the sewer access cleanouts must be sealed to prevent cross-contamination. The flanged tees for pipes larger than 200 mm diameter usually provide an adequate opening to insert cleaning or thawing equipment. Standard fittings for smaller pipes do not provide adequate access in both directions. Special fittings with larger slot openings that can be sealed have been used (Figure 8-6). Special venting may be necessary when the building vents are not adequate.

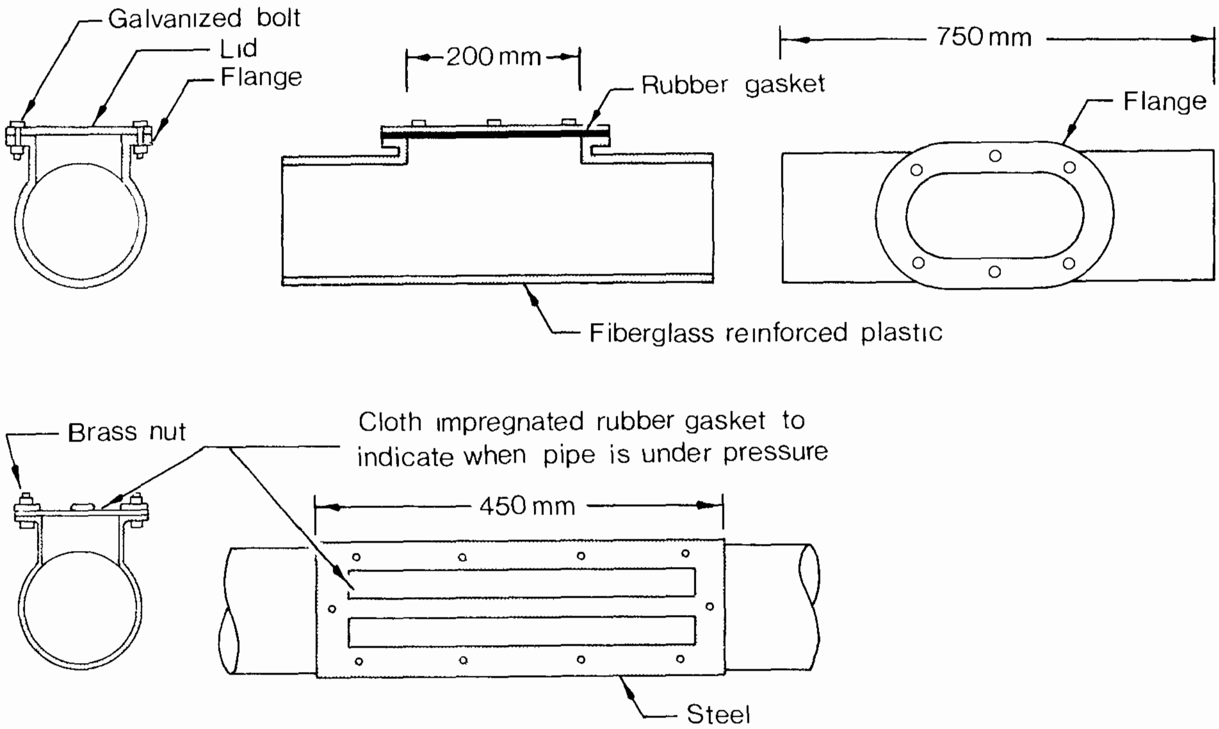


FIGURE 8-6. SEWER CLEANOUTS

8.4.3 Vaults

Vaults are the above-ground enclosures which contain the hydrants, valves, thrust blocks, intersections, bends, and other piping system appurtenances, including recirculation pumps, heaters and controls. Access to these appurtenances is provided through the vaults, which can be only slight enlargements of the utilidor, or small buildings. Usually they are individually designed and fabricated. Thrust blocking and vaults at bends may not be required where small-diameter pipes or rigid pipes are used. The vaults contain the expensive piping system appurtenances which can be a significant portion of the total utilidor cost. Vaulted appurtenances accounted for 30% of the cost for the two-pipe wooden box utilidor shown in Figure 8-1(b).

8.4.4 Utilidor crossings

Pedestrian and vehicle crossings must be provided where above-ground utilidors are used. The cost of these crossings is a function of the utilidor size and its height above the ground. Large or high utilidors require bridge-type structures for road overpasses (Figure 8-3). Costs in 1977 were approximately $35 000 in Inuvik, NWT.

Smaller utilidors can be protected by less expensive corrugated metal pipe culverts (see Figure 7-8).

The utilidor and road layout should minimize the number of crossings that are required. The roadway and drainage system must take into consideration the locations of utilidor overpasses. Steep approaches to the crossing can impair driver visibility. Long approaches can disrupt the surface drainage system, and the overpasses tend to become drainage paths that accumulate garbage.

Utilidors and piping can also be elevated above roadways or buried at road crossings. These alternatives may require expensive lift stations which can impede the complete drainage of the pipes and utilidor. Underpasses can be excavated, however, this is difficult and expensive in areas of ice-rich permafrost. In 1974, the roadway excavation, permafrost protection and utilidor reinforcing for an underpass in Inuvik, NWT, cost $70 000.

Pedestrian crossings can be a part of the roadway crossings but separate wooden stairways may also be required at certain locations.

8.5 Thermal Considerations

The placement of pipes within a utilidor provides possible thermal benefits in that the proximity of water mains to warm sewer pipes, and heating pipes if they are included, reduces the risk of freezing and partially compensates for heat loss. It is important to minimize the surface area of the utilidor to reduce heat loss. The size and shape of a utilidor may, however, be dictated by considerations other than heat loss. Most utilidors are no more thermally efficient than individual pipes with annular insulation, and utilidors containing large air spaces will be less efficient. The effects of utilidor shape and size on heat loss are illustrated in Figure 15-5. Information required to estimate heat loss and freeze-up time for pipes and utilidors is presented in Section 15.

All exposed utilidor surfaces should be insulated. Thermal breaks or penetrations should be isolated from the pipes. Insulated flanges and extra insulation at pipe anchors have been used. Additional insulation should be provided at appurtenances and vaults with larger surface areas than the utilidor.

Freeze-protection provided for utilidor piping can be similar to that for single pipes, and heat tracing can be used to maintain a minimum temperature. Temperature control within the utilidor is difficult when control heating or domestic hot water lines are included.

While soil cover and snow provide some natural insulation for buried utilidors, shallow-buried, and above-ground piping and utilidors are subject to extreme air temperatures. They must be designed for the lowest expected temperatures and wind conditions. The design must take into account:

a) short freeze-up time,
b) high maximum rate of heat loss,
c) high annual heat loss, and
d) expansion and contraction caused by changes in air temperature or because the pipes have been drained.

The most critical expansion and contraction problems occur when the system is started up, or when maintenance or emergencies require that the system be shut down and drained.

Two conditions requiring calculations are the maximum movement due to temperature changes and the maximum stress if movement is restrained. With metal pipe, it is generally impractical to restrain thermal movements. Maximum movement can be provided by the use of compression or sleeve-type couplings, expansion joints, "snaking" the pipe, or providing expansion loops. Most in-line expansion joints do not perform adequately under freezing conditions; however, a free-flexing bellows joint will operate even with residual water frozen inside [16].

8.6 Maintenance

Repairs or replacement of piping and subsequent reclosure of the utilidor must be considered in the cross-section design and materials selection. Extra materials and components used within the system must be available on-site. Standardization of components, materials and design greatly facilitates maintenance.

Below-ground utilidors should be the walkway-type for easy access. Alternatively, no air space should be provided in shallow-buried utilidors where the only access is by excavation. Above-ground utilidors need not have walkways. Access to pipes and appurtenances is facilitated by removable panels.

Vandalism, accidents, and weathering of exposed utilidors will result in extra maintenance and must be considered in the materials selection and design.

Repairs and service connections must be carried out only by authorized personnel. The service conduit design, particularly the connection to the utilidor, may be specified to ensure engineering and aesthetic compatibility.

8.7 Costs

Capital costs, maintenance and heating requirements, and service life are important factors in utilidor design and materials selection [2,11]. Capital costs can be reduced by lowering standards; however, this may be offset by higher operating and replacement costs. Above-ground utilidors must be particularly rugged to contend with the rigorous climatic conditions and vandalism. Numerous "low-cost" utilidors have not survived their intended lifespan.

The capital costs for utilidors depend on the number, size, and function of the enclosed pipes, the degree of prefabrication, the foundation requirements and local conditions. The cost breakdown for a two-pipe, wooden box utilidor on piles in Inuvik, NWT (Figure 8-1(b)) was:

Engineering - design	7%	17%
- field supervision	10%	
Materials (including transportation)		33%
Construction		50%

Material costs for the carrier pipe utilidor in Figure 8-1(f,g) are presented in Table A-3. The cost for the small utilidor in Figure 8-1(d) was approximately \$230/m in 1977. The water and sewer wooden box utilidor on piles constructed in a subdivision of Inuvik, NWT, in 1976, cost \$600/m for straight portions but average costs were \$670/m and

\$805/m when the costs for vaults and road crossings were included. Large utilidors with central heating lines are more expensive. Costs for the utilidor in Figure 8-1(a) were over \$1200/m.

Estimated annual maintenance costs in 1974 for utilidors in Inuvik, NWT, ranged from \$34 to \$91 per service connection.

8.8 References

1. Tobiasson, W., "Utility Tunnel Experience in Cold Regions", American Public Works Association, Special Report No. 41, pp. 125-138, 1971.

2. Gamble, D.J. and P. Lukomskyj, "Utilidors in the Canadian North", Canadian Journal of Civil Engineering, 2(2):162-168, 1975.

3. Rogness, D.R. and W. Ryan, "Vacuum Sewage Collection in the Arctic, Noorvik, Alaska; A Case Study", IN: Utilities Delivery in Arctic Regions, Environmental Protection Service, Ottawa, Ontario EPS 3-WP-77-1, pp. 505-522, 1977.

4. Reid, B., "Some Technical Aspects of the Alaska Village Demonstration Project", IN: Utilities Delivery in Arctic Regions, Environmental Protection Service, Ottawa, Ontario, EPS 3-WP-77-1, pp. 391-438, 1977.

5. Ryan, W., "Design Guidelines for Piping Systems", IN: Utilities Delivery in Arctic Regions, Environmental Protection Service, Ottawa, Ontario, EPS 3-WP-77-1, 1977.

6. Gamble, D.J., "Unlocking the Utilidor: Northern Uilities Design and Cost Analysis," IN: Utilities Delivery in Arctic Regions, Environmental Protection Service, Ottawa, Ontario, EPS 3-WP-77-1, 1977.

7. Fiberlite Products Co. Ltd, "Engineering Guide to Prefabricated Utilidors", Edmonton, Alberta, n.d.

8. Slipchenko, W., (ed), "Handbook of Water Utilities, Sewers, and Heating Networks designed for Settlements in Permafrost Regions", Northern Science Research Group, Department of Indian Affairs and Northern Developement, Ottawa, Ontario, NSRG 70-1, 1970.

9. Leman, L.D., Storbo, A.L., Crum, J.A., and Eddy, G.L., "Underground Utilidors in Nome, Alaska", Applied Techniques for Cold Environments, American Society of Civil Engineers, New York, New York, pp. 501-512, 1978.

10. Hoffman, C.R., "Above-ground Utilidor Piping System for Cold-Weather Regions", Naval Civil Engineering Laboratory, Port Hueneme, California, Technical Report R734, 1971.

11. Leitch, A.F. and G.W. Heinke, "Comparison of Utilidors in Inuvik, NWT", Department of Civil Engineering, University of Toronto, Toronto, Ontario, 1970.

12. Cooper, P.F. "Engineering Notes on Two Utilidors", Northern Science Research Group, Department of Indian Affairs and Northern Development, Ottawa, Ontario, 1968.

13. Porkhaev, G.V., "Underground Utility Lines", National Research Council of Canada, Ottawa, Ontario, Technical Translation TT-1221, 1965.

14. Reed, S.C., "Field Performance of a Subarctic Utilidor", IN: Utilities Delivery in Arctic Regions, Environmental Protection Service, Ottawa, Ontario, EPS 3-WP-77-1, pp. 448-468, 1977.

15. James, F., "Buried Pipe Systems in Canada's Arctic", The Northern Engineer, 8(11):4-12, 1976.

16. Gilpin, R.R. and M.G. Faulkner, "Expansion Joints for Low-Temperature Above-Ground Water Piping Systems", IN: Utilities Delivery in Arctic Regions, Environmental Protection Service, Ottawa, Ontario, EPS 3-WP-77-1, pp. 346-363, 1977.

SECTION 9

WASTEWATER TREATMENT

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9 WASTEWATER TREATMENT

9.1 General Considerations

This section is not a complete design text for wastewater treatment systems. It gives special emphasis to those factors which are unique to the cold regions. Reference is made to other manuals and texts for basic sanitary engineering criteria and procedures. The special factors for cold regions are not just responses to low temperatures but also include: remote locations, logistical problems during construction and operational resupply, permafrost and other unstable site conditions, lack of skilled manpower, very high energy costs, rapid turnover of operator personnel, and in some cases unique environmental aspects.

9.1.1 Treatment objectives

Basic treatment objectives are not unique to the cold regions. The fundamental purpose of wastewater treatment in all locations is protection of human health. The next priority is to protect the receiving environment. The guidelines, criteria and standards set by the applicable regulatory agencies must be considered prior to undertaking any design. Section 10 of this manual discusses impacts on the receiving environment.

9.1.2 Period of design

The design life (Section 2.6.2) for waste treatment systems is a function of the community or facility served. It can also be specified by the regulatory and/or funding agencies. It is essential to determine design life in the initial planning stages since this factor determines the service life and treatment capacity requirements based on present and future population.

9.1.3 Site selection

Most of the basic site selection criteria (i.e., advantageous topography, suitable discharge point, etc.) are applicable to the cold regions. Of special concern is the presence of permafrost under the intended site. The presence of permafrost will strongly influence the type of system chosen, and the economics of design and construction to ensure long-term stability of the system. Another factor requiring more emphasis in cold regions is easy, continuous access to all critical points in the system. Access roads and pathways must not be located where snow drifting or icing will occur. The layout of the treatment system itself must avoid creation of excessive snow drifts. If convenient access cannot be provided, and easily maintained, then winter time maintenance will probably not be performed. Distance requirements to avoid nuisance conditions are generally applicable in both temperate and cold regions. Lagoons should be no closer than 0.4 km (0.25 mi) from any residence. All treatment systems may experience odour problems due to operational difficulties, so any locations in close proximity to habitations should be avoided.

9.2 Wastewater Characteristics

Wastewater characteristics in cold regions can be different from those in temperate regions, both with respect to quantity and quality. In general, the total quantity tends to be close to the amount of potable water used by the community. Storm water is often excluded from the collection systems. Infiltration is also not usually a factor in the Arctic since collection systems are usually insulated and tightly sealed to ensure thermal integrity. Communities such as Anchorage, Ak, and others in the subarctic experience water wasting and infiltration, but design considerations are not different from conventional practice with high flows and low organic loadings. The wastewater at most other cold regions installations tends to be lower in volume and higher in strength than at comparable facilities elsewhere. The wastewater from most cold regions facilities is essentially domestic in character, with the possible addition of laundry wastes and extra amounts of garbage from institutional type kitchens.

9.2.1 Quantity

The requirements for total quantity of water needed are discussed in Section 3 of this manual. The resulting per person sewage flows depend on the type of installation and its permananoe. Table 9-1 summarizes typical sewage flows for a variety of cold regions situations.

TABLE 9-1. TYPICAL PER PERSON SEWAGE FLOW (L/person/d*)

1. Permanent Military Bases and Civilian Communities

a) > 1000 population with conventional piped water and sewage:

Thule Air Force Base, Greenland	303
College, Ak	265
Fairbanks, Ak	303
Ski resorts in Colorado and Montana	345
Average	300 L/person/d

b) < 1000 with conventional piped water and sewage:

Bethel, Ak	265
DEW Line, Greenland	208
Average	240 L/person/d

c) with truck haul systems, conventional internal plumbing:

Average	140 L/person/d

d) with truck haul systems, low flush toilets:

Average	90 L/person/d

e) no household plumbing, water tanks and honeybucket toilet:

Average	1.5 L/person/d

f) same as (e) above but with central bathhouse and laundry:

Average	15 L/person/d

2. Construction Camps

North Slope, Ak (1971)	189
"Typical" Canadian	227
Alaska Pipeline (1976)	258
Average	220 L/person/d

3. Remote Military with Limited Availability of Water

McMurdo, Antarctica	151
Barrow, Ak (DES Sta)	114
"Typical" Army Field Camp	129
Average	130 L/person/d

* 1 L/person/d = 0.264 gallons/capita/day US.

Separate facilities such as schools, laundries, restaurants and hotels with conventional plumbing tend to have loadings similar to conventional temperate zone practice.

Whenever possible, actual data from the specific site of concern, or one similar, should be used to establish a design value for per person flow. Where such data are not available, the average values on Table 9-1 should be used for the appropriate type facility. These values are all for permanent residential personnel. If an accurate population count is not available, it should be assumed for design purposes that there are 3.6 people per residence for military stations, and 4.5 people for remote civilian communities. For day workers whose residences are not serviced by the treatment system an allowance of 57 L/person per eight-hour shift should be made. In such estimating, the same person should only be counted once, either at work or at home.

9.2.2 Quality

The physical, chemical and biological characteristics of sewage in cold regions are strongly dependent on the type of installation and the sanitary facilities provided. As described elsewhere in this manual, these facilities can range from "honey bags" (as described in Section 13) and buckets to complete equipment in the home or centralized for community use. Table 9-2 summarizes the sanitary facilities provided at several cold regions installations of the institutional type.

TABLE 9-2. INSTITUTIONAL SANITARY FACILITIES IN COLD CLIMATES

	(units per person)			
	Toilets	Urinals	Sinks	Showers
Thule AFB, Greenland	1/10	1/27	-	-
P Mountain Radar, Thule, Greenland	1/15	1/45	1/8	1/14
50 Man Winter Camp Tuto, Greenland	1/10	1/25	1/6	1/10
Wainwright, Ak*	1/47	0	1/94	1/47

* See Section 11. This is a central facility for the village. Plans exist to supplement with home water delivery and "honey" bag pickup.

The grey water/black water concept is used at the Wainwright, Ak, central facility and should be considered wherever water conservation is an issue (see Section 11 and Appendix B). Black water is considered to be that related to human wastes from toilets, urinals, etc. Grey water is then the remaining wastewater from showers, sinks, laundries, etc. Table 9-3 summarizes the sources of domestic sewage from communities and military field bases.

TABLE 9-3. DOMESTIC SEWAGE SOURCES (% of average daily flow)

	Category			
Data Source	Toilet, Urinal	Shower, Sinks	Kitchen	Laundry
Bailey [1]	33	33	19	15
Witt [2]	26	29	14	30
Jesperson [3]	41	37	11	11
Given and Chambers [4]*	41	16	16	27
Flack [5]	33	37	4	26
Snoeyink [6]	39	34	7	20
U.S. EPA [7]	43	38	12	7
AVERAGE	37	32	12	19

*Adjusted for conventional toilets. Vacuum units used in study.

	Field Army Bases (1000-6000 pop) (% of average daily flow)
Photographic	5
Aircraft Washrack	9
Vehicle Washrack	3
Hospital	1
Toilets, Shower, Sinks	60
Kitchen	6
Laundry	16
	100%

9.2.2.1 Concentration of pollutants. The concentrations of wastewater constituents will vary with the amount of water used and the type of facilities employed. However, the actual mass loading of organics and related substances should be relatively constant on a per person basis. Table 9-4 gives estimated mass values for the major domestic wastewater sources. The values are based on a comparative analysis of a number of data sources. The final item, "institutional garbage grinders", reflects the common practice at military stations and many construction camps of grinding most of the kitchen wastes for inclusion in the wastewater stream.

TABLE 9-4. ESTIMATED SOURCES OF SEWAGE POLLUTANTS (g/person/d)*

Source	BOD_5	SS	Total N	Total P
Toilets	60.8	85.2	14.7	1.67
Bath/shower	5.33	5.12	0.31	0.04
Laundry	7.92	7.70	0.23	0.67
Kitchen	16.8	10.9	0.49	0.49
Subtotal	90.8	109	15.7	2.83
Institutional Garbage Grinders	59.0	58.8	1.31	0.95
Total	150	165	17.0	3.78

*lb/capita/day = (g/person/d) ÷ 454.

All the values in Table 9-4 are independent of the amount of water used for a particular activity. Combining these values with data in Tables 9-1 and 9-3 or other sources will allow determination of concentrations for a particular case. Two examples follow:

a) 200-man construction camp, all conventional facilities, central dining and kitchen with garbage grinder.

From Table 9-1: Assume flow = 220 L/person/d.

From Table 9-4:

	g/person/d			
	BOD_5	SS	N	P
Totals include toilets, baths, laundry, kitchen, garbage	150	165	17	3.8
x 200 people =	30 000	33 000	3400	755

Total Flow: 220 x 200 = 44 000 L/day.

Concentrations:

BOD_5	30 000 ÷ 44 = 680 mg/L
SS	33 000 ÷ 44 = 750 mg/L
N	3 400 ÷ 44 = 77 mg/L
P	755 ÷ 44 = 17 mg/L

b) Small community, truck haul, internal plumbing low volume flush toilets (assume 100 people).

Table 9-1: flow = 90 L/person/d.

Table 9-4: g/person/d

BOD_5	SS	Total N	Total P
91	109	16	3

Design concentrations:

mg/L = g/person/d ÷ L/person/d x 100 mg/g

BOD_5	1011 mg/L
SS	1211 mg/L
N	177 mg/L
P	33 mg/L

9.2.2.2 Temperature. The temperature of the raw wastewater entering the sewage treatment plant can be an important physical characteristic. The efficiency of most unit operations and processes can be strongly influenced by temperature. Temperature control is also necessary to prevent unwanted freezing either in the system or at the point of final discharge.

The energy level represented by moderate (10°C) to high incoming sewage temperatures should be considered as a resource. The treatment system and its protective elements should be designed to take full advantage of this available energy. For example, the municipal treatment plant in Fairbanks, Ak, extracts energy from the effluent via a heat pump and this is used to heat the entire facility.

The temperature of raw wastewater is a function of the raw water temperature, the water and sewage system design and characteristics, the use, number and plumbing (hot water) of buildings serviced, and the ambient temperatures. Some values for raw wastewater temperature are presented in Table 9-5.

TABLE 9-5. RAW SEWAGE TEMPERATURES AT TREATMENT FACILITY (°C)

<table>
<tr><th>Location</th><th>Winter</th><th>Summer</th><th>Notes</th></tr>
<tr><td>Fairbanks, Ak</td><td>0</td><td>2.8</td><td>Individual wells</td></tr>
<tr><td>Fairbanks, Ak</td><td>11.8</td><td>10.9</td><td>Water main at 15°C</td></tr>
<tr><td>College, Ak</td><td>18.9</td><td>18.3</td><td>Sewers in heated utilidor</td></tr>
<tr><td>Eielson, AFB, Ak</td><td>21.7</td><td>20.7</td><td>Sewers in heated utilidor</td></tr>
<tr><td>Juneau, Ak</td><td>2.2</td><td>8.9</td><td></td></tr>
<tr><td>Kenai, Ak</td><td>8.0</td><td>10-14</td><td></td></tr>
<tr><td>Homer, Ak</td><td>3-5</td><td>9-10</td><td></td></tr>
<tr><td>Dillingham, Ak</td><td colspan="2">3-4</td><td>April</td></tr>
<tr><td>Craig, Ak</td><td colspan="2">5</td><td>January</td></tr>
<tr><td>Kake, Ak</td><td colspan="2">4</td><td>December</td></tr>
<tr><td>Soldofna, Ak</td><td>3</td><td>8-9</td><td></td></tr>
<tr><td>Eagle River, Ak</td><td colspan="2">5</td><td>Initial operation, few services</td></tr>
<tr><td>Eagle River, Ak</td><td colspan="2">9</td><td>After 4 years</td></tr>
<tr><td>Inuvik, NWT</td><td></td><td>23</td><td></td></tr>
<tr><td>Whitehorse, YT</td><td colspan="2">3-15</td><td>Water main bleeders</td></tr>
<tr><td>Clinton Creek, YT</td><td>17</td><td>22</td><td></td></tr>
<tr><td>Emmonak, Ak</td><td colspan="2">28</td><td>Central facility, grey water only</td></tr>
<tr><td>Alaska</td><td colspan="2">20-24</td><td>Construction camps (Alyeska)</td></tr>
<tr><td>Hay River, NWT</td><td colspan="2">10-15</td><td>Airport facility</td></tr>
</table>

9.2.3 Flow variation

Institutional facilities in cold regions, such as military stations and construction camps, tend to have strong flow variations because a large portion of the population responds to the same schedule. The peak flow will usually occur in late afternoon when personnel are using the bath and laundry. Two such peaks will occur at those installations operating on a continuous two-shift, 24-hour cycle. The peak daily flow rate for design purposes should be three times the average daily rate for institutional facilities.

Civilian communities and similar residential areas have less sharply defined flow variations. In general, a single major peak, approximately at mid-day will occur. The time is dependent on transmission distance from the homes to the treatment system. The daily peak flow rate of these communities should be taken as two times the average daily rate. The U.S. Public Health Service uses a factor of 3.5 for designs in small communities (see Section 3.4).

Minimum flow rates are important to the design of grit chambers, monitoring devices, dosing equipment, etc. A minimum rate equal to 40 percent of the average rate should be used for design purposes.

9.3 Unit Operations

Practically all of the unit operations used in wastewater treatment are affected by temperature through viscosity changes in the water and/or changes in chemical reaction rates. An analysis during early design stages is necessary to predict the thermal status of major components in the system. If warm sewage is expected and the entire system is to be housed in a heated building, then conventional temperate zone practice can be used. If cold sewage is expected or significant temperature changes are predicted within the system, then adjustments will be necessary in the design of unit operations as described in subsequent sections.

9.3.1 Mixing

Mixing is an important function in waste treatment. It is required for flocculation, for the continual suspension of solids in liquids such as the mixed liquor in activated sludge, and for dissolving solids. All of these mixing activities are strongly dependent on temperature because of changes in the viscosity of the liquid. Figure 9-1 can be used to make the necessary adjustments in design criteria for temperature-induced viscosity changes. Further information on mixing can also be found in Section 4 since the general requirements are the same for water and wastewater.

9.3.2 Sedimentation

The settling of discrete particles in water is affected by the viscosity of the water. This is a factor in grit chambers and in primary settling tanks when flocculant chemicals are not used. Detention times must be increased to compensate for lower settling velocities in colder water. The multipliers on Figure 9-1 can be used to adjust design detention times. The temperatures shown are for the fluid and not the general air temperature. Alternatives to adjusting design detention times include housing the tanks in a heated enclosure and/or preheating the incoming fluid.

The settling of higher concentration flocculant particles is not as strongly affected by temperature. As shown on Figure 9-2, at concentrations of 2000 mg/L or less, temperature-induced viscosity effects are quite strong. At 6000 mg/L and higher, the concentration of particles present has a greater influence than fluid temperature. The multipliers shown on Figure 9-2 can be used for the design of settling tanks and thickeners. Values for sludge concentrations not shown can be determined by interpolation. Figure 9-2 demonstrates that settling units, such as upflow clarifiers, tube settlers, etc, which are designed for relatively high sludge concentrations, will require the least size adjustment for low-temperature operation.

Density currents must also be considered in the design of settling tanks and thickeners. If the incoming fluid is significantly different in temperature than tank contents, short circuting and/or excess solids loss may occur. Protective elements should be employed if necessary to maintain the temperature of tank contents as close as possible to that of the incoming fluid.

9.3.3 Filtration

Filtration of wastewater is affected by temperature-induced viscosity changes. The multiplier values from Figure 9-1 should be used to reduce filtration efficiency. Further details on filtration can be found in Section 4 since basic criteria are common for both water and wastewater.

9.3.4 Gas transfer

The solubility of gases in water increases as the temperature decreases. Air, oxygen, and chlorine are the commonly used gases in wastewater treatment. The efficiency of aeration and other gas transfer

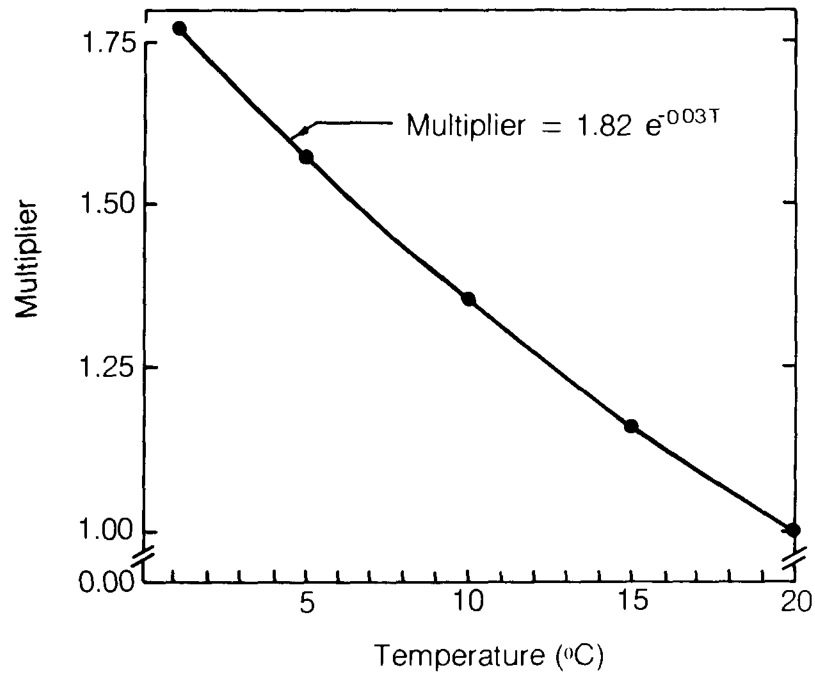


FIGURE 9-1. VISCOSITY EFFECTS VS TEMPERATURE

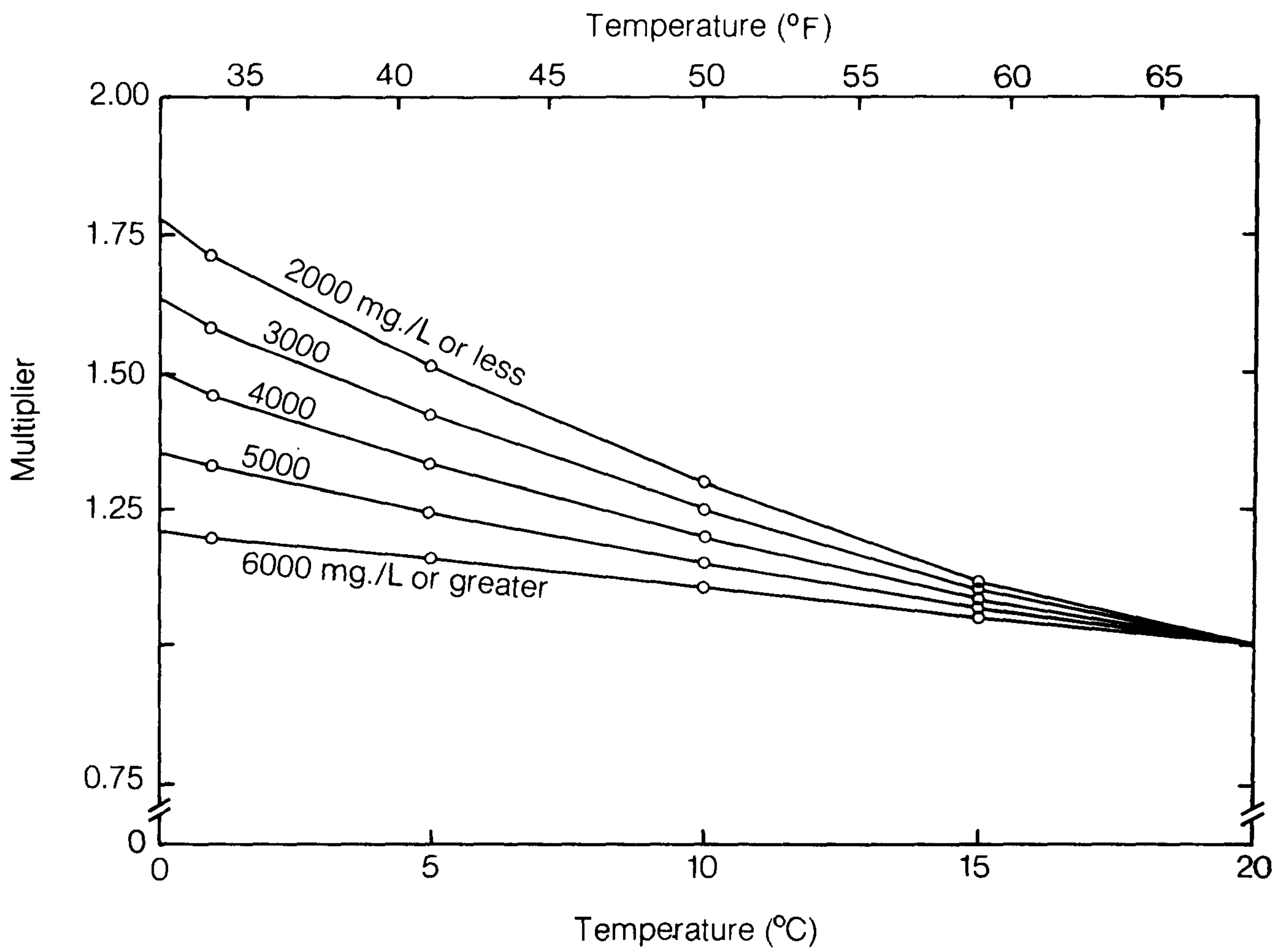


FIGURE 9-2. SETTLING DETENTION TIME VERSUS TEMPERATURE

operations should, in theory, be greater with low temperature wastewaters. However, the viscosity of the water also increases as the temperature decreases. This decreases the number of contacts between gas bubbles and water molecules. These two factors tend to compensate for one another, so the net practical effect is little improvement in overall gas transfer efficiency with low temperature wastewaters. Section 4.2.9 provides additional detail on aeration.

9.3.5 Adsorption and chemical reactions

Adsorption occurs in biological processes as well as in physical/chemical treatments with activated carbon. The rate of adsorption, as defined by the Gibbs equation, is inversely proportional to temperature, so adsorption should be more rapid at low temperatures. However, the increased viscosity of the water at low temperatures has the same effects as described above so there is no practical improvement in efficiency.

Both metabolic and chemical reaction rates tend to be slower at low temperatures. These effects must also be considered in preparing chemical solutions for use in wastewater treatment. The solubility of most chemicals decreases as the water temperature is lowered. Table 9-6 gives some representative values for typical treatment chemicals.

9.4 Unit Processes

Processes for preliminary, primary, secondary and advanced waste treatment are based on the unit operations or combinations thereof previously discussed. This section will only consider those factors of special significance in cold climates.

TABLE 9-6. VARIATION IN SOLUBILITY OF TYPICAL CHEMICALS WITH TEMPERATURE (grams/litre)*

Chemical	Temperature $0^{o}C$	Temperature $20^{o}C$
Alum	723	873
Ferrous sulphate	60	120
Sodium hydroxide	287	527
Calcium hypochlorite	215	228

* grams/litre x 0.00834 = lb/gal

9.4.1 Preliminary treatment

This can include screening, grit and scum removal and grinding or comminution. The latter can be a component, such as grinder pumps, in pressure sewage transmission systems discussed in Section 7. The use and proper maintenance of grease traps at appropriate locations, e.g., institutional kitchens, is absolutely essential for the successful operation of treatment processes as well as collection systems in cold regions.

9.4.1.1. Screening. The basic design for trash racks and bar screens is not different in cold climates. Since storm waters are usually excluded from cold regions sewer systems the channel design for screens or racks can be based on wastewater flow rather than storm water flow. In the arctic and subarctic it will be necessary to enclose the facility in a shelter to avoid icing problems and provide easy access for operation and maintenance. If warm sewage is expected it may not be necessary to provide supplemental heat for an insulated enclosure. Condensation and icing may occur on the inner surfaces of exterior walls so materials and coatings should be selected accordingly and mechanical or electrical controls located elsewhere.

9.4.1.2 Grit and scum. Designs for grit chambers, flotation chambers, and grease traps are also similar to temperate zone practice. Detention times should be increased for low temperature sewage as described in paragraph 9.3.2. Protective enclosures will be similar to those described above under 9.4.1.1. Problems with grease traps are not unique to institutional facilities in cold climates, but special attention should be given to their location and proper maintenance.

9.4.2 Primary treatment

The design detention time for settling during primary treatment will require adjustment as described in paragraph 9.3.2. If soil conditions permit, settling tanks should be designed in the conventional manner as partially buried structures. The presence of permafrost, particularly as ice-rich, fine-textured soils, will require above-ground tanks and/or special foundations. Temporary covers are recommended for buried tanks for winter operation in the Arctic and subarctic. Tanks above grade will require sidewall insulation and covers, or enclosure in a protective structure.

9.4.3 Biological processes

Systems which have been successfully used in cold climates include: lagoons, both facultative and aerated, activated sludge variations, and attached growth systems. Each has special requirements for successful cold region performance.

9.4.3.1 Facultative lagoons. Where sufficient land area and suitable soil conditions exist, facultative lagoons are probably the most cost-effective alternative for cold regions. The major responsible factors are simplicity, and economy of construction and operation.

Facultative lagoons should be designed for a BOD loading of up to 3.7 kg/ha. Winter performance in cold climates is reduced because of ice and snow cover and low temperatures and is roughly comparable to primary treatment. Total retention during this period is often required. Controlled discharge from such ponds in the late spring and early fall is a common practice in Canada and the north central U.S. Two or three cells are commonly used to avoid short circuiting. Figure 9-3 illustrates a typical two-cell arrangement. Figure 9-4 illustrates the use of a stop-log manhole for depth control.

The amount of ice cover to be expected on a facultative lagoon can be predicted by the method described in Section 5. If sufficient data are not available for such calculations a depth of 1 m should be assumed for most subarctic locations. The design depth should be based on winter conditions and allow 30 cm of freeboard, plus the ice thickness, plus 1.5 m from the underside of the ice to the lagoon bottom. Maximum depth during the summer period would be 1.5 m as maintained by the stop-log manhole.

Supplemental aeration may be needed for such lagoons in very special cases. Examples might be where fish canning, animal slaughter or other food processing imposes a brief but intense loading on the lagoon during the summer months. In these cases small floating aerators or similar devices can be used during the period of concern and removed for the balance of the year.

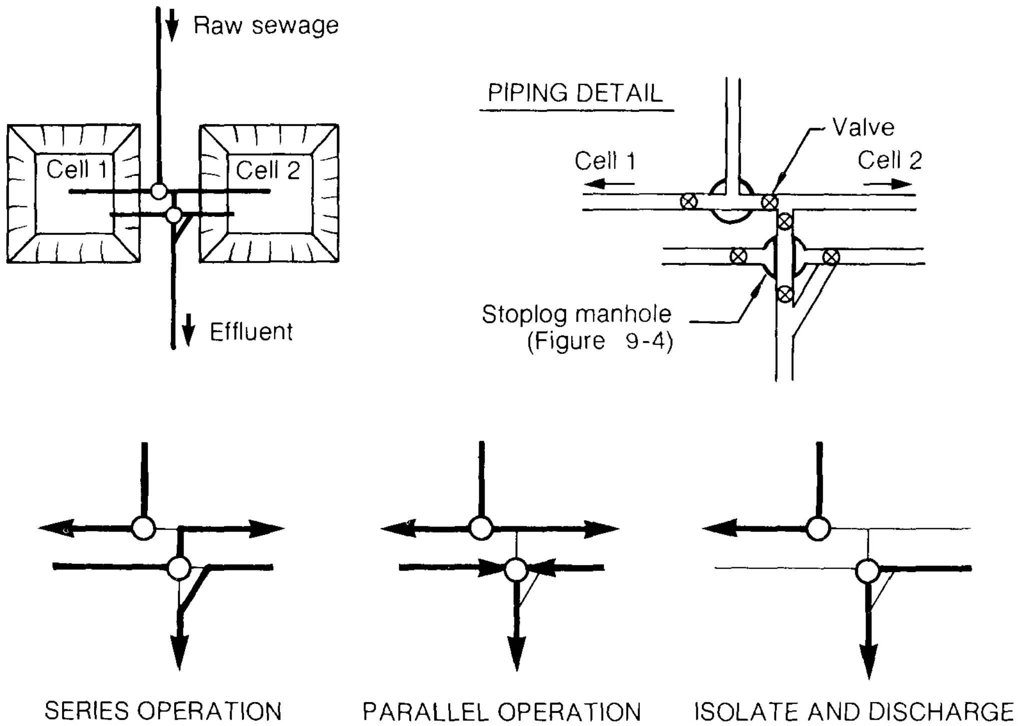


FIGURE 9-3. TWO-CELL FACULTATIVE LAGOON FLOW CONTROL

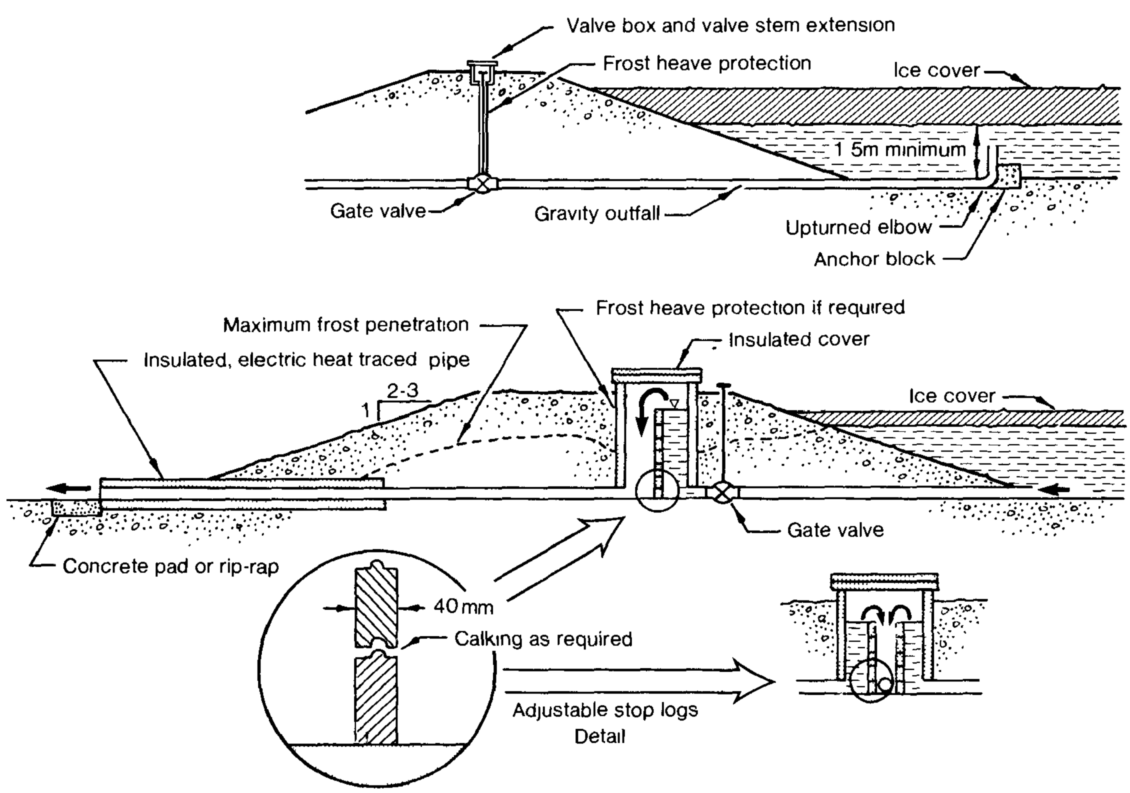


FIGURE 9-4. STOP-LOG MANHOLE

Standard temperate zone construction techniques can be used except where permafrost is present. Permafrost consisting of fine-textured, ice-rich soils should be avoided because thawing can result in failure or at least frequent repair and restoration of dikes and berms.

Lagoons can be constructed in permafrost that is physically stable after thawing. In this case a two-stage operation has advantages if time permits. The first stage is limited to stripping the vegetation and topsoil from the lagoon area. Actual construction can begin when thawing has progressed to a suitable depth. Construction techniques for dikes and berms, and the use of lining materials, are the same as described in Section 5 for water storage.

The shape of the lagoon can affect performance by influencing short circuiting and mixing. In general, square or rectangular cells where the length is not more than three times the width are preferred. The corners should be rounded in both cases. On occasion it is possible to take advantage of existing topography and use a natural depression or swale with minimum construction; even the use of an existing pond might be considered.

9.4.3.2 Aerated lagoons. These systems require less land area, more energy and more operational and management attention than facultative lagoons. Systems in use in cold climates range from low-intensity systems where algae may still be a factor to high-rate well-mixed units which are really a variation of activated sludge. Only the partial-mix, low-intensity systems will be considered in detail in this section because of their lower energy and O&M requirements.

Basic process design criteria are similar to those used in temperate zones. Design is based on:

$$\frac{S_e}{S_o} = \frac{1}{1 + Kt} \tag{9-1}$$

where: S_e = effluent BOD (mg/L),

S_o = influent BOD (mg/L),

t = detention time (days) = $\frac{V}{Q}$,

V = volume of basin,

Q = daily flow,

K = overall reaction coefficient (base e).

winter (0.5°C) = 0.14

summer (16-20°C) = 0.28

For basins in series, the equation becomes:

$$\frac{S_e}{S_o} = \frac{1}{(1 + \frac{Kt}{N})^N} \qquad (9\text{-}2)$$

where: N = number of basins.

This can be transposed to:

$$Kt = N\left[\left(\frac{S_o}{S_e}\right)^{\frac{1}{N}} - 1\right] \qquad (9\text{-}3)$$

Using the specified K values, the BOD values required for a particular design, and a range of N values (1-4), equation (9-3) can be repetitively solved to determine the optimum number of basins. In general, winter conditions govern the number and size of basins, and summer conditions are critical to adequate oxygen transfer.

The effective treatment volume must reflect ice cover in the winter and sludge accumulation on a year-round basis. Ice will not form continuously over the entire surface. Even in extreme weather there will be small areas of open water where air will bubble to the surface from the submerged aeration system. Aerated lagoons in central Alaska (freezing index >2800°C-days) have been designed for a 30-cm winter ice cover. A single-cell lagoon near Anchorage, Ak, (freezing index 1250°C-days) receiving warm sewage has a 5-cm observed winter ice cover. If specific values are not available, an assumed factor of 15% for depth of ice cover is recommended. A factor of 5% is commonly used to allow for sludge accumulation on the bottom. The lagoon volume required for winter treatment must be in addition to both of these factors.

A design for minimal heat loss would include vertical sidewalls but this increases construction costs. Sloping sidewalls (1:2 or 1:3) are most common. A square configuration with rounded corners is recommended to minimize heat loss and hydraulic short circuiting. The dimensions of such a basin can be determined as shown on Figure 9-5.

Some form of submerged aeration is generally used; floating aerators and other surface devices create icing problems. Inlet and outlet structures are similar to those described previously for facultative lagoons. The oxygen requirements for aeration design are based on summer conditions when biological activity is at maximum rate. For partial-mix lagoons the oxygen required is usually specified as double the organic loading:

$$O_2 = (2)\ (BOD)\ (Q)\ (10^{-6})$$

where: O_2 = kg/day oxygen required,
BOD = influent BOD_5 (mg/L),
Q = flow (L/d).

Under standard conditions, air contains approximately 0.28 kg/m^3 oxygen.

$$\text{Air Required } (m^3/s) = \frac{(2)\ (BOD)\ (Q)\ (10^{-6})}{(E)\ (0.28\ kg/m^3)(86\ 400\ s/d)}$$

$$= \frac{8.27 \times 10^{-11}\ (BOD)\ Q}{E}$$

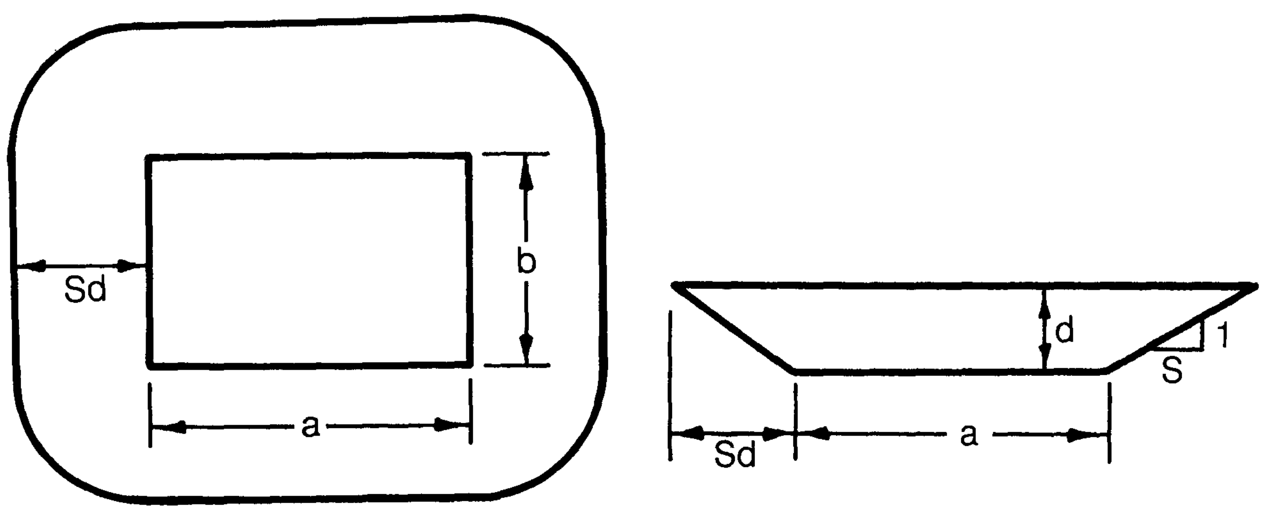
where: E = aeration efficiency,
$m^3/s \times 35.31$ = cfs.

The aeration efficiency depends on a number of factors such as depth of basin, type of diffuser, mixing turbulence and basin configuration. The E value for partial-mix lagoons with submerged tubing is approximately 16%. For a typical case with a raw sewage BOD of 240 mg/L and a flow of 10^5 litres per day, the air requirements would be:

$$\text{Air Required} = \frac{(8.27 \times 10^{-11})(240\ mg/L)(10^5\ L/d)}{(0.16)}$$

$$= 0.012\ m^3/s.$$

Calculation of basin volume for any rectangular basin with sloped sides and round corners



$$\text{Volume} = V = d\,[(a+Sd)\,(b+Sd) + .0472\,S^2\,d^2]$$

Note: The last term ($.0472\,S^2\,d^2$) can be dropped for preliminary estimates

FIGURE 9-5. DIMENSIONS OF LAGOONS

Figure 9-6 illustrates the air and power requirements for a 3-m deep partial-mix aerated lagoon.

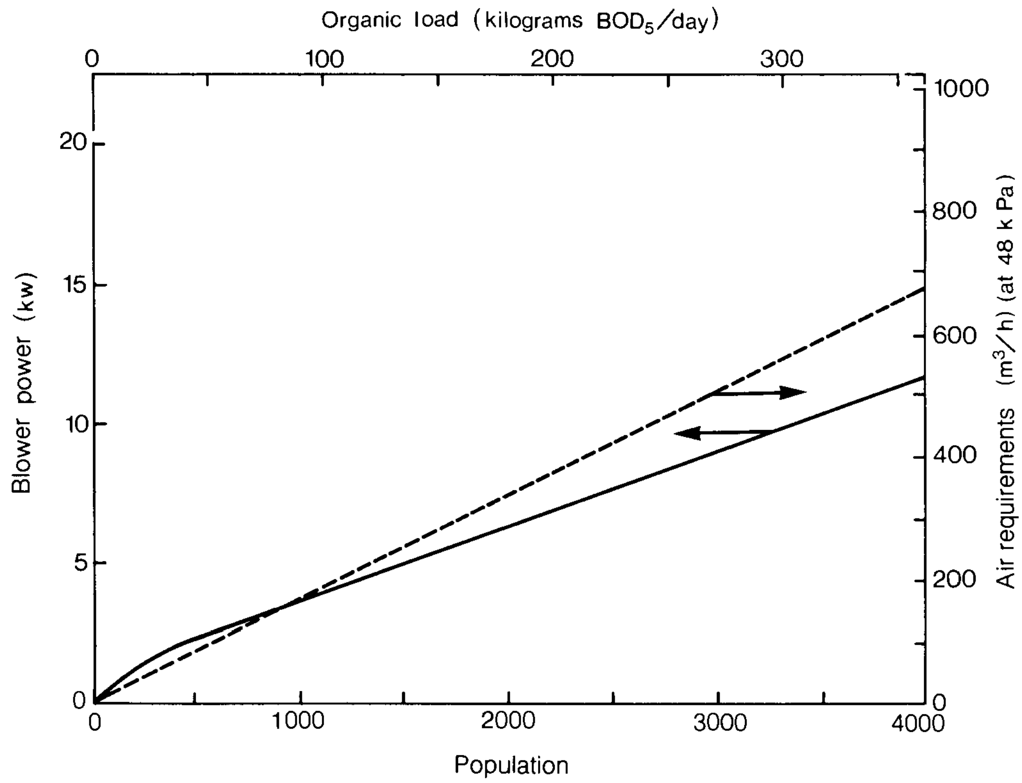


FIGURE 9-6. POWER AND AIR REQUIREMENTS FOR 3-m DEEP PARTIAL-MIX AERATED LAGOON

Table 9-7 summarizes the characteristics of typical aeration equipment for cold climate partial-mix lagoons. An ice cover will form over such lagoons in the winter. However, even under extreme temperature conditions there is sufficient open water for the applied air to exhaust to the atmosphere. Protective and heated housing will be required for blowers, pumps, and related controls. Such enclosures must provide an external air intake for the blowers but preheating of the air is unnecessary.

TABLE 9-7. CHARACTERISTICS OF TYPICAL AERATION EQUIPMENT

Equipment	O_2* (kg, Standard Conditions)	Common Depth** (m)
Submerged Tubing	0.3-1.0/100 m	1-3
Air Gun	0.4-0.7/unit	3.5-6
Helical Diffuser	0.5-1.9/unit	2.5-4.5

Summertime algae blooms will occur in these partial-mix ponds throughout the Arctic and subarctic. The requirements of federal and/or local regulatory agencies with respect to removal of algae must be determined prior to design for a specific site. Techniques for algae removal are available, and the criteria are not unique to cold regions. Addition of algae-removal equipment to an aerated lagoon will increase costs and complexity, and possible reslt in the selection of some other basic process for treatment. Typical cost relationships for lagoons in Alaska are given in Section 9.7.

9.4.3.3 Activated sludge variations. Systems in use in cold regions include conventional and oxygen activated sludge, contact stabilization, extended aeration and oxidation ditches.

Many of these systems are enclosed in heated structures and receive warm sewage on a year-round basis. Basic process design criteia for these situations are no different than conventional temperate zone practice.

Speecial attention must be given to system details, appurtenances and process controls. The humidity inside such buildings will be quite high due to exposed water surfaces. Condensation and icing can occur on inner surfaces of exterior walls, doors, and windows. Control panels and similar elements should be located away from such surfaces to avoid water and/or ice damage.

Ventilation of such structures is necessary, but the impact of the exhause on the adjacent community must be considered. Ice fog can be created under extreme conditions, resulting in aesthetic and safety problems. Dehumidification or heat recovery with induced condensation will control the problem.

Systems that are exposed to the weather and/or expect to receive low-temperature wastes may require modification of basic design criteria in addition to the general factors discussed above.

Conventional or oxygen activated sludge and contact stabiliation . These types of systems will probably be enclosed, but in either case they may receive low-temperature wastewaters. Reaction rate coefficients are presented in Table 9-8 for use in the equation:

$$K_T = K_{20}\ \Theta^{(T-20)}$$

TABLE 9-8. TEMPERATURE COEFFICIENTS FOR BIOLOGICAL TREATMENT

Process	θ	Temperature Range °C
Oxidation Pond	1.072 - 1.085	3-35
Facultative Lagoon	1.06 - 1.18	4-30
Anaerobic Lagoon	1.08 - 1.10	5-30
Aerated Lagoon	1.026 - 1.058	2-30
Activated Sludge	1.00 - 1.041	4-45
Extended Aeration	1.037	10-30
Trickling Filter (conventional)	1.035	10-35
Biofilter (plastic media)	1.018	___
Rotating disc		
Direct filter recirculation	1.009	10-30
Final effluent recirculation	1.009	13+
Final effluent recirculation	1.032	5-13

Significant ice formation must be avoided in the aeration compartments of these systems. An ice cover will inhibit atmospheric aeration and will entrap mixed liquor solids. Both factors may reduce treatment efficiency. Tank design should provide minimum exposed surface area. Evaporation from liquid surfaces and the cooling effect of the wind are major factors in winter time heat loss. An unheated protective shelter over the tanks will reduce both and allow satisfactory performance. An alternative would be temporary tank covers and wind breaks during the winter period only.

Settling tanks and clarifiers associated with these systems should receive protection to reduce heat loss and inhibit formation of density currents. Protective elements in the northern temperate zone can be limited to those required for operator safety (prevent icing on walls, ladders, etc.), and to overflow weirs and scum removal points where freezing is most likely to occur.

Extended aeration systems are available as prefabricated "packaged" units of up to 3800 m^3/d capacity. Smaller sizes are also available completely installed in a prefabricated shelter ready for direct installation. Basic process design criteria are comparable to temperate zone practice if warm sewage is to be received at an enclosed and heated treatment unit.

It is not necessary to provide a continuously heated building to maintain treatment efficiency; operator convenience and comfort are the only justifications for such energy inputs. If the incoming raw sewage is about 10°C or warmer there is sufficient heat in the liquid to sustain the process. Protective elements (i.e., tank covers, burial, wind breaks, unheated shelters) are useful to reduce heat losses. A stand-by heat source is also recommended for emergency situations.

Extended aeration systems have been successfully operated with mixed liquid temperatures of 1° to 5°C, producing effluent BOD_5 and SS of secondary quality. Mixed liquor concentrations tend to increase more rapidly under these conditions so more frequent sludge wasting is required. Design organic loadings (F/M ratio) of up to 0.08 g BOD/g MLSS/day and MLSS concentrations of 3000-4000 mg/L are recommended for low-temperature operation. Pumps, motors, blowers, external piping, valves and similar appurtenances require protective enclosures and heat.

Design of these units for military and construction camps must consider the potential for intermittent loading and strong fluctuations in population. Equalization tanks can damp out strong daily variations in flow. Where regular population changes are expected the design can provide two or more smaller units for parallel operation under peak conditions. Only one unit would be operated under low flow conditions.

These small-scale systems are particularly sensitive to situations created by water system bleeding and/or infiltration in the community. Either can hydraulically overload the system. The potential for these conditions must be evaluated prior to design. It must also be verified that the capability will exist to operate the type of system proposed.

Oxidation ditches have been successfully used in subarctic Alaska. Basic process design criteria are similar to practice elsewhere. Design for low-temperature operation should conform to extended aeration criteria given above.

Modifications to temperate zone configurations are required to reduce heat loss. As shown on Figure 9-7, vertical side walls and a thin

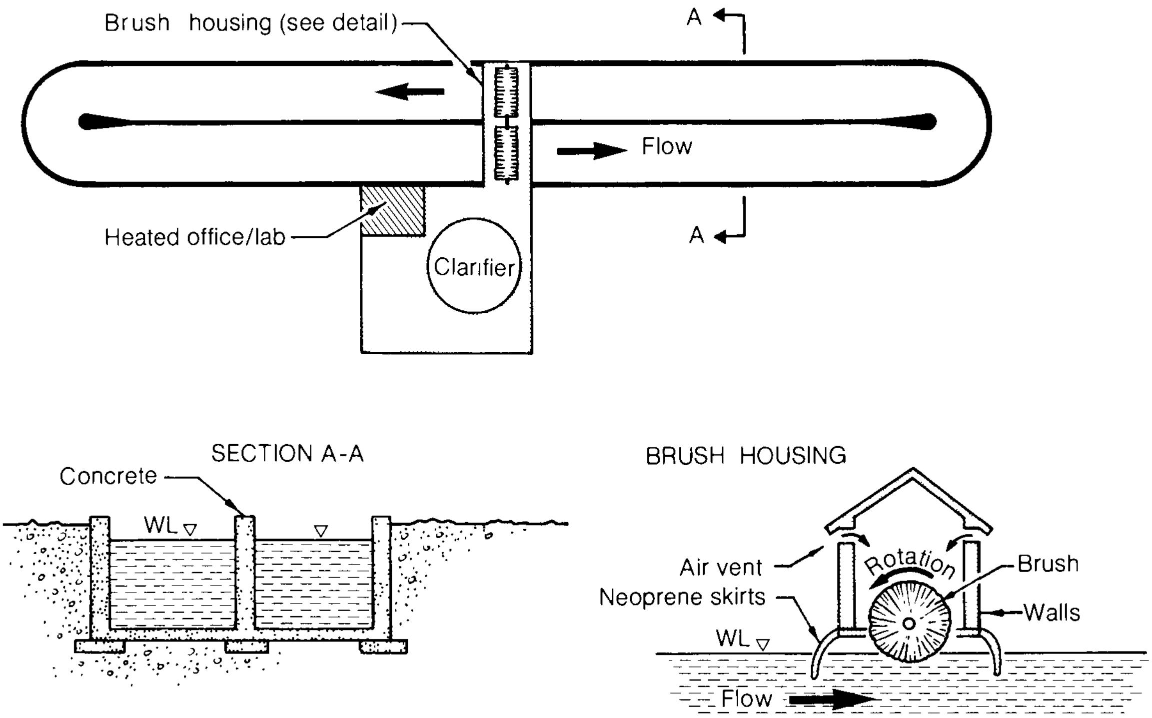


FIGURE 9-7. OXIDATION DITCH FOR SUBARCTIC

vertical centre island reduce surface area and heat loss in the ditch. Also shown on the same figure are the protective housing neoprene skirts to prevent icing around the brushes. The clarifier units for such systems should be enclosed but need not be heated. Cautions regarding location of controls, etc., on exterior walls should be observed.

These systems are potentially applicable over the same range previously indicated for extended aeration. They can be constructed on-site and attempts at prefabrication have been made in the past in the smaller sizes. All the cautions and limitations previously indicated for extended aeration apply.

9.4.3.4 Attached growth systems. These would include rotating biological discs, trickling filters, and similar devices with plastic, rock, or wooden media. Since they depend on a thin film of water for treatment they are susceptible to freezing. Units are, therefore, generally enclosed in a heated structure. However, if low-temperature wastewater is expected, the reaction rate coefficient from Table 9-8 should be used for design. Clarifier tanks need not be heated but should be protected as described in pervious paragraphs of this section.

Configuration of these systems follows temperate zone practice, with some form of preliminary clarification and final settling with recirculation common. Basic process design criteria are not unique for cold climates. Adjustments to the design rates for low-temperature wastewater should be made using the θ values in Table 9-8.

Limited experience with disc systems to date tends to indicate a greater level of system reliability with a lesser level of energy and operator skill compared to complete-mix biological or physical/chemical treatments. They can also be designed to provide nitrification in addition to BOD and suspended solids removal.

9.4.3.5 Physical/chemical processes. The biological systems described in previous paragraphs are capable of secondary treatment at best. Physical/chemical systems, depending on the units in the process, can be designed to produce almost any level of effluent quality desired. In most applications they are used to achieve a high level of organic and solids removal and/or nutrient removal. As in temperate zone practice, they can either follow preliminary biological treatment or the entire process train can be physical/chemical. It is conventional practice, in all climatic zones, to install such units in heated buildings. Basic process design is not, therefore, unique to cold regions, except when low-temperature sewage is expected. Adjustments can then be made as described in Section 9.3. An alternative is to warm the raw sewage in an equalization tank in a heated structure. This will stabilize and enhance performance of the system.

These units were selected for most of the camps during construction of the Alaska pipeline. Advantages claimed included: minimum space requirements; minimum site impact during construction and restoration; consistant high quality performance; and, operation could be matched to varying flow or organic loading. Disadvantages observed during operation included very high costs due to intense labour requirements, chemicals and energy.

Estimated chemical costs for a typical 95 m^3/d system ranged from $0.32 to $2.33 per 1000 L. A comparison of annual costs, manpower and energy is given on Table 9-9. The two systems compared are capable of producing generally equivalent effluents since the physical/chemical units were only designed for organic (i.e., BOD) and suspended solids removal, not nutrients.

TABLE 9-9. COST COMPARISON - CONSTRUCTION CAMP WASTEWATER TREATMENT SYSTEMS* (1976 $)

Process	Amortized Annual Costs Equipment and Mtl. ($1000)	Manpower (MH/day)	Energy (kW/day)
Extended Aeration[1]			
Capital Equipment	30.6	5-10	180
Parts and Chemicals	11.4-14.8		
Physical Chemical[2]			
Capital Equipment	31.3	24	400
Parts and Chemical	19.4-71.9		

* 95 m^3/d for Alaska pipeline construction camps

[1] with: 6-hr equalization, pumps, blowers, aerobic digestor, chlorination. 5-year life @ 15%.

[2] with: 12-hr equalization, pumps, blowers, centrifuge, chemical feed, chlorination. 5-year life @ 15%.

Based on experience to date, physical/chemical treatment should only be considered if very high effluent requirements exist in conjunction with site conditions that preclude other forms or combinations of treatment.

9.4.3.6 Land treatment processes. These concepts are capable of very high levels of treatment depending on the process and operational mode. In addition to normal organics and suspended solids, removal of nutrients, metals, bacteria and virus are possible.

Basic process design criteria are similar to those used in temperate regions since these already include factors for general weather conditions and low-temperature periods. The land treatment component is usually preceeded by some other form of treatment, typically a lagoon. Depending on the concept, additional storage may be required for inclement weather or other seasonal constraints. Treatment and storage functions can be combined in a multi-cell facultative lagoon.

The practical range of land treatment options is limited in permafrost regions. Shallow permafrost and extreme winter temperatures limit the horizontal and vertical movement of water in the soil profile. During the summer it would be possible to operate an overland flow process under the conditions described. Basic process criteria would be similar to temperate zone practice. During the operational period high removal efficiencies for BOD, SS, nitrogen and metals are possible with moderate removal of phosphorus expected. However, an alternate discharge or storage would be necessary for most of the year.

Slow rate land treatment is feasible anywhere in the cold regions where silviculture or agriculture is practiced. The wastewater is sprinkled or spread on the ground surface and the vegetation is a component in the treatment process. The percolate can be recovered for reuse or allowed to move into the groundwater. The operational season is limited to the period of unfrozen surface soil conditions. Peak performance is attained during the growth period of the vegetation. Percolate of drinking water quality can be achieved in a properly designed and operated system. Alternative discharge or storage would be required during the period when surface soils are frozen.

Rapid infiltration has the greatest promise for cold climates. It depends on relatively high rate applications on relatively coarse-textured, free-draining soils. These can be found throughout cold regions in alluvial river valleys and coastal areas. Very high BOD, SS, bacteria, virus and phosphorus removal can be achieved, and moderate nitrogen removal depending on the mode of operation. Rapid infiltration can also be operated on a year-round basis in some locations so extensive storage is not needed. Treatment to primary effluent quality is needed to avoid rapid clogging of the soil surface. A facultative lagoon would more than suffice. Operation is similar to percolation ponds except that a number of beds, or cells, are alternately flooded and dried to improve treatment and prevent clogging.

A thorough site investigation is required to ensure that the applied wastewater will enter the soil and move down and away from the application site. Experience is limited in the arctic and subarctic and optimum criteria are not available. Pilot tests are recommended for large-scale operations. Experience in northern New England suggests a value of approximately 111 000 m^3 per year as a conservative estimate of annual application. That would require one hectare of basin surface for every 750 m^3/d of wastewater flow.

9.4.3.7 Disinfection. The need for and the degree of wastewater disinfection to be achieved, and often the agent to be used, are specified by the regulatory agencies of concern. Typical coliform contents of cold regions wastewaters are shown in Table 9-10. Chlorination is the most commonly used technique in the cold regions but lime has also been tested. Basic process criteria are similar to temperate zone practice with respect to contact time and properly baffled chambers to prevent short circuiting. The selection of either gas or hypochlorite as the chlorine source and the related safety measures also follow standard practice as modifed by logistical resupply problems for many cold regions locations.

TABLE 9-10. TYPICAL COLIFORM CONTENTS IN COLD REGIONS WASTEWATERS*

Waste Type	Typical Location	L/person/d	Total Coliforms number/100 ml
Weak Sewage	Dawson	5915	1.0×10^5
Holding Tank Effluent	Aklavik	68	1.0×10^7
Honey Bags	Aklavik	1.3	5×10^8
Lagoon Effluent	Inuvik	545	1.0×10^5

* Source: International Environmental Consultants, Report on Alternatives to Disinfection (1978).

Erosion type chlorinators have been used at small remote facilities in Alaska. It is sometimes difficult to maintain a specified dosage but they offer operational simplicity. They should be housed in a separate compartment constructed of noncorroding materials, along with the tablet supply in a sealed container. In the past, extreme corrosion of metals and mechanical parts has occurred when exposed to the humid atmosphere of an enclosed treatment plant building.

Effluents from lagoons and other exposed treatment units will be at or near $0^{o}C$ under extreme winter conditions. Some thermal protection for the contact chamber is therefore essential.

9.4.3.8 Sludge. Only in-plant sludge management is discussed in this paragraph. Final sludge disposal is described in Section 13.

Large-scale conventional facilities, and those operating within a heated environment can be expected to produced sludge at rates similar to conventional temperate zone practice. Typical values are summarized in Table 9-11.

Aerobic treatment systems designed for low-temperature operation will tend to generate sludge at a rate similar to moderate temperature units but, because of lower metabolic activity, cannot oxidize it as fast. There will, therefore, be a higher rate of accumulation in the winter than experienced in conventional practice. As a result, winter

TABLE 9-11. TYPICAL SLUDGE PRODUCTION RATES*

Process	Dry Solids g/person/day	Solids Content of Wet Sludge %
Primary Settling	54	6
Trickling Filter Secondary	18	4
Primary plus T.F. Secondary	72	5
Primary plus high-rate Activated Sludge	82	5
Conventional Activated Sludge Secondary	32	0.5-1
Primary plus conventional A.S. Secondary	86	2-3
Extended Aeration Secondary	40	2
Lagoons	60	20**

* Average 24-hr values, from temperate climate experience.

** High value due to long-term consolidation of sludge on lagoon bottom. Data from partial-mix aerated lagoons in Alaska.

sludge wasting from exposed extended aeration plants will be required about twice as frequently as in more temperate climates.

Temperature inhibitions on digestion increase the rate of sludge accumulation in all types of lagoons. Values of 0.25 to 0.40 m^3/1000 people/d have been reported for sludge accumulation in cold climate facultative lagoons. Sludge will also accumulate at a faster rate in aerated lagoons and available data indicates that the assumption of 5% of total lagoon volume for sludge (9.4.3.2) is conservative, so that cleaning and sludge removal might be required on a 10-15 year cycle.

The accumulation of undigested winter sludge imposes a high oxygen demand on a lagoon when liquid temperatures warm up in the spring. Supplemental surface aeration may be helpful for odour control during this period.

Procedures for sludge digestion follow temperate zone practice. It is necessary to provide additional heat and/or insulation to maintain anaerobic digestion in cold climates. Burial of digestor tanks is common in the subarctic to provide natural insulation. Aerobic digestion is less temperature-sensitive but produces a less stable product.

Dewatering of sludge prior to disposal also follows conventional temperate zone practice. One exception is the use of natural freeze-thaw cycles for dewatering. If sludge is flooded on exposed beds and allowed to freeze, the solid particles will settle readily upon thawing. Approximately 50% of the total volume can be decanted from the beds as supernatant and returned to the treatment plant. The thickened sludge can either be left on the beds for complete drying or disposed of directly.

9.5 On-Site Treatment

These systems might directly serve a single dwelling or a cluster of dwellings. Any system that does not depend on centralized collection and treatment for an entire community falls in this category. Discharging systems such as septic tank/soil adsorption combinations, or low to no discharge units represented by a variety of toilet units and recycle systems, are included.

9.5.1 Systems with discharge

Septic tanks and similar units fall in this category. Basic process design criteria are similar to those used in temperate zones. Section 10 discusses special aspects of cold climate septic systems.

Small-scale aerobic units, usually based on the extended aeration process, are available for individual dwellings or clusters of dwellings. These are generally heated and housed so design is conventional. If properly operated these units can, in theory, achieve secondary quality effluent and could, if allowed by the applicable regulatory agency, be designed for point discharge to surface waters. If properly operated, the reduction in BOD and suspended solids achieved would permit effluent disposal in a leach field smaller than that required for septic tank effluents. In all cases, the critical aspect is proper operation, plus a method for positive solids separation and solids disposal. General experience has shown that neither the average homeowner or similar personnel have the competence and dedication required to service such units. They should only be considered if some permanent provision can be made for management and maintenance of the units on a regular basis by some outside authority.

Intermittent or seasonally occupied facilities are common in cold regions. Several arrangements are available for small-scale operations either with or without discharge. In the former case, a small physical/chemical packaged plant can be run intermittently and still give satisfactory removal efficiencies. Operator skills, resupply and sludge management can be problems. For a small facility a two-cell, controlled-discharge pond, operating in parallel might be suitable. Residence time prior to discharge would be a full year. If occupancy is only in the warm summer months, an evapotranspiration bed preceded by a septic tank or aerobic unit will provide a no-discharge system. Design would be the same as for a temperate zone location, with inclusion of climatic data specific to the site and consideration of permafrost under the bed.

9.5.2 Low or no discharge systems

These include pressure or vacuum toilets, vault toilets, and a whole variety of toilet units for the individual home based on electrical, mechanical or biological processes.

Low water use toilets, as well as other conservation devices, reduce the volume of liquid to be managed but not the mass of pollutants. The same is true of separation of waste streams into "black" and "grey" water. Both streams require comparable treatment even through the total volume may be reduced. Although the volume of liquid may be less, leaching fields or other soil adsorption systems receiving such wastes should be conventionally designed and not otherwise reduced in size if BOD loading is unchanged. Tank size for other forms of "packaged" treatment for such wastes may be reduced but the energy and/or chemical requirements will be higher because of higher concentrations of pollutants.

Vault toilets are best suited for seasonal use, particularly in the summer. They are most widely used at camps and recreational sites. There can be problems in these cases because of indiscriminant dumping of trash and garbage which increases the clean-out frequency. In any event, periodic cleaning and disposal of vault wastes is required. Basic design is similar to conventional practice.

Appendix B describes various types of household water conservation alternatives, including toilet systems. Recirculating chemical toilets are in common use in airplanes and travel trailers. Capital costs are high ($100-$1000) and chemicals are expensive. The mechanisms are complex, maintenance is required, and periodic disposal of collected material is still necessary.

Variations include single-pass or recycle toilets which use a fluid other than water. Fuel oil has been tried on a single-pass basis with the entire mixture then burned for heat. The fire hazard at the toilet was considered significant. An alternative is to mix the waste from low water use toilets with fuel oil for burning in boilers. Either approach requires complex equipment and skilled maintenance. Recycle toilets based on mineral oil are available. The specific gravities are sufficiently different that the oil and waste separate in a holding tank and the oil is recycled. Disposal of the collected wastes is still required and costs for a single unit may approach several thousand dollars.

Incinerating toilets, whether based on oil, gas or electricity, require considerable energy, are complex to maintain, and can be aesthetically objectionable, particularly where a temperature inversion exists and vent stack emissions sink rather than rise.

Composting toilets are in wide use in Scandanavia for vacation homes. A full-scale unit can receive all feces, urine, and kitchen wastes from a household. Wash water and other liquids must be discharged elsewhere. Successful operation requires a degree of commitment and dedication not commonly found in the North American Arctic and subarctic.

The most common nonwater carriage system in use is the honey bag toilet. Pickup, handling and disposal of the bags creates potential health problems. Efficient systems of this type are in operation in coastal communities in Greenland, where pickup and disposal is a reliable municipal service. Section 13 discusses ultimate disposal.

9.6 Operation and Maintenance

Repeated studies of treatment systems in cold climates have shown that performance does not achieve the design goals due to poor operation and maintenance. Initial operator training is essential to successful system performance. Another critical element in the design process for wastewater treatment is the preparation of the operations and maintenance manual. It is even more important in the arctic and subarctic because of the remote locations, the general lack of skilled personnel, and the relatively rapid turn-over of operators at both military and civilian treatment systems. In the former case, a one-year tour of duty is normal. This lack of continuity and experience results in a situation where the operator's only routine source of guidance and assistance is the manual. Minor details which may appear self-evident to the designer/author may be critical to the operator/reader.

9.6.1 Contents of O&M manuals

The basic requirements for process operation and maintenance may not differ from conventional temperate zone practice but the cold regions O&M manual should explain them in greater detail since it may be the only information source. Special winter operational requirements must be clearly defined. These may include draining lines, winterizing pumps, activating heat tapes, etc. Equipment for emergency or future use must be clearly identified. For example, a heat tape intended to thaw a pipe need not be continuously operated, and extra pumps and blowers may only be for standby.

9.6.2 Design for O&M

Attention to detail during design of a system will help relieve or avoid subsequent operational or maintenance problems. Many typical examples, such as condensation and control panel locations, were discussed previously in this chapter as they relate to a particular process design. Other generally applicable items would include:

a) Alarm systems to indicate failure in the process (i.e., power failure, overflow, etc.) are essential, particularly for small units that receive intermittent attention.

b) The air circulation and heat distribution in an enclosing structure must be carefully planned. Often the temperature at the floor level and in "blind" spots can be below freezing, resulting in freezing of pipes and appurtenances.

c) The depth and location of winter ice and snow cover must be considered to ensure easy access to all critical components.

d) Pumps and other intermittently used facilities must either be protected or winterized each year.

e) Coordination must be established with other critical elements in the community or camp to avoid unexpected or adverse effects on the system. Dumps or spills of toxic materials must be controlled. An improperly maintained or located grease trap could freeze or impose excessive organic loads on a system.

f) Some remote systems may be subject to power failures and voltage variations. Provisions should be made to protect electrical equipment from burning out due to low voltage.

9.7 Costs

There are no simple rules of thumb for estimating costs of cold regions waste treatment systems because of the limited data base, the extreme variability of logistical problems, and high labour rates. Most temperate zone cost data do not include the small-scale systems commonly required in the Arctic. The selection of appropriate indices and trend factors can also be a problem; extrapolation from temperate zone values is not recommended except for large communities. Two sources of cost data for waste treatment in Alaska were available. The first compares construction costs for facilities at the Alaska pipeline camps and is summarized on Table 9-9. The other is from a series of partial-mix aerated lagoons constructed by the U.S. Army Corps of Engineers, Alaska District, in 1972 at various locations in Alaska. These data are summarized on Tables 9-12 through 9-15.

Anchorage, Ak, was adopted as the base and the individual costs from remote sites were used to generate the relative cost factors shown on Table 9-13. This gives an approximation of the variation in costs due to location.

Construction costs for a large (3800 m^3/d) partial-mix aerated lagoon near Fairbanks, Ak, are summarized in Table 9-14. Estimated O&M costs for smaller lagoons are given in Table 9-15.

TABLE 9-12. CONSTRUCTION COSTS - PARTIAL-MIX AERATED LAGOONS (1972 $)

All single-cell, membrane-lined, including control building with blowers and erosion chlorinators. Size range: 10 000 - 14 000 gpd (38-53 m^3/d). Cost values are the average of six installations* and are expressed in dollars per 1000 gal (3.785 m^3) of average daily flow.

Lagoon	
Materials and equipment	$3 400
Labour	2 900
	$6 300
Control Building	
Materials and equipment	$1 600
Labour	1 100
	$2 700
Actual Construction	9 000
Mobilization and Demobilization (15%)	1 400
Design, Inspection, Misc. (13%)	1 200
Total Cost	$11 600

* Locations: Tin City, Cape Lisburn, Tatalina, Indian Romanzof, Cape Newenham (Alaska).

TABLE 9-13. RELATIVE COST FACTORS - PARTIAL-MIX AERATED LAGOONS (1972 $)

All single-cell, membrane-lined, including control building with blowers and chlorination. Size range: 10 000 - 30 000 gpd (38-114 m^3/d). Based on total costs including all construction, mobilization demobilization, design and inspection. Costs expressed as an index relative to Anchorage.

Location	Cost Factor
Anchorage	1
Cape Romanzof	3.3
Cape Newenham	3.6
Indian Mountain	4
Cape Lisburne	4.3
Tin City	4.6

TABLE 9-14. CONSTRUCTION COSTS - EIELSON AFB AERATED LAGOON (1972 $)

A 3800 m^3/d, two-cell lagoon, lined with butyl rubber membrane. Helical aeration diffusers, 28 m^2 control building with blowers, and a chlorine contact chamber.

Lagoon		
Materials and Equipment		$280 000
Labour		108 000
		$388 000
Control Building		
Materials and Equipment		81 000
Labour		47 000
		$128 000
Actual Construction		$516 000
Mobilization and Demobilization (9%)		46 000
Design, Inspection, Misc. (13%)		73 000
	Total Cost	$635 000
Cost by engineering discipline:		
Civil Engineering		45%
Mechanical Engineering		50%
Electrical Engineering		5%

TABLE 9-15. ESTIMATED ANNUAL OPERATION AND MAINTENANCE COSTS - PARTIAL-MIX AERATED LAGOONS IN ALASKA (1972 $)

	Labour	Materials
Elendorf AFB 11 m^3/d sigle-cell	$4 000	$1 000
Widwood, AFS 60m^3/d tw-cell	$2 200	$1 000
Kig Salmon AFB 30m^3/d sigle-cell	$7 300	$4 000

The influence of remote location is apparent when the values for Elmendorf AFB, in Anchorage, are compared to those for King Salmon AFB, which is on the Alaska Peninsula.

9.8 References

1. Bailey, J.R. et al, A study of flow reduction and treatment of wastewaters from households. U.S. Federal Water Pollution Control Administration, Contract Report 14-12-428, 1969.

2. Witt, M.D. et al, Rural household waste characterization. Proceedings of the National Home Sewage Disposal Symposium, ASAE pubs., Proc. 175, 1974.

3. Jespersen, F., The vacuum sewage system. Utilities Delivery in Arctic Regions. D.W. Smith (ed.), Environment Canada Rpt. EPS 3-WP-77-1, pp. 364-387, Ottawa, 1977.

4. Given, P.W. and H.G. Chambers, Workcamp sewage disposal. Some problems of solid and liquid waste disposal in the northern environment, Environment Canada Rpt. EPS-4-NW-76-2, pp. 1-42, Edmonton, 1976.

5. Flack, J.E., Design of water and wastewater systems for rapid growth areas. Environmental Resources Center, Colorado State University Press, 149 pp, 1976.

6. Snoeyink, V.L. et al. USAF Mobility Program Wastewater Treatment System, U.S. Air Force Tech. Rpt. AFWL-TR-71-169, 60 pp, 1972.

7. U.S. Environmental Protection Agency, Process design manual for wastewater treatment facilities in sewered small communities, EPA-625/1-77-009, 1977.

9.9 Bibliography

Alter, A.J. Sewage and sewage disposal in cold regions. U.S. Army, Cold Regions Research and Engineering Laboratory. Monograph III-C5b, 106 pp, 1969.

Alter, A.J. Water supply and waste disposal concepts applicable in permafrost regions. Proceedings of the 2nd International Permafrost Conference, Yakutsk. North American Contribution. Academy of Sciences, National Research Council, pp. 557-581, 1973.

Alter, A.J. The polar palace. The Northern Engineer, University of Alaska, 5:2, 4-10, 1973.

Antonie, R.L. Rotating biological contactors for secondary wastewater treatment. Lake Tahoe Wastewater Treatment Seminar Manual, 1976.

Benjes, H.H., Small community wastewater treatment facilities - biological treatment systems. Design Seminar Handout, Small Wastewater Treatment Facilities, U.S. Environmental Protection Agency, Cincinnati, Ohio 1978.

Buens, G.E., Evaluation of aerated lagoons in a cold climate. Proceedings 22nd meeting Western Canada Water and Sewage Conference, pp. 21-40, 1970.

Christianson, C., Cold climate aerated lagoons. Proceedings 2nd Int. Symp. on Cold Regions Engineering. J. Bwolich and P. Johnson (ed.), University of Alaska, Fairbanks, pp. 318-351, 1977.

Clark, S.E. et al, Biological waste treatment in the far north. U.S. Environmental Protection Agency (FWQA), Project Report 1610, 36 pp, 1970.

Clark, S. et al, Alaskan industry experience in arctic sewage treatment. Working paper No. 13 at 26th Purdue Industrial Waste Conf., Purdue Univ, Lafayette, Indiana, 1971.

Clark, S., Coutts, H., and Christianson, C., Design considerations for extended aeration in Alaska. Murphy, R. and Nyquist, D. (ed.), Water Pollution Control in Cold Climates, U.S. Environmental Protection Agency, Water Pollution Control Research Series 16100 EXH 11/71. pp. 213-236, 1971.

Clark, S.E. et al, Alaska Sewage Lagoons. 2nd Intl. Symp. on Waste Treatment Lagoons, U.S. Federal Water Quality Administration, Washington, D.C., pp. 221-230, 1970.

Coutts, H., Arctic Evaluation of a small physical-chemical sewage treatment plant. U.S. Environmental Protection Agency, Arctic Environmental Research Lab., Fairbanks, Alaska, 1972.

Eckenfelder, W.W. and A.J. England, Temperature effects on biological waste treatment processes. Symposium on Water Pollution Control in Cold Climates, R.S. Murphy and O. Nyquist (ed.), University of Alaska, Fairbanks, pp. 180-190, 1970.

Gordon, R. and Davenport, C., Batch disinfection of treated wastewater with chlorine at less than $1^{o}C$. U.S. Environmental Protection Agency, Washington, D.C., EPA-660/2-73-005, 1973.

Grainge, J.W. et al, Management of waste from arctic and subarctic work camps, report for Task Force on Northern Oil Development. Report 73-19, Information Canada Cat. No. R72-10173, 153 pp, 1973.

Grainge, J., Impact of community planning on quality of life in the north. Proceedings of Third National Hydrotechnical Conference, Quebec, pp. 483-500, 1977.

Grainge, J.W., Shaw, J.Q. and Slupsky, J.W., Report on Toilet Units. Public Health Engineering Div., Dept. of Environment, Edmonton, Alberta. Manuscript Report NR-71-2. 21 pp, 1971.

Grube, G. and Murphy R., Oxidation ditch works well in subarctic climate. Water and Sewage Works, Vol. 116, No. 7, pp. 267-271, 1969.

Heinke, G.W. and D. Prasad, Disposal of concentrated wastes in northern areas, Environment Canada Report EPS 4-NW-76-2, pp. 87-140, Edmonton, 1976.

Hickey, J. and Duncan, D., Performance of single family septic tank system in Alaska. JWPCF 38: 1298-1309, 1966.

LeGros, P.G., and N.L. Drobny, Viruses in polar sanitation - a literature review. U.S. Navy, Civil Engr. Lab. Tech Rpt. R-505, 15 pp, 1966.

Lin, K.C. and G.W. Heinke. Plant data analysis of temperature significance in the activated sludge process. JWPCF, 49(2):286-295.

Metcalf and Eddy Inc. Wastewater Engineering: Treatment, Disposal, Reuse. McGraw-Hill Book Co., New York, 920 pp, 1979.

Middlebrooks, E.J., C.D. Perman and I.S. Dunn, Wastewater stabilization lagoon linings, U.S. Army Cold Regions Research and Engineering Laboratory, Special Report, in press, 70 pp, 1978.

Morrison, S.M. et al, Lime disinfection of sewage bacteria at low temperature. U.S. Environmental Protection Agency. EPA 660/2-73-017, Washington, D.C., 90 pp., 1973.

Murphy, R. and Ranganathan, K., Bio-processes of the oxidation ditch in a sub-arctic climate. IN: Davis, E. (ed), International Symposium on Wastewater Treatment in Cold Climates, Environment Canada Report EPS 3-WP-74-3, Ottawa, 1974.

Murphy, R.S., et al, Water supply and wastewater treatment at alaskan construction camps. U.S. Army Cold Regions Research and Engineering Laboratyr, Report in press, 1978.

Orr, R.C. and D.W. Smith. A review of self-contained toilet systems with emphasis on recent developments. Utilities Delivery in Arctic Regions. D.W. Smith (ed.). Environment Canada Rpt. EPS 3-WP-77-1, pp. 266-308, Ottawa, 1977.

Otis, R.J., et al. On-site disposal of small wastewater flows. U.S. Environmental Protection Agency, Washington, D.C., EPA-625/4-77-011, 1977.

Puchtler, B., Reid, B., and Christianson C., Water-related utilities for small communities in rural Alaska. U.S. Environmental Protection Agency, Washington, D.C., EPA-600/3-76-104, 1976.

Reed, S.C. and R.S. Murphy, Low temperature activated sludge settling. Journal S.E.D. ASCE, SA4, 747-767, 1969.

Reed, S.C., Alternatives for upgrading USAF wastewater lagoons in alaska. U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, 94 pp., 1976.

Reed, S.C. et al, Land treatment of wastewater for Alaska. Proceedings Second International Symposium on Cold Regions Engineering, J. Bordick and P. Johnson (ed.), Univ. of Alaska, Fairbanks, pp. 316-318, 1977.

Reid, B.H., Some technical aspects of the Alaska village demonstration project. IN: Utilities Delivery in Arctic Regions, Environment Canada Rpt. EPS 3-WP-77-1, pp. 391-438, Ottawa,1977.

Reid, L.C. Jr., Design and operation of aerated lagoons for the arctic and subarctic. Presented at the U.S. EPA Technology Transfer Design Seminar, Anchorage, Ak., April 9-10, 1975, 29 pp, 1975.

Ryan, W., Design and construction of practical sanitation facilities for small Alaskan villages. Permafrost. Proc. of the 2nd International Conference, Yakutsk. North American Contribution. National Academy of Sciences, National Research Council. pp. 721-730, 1973.

Sletten, R.S., Land application of wastewater in permafrost areas. 3rd International Permafrost Conference, National Academy of Science, Washington, D.C., 1978.

Smith, D.W. and P.W. Given, Evaluation of northern extended aeration sewage treatment plants. Proceedings 2nd International Symposium on Cold Regions Engineering, J. Burdick and P. Johnson (ed.), Univ. of Alaska, Fairbanks, pp. 291-316, 1977.

Tilsworth, T. et al. Freeze conditioning of waste activated sludge. Proceedings 27th Industrial Waste Conference. Purdue University, 486-491, 1972.

U.S. Army. Domestic wastewater treatment TM 5-814-3, in press. U.S. Army Corps of Engineers, Wash. D.C., 1978.

U.S. Environmental Protection Agency, Process design manual for land treatment of municipal wastewater, EPA 625/1-77-008, Washington, D.C., 1977.

U.S. Navy. Design Manual, Cold Regions Engineering, NAVFAC DM-9. Dept. of Navy, Naval Facilities Engineering Command. Alexandria, Va., 1975.

SECTION 10

WASTEWATER DISPOSAL

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10 WASTEWATER DISPOSAL

10.1 Discharge Standards

A total water management program requires the return of the water to the environment. The treatment requirements in northern locations must normally be based on winter receiving water characteristics, which include critically low flows and dissolved oxygen levels. Two general approaches used to control man-created wastewaters are:

1) basic effluent standards, and
2) specific stream standards.

Most North American locations make use of a combination of the two types of standards. The important aspects of the two approaches to water management are presented below. Details of subsurface disposal, outfalls, intermittent discharges, land disposal, swamp discharge and sludge disposal follow the discussion of standards.

10.1.1 Environmental conditions

Present knowledge of how arctic and subarctic river, lake and estuary systems respond to wastewater discharges is limited. Some basic information on the physical and chemical conditions, and the ecology of streams and rivers has been gathered. The annual cycles in subarctic lakes are just now becoming subjects of more interest and study [1,2]. Not only is information on how aquatic systems function limited, but the situation is compounded by extremely varied conditions throughout the North.

The environmental conditions within northern rivers and lakes vary considerably with time of year and location. Winter flow in many rivers is negligible, while summer flows may be high and carry heavy sediment loads. Ice cover is the rule, rather than the exception, with water temperatures at $0^{o}C$ in the winter, and generally low during the remainder of the year. During periods of ice cover, the concentration of dissolved oxygen (DO) progressively reduces. Near the mouths of most major rivers in Alaska, natural winter DO levels are well below generally recommended minimums, as shown in Table 10-1 [3]. The organisms present have adapted to these harsh conditions through such methods as reduced metabolic rates and migration. However, tolerance levels have not been well defined.

TABLE 10.1 WINTER DISSOLVED OXYGEN CONCENTRATIONS IN SELECTED STREAMS

Stream/Location	Dissolved Oxygen mg/L	% saturation	Date of Sample
Yukon River			
near Eagle, Ak (1664 km upstream)	10.5	73	Mar. 1971
near Alakanuk, Ak	1.9	13	
Tanana River			
near Fairbanks	9.9	69	23 Feb. 1970
at Yukon River	5.7	40	
near Fairbanks	10.8	75	5 Mar. 1970
at Yukon River	6.5	46	
Colville River			
at Umiat	7.5	52	Mar. 1969
Kuparuk	8.4	58	Mar. 1969
	8.4	58	Feb. 1971

Based on Reference [3].

Few studies of the effects of wastewater discharges on these waters have been conducted. Gordon [4] showed in laboratory experiments that indigenous bacteria exerted an oxygen demand at low temperatures, and the addition of organic and inorganic nutrients increased the rate of oxygen utilization. Murray and Murphy [5] also studied the biodegradation of organic substrates at low temperatures. They found that the food-to-microorganisms (F/M) ratio was more important than temperature in determining the rate of DO depletion.

In another study, the effect of ice cover on the DO content of the Red Deer River in Alberta was measured [6]. In this river, which receives municipal effluent, the initial five-day, 20°C biochemical oxygen demand (BOD) of the river below the outfall and the rate constants established by BOD bottle tests were found to bear little relation to oxygen uptake in the ice-covered, shallow river. Total organic carbon (TOC) was closely related to oxygen depletion. It was concluded that biological oxidation under river ice was a complex reaction and the bottom characteristics and benthic demand were very important. The bottom of

Red Deer River is mainly gravel and rock, allowing a large surface area for the growth of microorganisms.

In evaluating the effect of wastewater discharges from construction camps, Greenwood and Murphy [7] estimated that a 300-man camp located near the mouth of the Colville River, Alaska, could store wastewater for nine months, discharge it during a one-month period in June, and increase the stream BOD by only 0.0026 mg/L with proper dilution. This approach, the use of dilution, is a very real alternative which warrants careful consideration.

The results of many of the studies and evaluations differ but are not necessarily contradictory, because each study was conducted under different conditions. There are many gaps in the knowledge of aquatic kinetics yet to be filled before the assimilative capabilities of a northern receiving water can be accurately assessed or predicted.

Assimilative capacities of northern rivers in the winter are undoubtably lower, and perhaps much lower, than rivers of similar physical characteristics located in temperate zones. Considering the complexity of the ecosystem, the great range of physical characteristics, and the impossibility of comparing these rivers to those in areas where much more research and experience has been documented, it will be quite some time before northern water systems can be accurately modelled. Oxygen utilization rates and reaeration coefficients at temperatures near $0^{o}C$ need further development. In the interim, the aquatic integrity must be protected by knowledgeable utilization of the limited data coupled with common sense.

10.1.2 Standards

Standards to protect the ecological, aesthetic and sanitary integrity of receiving waters can be divided into three types [8]:

1) standards based solely on receiving water quality,
2) standards based on the quality of the effluent discharge,
3) standards which combine both of the above.

Physical, ecological, and assimilative capacity characteristics of receiving waters vary considerably, as do land use and population density. These variations, together with the economic limitations and social structure, make standards based on a combination of receiving water quality and effluent discharges appear the most reasonable.

The interim guidelines for wastewater treatment for the Yukon and Northwest Territories were established on a community-by-community basis [12]. Decisions on treatment recommendations were based on comprehensive studies of expert opinion on public health and environmental needs. Of course, they are subject to modification as community conditions or environmental requirements change or as more information becomes available. Exact treatment techniques were not specified; rather, general effluent quality objectives were established. This appears to be a sound approach to meeting the environmental quality needs of the North.

Presently, the State of Alaska and the U.S. Environmental Protection Agency require mandatory secondary treatment, with further treatment of the wastewater required if it is to be discharged to sensitive receiving waters. These standards were established on a nationwide basis. Contact should be made with the appropriate territorial water board, provincial government agency, federal government agency or, in Alaska, the Department of Environmental Conservation, to establish the required quality for discharge to available receiving waters.

10.1.3 Microbiological considerations

The survival of pollution indicator microorganisms has been shown to be longer in cold water than in warm. Gordon [9], Davenport *et al* [10] and Bell *et al* [11] have presented detailed information on the extended survival of these organisms in northern rivers. This information identifies the need for careful consideration of disinfection to ensure that water uses are not seriously affected.

10.2 Subsurface Land Disposal

Several methods of wastewater disposal into soil are or have been practiced, including absorption field disposal of septic tank or aerobic treatment effluents, direct burial in pits, disposal in ice crypts or snow sumps, and dumping and covering in a landfill.

10.2.1 Septic systems

Septic systems can be used in some arctic and subarctic locations. The presence of, and depth and thickness of permafrost, the type of soil and its percolation rates, and the frost penetration depth will influence the use of septic systems. General septic system design information is available from several sources, such as the "Manual of Septic Tank Practice" [13], and the "Private Sewage Disposal Systems Instructions to Installers, 1978" [14].

The basic functions of septic tanks are: a) removal of settleable and flotable solids, b) sludge and scour storage, c) some anaerobic biological treatment, and d) to condition liquids for ground adsorption (hydrolyze solids).

Some efficiency information for septic tanks used in cold climate regions are presented in Table 10-2.

TABLE 10-2. EFFICIENCY OF SEPTIC TANKS

Conditions	Percent BOD	SS	Removal Total Solids	References
Average of 10 Air Force Base sites in Alaska	33	42	22	[15]
Tanks in heated houses	46	64	48	[15]
Tanks - steam heated	40	31	34	[15]
Tanks - unheated	14	38	30	[15]
Field study at College, Alaska, 2.5-day detention time	28	43	-	[16]
Lab study, U.S. PHS, temperature 4-10°C, 2-day detention time	49-52	83-89	31-41	[17,18]
Lab study, University of Washington, temperature 4.4 and 15°C, 4.5-day detention time	49-52	83-86	31	[17,18]
Normal primary sedimentation	20-40	45-70		[17,18]

The sizing of the system should follow procedures in the "Manual of Septic Tanks Practice" [13].

10.2.1.1 Soil conditions. The most critical aspect of arctic and subarctic septic systems design is the soil condition. Figure 10-1 shows examples of soil profiles found in subarctic areas of Alaska. The type of soil will influence the frost penetration depth. Its location with respect to surface and groundwater will also influence frost penetration and frost heave. In locations where permafrost is deep it may be possible to install an absorption field. However, groundwater (suprapermafrost water) movement patterns should be investigated, along with potential groundwater supply locations. Percolated water from the absorption field may move down to the frozen soils and then tend to move horizontally. Depending upon the total temperature regime, the wastewater may cause additional thaw of the permafrost.

Thermal protection for the tank and adsorption field should be designed for the worst winter conditions, minimum or no snow, and low

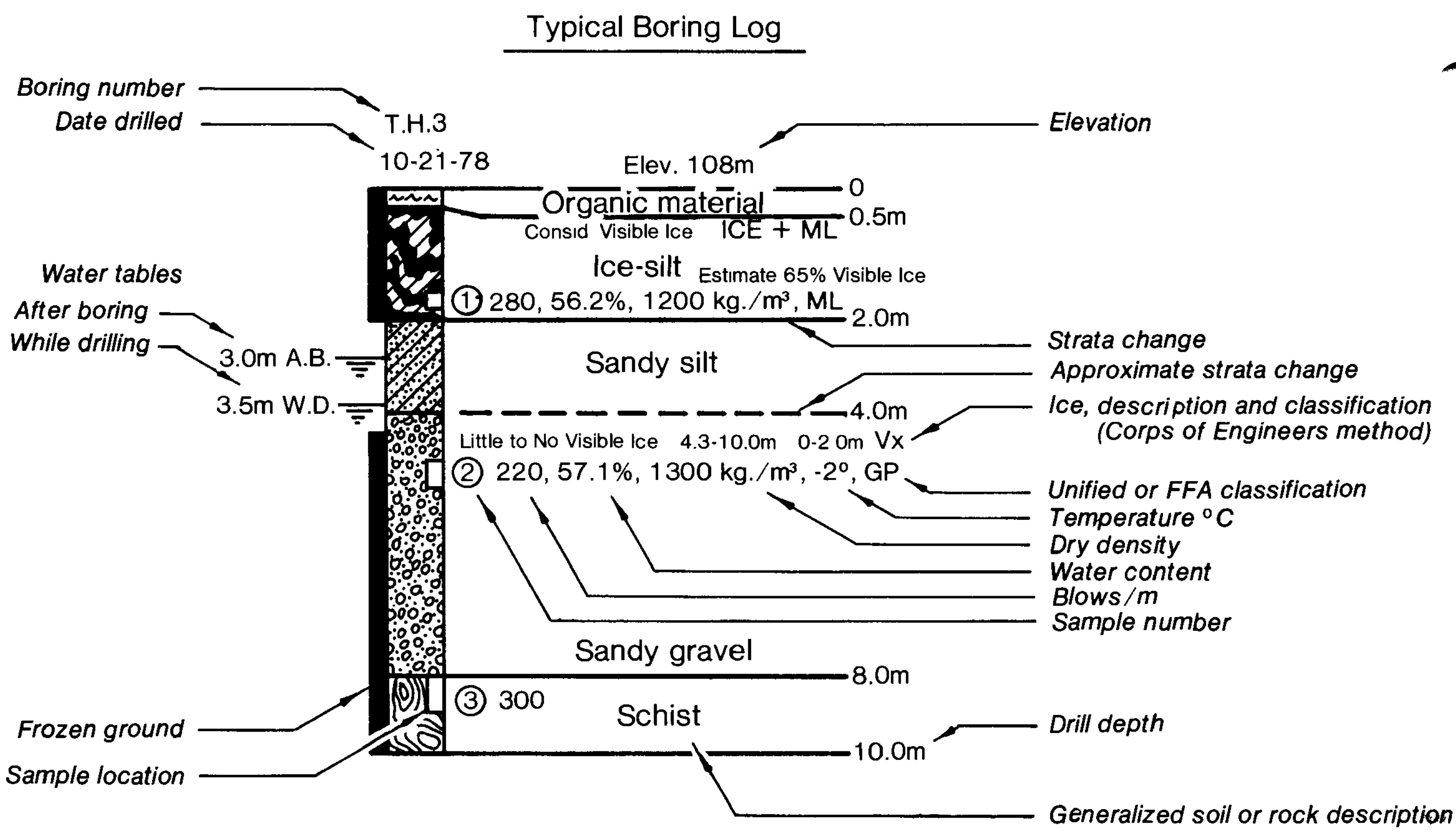

FIGURE 10-1. SOIL PROFILES

temperatures. Freezing prevention should be designed into the system. Year-round operation will require continuous heat additions in the form of warm wastewater or external heating inputs. Methods of preventing freezing which have been used include:

1) housing the septic tank in a warm structure above or below ground;
2) placing a steam line along pipes or around septic tank;
3) placing an electric heat tape along pipes or around septic tank;
4) applying insulation around septic tank and over top of pipes (foam, sheets, snow cover, earth cover, etc);
5) use of warm water to increase the heat input of wastewater.

In locations where the need for wastewater disposal is seasonal, such as in recreational areas, the tank may be pumped out after the recreational activities have ceased. A minimum of one week between the cessation of flow and pumping should be allowed. When the facilities remain in operation year-round, but at a reduced flow during the winter months, more than one system may be used in parallel to allow part of the unit to be shut down and pumped.

10.2.1.2 Absorption field design. The soil absorption system serves as an additional sewage treatment unit. This component is a subsurface distribution system which delivers the settled sewage flowing from a septic tank to the soil found suitable for ultimate disposal. A soil absorption system may be one of three different types: absorption trenches, mound seepage beds, and seepage pits. The absorption trench system provides the advantage of discharging the settled sewage near the surface of the ground and over a wide area. The seepage pit, in comparison, discharges into deeper soil strata at concentrated points.

Heat loss control is the key consideration in cold climate systems. Figure 10-2 shows how insulation can be used to reduce heat loss during winter periods. It should be noted that the freezing front will move down between trenches and may cause the formation of a finite thawed area.

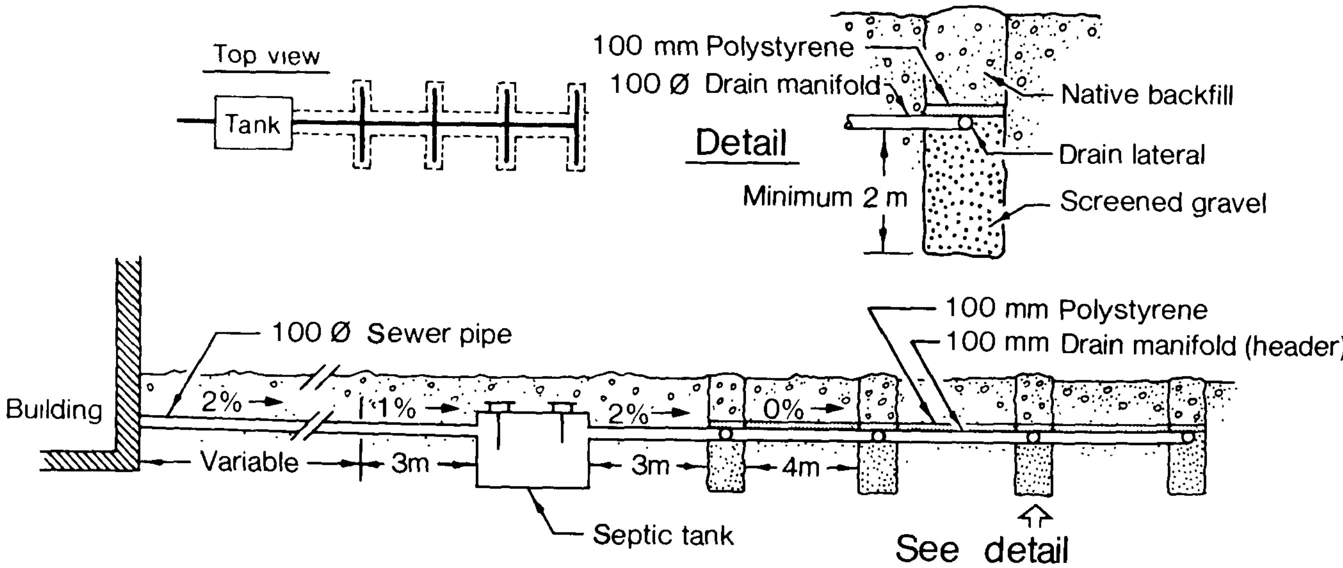

FIGURE 10-2. INSULATION IN SOIL ABSORPTION FIELDS

10.2.1.3 Dosing tank techniques. When the quantity of sewage exceeds the amount that can be discharged in approximately 150 linear metres of absorption field tile, a dosing tank should be used. Such a tank allows proper distribution of wastewater to different parts of the field. This technique also allows the absorption field a period of time to percolate the water.

In cold climates a small continuous discharge may freeze due to rapid heat loss to the soil. In this case, a dosing tank allows a larger volume and a greater amount of heat to be discharged at one time. This provides for greater penetration of the absorption field. In some locations it may be desirable to pump the effluent to a suitable absorption area.

The dosing tank should be equipped with an automatic siphon which discharges the tank once every three or four hours. The tank should have a capacity equal to about 60 to 75 percent of the interior capacity of the tile to be dosed at one time. (See Section 7.)

10.2.1.4 Clean-out requirements. Due to the normally low temperatures during all or part of the year, sludge digestion and hydrolization rates will be low and sludge accumulation higher than in temperate climates. This condition results in a more frequent need to remove sludge from the tank. Sludge removal frequency should be every 12 to 24 months in Alaska and northern Canada.

10.2.2 Mechanical systems

Several mechanical treatment systems are available for small and moderate quantities of wastewater. These are discussed in Section 9. Subsurface disposal of effluent from such plants requires special consideration.

10.2.2.1 Soil conditions. The most critical aspect of aerobic effluent disposal is the solids loading. Aerobic systems frequently have excessive suspended solids concentrations in the effluent. These systems should, therefore, include positive solids separation.

10.2.2.2 Absorption field design. As with septic systems the key consideration must be freeze prevention. With a properly designed solids separation system clogging of the field will be minimized.

10.2.2.3 Sludge disposal. To prevent clogging of the absorption field, sludge must be removed frequently from systems in use in cold regions. Disposal practices are discussed in a later section.

10.2.3 Seepage pits

Deep pits are used in some areas for the disposal of wastewater. Normally, the area required is fairly large and, therefore, use is limited to a small number of dwellings. The major concerns are proper freeze protection and prevention of nitrate and bacterial contamination of the groundwater. They are generally much easier to protect from freezing than an absorption field, and much less excavation is usually required.

10.3 Outfalls

Outfalls to surface water are the most common wastewater discharge technique. Design and operation of the discharge systems requires understanding of the receiving water quality and quality of the discharge. It may be necessary to operate the discharge on an intermittent or seasonal basis. It is advisable to design the outfall pipe so that is does not pass through a water-air interface. This will prevent damage during periods of ice cover.

10.3.1 Receiving water

The type of receiving water bodies and the effluent standards which pertain are important factors in the type of outfall structure designed.

10.3.1.1 Ponds and lakes. Ponds are generally shallow, with depths up to two metres. Surface areas range from a few 100 to a few 1000 m^2, and retention times are often extremely long, one to six months. Freeze depths may vary from 0.5 to 1.5 m. Figure 10-3 shows ice thicknesses reported for different locations. Ice thickness can be estimated mathematically by assuming worst conditions of no snow cover and minimum heat input.

The use of a pond to receive treated wastewater would effectively convert it to a polishing lagoon. Fencing and posting to that effect is required. Local regulatory agencies should be consulted before this approach is adopted.

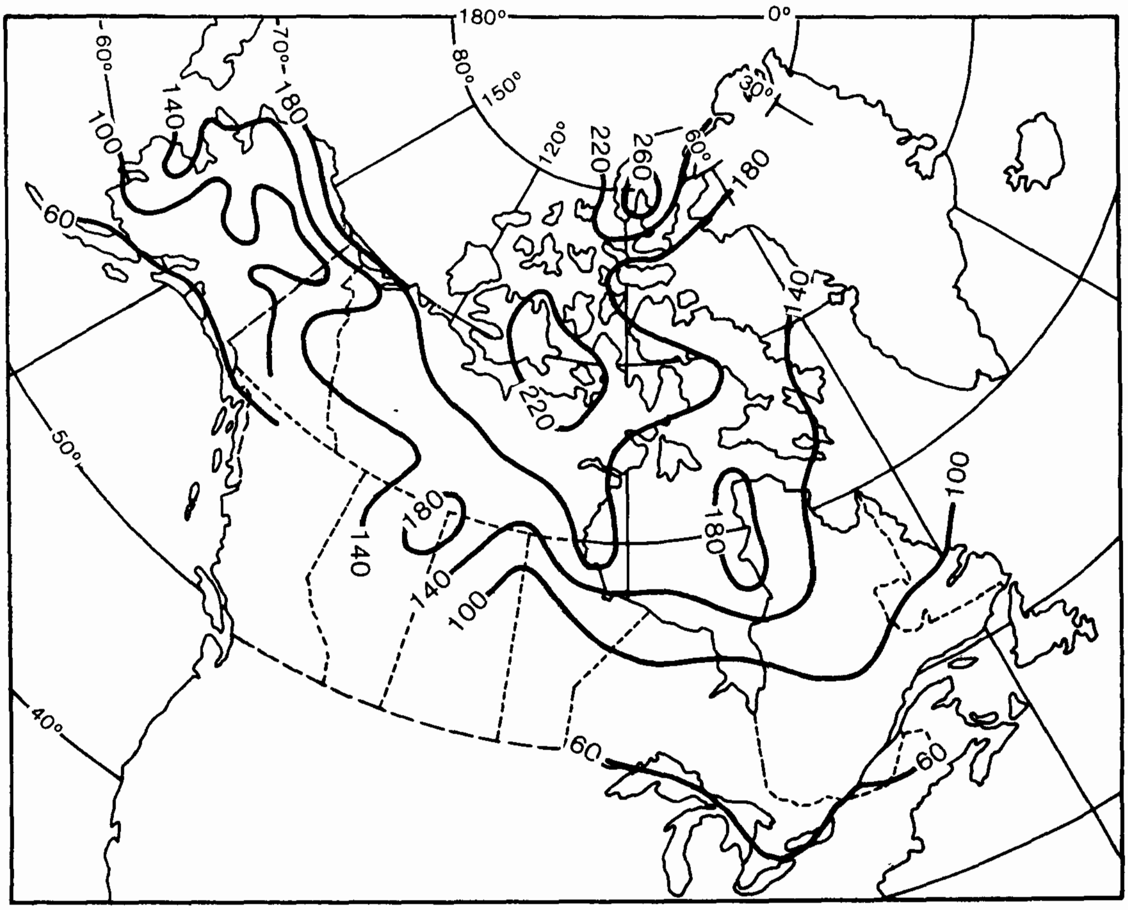

FIGURE 10-3. MAXIMUM ICE THICKNESS OBSERVATIONS, 1969-70
(Values in cm)

Lakes may have the ability to absorb a greater volume of wastewater; however, regional regulations must be reviewed. Important considerations include surface area, depth, volume-inflow relationships, nutrients, flora and fauna, and benthic populations. Effluent quality, especially with regard to microorganisms, must be high if there is a potential for fishery or recreational use of the lake.

10.3.1.2 Streams and rivers. Northern streams and rivers are the most common receiving waters for wastewater. Flow, ice depth and movement are the most important factors to be considered. Dissolved oxygen conditions through the winter and downstream uses are of particular importance in selection of the type of outfall structure to be used.

10.3.1.3 Oceans. Where possible, ocean discharge is desirable. Normally, the ability to absorb quality variations is very great. If initial dispersion by outfall design and tidal movement is not obtained, however, wastewater will concentrate on the surface, because fresh water and sewage are less dense than salt water. The result is a visible slick. The major advantage of sea disposal is dilution.

The design of the outfall must consider ice movement due to tidal action, currents, near-by rivers and wind action. Figure 10-4 shows the general design of an ocean outfall for the north coast.

10.3.2 Types of outfalls

Three basic types of outfalls exist: free fall from a pipe, submerged diffusers, and weir structures.

10.3.2.1 Freefall. Freefall structures utilize an insulated pipe to transport treated wastewater from the treatment facility to the discharge point. Provisions must be made for freeze prevention. Cold air penetration into the end of the pipe could create ice blockage of the line.

10.3.2.2 Submerged pipe. Unique factors of concern in the design of submerged outfalls are the problems associated with ice scour, and freeze and ice damage protection of any portion of pipe crossing the air and water interface.

10.3.2.3 Weirs. Weirs develop a number of problems if not properly designed. During winter operation the unfrozen effluent must move to the

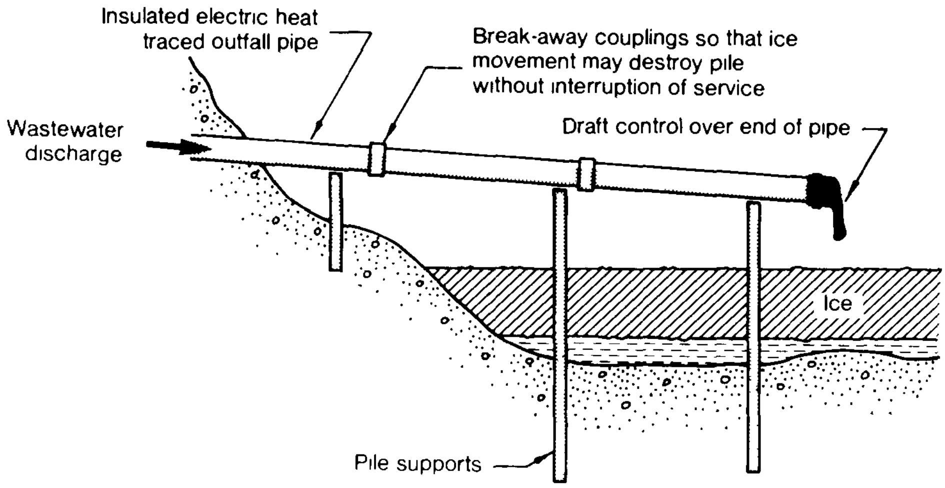

FIGURE 10-4. EXAMPLE OF AN OCEAN OUTFALL DESIGN

surface where cooling will occur. The effluent is then discharged to the surface of a stream or channel. Serious icing problems can result. Figure 10-5 shows a design which has been used successfully.

10.4 Intermittment Discharge

Winter dissolved oxygen conditions in many streams will preclude wastewater discharge. In other locations, the volume of effluent may be so small as to require slug discharge to prevent freezing.

10.4.1 Thermal considerations

Due to the location or type of discharge system used, heat loss may be so great and the volume so small, that the effluent will freeze before or right at the end of the discharge line. The potential for freezing can be determined through the procedures given in Section 15. Such problems are most common when freefall systems are used. To eliminate this condition treated effluent should be stored in a manner that will prevent freezing, and discharged when sufficient volume has accumulated that complete expulsion from the discharge line is ensured.

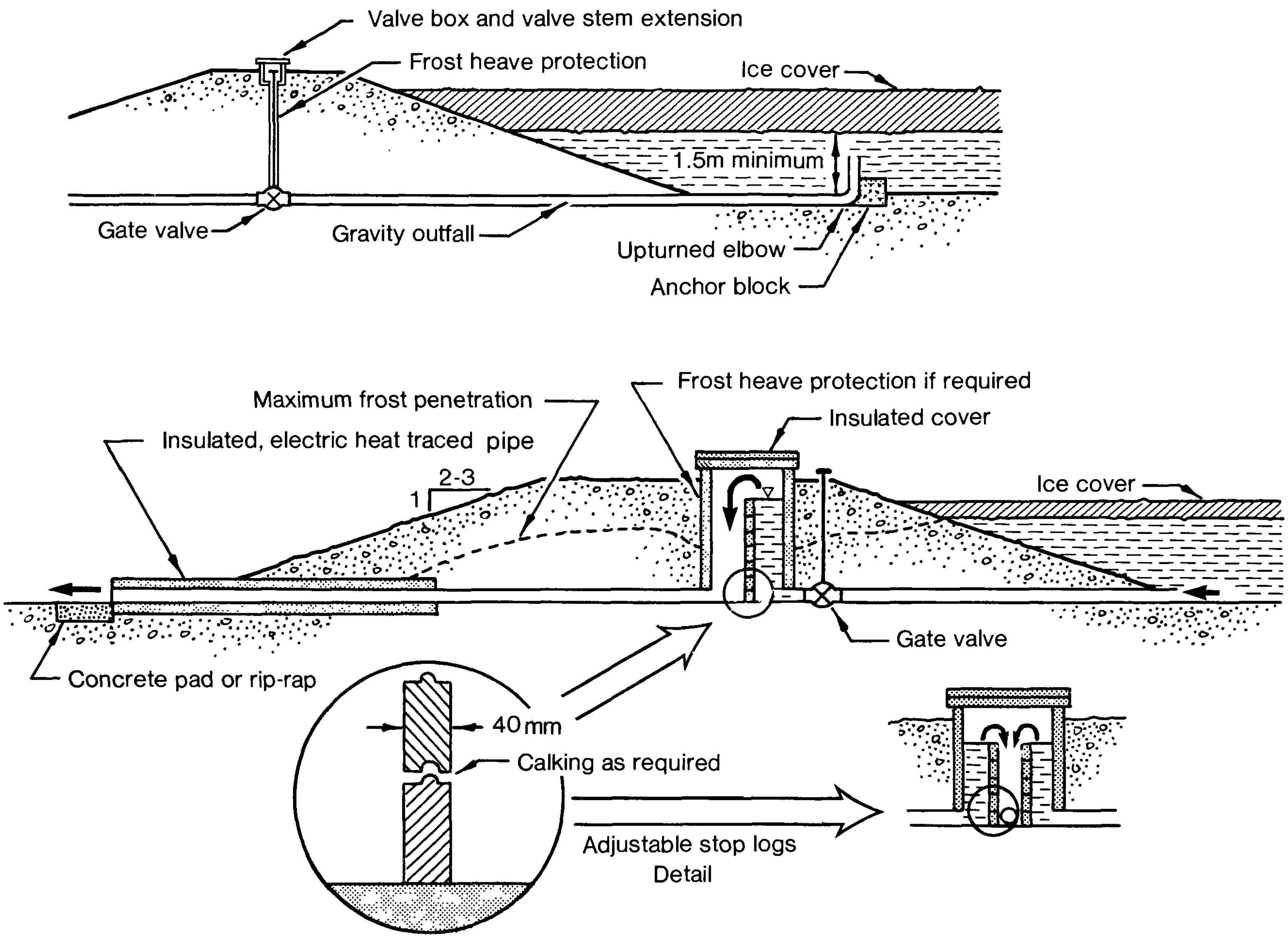

FIGURE 10-5. LAGOON WEIR DESIGN

The discharge mechanism could be a syphon or pump, but must ensure that a trickle discharge does not occur.

10.4.2 Seasonal discharge

Discharge of wastewater at times of maximum or substantial stream flow is highly desirable because this eliminates the addition of oxygen demanding materials to receiving water during the winter period. The timing of this type of discharge will vary with the location.

10.4.2.1 Flow management lagoons. Flow management lagoons are used to control discharge of organics or nutrients to streams or lakes during periods of concern. Such systems were used at Trans-Alaska Pipeline camps to hold wastewater for extended periods through the year. The holding lagoons were pumped out during open water periods. Discharge to the lagoons was through French drains.

10.4.2.2 Polishing lagoons. Discharge of treatment facility effluent to a polishing lagoon may be necessary where the only available receiving water is sensitive to nutrient additions. Polishing lagoons provide additional BOD removal and phosphorus removal by chemical coagulation during ice-free periods. Conventional or pumped discharge can be used.

10.4.2.3 Total retention. Total retention lagoons rely on percolation and evaporation to dispose of the accumulated water. Percolation can be provided by proper selection of the location of the lagoon. Gravel and sand gravel areas can be formed in some northern areas. The lagoon should be sized to hold an entire winter's wastewater flow (approximately 250 days). This allows for a particularly severe winter during which the percolation route is sealed off by freezing. Discharge facilities also should be included.

The water source of the community should be monitored for contamination if groundwater is used. The percolate and groundwater flow patterns should be studied to ensure that health problems will not occur.

Net evaporation can be estimated only roughly from wet and dry bulb data and precipitation records. Normally, evaporation is estimated on the basis of evaporation pan tests and corresponding coefficients; however, very little data is available in the North. Care must be taken in the design to discourage abnormal snow accumulation.

10.5 Land Disposal

Land application of wastewater requires maintenance of the soil permeability. In some cold climate areas this may be possible through special design. However, many areas are unsuitable. The presence of permafrost will limit vertical movement of the wastewater, and winter freezeback of the active layer may prevent horizontal movement. It may be possible to design a suitable system in areas where thawed zones extend to a water body which does not completely freeze.

Another approach warranting consideration is the use of a retention-land disposal system, making use of land disposal during the warmer parts of the year and retention through the winter.

In general, land disposal is similar and subject to the same constraints as land treatment. The major difference is that land disposal systems are mainly concerned with getting the effluent into the ground and away from the site. The major concern is that the effluent moves in an acceptable direction and does not present a hazard to public health.

10.5.1 Soil conditions

Arctic areas underlain with permafrost generally will be limited to non-infiltration land disposal techniques. Overland flow techniques may be suitable; however, little or no control studies have been conducted. Essential considerations include winter storage requirements.

Suitable areas can be located for infiltration approaches in areas of discontinous permafrost. Again the winter storage requirements are paramount. Design details are available in the U.S. Environmental Protection Agency's "Technology Transfer Design Manual of Land Disposal" [22].

10.5.2 Annual cycle

Annual cycles involve the management of wastewater in conjunction with winter and summer conditions. Complex installations may allow land disposal of effluent during the summer and fall, discharge during early winter, and ice mounding in late winter.

10.5.3 Loading rates

As with absorption fields, the allowable application rate is a function of the soil hydraulic capacity. Methods for estimating application rates are given in the "Design Manual of Land Disposal" [22].

The effects of untreated wastewater disposal in cleared areas were studied in the Northwest Territories [23]. Only one application of wastewater was made to the test plots. The soils were identified as fine glacio-lacustrine sands with no permafrost at the Fort Simpson site, and a 30-cm thick organic layer underlain by high ice content clayey till at the Normal Wells site. The loading rates varied from 1.3 cm to 20.3 cm, and results indicated no apparent adverse effects on the vegetation. There were indications that pioneer vegetation in disturbed areas with low nutrient availability may benefit from sewage irrigation. Suitable loading rates were not examined.

Slow infiltration land application was studied at an interior Alaska location [24]. The soil, classified as a sandy-silt, was able to accept 15.2 cm of secondary lagoon effluent per week for the summer test period. Performance data is presented in Table 10-3.

10.6 Swamp Discharge

The use of natural swamps for treating or polishing wastewater has received considerable attention in recent years. Swamp discharge has been practiced in several places in the North; however, detailed studies have been limited. It is important to design the outfall diffuser for maximum dispersion into the swamp.

10.6.1 Area affected

Discharge of untreated wastewaters to a swamp at Hay River, Northwest Territories was investigated in detail by Hartland-Rowe and Wright [26]. Assuming no equilibrium, they estimated that the effect of the effluent could be detected in an area of 35 m^2 per each man-year of sewage discharged. If equilibrium conditions were assumed after five years of operation it was estimated that 110 m^2 were ecologically influenced by each contributing person.

Higher quality effluents would be expected to influence less area. In a study by Fetter et al [27] the polishing capability of a natural marsh of 156 ha with an average depth of 0.5 m was assessed. The wastewater flow was approximately 1000 m^3 per day, which constituted about 20 percent of the flow into the marsh. The discharge was found to attain the following reductions:

TABLE 10-3. RESULTS OF SPRAY APPLICATION OF LAGOON EFFLUENT AT EIELSON AIR FORCE BASE (15-cm lysimeters)*

Test Cell	Application rate cm/m/wk		TOC mg/L	BOD mg/L	SS mg/L	FC per 100 ml
1974						
A	0.75	Mean	22	-	6	-
		Max	47	-	10	-
		Min	13	-	3	-
B	1.20	Mean	25	-	4	-
		Max	34	-	8	-
		Min	10	-	2	-
C	1.7	Mean	23	-	13	-
		Max	36	-	28	-
		Min	13	-	5	-
1975						
A		Mean	-	3	136	802
		Max	-	8	511	2 400
		Min	-	0	11	0
B		Mean	-	11	11	20 350
		Max	-	50	29	102 000
		Min	-	2	4	0
C		Mean	-	5	63	7 656
		Max	-	18	428	36 000
		Min	-	0	7	16

* References [24] and [25].

Parameter	Percent Reduction
BOD	80.1
Coliform	86.2
Nitrate	51.3
COD	43.7
Turbidity	43.5
Suspended Solids	29.1
Total Phosphorus	13.4

10.6.2 Management

In general, swamp areas can provide effective polishing of effluent from treatment plants. If excessive BOD and suspended solids are allowed to enter the area, normal aerobic-anerobic relationships may be shifted severely to the anaerobic side. Such a condition could result in the release of excessive odours and decreased performance of the area.

The area should be well posted at 50 to 100-metre intervals. The signs should identify the area as part of the wastewater treatment system.

10.6.3 Effects

The principal effect of swamp use is that the area must be assumed to be a part of the treatment system and access limited or discouraged. Depending upon the quality of the effluent applied and the degree of disinfection, the area will function as a facultative lagoon.

The wastewater discharge will increase the number of pathogenic bacteria present. It will also add heat to the system during the winter.

Considerable icing may occur due to the shallow water. Ice build-up may retard break-up in the spring.

10.7 Sludge Disposal

All wastewater management techniques require the disposal of sludge. This section presents only those techniques which make use of unique cold climate conditions.

10.7.1 Sludge drying/freezing

Sludge drying is a common practice at most wastewater treatment facilities. However, very few sludge drying facilities have been constructed in cold regions. Sludge dewatering by freezing has been investigated by several groups [28]. It was found in one study that application of 10 to 15 cm of sludge during freezing conditions resulted in good freeze-assisted coagulation.

10.7.2 Sludge pits

Sludge disposal pits are one of the most commonly used methods of disposal. Pits can be excavated in almost any material. Permanent ice, snow, permafrost, various soils and rock have been used. Several years ago, considerable work was done by the U.S. Army Cold Regions Research and Engineering Laboratory (U.S. ACRREL) on the use of ice crypts [29].

Snow pits were also studied by U.S. ACRREL. In this case, sewage discharged to snow will travel downward, forming a sump until it freezes. The depth of the sump is dependent on the rate of heat addition (volume and temperature of the sewage). The vertical pit will develop until the percolating liquid freezes to form an impermeable bottom [30].

The performance of pits in permafrost or periodically frozen soil was investigated by Heinke and Prasad [31]. Their recommendation is presented below:

> "Based on the results of a two year laboratory study, simulating a waste pit, it is concluded that it does not provide satisfactory treatment of human wastes (honey-bags). The waste pit served as a holding tank only at -5°C operation. When the pit was operated at +5°C for about three months each year to simulate summer conditions, insignificant changes in the values of the physical-chemical parameters were observed. The sole significant change was a four-fold increase in the production of volatile acids. A significant increase in the heterotrophic bacterial population was observed each year in the latter part of +5°C operation. No increase in psychsophilic bacteria was noticed. Pathogens are likely to remain viable in the pit for many years.
>
> "Although a waste pit is not a satisfactory treatment method, it is considered better than disposal at an open dump or in a lagoon, which is designed to receive sewage. Location of the pit is most important. It should be as far away as practical

from the community and on a site that will not be needed for other purposes in the future and which does not drain towards water supply sources. The pit should be sized on the basis of 20 cu ft per person per year. For a community of 5000 people, a pit of 100 x 25 x 4 ft deep would be required. A freeboard of 2 feet should be allowed, the contents to be covered by 2 feet of soil when the pit is full and a new one dug. Where soil conditions require it, the pit should be lined with heavy plastic sheets to prevent seepage through soil to prevent possible contamination of ground and surface water. Truck access for easy dumping is required. A honey-bag disposal station, on the Greenland model and as described in the report, could be considered together with a waste pit installation. It would improve considerably the solids handling aspect but at a sizeable cost."

10.7.3 Lagoon sludge disposal

Disposal of sludge accumulated in lagoons has seldom been considered. Removal of sludge from lagoons is infrequent. Normal practice is to move the sludge to a separate holding area, preferably near the landfill, and cover it with 0.5 to 1.0 metres of soil.

10.7.4 Landfill

Although landfill dumping of undiluted and treatment plant sludge is practiced, it is not a recommended procedure without proper evaluation of the impacts. Principal considerations are proper isolation, frequent cover, knowledge of soil conditions and permability, groundwater depth and direction of movement, and access control for people and animals.

10.8 References

1. LaPerriere, J.D., T. Tilsworth and L.A. Casper, The Nutrient Chemistry of a Large, Deep Lake in Subarctic Alaska. Institute of Water Resources Report No. IWR-80, Univ. of Alaska, Fairbanks, 1977.

2. Alexander, V., Dynamics of the Nitrogen Cycle in Lakes. Institute of Marine Science Report Number R71-7, Univ. of Alaska, Fairbanks, 1970.

3. Schallock, E., Low Winter Dissolved Oxygen in Some Alaskan Rivers. U.S. Env. Prot. Agency Report No. EPA-660/3-74-008, Corvallis, Oregon, 1974.

4. Gordon, R.C., Depletion of Oxygen by Microorganisms in Alaskan Rivers at Low Temperatures. IN: R.S. Murphy, Water Pollution Control in Cold Climates Symposium, U.S. Env. Prot. Agency, Washington, D.C., 1970.

5. Murray, A.P. and R.S. Murphy., The Biodegradation of Organic Substrates Under Arctic and Subarctio Conditions. Institute of Waster Resources Report No. IWR 20, Univ. of Alaska, Fairbanks, 1972.

6. Bouthillier, P.H. and K. Simpson, Oxygen Depletion in Ice Covered Rivers. Jour. of the Sanit. Eng. Div., ASCE, 98, SA2, 341, 1972

7. Greenwood, J.K. and R.S. Murphy, Factors Affecting Water management on the North Slope of Alaska. Institute of Water Resources Report No. IWR 19, Univ. of Alaska, Fairbanks, 1972.

8. Cleary, E.J., Effluent Standards Strategy: Rejuvenation of an Old Game Plan. Jour. Water Poll. Control Fed., 46, 1,9, 1974.

9. Gordon, R.C., Winter Survival of Fecal Indicator Bacteria in a Subarctic Alaskan River. U.S. Env. Prot. Agency Report No. EPA-R2-72-013, Corvallis, Oregon, 1972.

10. Davenport, C.V., E.B. Sparrow and R.C. Gordon, Fecal Indicator Bacteria Persistence Under Natural Conditions in an Ice Cover River. J. Appl. and Env. Micro., 1977.

11. Bell, J.B., W. Macrae and J.F.J. Zaal, The Persistence of Bacterial Contamination in the North Saskatchewan River in the Vicinity of Edmonton, Alberta. Environmental Protection Service, Edmonton, Alberta, 1977.

12. Canada. Dept. of Environment. Interim Guidelines for Wastewater Disposal in Northern Canadian. Water Pollution Control Directorate. Environmental Protection Service, Dept. of the Environment, Ottawa, Ontario, 1974.

13. Anon, Manual of Septic-Tank Practice. Public Health Service Publication no. 526, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 1967.

14. Alberta Labour. General Safety Services Division, Plumbing Inspection Branch, Private Sewage Disposal Systems Instruction to Installers, 1978. Edmonton, Alberta, 1978.

15. Straughn, R.O., Septic Tanks at Remote Air Force Installations in Alaska. Environmental Engineering Section, Arctic Health Research Center, College, Alaska, 1967.

16. Lamphere, E.M., Operation of Experimental Septic Tank Units Under Subarctic Conditions. Proceedings, Third Alaskan Science Conference, Sept. 22-27, 1952, Mt. McKinley National Park. Alaska Div. Am. Assoc. for the Advance of Science, Fairbanks, 1952.

17. Hindin, E., R.H. Green and G.H. Dunstan, Septic Tank Performance at Low Temperatures. Report No. 27, Div. of Industrial Research, Inst. of Technology, Washington State Univ., Pullman, 1962.

18. Hickey, J.L.S., and D.L. Duncan, Performance of Single Family Septic Tank Systems in Alaska. Jour. Water Pollution Control Federation 28, 8, 1298, 1966.

19. Grainge, J.W. and J.J. Cameron, Sewage Lagoons in Northern Regions. Presented at the U.S. Environmental Protection Agency Technology Transfer Design Seminar, Anchorage, Alaska, 1975.

20. Reid, L.D., Jr, Design and Operation of Aerated Lagoons for the Arctic and Subarctic. Presented at the U.S. EPA Technology Transfer Design Seminar, Anchorage, Alaska, 1975.

21. Murphy, R.S., G.V. Jones, S.F. Tarlton, Water Supply and Wastewater Treatment at Alaskan Construction Camps. U.S. Army Cold Regions Research and Engineering Lab. report in press, Hanover, New Hampshire, 1977.

22. Technology Transfer Design Manual of Land Disposal, U.S. Env. Prot. Agency, Washington, D.C., 1977.

23. Fahlman, R. and R. Edwards, Effects of Land Sewage Disposal on Sub-Arctic Vegetation. IN: Arctic Waste Disposal, Report No. 74-10, Environmental-Social Program, Task Force on Northern Oil Development, Government of Canada, Ottawa, Ontario, 1974.

24. Sletten, R.S., Feasibility Study of Land Treatment at a Subarctic Alaskan Location. IN: R.C. Loehr, Land as a Waste management Alternative, Ann Arbor Science Publishers, Michigan, 1977.

25. Smith, D.W., Land Disposal of Secondary Lagoon Effluents, Pilot Project. Institute of Water Resources Report No. 59, Univ. of Alaska, Fairbanks, 1975.

26. Hartland-Rowe, R.C.B. and P.B. Wright, Swamplands for Sewage Effluents, Final Report. Environmental-Social Committee, Northern Pipelines, Department of Indian Affairs and Northern Development, Ottawa, Ontario, 1974.

27. Fetter, C.W., Jr., W.E. Sloey and F.L. Spangler, Use of a Natural Marsh for Wastewater Polishing. Special Report of the Dept. of Geology, Univ. of Wisconsin, Oshkosh, 1976.

28. Tilsworth, T., Sludge Production and Disposal for Small Cold Climate Bio-Treatment Plants. Institute of Water Resources Report No. IWR-32, Univ. of Alaska, Fairbanks, 1972.

29. Ostrom, T.R., et al, Investigation of a Sewage Sump on the Greenland Icecap. Jour. W.P.C.F., 34, 1, 56, 1962.

30. Reed, S. and Tobiasson, Wastewater Disposal and Microbial Activity at Ice-Cap Facilities, Jour. Water Poll. Control Fed. 40, p. 2013, 1968-70.

31. Heinke, G.W. and D. Prasad, Disposal of Human Wastes in Northern Areas. IN: Some Problems of Solid and Liquid Waste Disposal in the Northern Environment. Environment Canada Report EPS 4-NW-76-2 pp. 87-140, 1976. Also in Proc. 3rd Canadian Hydrotech. Conf., Canadian Soc. Civ. Eng., Laval University, Quebec, 1977. pp. 578-593.

SECTION 11

CENTRAL FACILITIES AND REMOTE CAMPS

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11 CENTRAL FACILITIES AND REMOTE CAMPS

11.1 Introduction

Many cold climate communities are located where it is difficult, if not impossible, to construct and operate conventional water supply and wastewater systems piped to the individual homes. Ice-rich permafrost, soils with deep frost penetration, rock, and low density distribution of housing are among the factors limiting the use of conventional water supply and wastewater system services in some communities. Nearly all such communities are native villages with less than 600 people.

One alternative for these communities is to provide at least one facility, centrally located, where certain sanitation services can be obtained. For example, a central facility might provide a place to obtain safe water to drink, a sanitary means of waste disposal, a place to bathe and a place to launder clothes. Any combination of these sanitation services may be provided.

This section discusses the design considerations for providing a central facility in communities where piped services to individual houses are not feasible. Considered in the discussion are the level of service to be provided, sizing of utilities and services, energy conservation, fire protection, construction techniques and cost factors.

In addition to those people who have lived in the cold climate regions for thousands of years, the search for oil, gas and minerals has brought industrial workers to the far north in large numbers. Also man comes to the cold regions for purposes of national defense, research, communications, and development of other natural resources. Early housing and utility services were crude. Now, however, improved temporary and permanent camp facilities enable workers to live in relative comfort, safety and health with a minimum impact on the environment.

The central facility concept for achieving sanitation services has application in remote camps as well as in villages. The need for sanitation services and environmental protection is similar in remote camps and in the villages, but they are discussed separately in this manual because the economic, social, cultural, institutional, and operation and maintenance aspects of the facilities are so different.

Remote camps include those used by the natural resource development industries in support of their efforts to explore, develop, and produce natural resources. In addition, there are large temporary pipeline construction camps, small permanent pump station camps and industrial services camps. The military uses remote camps to support its DEW line facilities, and is interested in more efficient remote camps for troops in the Arctic. There are also remote camps for road constructors and developers of other natural resources.

11.2 Central Facilities

11.2.1 Level of service

Central facilities can provide a variety of levels of service, depending on the needs and desires of a community, convenience, the cost of operating and maintaining the system, and funds available.

Defining the level of service to be provided is not always easy, but it is one of the most important considerations in the early stages of a project. Decisions on the types of services to be provided should be made only after carefully considering funds available for construction; operation and maintenance available within the community and from outside sources; what the community wants; social and cultural customs; community willingness to participate in the project; availability of good operators; and availability of technical and management expertise. Section 2 provides other useful information to consider during the planning stage of a project.

Realistic consideration of these factors with the meaningful participation and involvement of the community in the decision-making process is essential to, but in no way a guarantee of, a successful project. A successful project is one which satisfies the sanitation needs of the people for whom it is built.

A minimum level of service for a central facility might be a simple watering point from which people can obtain safe water to drink. This single service may be appropriate for some communities based on the above considerations. It is discussed in detail in Section 6.

Other services to be considered include providing a place to wash and dry clothes, bathing facilities, a place to safely dispose of honeybucket and other wastes, toilets and wash basins. Saunas can supplement the use of showers, but local custom, and willingness to use them and pay for their use, must be carefully considered before they are installed in the facility. Figure 11-1 from Brown, et al [1] shows a floor plan for a typical central facility. Table 11-1 lists the services provided in 14 typical central facilities constructed in Alaska.

Central facilities often may be constructed as the first installment on a more complete system. Therefore, each central facility should be designed so that its basic water supply and wastewater treatment systems can be expanded to provide increased service. Typical expanded services might be a haul system, or in some cases, a water and sewer system piped to individual houses.

Whenever possible, arrangements should be made for the central facility to serve or be served by other major community facilities such as schools, health clinics and power generating facilities. The revenue produced by serving these facilities can be substantial and provide stability to the income derived from community use of the central facility. Also, the use of electricity and waste heat from community or other large power plants can result in fuel savings and significant increases in overall system efficiency.

Experience with central facilities has been limited to communities between about 25 and 600 people. Most of the facilities have been one or two storey structures with between 80 and 325 square metres of total floor space. Roughly half the space is used directly by the consumer, while the mechanical operations, storage space and operator work areas account for the remainder. Typical central facilities are illustrated in Figures 11-2 and 11-3.

When facilities are constructed in remote areas of the North, where the climate can be exceedingly unforgiving and where electrical power service may be unreliable, the most important design criteria are to simplify construction and operation, and provide a high degree of reliability. Unfortunately, this is easier said than done. To deal effectively with the harsh climate and with some of the difficult water supply and waste disposal problems encountered in the Arctic, some degree of complexity is frequently unavoidable.

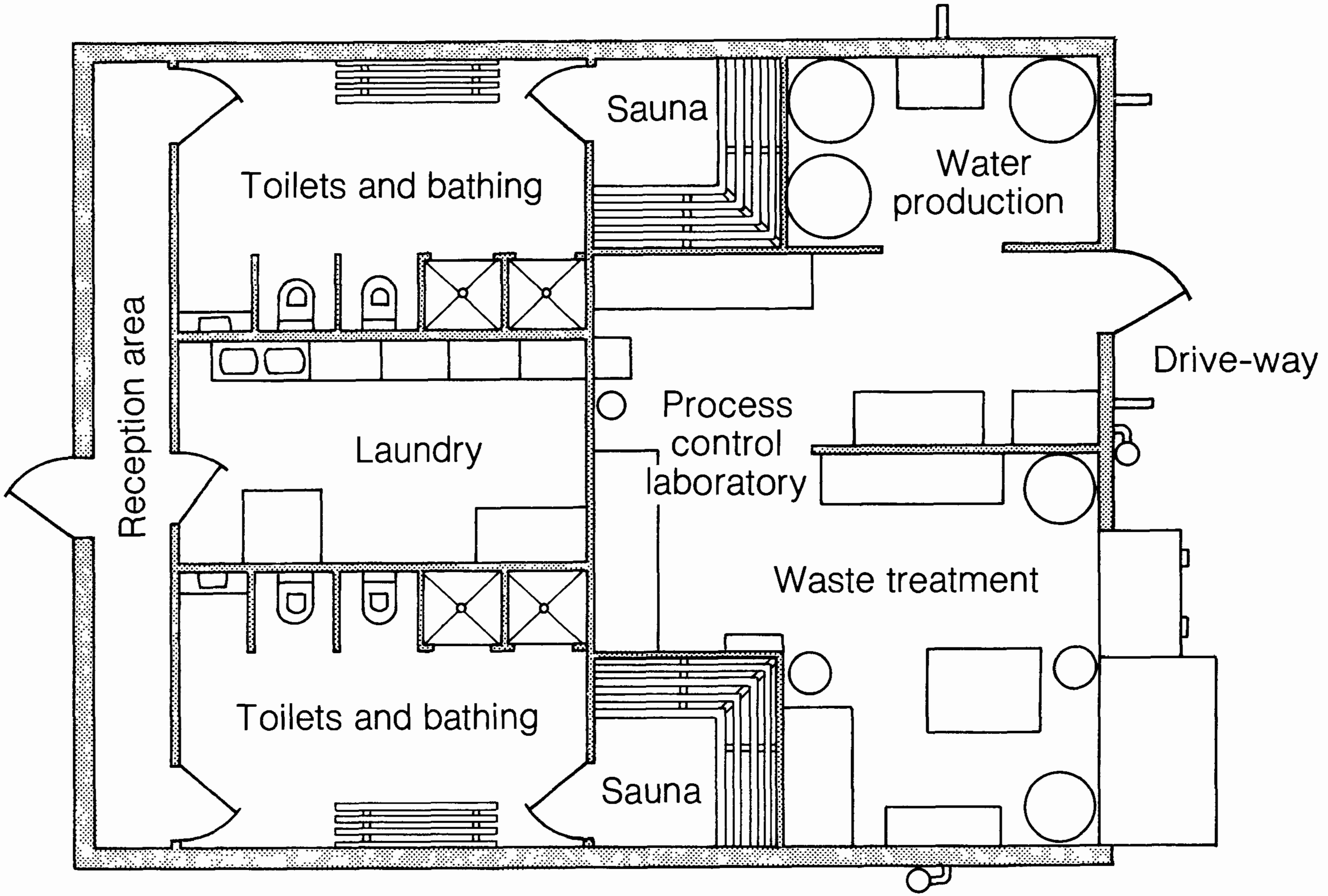


FIGURE 11-1. ENVIRONMENTAL SERVICE MODULE [1]

TABLE 11-1. CENTRAL FACILITIES IN ALASKA: SERVICES PROVIDED

Community	Population	Water Point	Washers	Dryers	Showers	Toilets	Saunas	Incinerator	Honey-bucket Dump	Other Facilities Served
Wainwright I*		yes	4	4	8	8	2	yes	yes	Schools
Wainwright II	341	yes	4	5	8	8	2	no	yes	Schools
Emmonak	545	yes	4	3	8	6	2	yes	yes	Schools, Community centre
Northway	40	yes	3	3	2	2	no	no	no	Clinic
Chevak	447	yes	3	3	2	0	no	no	no	Clinic
Nulato	330	yes	4	4	4	6	2	yes	yes	School, Clinic
Selawik	521	yes	4	4	4	6	2	yes	yes	School, Clinic
Alakanuk	512	yes	4	4	4	6	2	yes	yes	School, Clinic
Pitkas Point	85	yes	3	3	4	4	2	no	yes	School
Koyukuk	124	yes	3	3	3	3	no	no	yes	School
Beaver	101	yes	3	3	3	3	2	no	yes	School
Kongiganak	200	yes	4	4	6	4	no	no	yes	School
Tanana	450	yes	6	6	8	4	no	no	yes	School
Council	25	yes	no	no	no	(privies) yes	no	no	no	none

*Wainwright I was destroyed by fire in 1973.

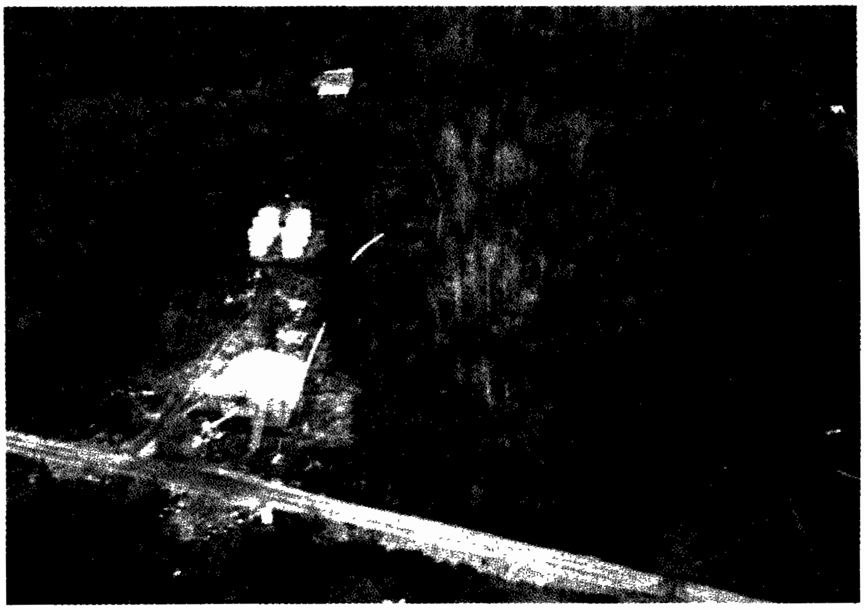


FIGURE 11-2. AERIAL VIEW OF CENTRAL FACILITY

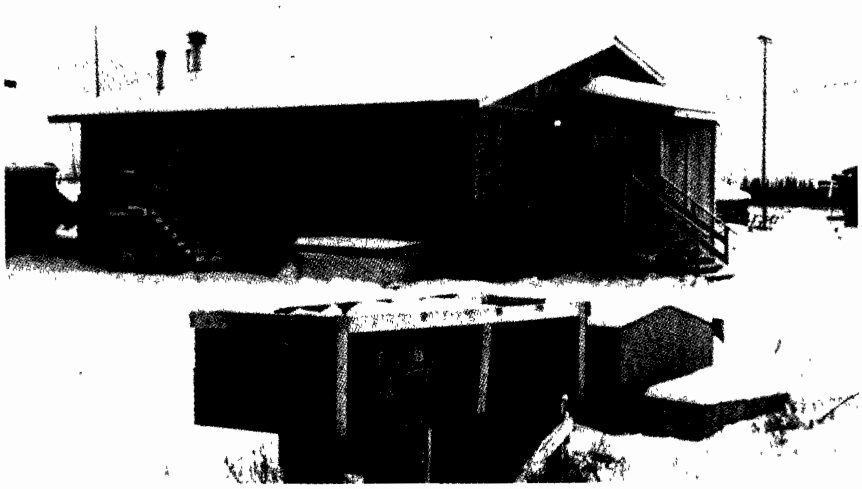


FIGURE 11-3. GROUND VIEW OF CENTRAL FACILITY

11.2.2 Design population and flows

Specific design criteria for the services selected are as varied as the communities. First, the design population, water supply requirements, and the amount and type of wastewater must be considered.

The following example, from the Alaska Department of Environmental Conservation (ADEC) [2], is presented to illustrate one way to estimate these design criteria. The approach was used to design a central facility for the small community of Pitkas Point on the lower Yukon River in Alaska. (Minor modifications have been made in the example for this manual.)

The community had a population of approximately 80 people. There were about 15 houses within a radius of 0.5 km. A small creek by the community provided a good, reliable source of water. There was a one-teacher school located near the centre of the community. No permafrost existed and soils were generally silty sandy gravel with a water table over 7 m deep. Electrical power was available from the nearby community of St. Marys and a good gravel road connected the two; no other utility services were available. Water was carried in pails from the creek to the homes and honeybuckets were dumped into the Yukon River.

Allowing for growth, the following assumptions for design populations and per person loadings were used:

- 120 people and 20 families @ 10 L/person/day;
- one teacher plus a family of three @ 375 L/person/day;
- 40 students @ 60 L/student/day;
- one honeybucket per family/day @ 20 L/bucket and 50 000 mg/L BOD loading (includes some grey water);
- two showers/person/week;
- three water closet uses/person/week (assume low water use toilets);
- one washer load/family/day.

Daily water flows were determined as follows:

Laundry: 20 x 160 L/use	=	3 200
Showers: 120 x 2/7 x 120 L/use	=	4 115
Water Closets: 120 x 3/7 x 15 L/use	=	475

Teacher (and family):	4 x 375 L/person	= 1 500
Students:	40 x 60 L/person	= 2 400
Honeybuckets:	20 x 20 L/family	= 400
Miscellaneous:		= 375
Subtotal (wastewater)		= 12 365 L/d
Offsite use:	102 x 10 L/person	= 1 200
Subtotal		= 13 565 L/d
Total Water Consumption (less honey-bucket wastes) = 13,565 - 400		= 13,165 L/d

Based on the assumptions and calculations outlined above, a water supply rate of 14 000 L/day and wastewater flow of 13 000 L/day were selected for design purposes.

At the present time no definitive studies exist to provide the designer with exact criteria on water supply and waste flows for central facilities. Until such data can be obtained from existing and future central facilities, rational approaches to arrive at these design criteria, such as illustrated above, can be used.

11.2.3 Selecting and sizing services

Selecting sizes and types of service (showers, laundry, saunas, sewage dump station, washrooms, etc.) must be done on a case-by-case basis. Careful consultation with people in the community (perhaps even with the use of a well designed, administered and interpreted questionnaire [3]) is essential to providing the best possible service. The questions that must be answered include: How many hours per day and per week will the facility be open? How often will people use the services provided per day and per week? How much are the people willing to pay for the services? Given the community responses to the questions, some design estimates can be made.

One formula used by ADEC [3] for determining the number of units (showers, washers, and dryers, etc.) is as follows:

$$\text{NUMBER} = \frac{\text{uses/week} \times \text{cycle time/use}}{\text{time available/week}} \times \text{P.F.} \qquad (11\text{-}1)$$

where: P.F. is a peaking factor to account for the fact that use of a service will not be spaced evenly throughout an entire week. Typical P.F. values for design might range between 1.5 and 3.5.

11.2.3.1 <u>Washers</u>. Commercial washers should be used. They range in capacity from 6.8 kg (weight of dry clothes that can be placed in them) up to about 15.9 kg. An average washer cycle is about 40 minutes including loading and unloading time. Smaller units are significantly cheaper, but larger ones can handle bulky items such as sleeping bags, small blankets, and parkas, and have proved particularly useful.

Horizontal axis washers, and especially washer-water extractors, tend to vibrate during use [4]. It is, therefore, necessary to provide a solid base such as concrete or heavy timbers to prevent the vibration. Vertical axis washers do not vibrate as much, but they are normally available only in smaller sizes. Top loading vertical axis washers also use about 40% more water than the front loading horizontal axis machines for an average wash load [5].

Past facility designs have frequently used two loads/family/week to estimate the number of washing machines needed. In smaller communities where the facility will be conveniently located, designs of one load/family/day have been used. As noted earlier it is important to seek guidance from the community involved to arrive at a suitable use factor. As a practical matter, a minimum of three washers and three dryers should be provided, regardless of community size. This will enable service to continue on a more or less uninterrupted basis when one or more of the machines is out of service. Dependability of service is important to user satisfaction with the central facility. Also, the units should be installed so that they are readily accessible for maintenance and repair.

11.2.3.2 <u>Dryers</u>. There are many types of dryers available: hot water, electric, steam, hot air, and hot liquid. It is difficult to choose the "best" type for a particular application.

Electrically operated dryers are the easiest to maintain but they are also the most expensive to operate. According to ADEC [2], electrical energy can cost over ten times as much as that derived from bulk fuel oil. ADEC [3] calculated that for an 8.2 kg capacity dryer requiring 21.6 MJ/h (5.9 KW), 45 minutes/load and \$0.056/MJ (\$0.20/KWh), a very low electrical cost in remote areas, the electrical cost for heating alone would be \$0.89/load. Comparable heating costs using oil were calculated to be about \$0.11/load.

Hot water has been used for dryers in several central facilities with satisfactory results. One major disadvantage of hot water is the likelihood of broken or damaged pipes and heat exchangers in the event of freezing. Hot water as a source of dryer heat is also of marginal quality. In order to provide sufficient heat to the dryers, the hot water system must be operated at its upper limit for temperature and pressure. This increases the chance of vapour locks in the system due to "flashing". Hot water dryers are not commercially available, although steam operated dryers can be used with virtually no modification. The primary advantage of hot water dryers is that they can be run directly off of a single hot water furnace, which may also provide building heat and a domestic hot water supply. Also, remote community operators are generally more skilled in the operation of hot water heating systems than steam heating systems.

A hot air furnace with appropriate duct work can provide dryer heat. Such a system requires one less heat exchanger and is not damaged by freezing, but ducting must be well insulated to reduce heat losses and, most important, an extra furnace is required [3]. Advantages and disadvantages of separate <u>vs</u> multipurpose furnaces are discussed in Section 11.2.7.3. Dryers heated by hot air furnaces are not commercially available, but typical electric dryers can be converted readily for this application.

Steam operated dryers would appear to be a good choice because of the excellent heat carrying capacity of steam. However, few people in the remote areas are familiar with the principles and operating characteristics of steam systems. In addition, the relatively high operating temperatures and pressures require more maintenance. Freezing can damage steam dryers (although the potential is somewhat less than with hot water) and the heat exchanger coils tend to require frequent cleaning to maintain efficiency.

Hot organic fluids such as "Dowtherm" or "Therminol" can also supply dryer heat [6,7]. These systems can be efficient, although they operate at relatively high temperatures (177°C). Numerous operational, maintenance, and safety problems can occur, particularly if initial construction is poor [5]. One advantage, besides efficiency, is that freezeups do not result in damage to this type of heating system.

Experience indicates that dryers generally should be sized at least 1.5 to two times larger than the washers. This will accommodate the tendency for people to put more than one washer load in a dryer and will also account for the fact that it generally takes longer to dry clothes than to wash them. Appropriate dryer sizes can be determined after the washers are selected.

Drying cycle times vary with the type of system used. Manufacturers' literature can provide this information. For hot water systems, the cycle time will be about 45 minutes. An additional 10 minutes to load and unload clothes can be used when estimating total cycle times.

There are many acceptable brands of washers and dryers readily available on the market. After the type and size of equipment have been selected, the choice of model should be based on the availability of spare parts and the range of sizes available.

11.2.3.3 Showers. The number of showers required can be estimated using Equation 11-1. The showers normally should be divided between men's and women's shower rooms. Previous designs have frequently used two showers/person/week for usage rates and an average use time of about 10 minutes.

Because of the great expense of heating water, shower flows should be limited to the extent practicable. Inaccessibility of a water source and difficult treatment requirements will also dictate the need for water conservation. Timers, flow regulators and flow shower heads are the most useful devices for conserving water. Reid [6] reports adequate and satisfying showers using only 23 L/shower with these devices. Conventional shower heads use about 25 L/minute, while low flow shower heads with flow rates of 5 to 12 L/minute are readily available at a cost of approximately $10 [5].

Minuse Systems Inc. [8] reports a device which can give an adequate shower using only 1-2 L/minute. The special shower head mixes water with air from a small electrically operated blower to create a fine stream effect. A glass or rigid door is required for the shower stalls. The increased complexity and cost of this system must be compared with the apparent water and energy savings. Alternatively, with a simple self-closing hand-held shower unit, developed by the U.S. Navy, an adequate shower can be obtained with only 10 L of water [9]. More detailed information is available in Appendix B.

11.2.3.4 Saunas. Early central facilities included saunas primarily as a means to reduce water consumption, based on the premise that actual "bathing and cleansing" would take place in the sauna and the showers would then be used simply to rinse off. Since saunas use virtually no water, savings were anticipated to be substantial. However, experience has shown that persons taking saunas take showers not only to rinse, but to cool off as well.

The other reason saunas were included is that they are a part of the native culture in many southwest Alaska communities. In those communities where saunas are not part of the local custom, they are not used enough to justify their installation. If not used, saunas do not generate enough money to pay for operation and maintenance. Reid [6] reports that saunas consumed 14.2 percent of the total fuel used in the central facility at Emmonak, Alaska.

Nevertheless, the saunas in the central facilities at Emmonak, Alakanuk, and Pitkas Point in Alaska are extremely popular and successful. Saunas are a local custom in these communities and the people are attracted to the central facilities to use the saunas and socialize. These saunas produce substantial revenue; for example, in Alakanuk and Pitkas Point, approximately 2/3 of the total revenue from the village is attributable to use of the saunas. These people are clearly willing to pay the cost of providing the sauna service, and more.

Saunas represent a special challenge because it is very difficult to provide the high quality of heat needed to make them operate satisfactorily. Saunas constructed in central facilities so far have used sauna stoves as a source of heat except for one that has used waste heat from an incinerator [4]. Electric sauna stoves are the easiest to maintain; however, they can be prohibitively expensive to operate. Also used are fuel oil fired sauna stoves. They perform adequately and are reasonably efficient, but can be a safety hazard. Overheating can cause cracks in the fire box allowing fumes to escape into the sauna room.

One promising concept uses hot water from the central building heating system in series with an electric heater. The bulk of the heating needs can be provided by the low cost oil-fired system. The electric heater must only provide the small increment of heat which is not available from a conventional hot water system.

With a regulated heat source and plenty of insulation, the cost of operating a sauna can be reduced. Maintenance, of course, is negligible other than that needed for the heating source.

11.2.3.5 Restrooms. Most central facilities providing more than just a simple watering point also should provide restrooms. There should be separate men's and women's restrooms, each with lavatories and toilets. Equation 11-1 can be used to derive the number needed. In central facilities serving large communities, urinals should be provided for the men's room.

Lavatories are not unique to central facilities and need little discussion except to suggest that where water is scarce or expensive to treat, they should have automatic closing valves.

Where water is readily available at low cost, flush tank toilets are appropriate. They are simple to operate and require no additional power source. Nevertheless, conventional flush toilets which use an average of 20 L/flush are unnecessary. Flush toilets which operate on the same simple principles as the conventional variety but use only about 3 to 12 L/flush are readily availalbe [5, 10]. For virtually the same operation and maintenance costs, considerable savings can be realized over procuring, treating and pumping the water, and treating and disposing of the wastewater.

Where water is in short supply, or procurement or treatment costs are high, other types of toilets should be considered. One such toilet has a vacuum rather than gravity collection system and only uses about 1.5 L/flush [5]. Recirculating chemical toilets use only about 10 to 30 L of water per 150 flushes [5]. The contents of the recirculating toilets can be transported to the treatment system by vacuum, gravity, or manually. Substantial water savings can be realized with these systems, but there are chemical costs and mechanical systems to be maintained. Units are available which flush mechanically or electrically. Reid [7] concluded that recirculating toilets installed in central facilities were of poor design for the application and were fragile. Refer to Appendix B for details on available toilet units.

11.2.3.6 Water storage. Central facilities should have storage capacity for treated water. Depending on the reliability and availability of the water source, water source flow capacity, and fire flows, storage may range from less than one day's to nine months' design flow. The amount of storage should be sufficient to ensure a minimum level of service for the duration of any anticipated power outage or equipment breakdown. Storage capacity amounting to about one day's total design flow has been used frequently for central facilities where water sources are reasonably available and water treatment requirements are not unusually difficult. Water conservation will ensure several days reserve to provide minimum services such as drinking water supply and showers. Details for sizing and designing water storage systems are contained in Section 5.

11.2.4 Space considerations

Lack of sufficient space has been a serious problem in previous central facilities. The early emphasis on saving space resulted in problems for both operators and users of the facilities. Equipment and facilities were squeezed together so much that vital repair and maintenance functions could not be performed without major efforts to move piping and equipment. Inaccessibility breeds frustration and inattention by operators and necessary maintenance routines are not performed.

Vital components must be easily accessible. Piping must be arranged so it does not interfere with basic maintenance and repair functions. Critical piping joints should not be located in walls. If they must be placed in walls, then removable panels should be provided for easy access. In addition, cramped space in the user's portion of the facility discourages use.

One of the more frequently overlooked space requirements for central facilities in remote areas is storage space. Transportation of bulky items like chemicals and general supplies to many remote communities is often limited to once per year. Hence, storage areas need to be sized to accommodate this quantity of supplies. Another often overlooked requirement is space to work on pumps and motors and to perform other general repair and maintenance functions. Table 11-2 shows the distribution of space among services and operating functions in a typical central facility with average water supply and wastewater treatment requirements.

TABLE 11-2. DISTRIBUTION OF SPACE IN A TYPICAL CENTRAL FACILITY

SPACE	PERCENT OF TOTAL
OPERATION	
Chemical/materials storage	10
Operator repair/office	10
Water treatment	5
Wastewater treatment	10
Heating/ventilating	5
Subtotal	40
SERVICE	
Laundry	25
Sauna/shower	15
Restrooms	10
Subtotal	50
MISCELLANEOUS	10
TOTAL	100 percent

11.2.5 Water supply and treatment

A central facility must provide water that is chemically and bacteriologically safe, which is more convenient than other sources, and which tastes and appears better than alternate sources. Providing the degree of water treatment to meet these requirements is essential if the facility is to be used.

The central facility concept has some options for water supply and treatment that are not normally available to piped utility systems. For example, where good water is scarce or treatment is difficult, the central facility can use a small system for potable water only (showers, lavatories and drinking). Other needs for toilet flushing and laundering might be met with recycled water or water of less than drinking water quality.

Special effort should be made to ensure the best raw water quality possible before it is brought to the central facility for additional treatment prior to being used. For example, an infiltration gallery might be used, where appropriate, to provide a minimum level of pretreatment and reduce the need for more extensive in-house treatment.

Otherwise, water supply and treatment requirements for central facilities are not particularly unique compared with other water supply needs in the Arctic. Details on water supply and treatment systems are discussed in Sections 3, 4 and 6.

11.2.6 Wastewater treatment and disposal

Detailed wastewater treatment and disposal alternatives are discussed in Sections 9 and 10. These alternatives, with modification, are appropriate for central facilities. For example, special consideration must be given to treating laundry wastes, large variations in influent temperatures, foaming, shock loads from honeybucket wastes, and the fact that, hydraulically, flows will be limited to the operating periods of the facility unless other users, such as schools, are serviced.

A major portion of the wastewater flow in a typical central facility will come from the washing machines. Laundry wastewater resembles domestic wastewater in many ways (see Table 11-3) [11] but it does not contain all of the essential nutrients to sustain the organisms necessary for effective biological treatment. This problem can be overcome by adding domestic wastewater from toilets and honeybuckets, and by serving other facilities such as schools.

TABLE 11-3. TYPICAL LAUNDRY WASTEWATER CHARACTERISTICS

Substance	Range (mg/L) Minimum	Average	Maximum
ABS	3.0	44.0	126.0
Suspended Solids	15.0	173.0	784.0
Dissolved Solids	104.0	812.0	2064.0
COD	65.0	447.0	1405.0
Alkalinity	61.0	182.0	398.0
Chloride	52.0	57.0	185.0
Phosphates	1.4	148.0	430.0
pH	5.1	--	10.0
Nitrates	--	1.0	--
Free Ammonia	--	3.0	--
Sulfates	--	200.0	--
BOD*	80.0	1260	371.0
Temperature*	20°C	21°C	22°C
Coliforms*	--	2000/100 ml	--

*Based on data reported by Aulenback, et al [11].

Sudsing detergents can cause excessive foaming. The use of low suds detergents is essential to control this problem. Large temperature variations due to laundry (hot), toilet flushes (cold) and showers (warm) can be upsetting to treatment systems.

Central facilities should be designed to handle honeybucket wastes, but experience shows it is very difficult to get people to use it for that purpose. Many people seem to be self-conscious about carrying their own honeybuckets to the central facility for disposal and prefer, instead, to dump the wastes near their homes. Figure 11-4 shows a typical honeybucket dump station in a central facility.

A large flow equalization system is essential to overcome treatment problems due to flow variations. Where package sewage treatment systems are used, the rule of thumb for conventional design is 10-20 percent of the average daily flow volume. For central facilities where the entire flow can be assumed to come in 10 hours or less, it could be necessary to provide holding capacity for over 50 percent of the average daily flow for proper equalization. Therefore, for design purposes the flow should be spread over a 24-hour period (at least for small biological package treatment systems). The volume of the equalization system depends on the actual flow regime, with at least 50 percent of the average daily flow volume being needed in many, if not most, cases. In addition, multiple package treatment systems in parallel can often be used effectively to handle large variations in flow.

Data on the characteristics of wastewater from central facilities are very limited. Nevertheless, data from three facilities which provide all services offered in central facilities in addition to servicing adjacent schools suggest that BOD, COD and total solids are roughly 300 mg/L, 700 mg/L and 1600 mg/L, respectively [4]. Suspended solids ranged from about 400 mg/L to 1365 mg/L, with no apparent reason for the higher value which was an average of five samples.

Treatment of wastewater at central facilities can consist of any of the conventional techniques, including lagoons, aerated lagoons, lagoons with pretreatment (such as simple aeration), biological extended aeration and physical-chemical. Even wet oxidation has been suggested for remote military camps by Brown et al [1]. No single technique can be recommended. Once effluent standards are established, however, the system which offers the least operation and maintenance requirements should be used where possible.

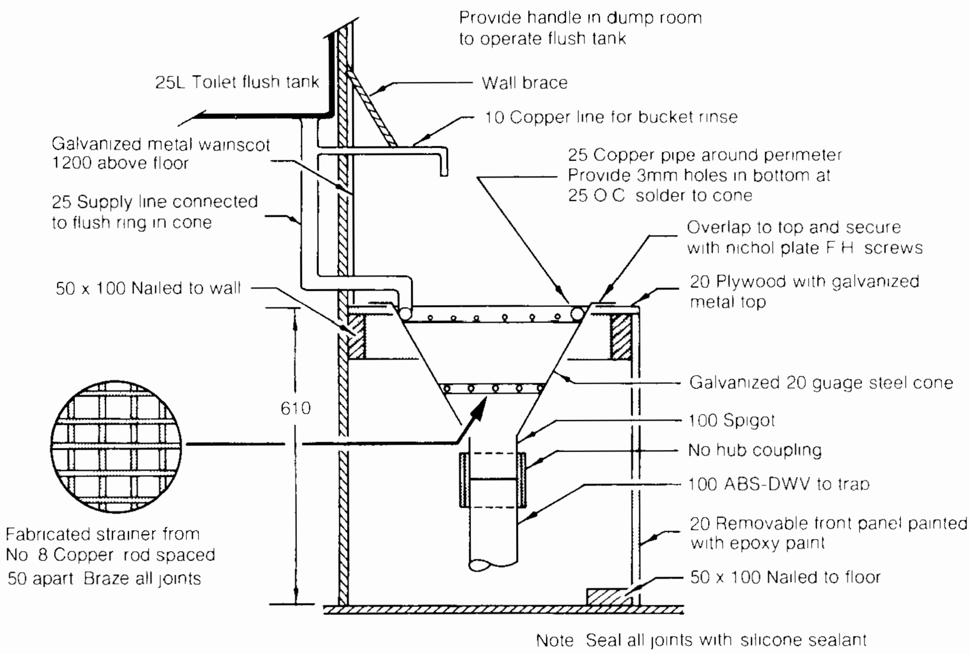


FIGURE 11-4. TYPICAL HONEYBUCKET DUMP STATION

Puchtler et al [4] concluded that the cost of operating and maintaining water-related utilities in rural Alaska is directly related to the level of waste treatment provided. Although costs can be substantially higher for complex wastewater treatment systems, the Alaska Department of Environmental Conservation operating experience suggests that wastewater treatment is not a major factor when compared with the total cost of providing the other services in a central facility.

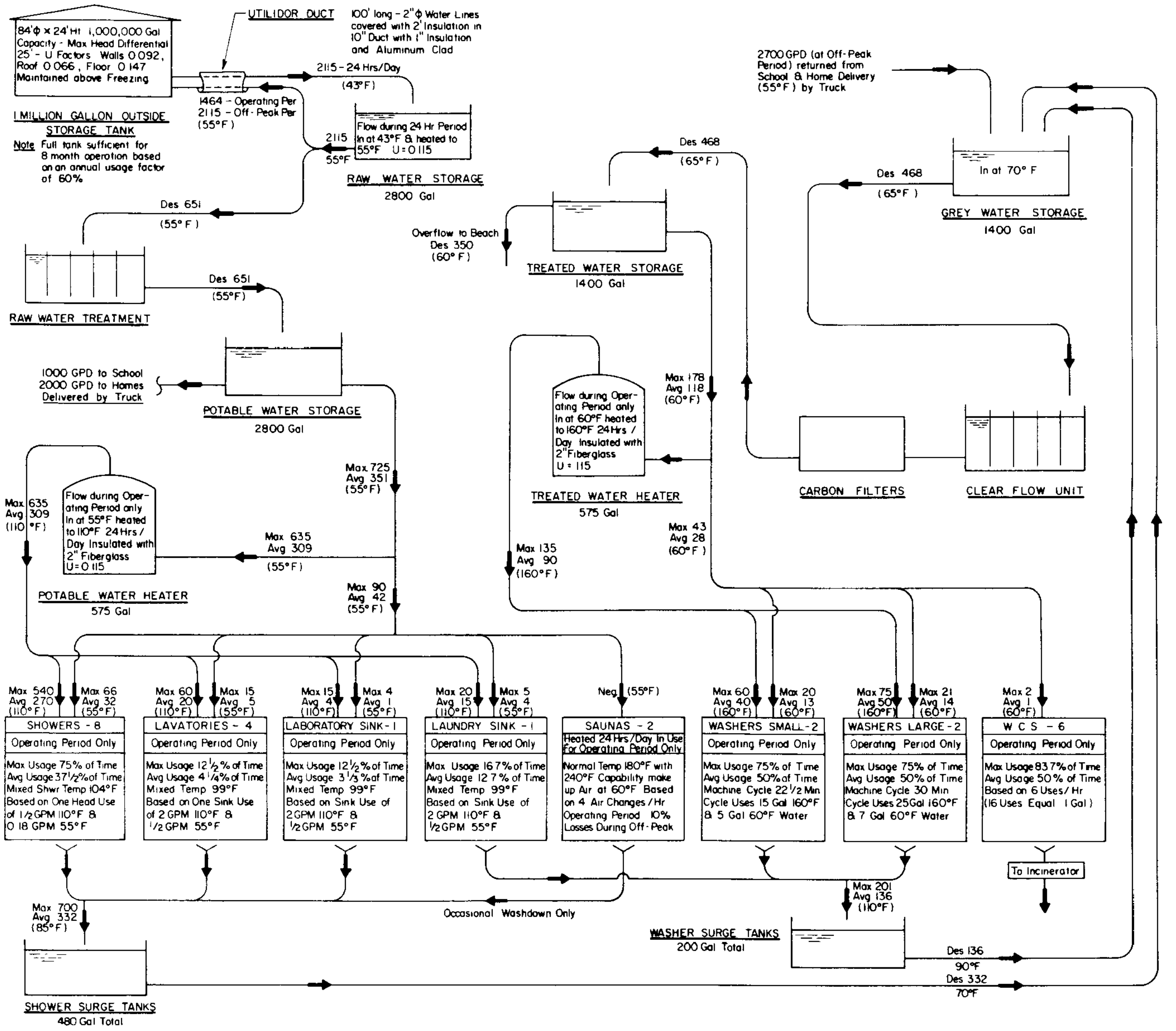
11.2.7 Energy Conservation

Section 14 provides details on this subject. The following discussion pertains primarily to those aspects of energy conservation related to central facilities. Figure 11-5 shows a detailed energy balance diagram for a central facility at Wainwright, Alaska, using several energy conservation techniques.

11.2.7.1 Electrical power. A dependable source of electrical power is a critical ingredient in operating a central facility in remote areas. Seldom, however, do the small communities in cold climates have reliable sources of electricity, due primarily to the difficulty of operating and maintaining diesel-powered generator systems. In many communities, operators are poorly paid and funds are rarely sufficient to support even minimum preventive maintenance routines. Other communities do not have a source of electrical power and it must, therefore, be provided as part of the central facility.

In all cases, standby power is essential. A standby source of power for building heat would be the minimum acceptable. Capability to provide the other central facility services is based on the importance of the service to the community and judgement on the reliability of the primary electrical energy source.

Electrical power in remote areas frequently varies greatly in voltage and frequency. Such fluctuations reduce the useable life of electrical high and low voltage and frequency protectors. Here again, however caution must be exercised. Rarely can the operators of central facilities repair or adjust these electrical controls without training and assistance. Skilled electricians must sometimes be sent to the community to perform necessary repairs. This is a significant disadvantage of



1. The operating period is defined as 10hrs per day, 7 days per week The off-peak period is the remaining 14 hrs per day
2. Water flows are indicated beside the flow lines All flows are in G P H unless otherwise stated Maximum is the flow to be expexted in any one hour during the operating period and is used for the design of individual units Average is the flow to be expected over the 10 hr operating period and is used for the overall system design Design is the avg uniform flow to maintain & operate the system
3. Additional design criteria is given inside the illustrated equipment boxes
4. Area heating calculations are based on
   Outside ambient at -30° F
   Minimum outside temp -56°F
   Building U-factors (all U-factors in BTU/°F/ft^2/hr)
   Inside walls = 0 306 , Ceiling = 0 036
   Outside walls = 0 057, Floor = 0 030
   Sauna U-factors
   Inside walls = 0 073, Ceiling = 0 025
   Outside walls = 0 033, Floor = 0 030
   Drive thru U-factors as for building
   The community complex area (washrooms, laundry, entrance & center hall) is heated directly The drive thru area is to be heated with a standard type unit heater The raw and threated water areas are heated both directly by the community complex area heater and indirectly by heat transfer from process The incinerator area is heated indirectly by heat transfer only
5. This flow sheet is intended only as an overall criteria guide and does not indicate such items as pumps, valves etc

HEAT DATA IN BTUs / HR

Heat Use	Operating Period	Off Peak Period	Unit Design
Dryers	140,000	—	105,000 (210,000)
Community Complex Heater	151,600	24,750	183,000
Treated Water Heater	76,900	1,900	168,600
Potable Water Heater	143,500	1,900	218,200
Raw Water Tank Process (67,180) Outside Storage (140,700)	207,880	142,680	265,300
Saunas	24,190	6,020	25,600 (51,200)
Drive Thru Heater Future	12,980	4,430	17,900
Total	757,050	181,680	N A

DRYERS - 2

Operating Period Only

Max Usage 100% of Time Avg Usage 66% of Time Each Dryer Uses 950 SCFM Air at 160°F when operating

DRIVE THRU HEATER

24 Hrs / Day

Based on maintaining 40°F with 2 Air Changes / Hr during the Operating Period & 10% Air Loss during the Off-Peak Period Make Up Air at Outside Ambient

COMMUNITY COMPLEX HEATER

Based on maintaining Temp in Complex, Raw Water and Treated Water Areas at 60°F 24 Hrs / Day Washroom Shower Areas to be maintained at 70°F during Operating Period Plenum Temp at 100° F 4 Air Changes / Hr during the Operating Period 10% Air Loss during the Off-Peak Period Make Up Air at Outside Ambient

FIGURE 11-5. WATER, WASTEWATER AND HEAT FLOW AVDP - WAINWRIGHT, ALASKA.

voltage and frequency protectors and must be considered carefully against the need to replace or repair damaged electrical equipment. In spite of these problems the U.S. Public Health Service and ADEC use voltage protectors because of their experience with damaging voltage fluctuations in villages.

11.2.7.2 Heat Recovery. Heat recovery is discussed in detail in Section 14. Central facilities offer a unique opportunity to capitalize on waste heat recovery because of the relative closeness and availability of heat sources within the facility. These sources may include generators, heating furnaces, building exhaust air, dryer exhaust air, incinerators and warm water. Recoverable waste heat can be used to supplement heating needs of a central facility including heat for saunas, hot water, clothes dryers, and building air. Figure 11-6 illustrates an example where 80 percent of the total energy can be recovered from a diesel generator. By using efficient heat exchanges Reid [6] estimated that it is possible to recover up to 50 percent of the net heat input to an incinerator.

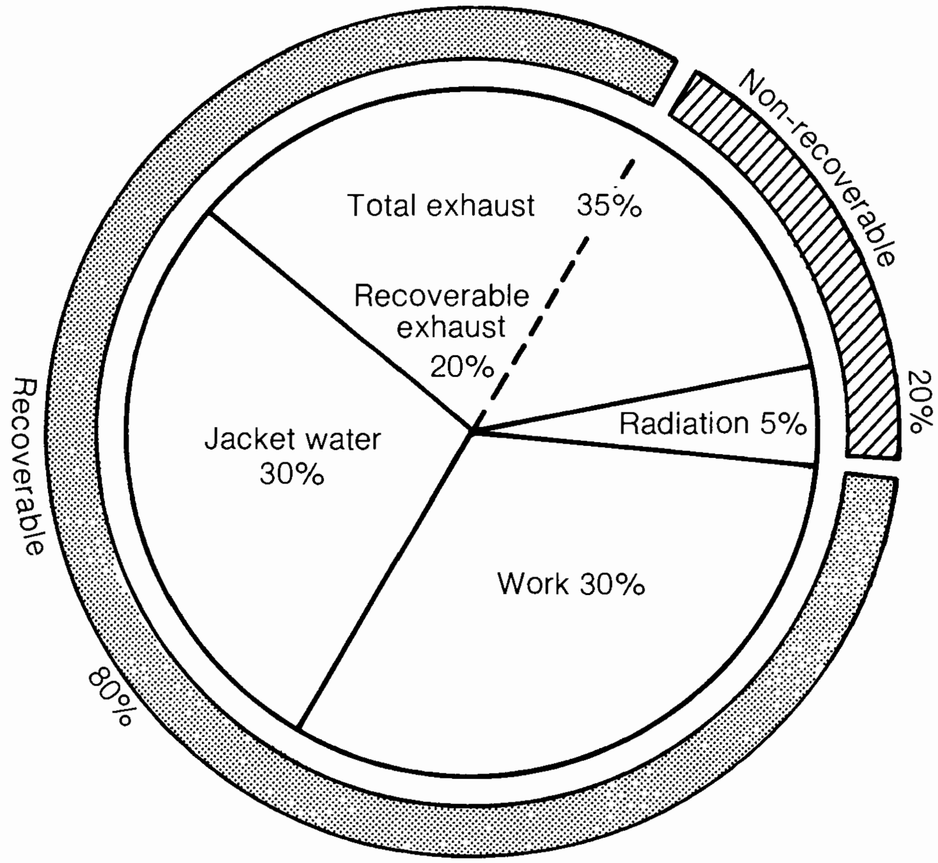


FIGURE 11-6. EXAMPLE OF ENERGY RECOVERY FROM A DIESEL GENERATOR

11.2.7.3 Heating system. Another important design consideration for central facilities is choosing a heating system. The basic questions to be answered are: What type of system is most desirable - hot water, hot air or steam? and should there be a single source of heat to meet the facilities heating needs or should there be separate sources of heat designed especially for the services where they are needed? Answers to these questions require considerable analysis of the heating needs and the relative difficulty of maintaining the desired level of service in a central facility. Nevertheless, the following is provided for general guidance to the designer.

a) Choosing the type. Hot water heating systems are the most popular in remote areas, probably because they are better understood than other systems. With proper maintenance they can be as serviceable as other choices. The primary disadvantage of a hot water heating system is its potential for damaging piping systems during facility freeze-ups. Also, hot water systems cannot provide the high quality heat needed for saunas, and the heat available for hot water dryers is marginal. Ethylene or propylene glycol can be used with hot water. These fluids can prevent the freezing problems with hot water but they are slightly less efficient (10-20 percent) in heat exchange properties than water, require more attention in handling and maintenance, and can be corrosive.

Inhibitors can be used to control corrosion but they tend to break down at high temperatures and maintaining the proper concentration becomes another chore for operators. One way to achieve the higher quality heat for all services in a central facility and avoid damage due to freezing is to use special organic fluids instead of water or glycols. These systems operate on the same principle as hot water, but the fluids can be fairly expensive and the plumbing system must be more elaborate to handle higher temperatures. Sloppy installation of the plumbing system can be difficult to repair, and faulty joints can leak hazardous fumes into the central facility [4].

Steam has a relatively high capacity to carry heat; hence, a steam heating system can readily meet all of the heating needs in a central facility. The main disadvantages of a steam system are that people in remote areas are generally unfamiliar with the higher temperatures and mechanics of steam, and the hot pressurized vapour is more hazardous. This makes operation of the steam system more difficult and results in higher maintenance costs and down time compared with hot air or hot water systems. Pipe damage due to freezing is generally limited to low points or restrictions in the piping system.

Hot air does not have the heat carrying capacity of water or steam, but it can be used effectively for dryers and saunas if separate heat sources are used and the furnace is close to the place where heat is needed. Hot air furnaces can be used for building heat also, although controlling building pressure becomes a problem, and ducting consumes more space than the plumbing for hot water systems.

b) Single versus multiple heat sources. A single heat source (e.g., one central boiler serving all heat needs) for a central facility offers simplified maintenance requirements and reduced fire hazards compared with several heat sources (e.g., separate heating vents for building heat, hot water dryers and other services). Stand-by capability for a single heat source can be partially achieved by providing complete spare burners. Control systems for distributing heat from a single source are more complex than individual control for each of several heat sources.

Multiple heat sources can be used to meet the specialized heating needs in the central facility. They can serve as back-up sources of building heat since all units are not apt to be out of operation at one time. If multiple sources are selected, compatible equipment with interchangeable parts should be used. This will reduce the need for a large spare parts inventory and make maintenance easier.

11.2.7.4 Water conservation and reuse. Fresh water is extremely difficult to obtain in many remote communities and/or complex treatment, such as distillation, reverse osmosis, or freeze-thaw techniques, may be required. In addition, energy costs to run treatment equipment and provide hot water can be substantial. Hence, every effort should be made to reduce total water use.

Where fresh water is scarce, or costly to provide, the designer should consider ways to provide water based on quality needs. For example, one can provide high quality water for drinking water fountains, watering points, showers and lavatories by using a small complex treatment system. A less complex treatment scheme may be appropriate for toilets and washing machines. Also, saline or brackish water may be adequate for toilet flushing if it is readily available.

Recycled water may be used for washing machines and toilets to conserve water [6]. However, caution should be used because of the difficulty of providing consistently good effluents from wastewater treatment systems. In practice, physical-chemical systems are capable of providing a fairly stable effluent suitable for reuse in toilets and washing machines, if they are operated properly. Biological treatment systems tend to produce erratic results and secondary effluent should not be reused unless additional treatment, such as filtration, is provided. Dissolved solids in recycled water further complicate the usefulness of this water conservation technique.

In summary, water reuse involves costly and complex treatment systems and equipment. Where they are not absolutely necessary, water conservation and reuse practices which add to the operating and maintenance cost of a central facility probably have limited value. Water reuse is not recomended unless raw water is extremely scarce or it is difficult to treat. It is usually more economical and simpler to use to flow reduction techniques to reduce consumption [9].

11.2.7.5 Incineration. Incinerators have been installed in several central facilities for the primary purpose of disposing of waste treatment plant sludges, honeybucket wastes, and other solid wastes in a sanitary manner. Incineration theoretically offers an "ultimate" solution to the problem of organic waste disposal; therefore, environmental and health effects from these wastes can be avoided. Recognizing that incineration requires a substantial amount of fuel oil, and electrical input to "burn" the relatively wet wastes, extensive efforts have been made to capture waste heat for reuse in central facilities. Figure 11-7 illustrates a typical incineration process used at several central facilities [7]. Figure 11-8 shows the relationship between fuel consumption and moisture content of solid wastes during incineration. Clearly, significant fuel

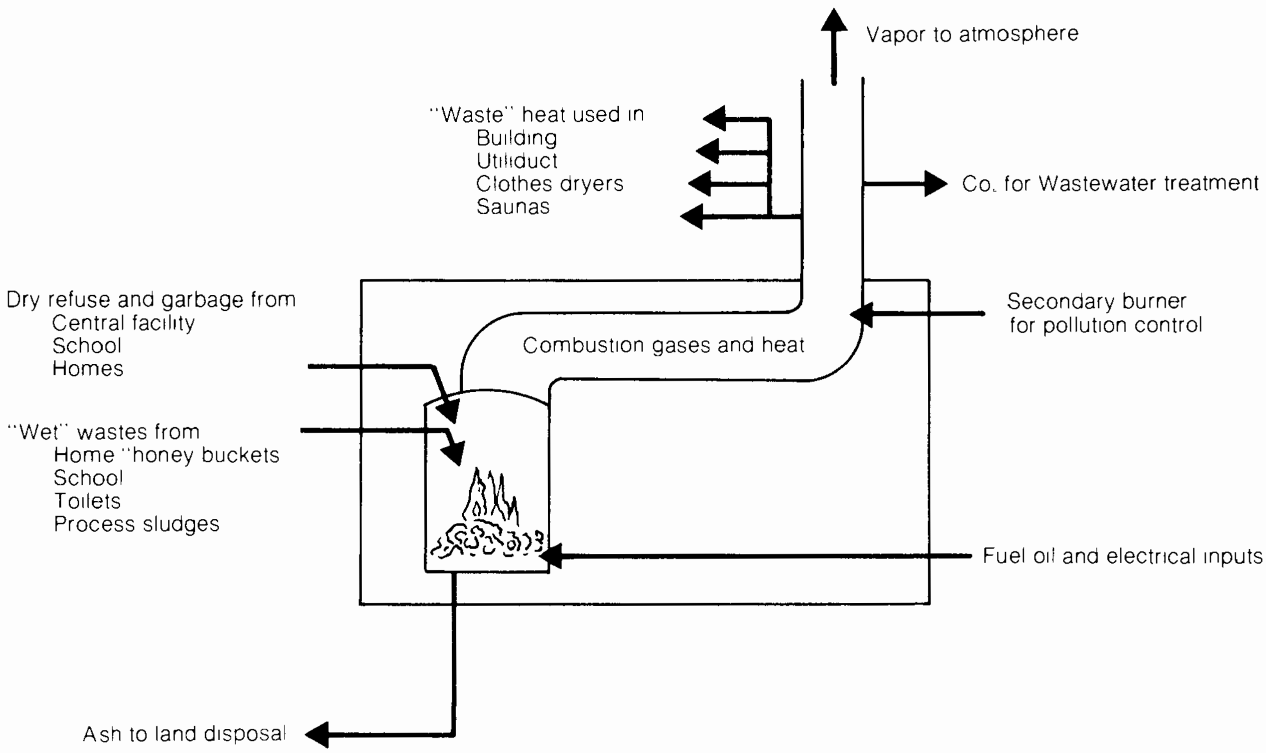


FIGURE 11-7. SCHEMATIC OF INCINERATION PROCESS

Incineration has been designed here to be integral with sewage and solid waste disposal, and building heating.

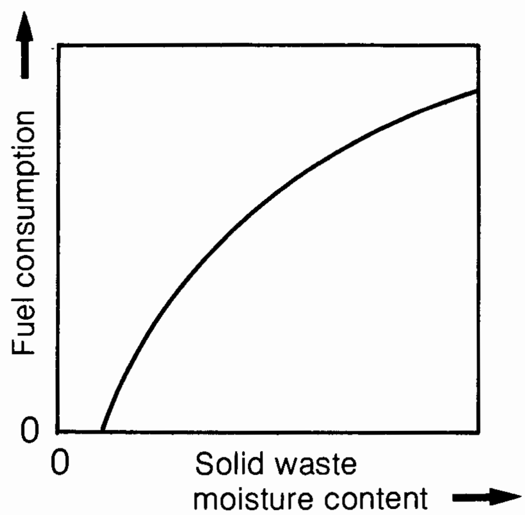


FIGURE 11-8. RELATIONSHIP BETWEEN FUEL CONSUMPTION AND MOISTURE CONTENT OF SOLID WASTE DURING INCINERATION

savings can be realized by dewatering high water content solid wastes. An optimum moisture content can be determined by comparing the cost of removing the moisture to the corresponding cost of incineration. This optimum moisture content usually falls in the range of 25 to 40 percent.

Little work has been done to establish good design criteria for incinerators in central facilities. The following information is based on limited data [7]: a heat recovery system performed at 25 percent efficiency (ability to achieve 50 percent recovery was calculated by making minor equipment modifications); the heat content (thermal value) of dewatered black water sludge ranged between 2481 calories/gram and 3808 calories/gram, based on four samples analysed; and, about one litre of fuel oil was required to "burn" 15 L of sludge.

In spite of the environmental and health benefits, incinerators have not proved very successful in central facilities. They are costly to operate and controls are much too complex for the semi-skilled operators in most small communities. On the other hand, for remote industrial camps where environmental concerns are great and costs of operation and maintenance are not so critical as for community central facilities, incineration offers excellent treatment for combustible solid waste and sludges. Section 13 provides additional information on incineration.

11.2.8 Fire protection

Conventional fire protection systems are often inappropriate for central facilities in remote communities. Unless a fire is controlled within seconds or minutes after it starts, there is little that can be done. Partial measures that can be helpful are: smoke detectors, sprinkler heads or Halon systems for critical fire hazard areas, accessible and clearly marked, and a liberal number of hand-operated fire extinguishers.

Loud sirens or alarms can be used to alert the entire community to fire problems.

Puchtler et al [4] made the following conclusion on fire protection for central facilities:

> "Providing full fire protection for public facilities in rural Alaska is unusually difficult and expensive. However, since fire is a major threat to facilities in cold climate regions, a decision not to provide this protection requires careful consideration of resources available for replacement. Insurance is generally not available except at very high premiums."

The ADEC has concluded that the level of fire protection required by fire codes designed for larger communities in warmer climates is not practical in the North. Its approach has been to provide only that level of protection which is convenient. For example, water storage tanks designed to meet the routine water supply needs for the central facility can be used to supply sprinklers. While this may not protect the entire facility according to fire codes, it makes the water that is stored available for fire suppression at least until the water is gone. Section 12 provides additional detailed information on fire protection for utilities in the cold climate regions.

11.2.9 Construction techniques

In addition to choosing the method of construction, the designer must consider whether to use preassembled modular units, prefabricated sections or precut material ready for assembly at the job site, or to "stick build" the facility on-site. Puchtler et al [4] concluded:

> "There is no single best method of constructing water-related utility facilities in rural Alaska. Local conditions, accessibility, etc., are so varied that a limited number of standard designs could not be expected to effectively meet the wide range of conditions."

The three basic options must be thoroughly analysed in relation to each specific project.

11.2.9.1 Modular. Since skilled labor in remote communities is generally unavailable, there are apparent advantages to using prebuilt component modular construction, particularly for the relatively complex systems often found in central facilities.

Among these advantages are [7]:

1) components can be built more cheaply in the South where equipment can be installed and where preassembled modular units can be tested prior to shipment north, and
2) modular units can be more economically "mass" produced.

The conceptual design for an environmental service module by Brown et al [1] stressed the importance of complete factory preassembly, testing, and debugging of modular facilities prior to shipment and installation at the site. This is confirmed by the U.S. Environmental Protection Agency which found, in its limited experience, that modular construction was not very successful, due in large part to inadequate testing of component systems prior to shipment to the field [4].

Another major consideration associated with modular construction is the tendency to compact the equipment and service areas in the modules to facilitate shipping and reduce structure costs. As stressed earlier, adequate space and accessibility to perform routine maintenance and equipment overhaul are essential, and crowded user space will discourage use of even the most needed services in the central facility.

11.2.9.2 <u>Prefabrication/precut</u>. Prefabricated buildings and component pieces of equipment have frequently been used in remote construction with good results. Advantages, compared with modular construction, include ease of shipment and minimum wasted space (crowded conditions and inaccessibility can be avoided), some flexibility to make minor changes to meet field conditions, and operators have an opportunity to become familiar with the central facility as it is being constructed. Compared with "stick-built" construction, assembly can be facilitated, fewer skilled labourers are needed at the job site to assemble complex systems, and there is less waste of materials. Precut construction is similar to the prefabrication technique and shares many of the same advantages and disadvantages except that there are more "pieces" to assemble.

11.2.9.3 <u>On-site fabrication</u>. The ADEC has had satisfactory experience with conventional wood frame construction. The main advantages are simplicity of construction and ability to use local labour. In addition, the operators selected for the facility can participate fully in the construction from the ground up. This helps them to better understand how the facility operates and will facilitate operation and maintenance functions. This technique offers the most flexibility to modify designs to meet field conditions. On the other hand, complete on-site construction can take longer and there will be more waste of materials than with the other techniques.

11.1.10 Cost factors

Table 11-4 shows construction and operating costs for three central facilities in Alaska. They represent facilities with minimum, average, and extensive degrees of complexity and levels of service, respectively.

TABLE 11-4. CONSTRUCTION AND OPERATING COSTS FOR THREE CENTRAL FACILITIES

Community	Population	Year Completed	Capital Construction Cost	Annual Operating Budget 1977*
Council, Ak	53	1978	118 000	20 000**
Pitkas Point, Ak	85	1976	350 000	60 400
Nulato, Ak	330	1976	860 000	85 700

* Does not include amortization
** Estimated

The Council facility consists of a simple watering point and three outhouses located conveniently for the village. The higher than usual construction costs can be attributed to the installation of a windmill to provide electrical power. It is backed up with a small fuel oil-fired generator. The well is about 65 feet deep and has no treatment other than provision for disinfection with chlorine. The village selected this minimum level of service because this was all they felt they could afford to operate.

The Piktas point central facility is considered to be of average complexity. It provides a watering point, secondary sewage treatment, showers, washers, dryers and saunas, and also water and sewer service to a school. It was designed for simple operation, has several redundant features to prevent freeze-ups, and was constructed using the construction management technique.

Conventional competitive bidding was used for construction of the Nulato facility. It is a very complex system electrically and mechanically. A high level of service is provided, including washers, dryers, saunas, tertiary sewage treatment, complex water supply treatment, sewer and water service to a school, watering point showers, and incinerator for solid waste and honeybucket waste disposal.

Due primarily to the fact that water supply and wastewater treatment requirements vary so much among the central facilities, dependable cost factors for estimating purposes cannot be established. The cost factors given in Section 2 may be used for general guidance, with special consideration for specific water supply requirements and wastewater treatment and disposal needs.

11.3 Remote Camps

11.3.1 History

Remote camps in the far North were used primarily to support military activities until the early 1960's. These camps were used for the military's DEW Line stations spaced across the top of North America, and for oil and gas exploration activities in the northwestern corner of Alaska. During the 1960's, private industry used remote camps in their search for oil and gas in the North. The early camps had few amenities for the workers and living conditions were crowded and often unsanitary. They served up to about 50 people.

With the discovery of commercial quantities of oil and gas at Prudhoe Bay in 1968, exploration activities virtually exploded. During the summer of 1969, a comprehensive survey of 35 active camps and 30 inactive sites on the north slope was conducted [12]. The survey found crowded living conditions, but generally good dining facilities. Twenty-three camps used electric heat and all had some form of pressurized water system. Sewage was almost exclusively dumped on the ground or into shallow pits chipped out of the permafrost. Garbage was generally dumped indiscriminately on the ground or into water bodies.

For all camps, the average consumption of water on a per person basis was estimated at 210 L/day. Eighteen sources of water were from rivers and seventeen were from tundra lakes. Most of the camps consisted of prebuilt modules which were transportable by Lockheed Hercules aircraft; a few were built on-site.

Due to concern by government, labour unions and environmental groups, industry has greatly improved remote camps and minimized their impact on the environment. Housing is comfortable; dining facilities are excellent; recreational facilities are provided; water is safe to drink; various types of package systems are available to treat sewage; and combustible garbage and sludges are incinerated prior to controlled land disposal. Recent camps have housed from 10 to over 1500 persons.

11.3.2 Facility description

Present day camps in the far North are generally quite similar in basic design and configuration. For mobile camps, geophysical crews (population 20 - 30) use prebuilt trailer modules on skids or tracks. The trailers each serve a specific purpose, including housing, dining, clothes washing/laundry, office, equipment/supply, water supply, and waste treatment. These trailers are particularly rugged and relatively small in size (approximately 2.7 m x 2.7 m x 6.8 m).

Semi-permanent camp configurations and facilities depend primarily on the number of people served. Modular trailer units can be combined with relative ease to meet specific needs. In the larger camps, recreational facilities are added to increase worker morale. Typical layouts for mobile camps and semi-permanent camps are shown in Figures 11-9, 11-10, 11-11. Permanent base camps to serve between 150 and 300 people have been constructed on-site, and by assembling complete prefabricated modules transported to the site by barge and large crawler tractors. Figure 11-9 shows one of these facilities located at Prudhoe Bay in Alaska.

A large majority of remote camps in cold climates are associated with the extraction and transportation to market of oil and gas reserves. Table 11-5 shows the types of petroleum industry related camps, populations served, and duration.

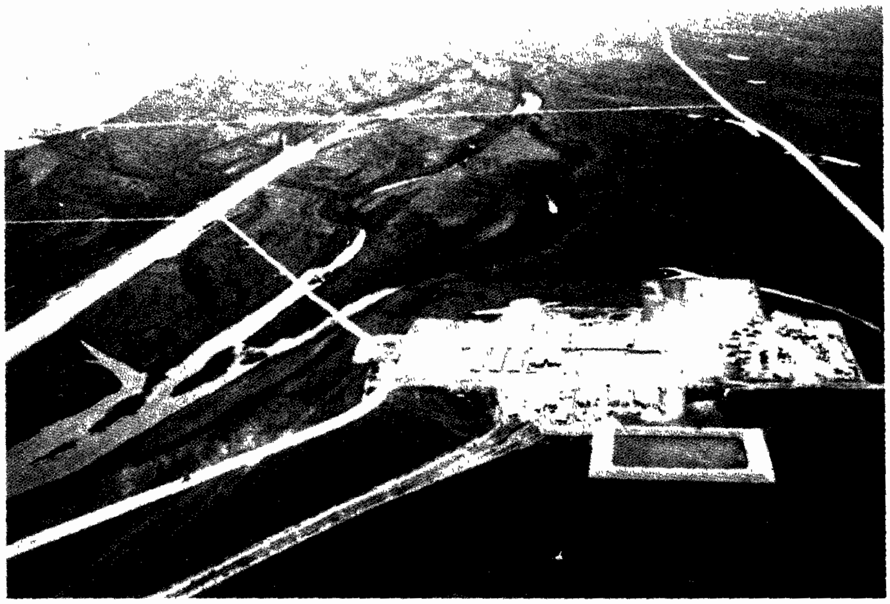


FIGURE 11-9. ROAD/PIPELINE CONSTRUCTION CAMP

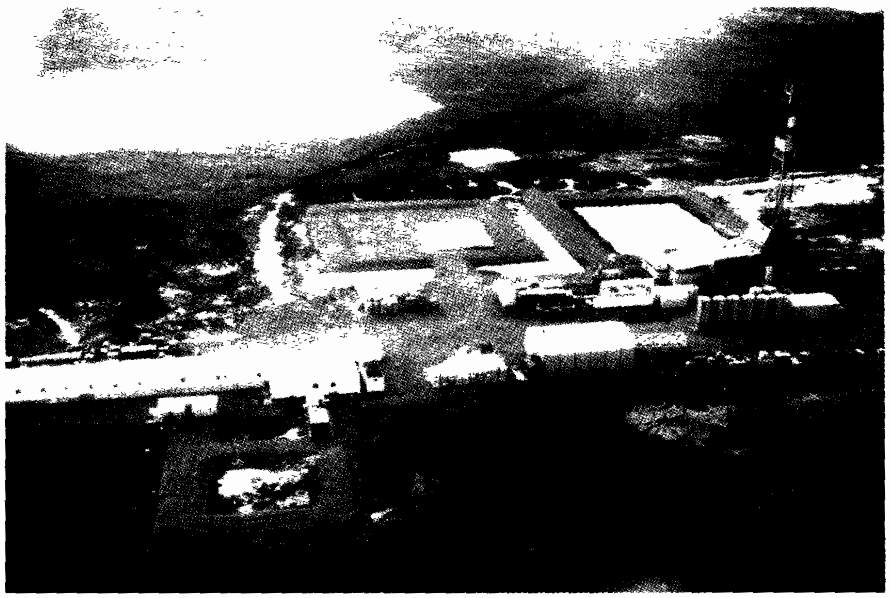


FIGURE 11-10. DRILLING RIG CAMP

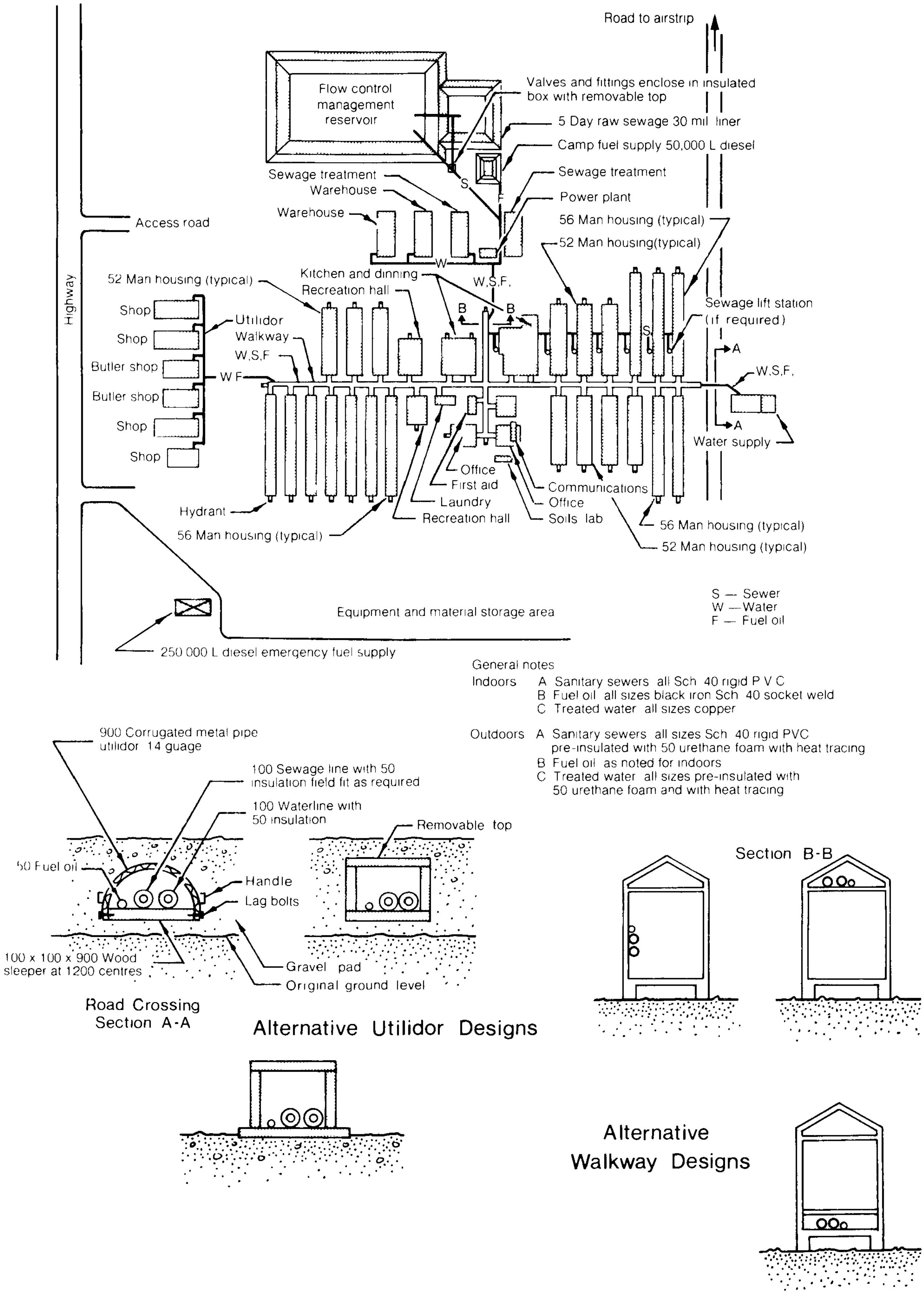


FIGURE 11-11. LAYOUT AND UTILITIES FOR A PIPELINE CONSTRUCTION CAMP

11-5. REMOTE CAMP SIZES AND DURATIONS

Type of Camp	Population	Camp Duration
Oilfield		
Exploratory	3 - 5	2 - 3 days
Geological	20 - 30	3 - 7 days (winter)
Development		
Drilling	50	30 - 90 days
Service	50 - 100	Varies
Production		
Base	150 - 300	20 years
Pipeline		
Construction		
Road	200 - 300	3 - 9 months
Pipeline	600 - 1000	3 - 9 months
Pump Station O&M	15	20 years

11.4 References

1. Brown, C.K., et al, "Conceptual Design of an Environmental Service Module", Report No. 75-01 for Defense and Civil Institute of Environmental Medicine. Ontario Research Foundation, July 1975.

2. Dowl Engineers, "Design Narrative for Pitkas Point Village Safe Water Facility", for the Alaska Department of Environmental Conservation, Juneau, Alaska, 1975.

3. Arctic Environmental Engineers, "Conceptual Design for Tanana, Alaska Facility", for the Alaska Department of Environmental Conservation, Juneau, Alaska, 1978.

4. Puchtler, B. et al, "Water-Related Utilities for Small Communities in Rural Alaska". Report No. EPA-600/3-76-104 (Ecological Research Series), U.S. Environmental Protection Agency, Corvallis, Oregon, 1976.

5. Cameron, J.J. and B. Armstrong, "Water and Energy: Conservation Alternatives for the North", Presented at Symposium on Utilities Delivery in Northern Regions, March 19, 20, 21, 1979, Edmonton, Alberta, Environmental Protection Service, Ottawa, Ontario, (in preparation).

6. Reid, Barry H., "Some Technical Aspects of the Alaska Village Demonstration Projects", IN: Utilities Delivery in Arctic Regions, March 16, 17, 18, 1976, Edmonton, Alberta, Environmental Protection Service Report, EPS 3-WP-77-1, pp. 391-438, Ottawa, Ontario, 1977.

7. Reid, Barry H. "Alaska Village Demonstration Projects: First Generation of Integrated Utilities for Remote Communities". Working Paper No. 22, U.S. Environmental Protection Agency. Arctic Environmental Research Laboratory, College, Alaska, 1973.

8. Minuse Systems, Inc., "A New Way to Reduce Household Water Use by 30%", Minuse Systems, Inc., 206 N. Man, Suite 300, Jackson, Calif.

9. Schatzbert, P. et al, "Energy Conservation Through Water Resource Management - A Reduced Flow Bathing Shower", Second National Conference on Water Reuse: Water's Interface with Energy, Air and Solids, Chicago, May 4-8, 1975.

10. Bailey, J.R. et al, "A Study of Flow Reduction and Treatment of Waste Water from Households". Water Pollution Control Research Series 11050 FKE, Dept. of Health, Education and Welfare, Washington, D.C., 1969.

11. Aulenback, D.B. et al, "Treatment of Laundromat Wastes", Report No. EPA-R2-73-108 (Environmental Protection Technology Series), U.S. Environmental Protection Agency, Washington, D.C., 1973.

12. Alaska Department of Health and Welfare, Federal Water Pollution Control Administration, Arctic Health Center, "The Influence of Oil and Exploration and Development of Environmental Health and QualityM on the Alaska North Slope", Fairbanks, Alaska, December 1969.

11.5 Bibliography

Anon, "Waste Disposal Systems for Polar Camps". Technical Note N-377, U.S. Naval Civil Engineering Laboratory, Port Hueneme, Calif., November 1959.

Anon, "Review of Polar Camp Sanitation Problems and Approach to Development of Satisfactory Equipment for a Polar Region 100 Man Camp". Technical Note N-032, U.S. Naval Civil Engineering Laboratory, Port Hueneme, Calif., August 1952.

Given P.W. and H.G. Chambers, "Workcamp Sewage Disposal, Washcar - Incinerator Complex, Ft. Simpson, NWT", IN: Some Problems of Solid and Liquid Waste Disposal in the Northern Environment, J.W. Slupsky [ed], Environmental Protection Service, Northwest Region, Edmonton, Alberta, EPS-4-NW-76-2, pp. 1-42, 1976.

Mecklinger, Sheldon, "Servicing of Arctic Work Camps". Department of Civil Engineering, University of Toronto, Toronto, Canada, April 1977.

Nehlsen, W.R., "A Development Program for Polar Camp Sanitation", Technical Note 476, Armed Forces Technical Information Agency, U.S. Naval Civil Engineering Laboratory, Port Hueneme, Calif., December 1962.

Sargent, J.W. and J.W. Scribner, "Village Safe Water Project in Alaska - Case Studies". Alaska Department of Environmental Conservation, March 1976.

Sherwood, G.E., "Specifications for a 25-Man Pioneer Polar Camp". Technical Note N500, U.S. Naval Civil Engineering Laboratory, Port Hueneme, Calif., 1963.

U.S. Defense Documentation Center, "Temporary Polar Camp Concept and Design Criteria". Technical Note N-436, Virgina, March, 1964.

U.S. Environmental Protection Agency, "Alaska Village Demonstration Projects". Report to the Congress, Washington, D.C., July 1973.

U.S. Naval Civil Engineering Laboratory, "A Temporary Polar Camp". Technical Note R 288, Port Hueneme, Calif., March 1964.

U.S. Naval Civil Engineering Laboratory, "Self Contained Sanitation Systems for 2 to 15 Man Polar Facilities". Technical Report R759, Port Hueneme, Calif, March 1972.

SECTION 12

FIRE PROTECTION

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12 FIRE PROTECTION

12.1 General

Fire prevention, fire alarm and warning systems, and methods of combatting fire in isolated northern communities present unique problems that cannot be practically resolved by superimposing southern fire codes and prevention standards.

The high cost of construction; the harsh climatic conditions (very low ambient temperatures, generally extreme winds, drifting and blowing snow); low population densities (most communities under 1000 in population, almost all with volunteer fire departments); the very long heating season; the dryness of materials and air; the generally poor community infrastructures, i.e., rough gravel roads, no piped water in most communities, little or no telephone service, are all factors which make it difficult to guard against and fight fires in cold regions.

The proposed design guidelines for fire protection given in this section are the result of experience and methods developed in the Northwest Territories, Canada, since 1970. Techniques and methods used in Alaska and Greenland are also noted.

12.2 Administration of Fire Prevention Standards

The following is a list of the governing authorities for fire prevention standards. In other northern regions or jurisdictions, local regulatory authorities should be consulted.

LOCATION	ACT (if applicable)	AUTHORITY
Northwest Territories, Canada	Fire Prevention Ordinance	N.W.T. Fire Marshal, Government of the N.W.T., Yellowknife, N.W.T.,
Yukon Territory, Canada		Yukon Fire Marshal, Government of the Yukon, Whitehorse, Yukon
Alaska, U.S.		State Fire Marshal's Office, Dept. of Public Safety, Juneau, Alaska 99811

12.3 Codes and Guidelines

Codes with respect to building spacing and water requirements for fire protection purposes vary with the location and governing authorities.

The main codes in use in temperate climates are:

- National Board of Fire Underwriters,
- National Fire Code,
- Uniform Fire Code, Insurance Advisory Organization,
- National Building Code.

Some of the guidelines are not practical or applicable for small northern communities and must be constantly adapted or altered to meet specific conditions under approval of the authority having jurisdiction.

Two sets of guidelines for water flow and storage requirements are given in Appendix I. Appendix I.1 gives a draft standard for water supplies for small rural isolated communities (such as Indian reserves throughout the various provinces of Canada) prepared by the Canadian Dominion Fire Commissioner's office. Appendix I.2 gives a guideline for water works design, prepared by the Province of Ontario.

12.4 Fire Prevention Criteria

12.4.1 General

Fire prevention criteria, such as building spacing, building location distances from roadways, access to buildings, fire escapes, building occupancy, requirements for sprinklers and smoke detectors and requirements for water distribution system flow and storage capacity in the North, are generally adopted from existing codes, such as the Building Codes and Fire Codes referred to previously, and as formulated by the authority having jurisdiction.

Although the purpose of fire protection systems is universal, the capability of water supply and distribution systems to meet the rigid requirements of codes cannot always be provided in small rural communities. Economic and physical constraints have dictated the limits of water supply and distribution systems, which in turn may prohibit meeting present codes and guidelines for fire protection. In such cases, the best practicable fire protection system developed often employs alternatives to water for fighting fires. Also, when a fire is extinguished with water at below 0°C temperatures the resulting ice can do more damage to the building than the fire.

There are numerous communities in both Alaska and northern Canada where there are no funds for necessary infrastructures, such as all weather roads to allow a fire truck to operate, let alone funding for the purchase of a fire truck. Despite the above, assuming communities are to be viable entities and fire protection treated seriously, the recommendaations made in this section are considered to be the achievable, practical, minimum level to be strived for.

12.4.2 Water supply fire protection requirements

General assumptions used when determining water supply values required for fire fighting are as follows:

- The water supply fire protection requirements are considered concurrently with the total community utility development planning. For instance, an indoor swimming pool can be also used to satisfy community fire storage capacity.
- Population is based on a 20-year forecast.
- Each community has its own unique set of characteristics. Population levels used to determine the standard of fire protection which should be provided will depend on a detailed economic analysis. The choice between a trucked or small piped or large piped system will be based on an economic evaluation over the 20-year forecast period.

The guidelines for water supplies in northern communities recommended in Table 12-1 are based on Appendix I and experience gained in Alaska and northern Canada.

12.5 Equipment

12.5.1 Trucks

Communities of less than 150 in population. The water truck can be used as the fire truck. See Section 6 for description and cost.

TABLE 12-1. FIRE PROTECTION GUIDELINES FOR WATER SUPPLY

TYPE OF SERVICE	COMMUNITY CHARACTERISTICS	FIRE PROTECTION WATER DELIVERY SYSTEM REQUIREMENTS
Trucked Water Delivery	- Trucked water supply only. - Bldg. spacing 12 m (minimum). - Community fire alarm system in operation. - Volunteer fire brigade.	- Community water point must be capable of delivering a minimum of 450 litres/ minute. - Fire truck/pumper is left with full tank in heated garage. - Domestic water truck is left full in heated garage as back up.
Small Diameter Piped System	- Small diameter piped system (flow based on consumption requirements only). - Hydrants can be provided to allow limited access to water for fire fighting. - Building spacing 12 m (minimum). - Community fire alarm system in operation. - Volunteer fire brigade.	- Water storage tank for fire fighting purposes to be supplied and located in central or strategic location in the community. Size of storage capacity to be based on the formula described in Appendix G. - Piping capacity of a minimum of 2500 litres/minute either from a truck mounted pump or insitu pump that will deliver water directly from the storage tank through an appropriate hose delivery system capable of servicing a 150 m radius from the storage tank. - A truck water point from the storage tank location will be provided capable of delivering 700 litres/minute for refilling the fire truck to combat fires in those areas not capable of being reached directly by hose. - All available fire and water delivery trucks to be kept in heated garages at all times.

TABLE 12-1. (CONT'D)

Large Diameter Piped Core System	- Large diameter core system with hydrants. - Remainder of community serviced by small diameter piped system with no fire flow provisions. - Building spacing core area with hydrant coverage 3 m (minimum). - Building spacing elsewhere 12 m (minimum). - Community fire alarm system in operation. - Volunteer fire brigade.	- Water storage tank for fire fighting purposes to be supplied and located in the community. Size of storage capacity to be based on the formula described in Appendix G. - Pumping capacity of a minimum of 2500 litres/minute either from a truck mounted pump or insitu pump that will deliver water directly from the storage tank through an appropriate hose delivery system capable of servicing a 150 m radius from the storage tank. - All hydrants on large diameter core system to be capable of providing 2500 litres/minute through either an in place pumping system or truck mounted pumps. Each hydrant should service a circular area with a radius of 70 m. - A truck water point from the storage tank location will be provided capable of providing 700 litres per minute for refilling of fire truck to combat fires in those areas not capable of being reached directly by hose.
Large Diameter Piped System Throughout Community	- Larger diameter piped system, i.e. minimum pipe size 150 mm or greater. All lines with hydrants in place every 70 m or less and capable of producing required	- Storage tank capacity as per formula given in Appendix G. - Water fire flow capacity as outlined in Appendix G.

TABLE 12-1. (CONT'D)

(cont'd)	- Building spacing minimum 3 m or as specified by the appropriate authority. - Community fire alarm system in operation. - Paid fire chief. - Volunteer fire brigade.	- Fire flow capacity can be provided through in place pumping system or truck pump.

Houses should be equipped with cartridge fire extinguishers and detectors.

Communities with no piped water.

A 4500-L capacity truck should be provided with a 2800 L/minute pump output rating.

Truck cost including assessories $ 50 000

Firehall cost (one bay) $100 000 ($500/m^2)

Communities with small diameter piped water, no hydrants.

Same as above.

Communities with large diameter piped water, with hydrants.

A 2273-L capacity truck should be provided with a 3800 L/minute pump output rating, to be used in conjunction with hydrant or storage tank facility.

Truck cost including accessories $ 60 000

Firehall cost (one bay) $100 000 ($500/m^2)

12.5.2 Other methods

Foam equipment, either cylinder or truck-mounted, is not recommended for northern use during low ambient temperatures of -25°C or colder. Such cold temperatures do not allow the aspirator to mix properly with the foam; a "soup" is produced.

Dry chemical. Large 350-lb ABC dry chemical extinguishers have been used in most communities in the Northwest Territories, Canada, with satisfactory results when properly utilized. Because of the large size of the unit, it is difficult to move in a hurry and should really be incorporated in a truck kept in a heated garage and ready to go. In those communities where it is best utilized, the unit is placed on a stand ready to be rolled onto a half ton truck or dump truck and taken to the fire. The unit must be serviced after each use.

Halon gas is useful in high hazard buildings and where electrical or mechanical equipment could be destroyed by wet system malfunction. This system is expensive and is not applicable in all buildings at this time.

Fire extinguishers for house use are recommended and should be the cartridge dry chemical ABC type. These have proven the most reliable and most economical to maintain. Commercially available units of various sizes have fusible links which automatically discharge when exposed to fire.

Smoke detectors are usually actived by sensing the products of combusiton. Such units may be installed in kitchens or next to furnaces. They are becoming more prevalent and in some cases are mandatory. All public government buildings and staff houses in the Northwest Territories, for instance, must have a permanently wired smoke or heat detector devices.

There are anumber of smoke detectors on the market, and as long as the unit has been approved by the Canadian Standards Association (CSA) and Underwriters' Laboratory (ULC) it will do a satisfactory job when used in accordance with the manufacturer's direections.

12.6 Community Fire Alarm Systems

Community fire alarm systems in the North, while highly desired by the communities, have been an extreme source of frustration for users, maintainers and designers over the years. A system is a failure unless it works when it is needed and works every time. Considering the factors of climate, lack of technically competent tradesment, constant turnover in personnel, et., a perfect operational record is a monumental achievement for a designer who must also produce an economical system.

The community fire alarm systems described in this section were delveoped by Mr. Ray Stoodley of the Government of the Northwest Territories, based on previous experience and personal knowledge of northern conditions gaind over the past two decades as an electrical contractor, and in his present position with the Government of the Northwest Territories.

It is essential to involve the local people in the design and installation process to the point where they see the merit of regular checks and any preventative maintenance required.

12.6.1 General system description

The previously adopted southern systems used standard drop zone annunciator panels (8-12 zones) and 1 hp single-phase repulsion induction motorized sirens. The present state-of-the-art in the North employs supervised multi-zone annunciator solid state equipment and leased telephone company cable pairs for call box signal and multi-siren activation.

12.6.2 System operation

Call boxes are located strategically throughout the community to provide maximum coverage. In the event of a fire the call box button is pushed, which sets off the sirens and thus marshalls the volunteer fire-fighters at the fire hall. At the same time, a graphic readout annunciator panel is activated at the fire hall. In other words, a red light on a large scale map of the community shows the location of the tripped pull box. The firemen note the location and proceed to the fire. The sirens continue until the annunciator panel alarm light is acknowledged by the arriving firemen. If in the interim another call box has been tripped, it will light up after the first light has been acknowledged and again set off the alarm. The system is constantly supervising itself, which means that a short in a cable pair or a severed line will sound a trouble alarm altering the appropriate staff to the problem.

A test button is provided, which by-passes the timing circuit and allows control of the siren for up to two minutes, at the discretion of the operator. (Two minutes is the maximum recommended time to operate these sirens.)

The system can accept signals such as low temperature, intrusion or any other dry contact, by simply adding the required annunciation and audible devices separately from the siren circuit. This allows the , system to be integrated with other critical community utilities such as water supply, etc., since in most small communities the diesel-generated power is unreliable. Under and over voltage protection is provided by a voltage limiter, which will disconnect the supply voltage when it drops to 105 volts AC and pick up again at 120 volts AC. A time delay of two to five seconds is fitted to prevent relay chatter. Disconnection of the system is preferred to a previously designed battery powered system which used AC power for charging-up as required. Even with battery standby provision, no power would be available during a power outage for siren operation; therefore, standby battery power is really superfluous. The system is fitted with a program clock device to sound a daily curfew for a predetermined time (constant blast of approximately 20 seconds). This also provides daily testing of the sirens.

12.6.3 System components

Sirens may be electronic or rotary multidirectional. Electronic sirens are used in smaller settlements with populations of 350 or less and restricted to a maximum community distance in any direction of 3 km.

Characteristics of this type are:

- low capital costs ($130 each);
- minimum or no maintenance;
- coverage of 110 DB @ 3 m in still air;
- uses 120 volt AC;
- lightweight (one man can change a defective unit);
- daily testing required to prevent heavy ice build-up.

Rotary multidirectional sirens are more cost-effective for larger communities. In general, where adequate coverage for a community requires 12 or more electronic sirens then one or two rotary multidirectional sirens are used.

Characteristics of this system are:

- 5 hp three-phase, 208 volts, high horse power required to ensure any ice build-up is sheared away on start-up;
- thermistor sensors in motor winding wired with normal motor overload circuit to prevent burn out;
- life expectancy of 20 years;
- coverage of 115 DB @ 30 m with an effective sound range in still air of 1050 m.
- cost of $2500 each.

Leased telephone cable pairs are preferred to individually installed and maintained cable plants for signal circuits because of lower capital and maintenance costs.

Graphic readout panels in the fire halls display all station call boxes with indicating lamps superimposed on a large-scale plasticized map of the community (see Figure 12-1). Also included are acknowledge, reset and trouble lights, and test buttons. The panel must be tailor made but eliminates any confusion as to where to go in situations where firefighters are made up of people with different languages.

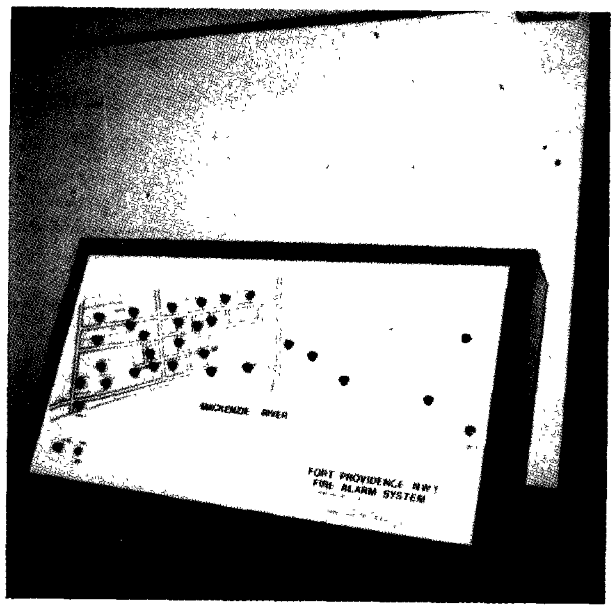

FIGURE 12-1. GRAPHIC ANNUNCIATOR PANEL DETAIL

Station indicating lamp call box assembly. Based on experience and past problems, the best call box for northern use is a CEMA-3 enclosure of special design to prevent entry of rain, sleet or driving snow. On opening the enclosure door, the caller merely pushes the red button for a moment. Behind the facia holding this push button is a pair of line fuses. One spare fuse provides protection for the station indicating lamp circuit. The indicating lamp used is rated at 60 watts, 8000 hours for long life and low maintenance. All related wiring between the indicating lamp higher up the utility pole and the call box is contained in a rigid PVC conduit. The rigid PVC results in a good, water-tight, noncorrosive and very easy field installation. Each call box is grounded at the base of the PVC. Where permafrost or soil conditions prevent the use of ground rods, a grounding mat buried a minimum of 60 cm for a length of 16 m is used.

Solid state relay equipment operates at between 5 and 35 volts DC and is capable of switching an AC load of up to 16 amperes. The relay is completely sealed and has an expected life of 20 years. Unlike previous designs, the solid state relays do not require matching relays on call box circuits located up to 8 km away from the main control system. Problems with end of line resistors or diodes are also eliminated since the new configuration does not require these components. Lightning surges and possible stray currents to call circuits are prevented by the telephone company lightning arrestor equipment.

12.6.4 Alternate system design

A system has been installed and is operating in Cape Dorset (population approximately 900) which is based on the use of a Bell Canada type 700 "Code-A-Phone" device. This device replaces both the solid state relay equipment and the graphic read-out panel. All other components, i.e., call boxes, sirens, etc., remain the same. Using a pre-coded number (e.g. 2222), any telephone in the community is able to set off the fire sirens. At the same time, a prerecorded message will ask in whatever language applicable, "Where is the fire?". The caller can then give the name and location. The firemen responding would play back the tape to ascertain the caller's identification and location.

ADVANTAGES:

- very low installation cost (40% of a standard system);
- assuming 80% telephone coverage, increased safety factory by virtue of quicker alarm activation;
- minimal maintenance;
- system will easily adapt to any number of sirens.

DISADVANTAGES:
- possible false alarms;
- possible confusion when the caller tries to tape the information;
- forgetting to reset the tape (although good for 12 hours it would be desireable to have the unit reset itself after each call has been acknowledged);
- cannot easily be tied in to equipment for other alarms, e.g., water flow, etc.

12.6.5 Cost

The average cost per signal circuit pair per month is $3.50. Between 12-36 pairs will be needed, depending on the size of the settlement. The average coverage per call box is one for every five homes or 30 people. Major buildings and installations must be considered separately. The installed cost of these systems is approximately $1 000 per call station. This includes the cost of siren and annunciator equipment.

The cable cost would be additional to the above figure and varies considerably between the western and eastern territories. Examples are Rankin Inlet, where the installed cable cost for 36 pairs was $2 300 and Fort Resolute, where the cable cost for 26 pairs was $8 300. Line pair rentals run approximately 50% lower in the east and central, compared with the western territories.

SECTION 13

SOLID WASTE MANAGEMENT

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13 SOLID WASTE MANAGEMENT

13.1 General

Solid wastes are one of the most important visual parts of an overall sanitation program for northern communities. Many priorities must be met with limited funds by those charged with the responsibility to provide for and improve social and environmental conditions in these communities. Providing jobs, housing, heat, light, water and sewage disposal have been given higher priority than solid waste management in the past, but it has recently received greater attention. Emerging legislation, research and pilot projects for solid waste management are evidence of increasing concern.

For the purpose of this manual, solid wastes are divided into three groups:

- municipal solid wastes: from households, commercial or institutional establishments;
- industrial and special wastes;
- human wastes from households and establishments.

The disposal of sludges from water and wastewater treatment plants is covered in Section 10. The disposal of human wastes without water carriage occurs because of the lack of piped water and sewer systems in many of the smaller communities. Because of the similarities in the storage, collection and disposal of garbage/refuse and human waste, the latter is discussed in this section, with reference made to other sections where relevant.

The objectives of solid waste management, north or south, must be to dispose of wastes without creating hazards, nuisances, or aesthetic blights for people and for the environment, and to achieve this in the most economical manner for a given situation. To achieve these objectives, it is necessary that each component of the solid waste management system, namely, storage in or at the house, collection and treatment/disposal, is properly carried out. Reviews of northern practices in solid waste management with recommendations for improvements have been carried out by a number of agencies [1-8,19,30,33].

13.2 Municipal Solid Wastes

Municipal solid wastes include all unwanted or discarded solid or semi-solid material from households, commercial and institutional establishments. While the type and quantity of wastes from these will be similar to those in southern communities, there are special considerations to be taken into account in northern communities. Most of the 'goods' consumed must be shipped from the South. This leads to greater quantities of packaging material in the waste. The isolation and high transportation costs make recycling of used machinery, mobile homes, automobiles, etc., as scrap raw material uneconomical and increase the quantities to be disposed of locally. Finally the combination of past social customs, inadequate health and sanitation habits and education make it difficult to implement effective solid waste management.

13.2.1 Quantity and composition of wastes

Data on refuse from work camps, military bases and airport facilities, which in many aspects are similar to southern communities, are shown in Table 13-1.

TABLE 13-1. QUANTITIES OF SOLID WASTE FROM CAMPS

Camp	Quantities
Air Force Base [10]	2.3 kg/person/day
Pipeline Construction Camps [11]	2.7 kg/person/day
Alaska-Federal Facilities [5]	2.7 kg/person/day
Fort Greely [5,15]	6.1 kg/person/day

Recently Wardrop et al [37] reported that facilities such as these in the Northwest Territories generated refuse at a rate of 2.7 to 4.4 kg/person/day. The Alaska Department of Environmental Conservation (ADEC) uses a generation rate of 3.6 kg/person/day for design purposes.

Little information regarding the density of refuse from such facilities is available. However, a recent survey at Alert, N.W.T., made by Wardrop et al [37] concluded that the refuse generated at this site had a density of 91 kg/m^3.

Table 13-2 tabulates ome recent information on solid waste quantities for communities with little industrial activity.

TABLE 13-2. QUANTITIES OF SOLID WASTE FROM COMMUNITIES

Camp	Quantities
Tuktoyaktuk, N.W.T. [9]	0.014 m^3/person/day (0.5 ft^3/person/day)
Alaska [5] (average of communities > 500)	2.8 kg/person/day 0.015 m^3/person day (0.54 ft^3/person/day)
Northern ONtario connumities [12]	0.005 m^3/person/day (0.18 ft^3/person/day)

For such communities, an average volume of about 0.005-1.015 m^3 should be used for planning purposes. The lower figure would apply when burning at the household or establishment is practised. Without special compaction or burning the average density may be about 130 kg/m^3 but considerable variation must be expected. On a weight basis, therefore, 1.8 kg/person/day can be used for design purposes.

Tables 13-3 and 13-4 provide the only available information on compostion of solid waste in residential communities. Table 13-3 reports a survey of two northern communities, Juneau and Anchorage, and provides a compparison with a southern community, Madison, Wisconsin, and the U.S. national average. It should be noted that both Juneau and Anchorage are larger, more temperate zone communities than many other norther communities.

Table 13-4, on the other hand, provides an estimate of domestic refuse composition for typical northern communities which may be helpful in small community design. This information is based on unpublished data collected by W.L. Wardrop and Associates Ltd. personnel during visits to several Arctic communities.

13.2.2 Household storage and collection

In the larger communities the practice of storage and collection of waste does not differ substantially from the practices in southern communities. In smaller northern communities garbage and refuse are

TABLE 13-3. COMPOSITION OF SOLID WASTES

Classification	Percent of Total Sample			
	Juneau, Alaska	Anchorage, Alaska	Madison, Wisconsin	U.S. National Average
Food Waste	15.2	15.2	15.3	17.6
Paper Products	45.8	43.7	42.4	31.3
Plastics	4.0	4.1	1.8	6.0
Rubber and Leather	1.3	0.9	--	--
Textiles	3.0	2.1	1.6	1.4
Wood	0.6	1.2	1.1	3.7
Metals	12.5	10.0	6.7	9.5
Glass and Ceramics	17.1	14.5	10.1	9.7
Garden Waste	--	6.5	13.8	19.3
Inerts (dirt)	0.4	1.7	7.2	1.4
Totals	99.9	99.0	100.0	100.0

TABLE 13-4. DOMESTIC REFUSE COMPOSITION FOR A TYPICAL ARCTIC COMMUNITY

Component	Composition by Weight
Combustibles (wood, paper, etc.)	50%
Metal	15%
Organic Wastes	15%
Moisture	20%

commonly stored at the house in readily available oil drums. They are probably the only type of container capable of sustaining the abuse by weather, people and animals. They are large enough to hold animal carcasses and other bulky refuse and heavy enough not be be upset by wind or dogs. Also, one can burn combustible waste in them for volume reduction. This practice should be encouraged. They are, however, difficult to lift manually onto the collection vehicle (Figure 13-1). Mechanical lifts can be attached to the side of the collection truck to avoid this problem. In some communities raised wooden platforms have been constructed to hold drums for garbage and honey bags so that they can be easily emptied (Figure 13-2). In many instances this attempt has been a failure, either because the platforms were not rugged enough, or they became an eyesore since they were covered much of the time with spillage. This eventually caused them to be abandoned. In other communities smaller metal or plastic pails are used. They are easier to handle, but are blown over by wind or upset by dogs, do not hold bulky waste, and burning cannot be practised. Plastic containers are also brittle at low temperatures. In all containers garbage will freeze to the walls, making it difficult to empty them in cold weather. A pilot study program using paper sacks was carried out by Environment Canada in two northern Canadian communities. The results were disappointing; the project had to be abandoned soon after its start, since the local population did not perceive it as an improvement over previously used methods [29]. In summary, there is much to recommend the continuation of the use of the readily available oil drums for storage at the house, but it also should be coupled with educational efforts to avoid the situations shown in Figure 13-3. Periodic cleaning and painting of drums is recommended.

In many communities there is some organized collection of garbage and refuse on a weekly or twice-weekly basis. Mandatory or universal collection is currently required in more than 50% of Alaskan communities greater than 500 people [5]. In all but the very small communities weekly collection, whether public or private, should be required. Garbage and refuse collection should be separate from the collection of bagged toilet waste, since the latter requires daily

FIGURE 13-1. GARBAGE COLLECTION

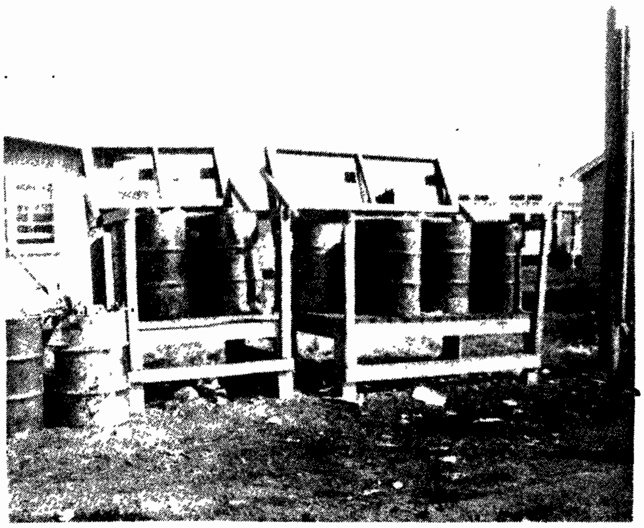

FIGURE 13-2. GARBAGE BARRELS ON RAISED WOODEN PLATFORMS

frequency and a separate disposal site. Vehicles vary in sophistication from the garbage packer truck as used in the south to tractor-drawn open carts (Figure 13-4). Most vehicles are of the open type and lose garbage within the community and along the road to the dump. This sets a bad example to the people and negates any educational efforts for cleanup. Enclosed or covered vehicles should be required with the appropriate degree of sophistication depending on the size of the community.

Garbage crews should also be made responsible for general street cleanup and maintenance, and thus set an example to the citizen. Without this, the appearance of many northern communities suffers from the indiscriminate disposal of garbage, refuse, vehicles and scrap items of all sorts in yards, on roads and beaches. This becomes progressively worse as the winter goes on, mercifully covered snow. Massive spring cleanups occur in most communities. Community-wide cleanups should be a general practice several times a year and their need particularly impressed upon the young in school.

13.2.3 Disposal methods

Alternatives for disposal of solid wastes in northern communities and camps include:

1) open dump/landfill;
2) modified landfill;
3) ocean disposal;
4) incineration;
5) milling and compaction;
6) recycling and reuse (haulback).

Currently the most often used method is the open dump, which in some cases can be termed a modified landfill. Seventy-six percent of Alaskan communities use a form of open dump/landfill method, 13% use ocean disposal and 11% employ incineration (all of these are U.S. federal facilities [5]). The open dump/landfill is also widely used in Canadian communities. The advantages and disadvantages of each method are discussed below.

FIGURE 13-3. A POOR EXAMPLE OF GARBAGE STORAGE AT THE HOME

FIGURE 13-4. GARBAGE CART AND STAND

13.2.3.1 Open dump/landfill. The main reasons for the use of the open dump are its simplicity of operation, its low cost, and the lack of suitable alternatives. The main arguments against its continued use are the many instances of complete disregard of even the most simple techniques of discrimination in the selection and operation of existing disposal sites. These poor practices, which are avoidable, make it difficult to convince regulatory authorities and the public to accept the open dump/landfill.

Parameters for disposal site selection include: avoidance of water pollution problems, avoidance of air pollution problems, feasibility of construction and maintenance of access road, site topography and size, availability of cover material, and wind exposure. The most important site selection criterion is that it should be located outside the watershed of the water supply source to eliminate any possible pollution effects. The site should be on high, dry ground to avoid drainage and groundwater problems [27]. If there is a prevalent wind direction, the site should be located down-wind from the community, so that unpleasant odours or smoke from burning at the dump are directed away from the settlement. The ground between the disposal site and the community must allow for the construction and maintenance of a year-round access road. The distance from the site to the nearest homes should be at least 1 km where possible. When there is a choice between alternative sites, the construction and maintenance costs for a multiple-use access road should be considered against those for a single-purpose waste disposal site access road.

A sloping site is preferable since it facilitates dumping and spreading operations. On flat land a slope can be created through deposition of waste and cover material, where available. The area for the dump/landfill operation should be large enough to allow for 5-10 years or longer operation, particularly when the cost of the access road is high. Usually land area is not a problem. A smaller area may be prepared and fenced for current usage, with adjacent room for expansion available. The fenced site should be large enough to allow for deposition of garbage and refuse and a close-by storage of cover material. The cold northern climate makes biological degradation of putrescible matter so slow that the value of occasionally covering the waste is really only in preventing garbage and paper from being blown around the site, and in reducing the danger of disease transmission through insects, birds and animals. Periodic compacting and covering of the waste is, therefore, recommended where at all economically possible. Availability of nearby cover material is, therefore, important. In some cases, snow has been used as a cover material. The requirement for fencing is based on similar reasoning. It will confine the blowing of waste to the site and may keep out larger land animals. It has also the psychological advantage of creating the impression of an "engineered" operation. Where there is a choice, a protected, less windy site will be preferable. The controlled burning of combustible material at the disposal site serves the useful purpose of volume reduction and odour control, but may create air pollution and smoke problems. In some areas it may also not be permitted.

The provision of space for dumping of large, discarded items such as automobiles, machinery, demolition material, etc. must also be considered. Where space allows, it is preferable to locate such an area near the garbage dump. This eliminates the need for a separate road and allows the periodic bulldozing and "compacting" of that area. Not providing such a facility will encourage indiscriminate dumping. It is also necessary to have available a tow truck or other vehicle capable of loading, hauling and unloading inoperable vehicles and machinery.

If these simple guidelines of site selection and operation are adhered to, the environmental effects of the open dump/landfill are minimized. Under these circumstances, the advantages of cost and ease of operation make it the most sensible method of waste disposal at the present time. The site should be selected by experienced people with the help of aerial photographs and inspection of alternative sites. It should not be left up to the garbage crew to choose the site(s). Reclamation of land from the ocean by the building of a berm off shore and the filling in with solid waste, earth and rock are carried out in Godthab, Greenland, and Pangnirtung, N.W.T. This may have application in other areas where land is scarce.

Because of the different nature of the waste, bagged human wastes should be disposed of separately from solid waste, as discussed later (see Section 13.4.3).

Figures 13-5 to 13-11 show some of the situations experienced at existing disposal sites.

13.2.3.2 Modified landfill. The proper application of sanitary landfill procedures is usually impossible in permafrost areas. The low temperature does not permit the degradation of putrescible matter to occur, but merely places the waste in cold storage. Excavation is extremely difficult and may create difficulties through destruction of the insulating layer. Earth cover material must often be transported considerable distances to the disposal site and is therefore expensive. Daily or even weekly covering becomes economically impossible. The small size of most communities makes it seldom practical to keep a bulldozer on the site continuously, as it is needed for other tasks in the community. For these reasons sanitary landfill is generally not a practical method of disposal in permafrost areas. In discontinuous permafrost areas, and where cover material is available at reasonable cost and the size of the operation allows the continuous presence of equipment, a form of landfill approaching the practices of sanitary landfill in southern areas is a practical alternative. The comments on site selection and preparation given earlier in the discussion of the open dump should be adhered to. Articles by Straughn [13] and Cohen [14] provide further information.

Another form of the modified landfill is a trench method. In communities which have piped service systems, tractor-mounted back-hoes are normally available for systems maintenance. These can be used to dig trenches at the solid waste disposal site, up to about 3 m deep. The refuse is dumped into these trenches and, when nearly full, they are covered with excavated material (about 1 m). New trenches are then dug. This method can be used in permafrost areas, provided the machinery is able to dig such trenches.

Another possible variation, not yet tried on a community scale in northern regions, is composting [31] of garbage, kitchen wastes and human waste either on an individual household basis or on a community basis. Experience with municipal composting operations in Europe would indicate that it is not likely to be economically feasible in most of the

FIGURE 13-5. A DIFFICULT SOLID WASTE HANDLING PROBLEM

FIGURE 13-6. A PROPER GARBAGE DUMP TRUCK WOULD HELP CONSIDERABLY

FIGURE 13-7. ATTEMPT TO CREATE A DUMPING SLOPE ON FLAT TERRAIN (a)

FIGURE 13-8. ATTEMPT TO CREATE A DUMPING SLOPE ON FLAT TERRAIN (b)

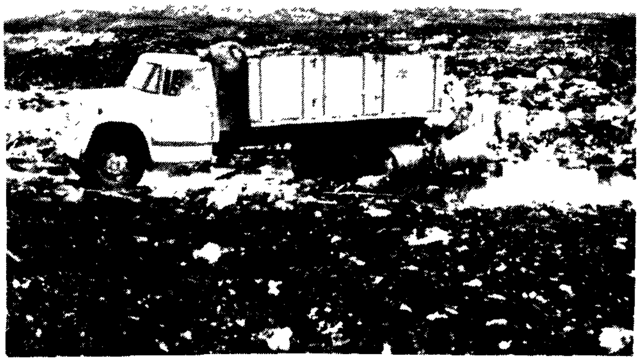

FIGURE 13-9. HOW WOULD YOU LIKE THIS JOB?

FIGURE 13-10. DISPOSAL OF GARBAGE AND HONEY BAGS AT THE SAME SITE. THIS SHOULD NOT BE DONE.

FIGURE 13-11. STORAGE TANK DISPOSAL ONTO GARBAGE DUMP

northern communities because of their small size and because of the climate.

13.2.3.3 Ocean disposal. Many of the smaller communities on the ocean dispose of their garbage and "honey bag" wastes by placing them on the ice in the winter, relying on spring breakup to wash away the material [5]. The remoteness of the communities, the relatively small quantities of waste involved and the vastness of the ocean make this practice tolerable for small communities. Future legislation may prohibit this practice.

13.2.3.4 Incineration. Incineration is a controlled process for oxidizing combustible waste to carbon dioxide, water and ash. Normal domestic garbage and refuse has an average heating value of about 11.6 megajoules/kg and thus can be considered a valuable fuel resource, particularly in northern areas where fuel must be brought in at great expense. Some years ago it was thought that incineration had great potential for Alaskan communities and might replace the practice of open dumps [5]. However, the experience of the few installations that have been built at federal facilities [5,10] and in parts of the Alaska

Village Demonstration Project (AVDP) has been that incineration of solid wastes is not economically feasible for communities because of high operative and maintenance costs. As a result, many installations are in fact not being operated now.

Zaidi and Curran [38] recently carried out three test runs on a new type of forced-air open pit incinerator constructed at the Gordon Indian Reserve in northern Saskatchewan. The rate of generation of domestic solid waste at Gordon, excluding the waste generated at the residential school, was in the range of 907-1360 kg/week, or 4.2-7 m^3 week. The average composition (weight %) of the waste samples burned was 46% paper, 37% food, 3% plastic, 8% metal and 6% glass. It should be noted that approximately 50% of the paper waste was disposable diapers.

The incinerator is a skid mounted, single chamber open pit type incinerator capable of burning approximately 227 kg/h of municipal type solid wastes. The combustion chamber is a refractory-lined metal box with an inside volume of 2.7 m^3. It is designed to achieve a temperature of 871°C by supplying up to 840 m^3/h of underfired and overfired air through manifolds and nozzles mounted on both sides of the combustion chamber.

From these three test runs it was found that the uncombustible residue obtained from the incinerator indicated a fairly complete combustion. The residue volume was approximately 15% of the refuse. Also, to get a good fire burning in the incinerator, the volume of the refuse at the beginning should be kept to a minimum. Therefore, it was recommended that the collection of refuse be done in three batches with the first one being the smallest [38]. Further testing of this facility is planned.

Incineration is one of the most common methods of disposing of solid wastes from industrial and military camps [36]. It is most effective in reducing animal scavenging of the camp site and the environmental effects of incineration are low. For very small, short duration camps for exploratory purposes backhaul or open burning is practised. For larger temporary and all permanent or semi-permanent camps incinerators of various designs are used; they are normally oil fired. Because of much better qualified operators than in communities, maintenance problems and costs are substantially reduced. Operating costs are generally not available. They are probably high when considered within an economic framework of a community, but are not significant when considered against the overall cost of industrial or military camp operations.

13.2.3.5 Milling and compaction. The purpose of milling and compaction is to reduce volume, and thereby make handling and disposal of the wastes cheaper and more manageable. Included here are methods to shred, mill or grind wastes, and to compact or bale wastes. They may be used ahead of landfilling, incineration or in conjunction with materials recovery. To date the record of a number of pilot or full-scale projects appears to increase overall disposal costs, rather than decrease them.

Refuse milling (or shredding, or grinding) is a process by which refuse is passed through a mechanical device, such as a hammer mill, which grinds it to a homogeneous mixture of a specified maximum size. This mixture is inoffensive, light, highly compactable, and easily handled. Paper plastic, wood, and cardboard are generally broken into three to four inch pieces. Glass is shattered so thoroughly into sandlike particles that it is impossible for the casual observer to detect it. The raw garbage is generally absorbed and is so finely mixed with paper and other materials that there is very little odour. The biggest problem is with soft plastic bags, which tend to stretch rather than tear apart [5].

Milling ahead of landfilling reduces the need for daily cover and the "nuisance aspects" of open dumps (odour, flies, rats, windblown material). It also reduces the volume to be transported and disposed of. Difficulties in northern operation of a hammermill, or other type of mechanical equipment, are with the input of frozen wastes and increased frequency of mechanical breakdown and difficulty of repair. Many communities are too small to justify the high capital cost and operating costs. Forgie [16] reported on a Canadian pilot project on shredding of solid waste. It showed that shredding by a hammermill may be technically feasible but failed to provide information on the economic feasibility for northern applications.

Compacting or baling is a process whereby waste, raw or milled, is compressed into bales, with a significant increase in density (up to . kg/L, which is about the density of water). After being banded, these bales are hauled to a landfill site, where they can be stacked in place. In this manner, greater landfill density can be achieved, and transportation costs are reduced, since greater payloads can be hauled. High pressure baling, which does not require banding, is planned for Fairbanks, Alaska.

There is a lack of published economic analyses of these methods which prevents a firm conclusion about their possible application in northern areas. At present it appears that their benefits can be achieved by simpler methods and managements as discussed previously [24].

13.2.3.6 Recycling and reuse (haulback). Recycling of waste into regenerated products is now popular. There are difficulties achieving this objective in the economic framework of southern communities, and in remote northern communities the picture is even less attractive. Recycling and reuse requires, in many cases, sorting and separation of wastes, as for instance in the recovery of metal cans, glass products, etc. The size of the operation and the availability of markets for the 'usable' waste products are important economic considerations. A northern location compounds the difficulties experienced in the southern communities. Populations are generally small; therefore, volumes of recovered materials are small. There are usually no local markets and, therefore, material must be shipped south over long distances and at high costs.

Some apparently successful projects of recycling scrap metal have been reported by Kelton [5]. In one project, approximately 40 000 tons of heavy metal scrap was removed from a Fairbanks junkyard and transported by the Alaska Railroad to Seward, where it was shipped to Taiwan for recycling, all without a government subsidy. Another example is in Anchorage, where a private wrecking firm collects, crushes and transports junked automobiles to Seattle, at a government subsidy of $22 per vehicle (1975). The problem of junked automobiles is discussed further in Section 13.3.

13.2.3.7 Costs and charges. Actual charges to the homeowner are not well documented. However, information is available on the actual cost for garbage collection and disposal in some northern communities. It is important to differentiate between actual costs and charges. The latter are mostly subsidized, and set without knowing real costs.

Gamble and Janssen [28, 32] describe a method to estimate the cost of garbage collection in small communities. For the example illustrated, Tuktoyaktuk, N.W.T., the cost per bag ranged between \$1.49 and \$2.89. There is a need to document costs of collection and disposal in a number of typical communities.

In Alaska, the average charge to the homeowner for collection of garbage (one drum per week) in incorporated municipalities of over 500 population was \$4.80 (2.50 to \$15.00) per month per household in 1974 [5], or about \$1.20 per drum. In communities of the N.W.T., charges varied between 40¢ and \$1.00 per drum in 1972 [20].

In Table 13-5, some typical values are given for the actual costs (labour, vehicle O&M, overhead, etc.) to maintain garbage collection and disposal in some representative northern communities [39]. The costs are given as either a flat rate charged per pick-up and/or as the cost per person per year to maintain such a system.

TABLE 13-5. GARBAGE COLLECTION COSTS

Community	Year of Survey	Population Serviced	Cost	
Coppermine	1976	758	\$1.30/pick-up	\$15/person/yr
Fort Liard	1977	225	\$1.25/pick-up	
Fort Resolution	1976	600	\$1.10/pick-up	
Gjoa Haven	1976	420	\$1.86/barrel	
Fort Good Hope	1976	443	\$1.28/pick-up	\$16.25/person/yr
Fort McPherson	1976	710		\$14.25/person/yr
Fort Norman	1976	232		\$38.47/person/yr
Paulatuk*	1977	147	\$1.15/pick-up	
Aklavik	1976	781		\$12.17/person/yr
Chesterfield Inlet*	1976	243		\$44.90/person/yr

* Labour contract only.

From Table 13-5 it can be seen that the smaller communities have the higher per capita cost. This is reasonable because each community will require similar infrastructures to allow for the garbage collection system.

13.3 Industrial and Special Solid Wastes

Included under this heading are solid wastes generated from industrial activities, special wastes such as discarded automobiles, mobile houses, ski-doos, vessels, oil barrels, machinery and other bulky waste, as well as special wastes associated with temporary or permanent camps.

It is believed that no comprehensive survey has been done of the solid waste problems of industry in Alaska and the Canadian northern territories and provinces. Kelton [5] has provided some information on the special problem of seafood processing wastes in Alaska, which are disposed of in the ocean or in a landfill. A great part of industrial activity in the North is connected with the extraction of raw materials (oil, gas, various minerals, etc.). It is beyond the scope of this manual to discuss the special solid waste management problems of these industries in detail. Reference should be made to the relevant information on such industrial wastes in other areas.

Special wastes, other than garbage and refuse, from communities and camps include discarded automobiles, mobile homes, construction equipment and materials, ski-doos, bulky containers and shipping material, and others. These wastes do not accumulate on a frequent basis and are normally not collected and disposed of routinely. However, provisions must be made to provide an incentive for reuse, where this is feasible, and more importantly, for a dumping area, which is controlled and operated by the municipality. In the absence of this, discarded material seems to be left almost everywhere. This contributes greatly to the too often justified impression of unorganized and poorly managed communities.

Some quantity information is available. Alter [6] stated: In cold regions it may be assumed that the following percent of the total weight or volume of each item becomes solid waste annually:

- Lumber, steel and other building material used in construction of fixed facilities such as buildings	3%
- Heavy equipment, tractors, machinery and vehicles	10%
- Miscellaneous freight such as canned goods, furniture, appliances, etc.	2-10%
- Magazines, books, newspapers, etc.	90%
- Office and household furnishings	5-10%
- Clothing	30%

These estimates may, in fact, be on the low side. For example, machinery and cars accumulate more likely at a higher rate. Kelton [5] estimated that of the 170 000 vehicles registered in Alaska in 1973 about 20 000 are junked each year. At an average weight of 1.5 tons per vehicle this amounts to 30 000 tons of scrap per year. Recycling in the larger and less remote communities may be economically feasible, but not likely to be the case in the more remote communities because of high freight rates. There is a choice to be made either between subsidizing backhaul or providing local junk yards. Forgetting about the problem is not acceptable. In the absence of state-or territory-wide policies, the minimum that a local community must do is to establish 'controlled' junk yards, prohibit the indiscriminate abandoning of discarded material on public and private property, and establish a collection method at a fee and on demand.

The special problems of solid waste management for temporary and semi-permanent camps (together with their water supply and wastewater disposal problems) have been discussed thoroughly by Grainge et al [18].

13.4 Human Wastes from Households and Establishments

The replacement of the "honeybag/honeybucket" system for human waste disposal with other methods would be the greatest single improvement in the living conditions of northern communities and would contribute to a reduction in waste-borne diseases [2].

Hanks [21] has conducted an exhaustive literature study on the relationship of solid wastes and disease. While the literature failed to permit a quantitative estimate of any solid waste/disease relationship, this was said in summary:

> "The communicable diseases most incriminated are those whose agents are found in fecal wastes - particularly human fecal wastes. Where these wastes are not disposed of in a sanitary manner, the morbidity and mortality rates from fecal-borne diseases in the population are high. Despite the fact that other factors are known to contribute to some reduction of these rates, the inescapable conclusion is that the continued presence in the environment of the wastes themselves is the basic causative factor. Therefore transmission - whether by direct contact vector transfer, or indirect contact - is due to environmental contamination of these wastes."

No other place in North America exists where this statement applies more than in northern communities. There is a lack of conclusive data for solid waste/disease relationships in northern communities, but the problem is there.

The bucket toilet system, better known as the 'honeybag' or 'honeybucket' system, exists because of the high cost of conventional piped sewer systems, and the unsuitability of the septic tank-tile bed system in most northern areas. Piped water and sewer systems, above or below ground, suitably modified to northern conditions, have been installed in many of the larger communities. The essential goal appears to be the replacement of the honeybag system by a piped system, by a holding tank/truck system, or by new methods such as internal recycle systems. However, because of the many priorities for funds, it is reasonable to expect that the honeybag system will continue to be widely used for a considerable number of years. Improvements in current practices are possible and discussed here. Surveys of communities' municipal servicing standards, including human waste, were made for the N.W.T. [19], the Yukon Territory [30] and Alaska [34].

13.4.1 Storage at the house and collection

Figure 13-12 shows a typical bucket toilet. Health officials recommend that honeybags be collected from all households daily. This also assists the collection procedure since a half-full bag is less likely to break. Daily collection, however, is the exception rather than the rule.

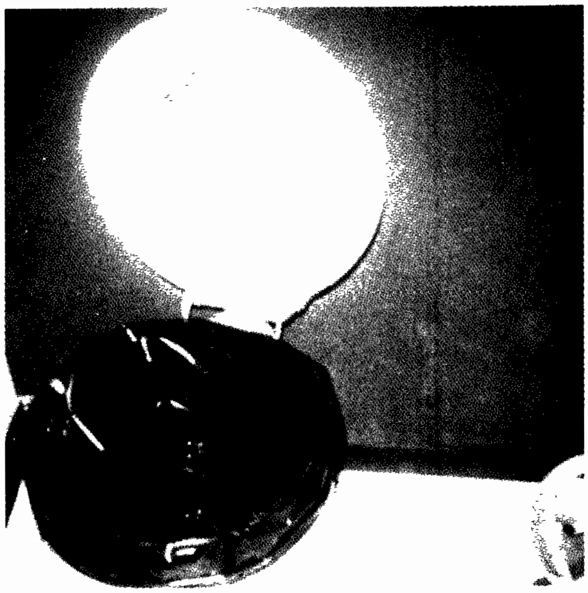

FIGURE 13-12. TYPICAL BUCKET TOILET

There are three methods of honeybag storage and collection [20]:

a) collection from oil drums in front of each household,

b) collection from the bathroom of each household,

c) collection from the service porch of each household.

a) The householder is supposed to remove the honeybag from the bucket toilet and place the sealed bag in a drum, reserved for this purpose, in front of his house. Often, the bag is left on the ground, where it is broken by birds, dogs or children, or where it can freeze to the ground in winter. The presence of honeybags lying around the settlement is aesthetically unpleasant. If broken, they constitute a danger to health. Removal of honeybag debris is unpleasant, inconvenient, and difficult. Handling, first by the householder and then again by the collector, increases the possibility of breakage. This method is not recommended (Figure 13-13).

b) A system of in-house collection of honeybags from the bathroom has been implemented in some communities. The honeybag collector enters the house and removes the honeybag and pail to the truck. After dumping,

FIGURE 13-13. MANUAL HANDLING OF HONEYBAGS STORED IN DRUMS IN FRONT OF THE HOUSE UNTIL COLLECTION

a new bag is placed in the pail and the pail is returned to the bathroom. The system is advantageous in that handling of the honeybag only once by the collector minimizes the chance of breakage. It is convenient to the householder, requiring no conscious actions on his part. Honeybags are not left around the roads of the settlement where they may be broken. Residents in at least one community have objected strongly to collection from the bathroom as a serious inconvenience, which dirties up the house and invades their privacy, and about which they were not consulted before the system was placed in operation.

c) A variant of b) is the service porch or "two-bucket" system. Each household has two plastic or metal pails for its toilet (Figure 13-14). Each morning the householder ties the top of the bag and places the plastic pail and full bag in the service porch for collection. The second pail, with an empty unused plastic bag inside, is placed in the toilet for use. The collector removes the used bag from the pail and replaces it with a fresh bag. The pail is left on the service porch for

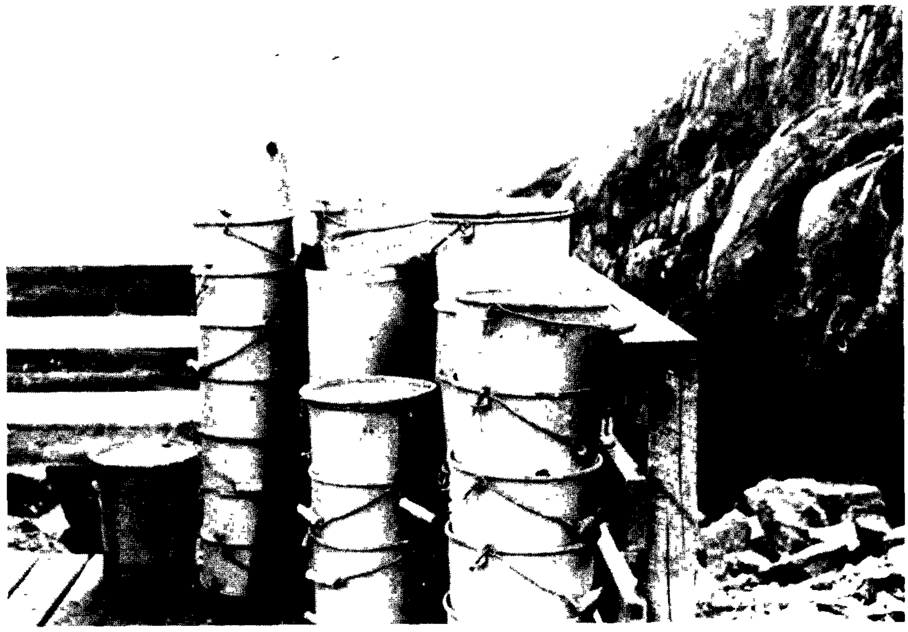

FIGURE 13-14. METAL BUCKETS USED FOR COLLECTION OF HUMAN WASTE

use the next day, and the "full" honey bag is taken to the collection vehicle for disposal. The two-bucket system is advantageous in that it minimizes handling of the bag, is clean, and does not leave honeybags lying around the settlement. The major objection to the in-house system - the invasion of privacy - is not present. The two-bucket system requires that all homes have an accessible service porch and two toilet pails.

Trucks, on which tanks or drums are mounted for storage, are used to haul the wastes to the disposal site. The most practical tank is a half-round shape with a large manhole having a hinged lid on the back in the flat cover. The flat top allows for a lower emptying point. Steps are provided on the side so that honey buckets can be carried up and emptied into the tank. The tanks usually have a capacity of 2000 to 3000 litres. The truck should be kept as small and manoeuvrable as possible to get close to the houses. The tank should be capable of being dumped at the disposal site. At the rear a large valved outlet pipe (at least 20 cm in diameter) is provided which can be opened to empty the tank. A small heater is needed to keep the short pipe and valve from freezing. The truck exhaust can also be routed to keep this valve warm and eliminate the need for a heater. A full opening, non-rising stem gate valve has proven best for this application as it must be capable of passing solids such as plastic bags. A steam cleaner should be mounted on the side of the tank so the honeybuckets can be cleaned before replacement in the house. Typical costs for the truck, tank and cleaning unit would be about $40 000 (1977).

Another type of truck has a large holding tank which is equipped with a dumping drum with spikes on the interior of the drum. The full honeybag is placed in the drum by the driver and broken on the spikes by an upward hand motion. The contents flow or are sucked into the holding tank, and the ripped bag is placed in an oil drum for the purpose of storage before disposal (Figure 13-15). In a simpler case, honeybags are placed in oil drums on the back of a tractor-driven cart or pick-up truck. The drums with their contents are dumped at the disposal area and the drums reused.

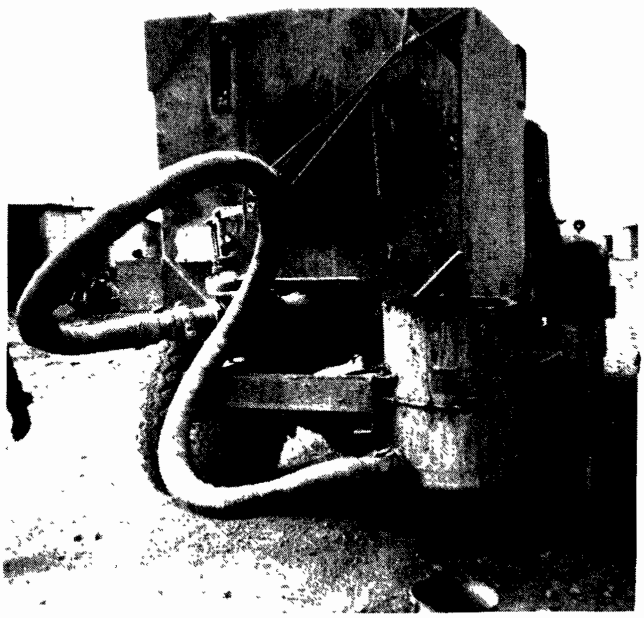

FIGURE 13-15. REAR VIEW OF HONEYBAG SUCTION VEHICLE

In some communities, homeowners must carry the bagged wastes to a disposal point. Normally, several disposal points are located in the village, and wastes are hauled from there by truck to the disposal site. Disposal points must be centrally located to all dwellings; otherwise their chances of being used regularly are small. The distance that individuals will haul wastes varies with many factors. Two of the more important considerations are training and education of the users and the ground conditions over which the wastes must be hauled. Experience indicates that the number of individuals who utilize a disposal point starts dropping off considerably after the distance exceeds 200 metres. Also, the people tend to haul longer distances in the winter because in most communities it is easier to get around and snowmobiles can be used. An extensive education program is invaluable in promoting the use of a disposal point when individuals are hauling their own waste.

13.4.2 Quantity and composition of human wastes

Heinke and Prasad [22,23] have provided data for honeybag wastes (Table 13-6).

Data from a Canadian community [9] substantiate the estimated volume of about 1.3 L/person/day.

13.4.3 Disposal

Disposal of the contents of honeybags can be accomplished in several ways. They are: at a treatment plant or a lagoon treating sewage from a piped system; at a sludge pit-lagoon; at a disposal site next to the garbage dump; on the ice; and in the ocean.

The most satisfactory disposal method for honeybucket wastes would be at a central facility, such as a treatment plant where the wastes are a small part of the total waste load to the facility. The treatment would be accomplished by one of the methods discussed in Section 9. A fly-tight closable box should be provided on the outside of the building which is convenient to use. It must be capable of being thoroughly washed down and cleaned daily. Above all, it must be aesthetically pleasing and easy to use; otherwise it will not be used. It must also be vandal-proof. This disposal method depends, of course, on the existence of a partial sewer system and treatment facility, where

TABLE 13-6. CHARACTERISTICS OF HUMAN WASTE (Honeybags)

Parameter	Average	Range
Volume, litres per person per day	1.3	-
pH	8.78	8.6 - 8.9
Alkalinity, mg/L	14 990	11 900 - 17 000
Total solids, mg/L	78 140	65 990 - 85 030
Volatile solids, percent of total solids	77.53	71.53 - 80.18
Dissolved solids, mg/L	39 290	32 500 - 53 620
COD, mg/L	110 360	80 750 - 134 820
Supernatant COD, mg/L	48 510	39 990 - 61 280
TKN, mg/L	8070	7280 - 9520
NH_3-N, mg/L	3920	3470 - 4060
Org. N, mg/L	4150	3696 - 5520
Phosphorus (PO_4), mg/L	3730	3400 - 4250
Volatile acids, mg/L	2490	2300 - 2670
Total Coliform Count, no. per 100 ml	5.4×10^8	1.5×10^8-2.3×10^9

honeybags are used only in a portion of the community. If the wastes are deposited in a lagoon a dumping point should be designed to prevent erosion of the lagoon dykes yet allow for easy access so the waste doesn't end up all over the dykes instead of in the lagoon. A platform with a hole cut out over the water seems to be satisfactory. Another problem with lagoon disposal is the plastic bags which are often used as liners in honeybuckets. They are not biodegradable and should not be deposited in the lagoon. It will be necessary to empty their contents into the lagoon and then deposit the bags at a landfill or burn them. If honeybag wastes are dumped at a treatment facility this must be taken into account in their design. Although the hydraulic load is small the organic and solids loading is quite considerable (see Table 13-6). The waste may also contain a high concentration of deodorizers such as formaldehyde and pinesol, which could affect biological treatment processes.

If a sewage treatment plant or lagoon does not exist, the most satisfactory method is to build a sludge pit, lagoon or trench. It must be accessible for easy dumping of the contents of haulage tanks. One way would be to cover it with a platform which contains a disposal hole, and covered with a fly-tight, hinged lid. The waste pit should be located on a site which will never be needed for other purposes, and as far away as practical from the community and water supply source. It should be sized for about 0.55 m^3 per person per year, and covered after one year's operation and a new pit dug. If the community has a partial sewer system and a lagoon is used as the treatment method, the sludge pit should be constructed adjacent to the lagoon and liquid overflow directed to the lagoon. Some of the liquid portion of the honeybucket wastes will seep out when the surrounding ground is thawed. As with privies, sludge pits are not a desirable form of waste disposal if the soil is frozen fine-grained silts or where there is a high groundwater table. If no other site is available, lining of the pit to prevent contamination of the groundwater may be required.

A laboratory study carried out at the University of Toronto [22,23] on a simulated waste pit showed that it is possible to treat honeybag waste by anaerobic digestion at 20°C and that the process may be applicable at lower temperatures, but at the expense of very long detention times.

However, it does not appear economically reasonable to build an anaerobic digester, with its requirement for heating, mixing and further treatment of supernatant effluent, for the overall primitive honeybag system. Disposal in a properly located, designed and operated waste pit or trench is preferable to disposal in a garbage dump or in the ocean. The two-year laboratory study, simulating a waste pit in permafrost, showed that it acts as a holding tank only. No waste treatment occurs. Pathogens are likely to remain viable in the pit for many years.

An improved method of handling and disposal of honeybags is practised in Greenland [8]. Two communities (Holsteinsborg and Egedesminde) have changed from the 'bucket-toilet' system to a 'bag' system. Homeowners are provided with strong paper bags lined with plastic, and closing clips, which are placed inside the bucket. The bags are picked up and transported by a flat truck to a disposal station (see Figure 13-16). One man at the disposal station empties the bags into a discharge pipe (see Figure 13-17) leading to the ocean, below low water level. The paper bags are burned. This system is considered a big improvement in Egedesminde. In Holsteinsborg plastic bags are used, rather than paper bags with plastic liners, and problems are experienced in burning the plastic bags. The cost of the disposal station could not be established but may be considerable, perhaps $150 000 (1973). It makes the solids handling much more acceptable to the operators. The expense of such a disposal station is justified only where the honeybag system will continue to be used for many years.

The dumping of honey bags at a landfill site, on the ice or in the ocean should not be encouraged, although there may be circumstances which make this practice tolerable. If honeybags are deposited at a landfill site, this should be separate from the garbage. Daily covering with at least minimal material will prevent animals and birds from getting into it. This is important to prevent disease transmission.

13.4.4 Costs and Charges

Presented in Table 13-7 are the actual costs involved for a honeybag collection system in some northern communities [39]. These costs are either given as a set charge per pick-up and/or as the actual annual cost per person. This includes labour, material, vehicle O&M, and overhead and profit costs for service provided by a contractor.

TABLE 13-7. HONEYBAG COLLECTION COSTS

Community	Year of Survey	Population Serviced	Costs	
Coppermine	1976	758	$1.20/pick-up	$32/person/yr
Gjoa Haven	1976	420	$2.15/pick-up	$50/person/yr
Fort Good Hope	1977	443	$1.85/pick-up	
Fort McPherson	1976	710	$1.50/pick-up	$32.10/person/yr
Paulatuk*	1977	145	$1.15/pick-up	
Chesterfield Inlet*	1976	243		$56.80/person/yr

* Labour and materials only.

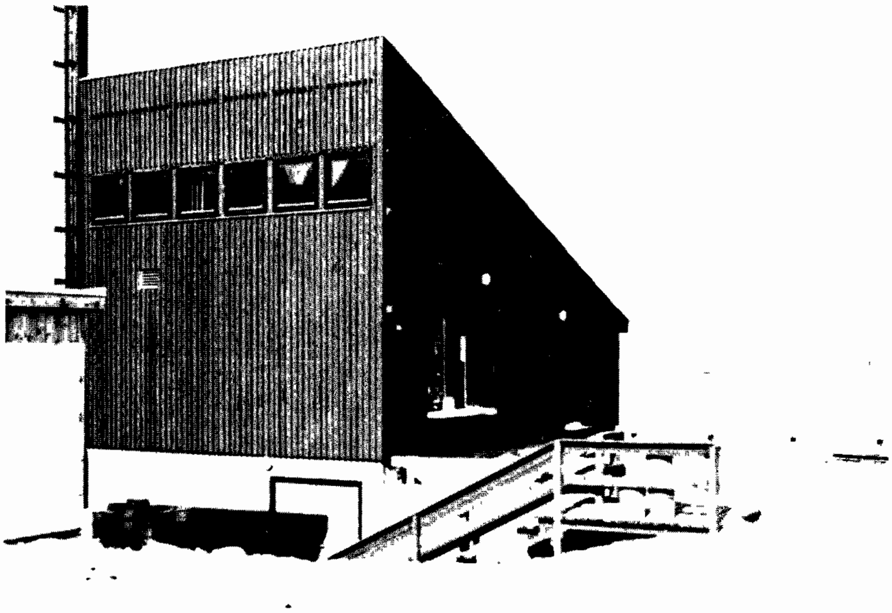

FIGURE 13-16. DISPOSAL STATION FOR HUMAN WASTE AT EGEDESMINDE, GREENLAND

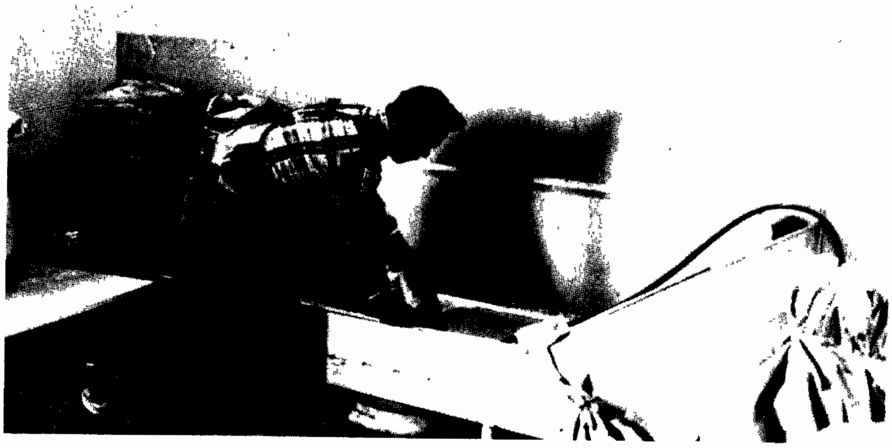

FIGURE 13-17. VIEW OF INSIDE OF DISPOSAL STATION, EGEDESMINDE, GREENLAND

Since all population sizes require similar infrastructures for the honeybag system, it can be seen that the smaller population sizes will have a higher per person cost. This, in fact, is supported by the above data.

13.5 References

1. Associated Engineering Services Ltd. "Solid Waste Management in the Canadian North", Environment Canada, Ottawa, March 1973.

2. Heinke, G.W., "Solid Waste Management in the Canadian North", Environment Canada, Ottawa, March 1973.

3. D.R. Stanley Associates Ltd. "Solid Waste Management in the Canadian North", Environment Canada, Ottawa, March 1973.

4. Underwood and McLellan, "Solid Waste Management in the Canadian North", Environment Canada, Ottawa, March 1973.

5. Kelton, K., "Comprehensive Plan for Solid Waste Management", Alaska Department of Environmental Conservation, Juneau, Alaska, January 1975.

6. Alter, A.J., "Solid Waste Management in Cold Regions", Scientific Research Data and Reports, Vol. 2, No. 2, Dept. of Health and Welfare, State of Alaska, College, Alaska, August 1969.

7. Grainge, J.W., "Study of Environmental Engineering in Greenland and Iceland", Manuscript Report No. NR-69-5, Div. of Public Health Eng., Canada Dept. of Nat. Health and Welfare, Ottawa, 1969.

8. Heinke, G.W., "Report on Environmental Engineering in Greenland and Northern Scandinavia", Publ. Dept. of Civil Eng. 73-05, Univ. of Toronto, October 1973.

9. Associated Engineering Services Ltd, "Report on Tuktoyaktuk Water Supply and Waste Disposal" to Govt. of N.W.T., Yellowknife, July 1974.

10. Smith, D.W. and Straughn, R.O., "Refuse Incineration at Murphy Dome Air Force Station", Arctic Health Research Centre, Fairbanks, Alaska, 1971.

11. Grundtwaldt, J.J., Tilsworth, T. and Clark, S.E., "Solid Waste Disposal in Alaska". In : Smith, D.W. and Tilsworth, T., Environmental Standards for Northern Regions, A Symposium, Institute of Water Resources, U. of Alaska, Fairbanks, 1975.

12. Can-Brit. Engineering Consultants Ltd., "Study of Solid Waste Management at Indian Settlements in Northern Ontario", for Environment Canada, Ottawa, March 1975.

13. Straughn, R.O., "The Sanitary Landfill in the Subarctic", J. Arctic Inst., Vol. 25, No. 1, March 1972.

14. Cohen, J.B., "Solid Waste Disposal in Permafrost Areas", Proc. Second Int. Conf. on Permafrost, Yakutsk, pp. 590-598, Nat. Acad. Sci., Washington, D.C., July 1973.

15. U.S. Army Corps of Engineers, "Technical Evaluation Study, Solid Waste Disposal, Fort Greely, Alaska, Office of the District Engineer, U.S. Army Corps of Engineers, Anchorage, Alaska, July 1972.

16. Forgie, D.J.L., "Shredded Solid Waste Disposal", IN Some Problems of Solid and Liquid Waste Disposal in the Northern Environment, Environment Canada Report EPS-4-NW-76-2, pp. 43-85, Edmonton, November 1976.

17. Black, R.J., Muhich, A.J., Klee, A.J., Hickman, L.H. and Vaughn, R.D., "The National Solid Wastes Survey - An Interim Report", U.S. Dept. of Health, Ed. and Welfare, October 1968.

18. Grainge, J.W., Edwards, R., Heuchert, K.R. and Shaw, J.W., "Management of Waste from Arctic and Subarctic Work Camps", Environmental-Social Committee, Northern Pipelines, Task Force on Northern Oil Development, Government of Canada, Ottawa, 1973.

19. Heinke, G.W., "Report on Municipal Services in Communities of the Northwest Territories", Information Canada, Ottawa, Cat. No. R72-12674, INA Publ. No. QS-1323-000-EE-A1, 1974.

20. Cadario, P.M. and Heinke, G.W., "Manual for Trucking Operations for Municipal Services in Communities of the Northwest Territories", University of Toronto, Publication of Department of Civil Engineering, October 1972,

21. Hanks, T.G., "Solid Waste/Disease Relationships, A Literature Survey", Publ. of Public Health Service, U.S. Dept. of Health, Education and Welfare, Report SW-K, Washington, D.C., 1967.

22. Heinke, G.W., "Preliminary Report on Disposal of Concentrated Wastes in Northern Areas", in Report 74-10, Environmental-Social Committee, Pipelines, Task Force on Northern Oil Develop., Inf. Canada, Cat. No. R72-13474, QS-1577-000-EE-A1, Ottawa, 1974.

23. Heinke, G.W. and Prasad, D., "Disposal of Concentrated Wastes in Northern Areas", IN Some Problems of Solid and Liquid Waste Disposal in the Northern Environment, Environment Canada Report EPS-4-NW-76-2, pp. 87-140, November 1976. Also in Proc. 3rd Can. Hydrotech. Conf., Can. Soc. Civ. Eng., Laval University, Quebec, pp. 578-593, 1977.

23. Stanley Associates Eng. Ltd., "Baling for Solid Waste Management at Baker Lake, N.W.T.", prepared for Northwest Region, Environmental Protection Service, Environment Canada, Edmonton, 50 pp., 1974.

24. Underwood McLellan and Assoc. Ltd., "Report on Study of Pollution Control Systems, Resolute, N.W.T.", Report to: Government of the Northwest Territories and Environment Canada, Environmental Protection Service, Edmonton, 1974.

26. Watmore, T.G., "Problems of Waste Disposal in the Arctic Environment", Industrial Wastes, 21(4), 24, 1975.

27. Zenone, C., Donaldson, D.E., and Grunwaldt, J.J., "Groundwater Quality Beneath Solid Waste Disposal Sites at Anchorage, Alaska", Groundwater, 13(2), 180-190, 1975.

28. Gamble, D.J. and Janssen, D.T.L., "Estimating the Cost of Garbage Collection for Settlements in Northern Regions", The Northern Engineer, 6(4):32-36, 1974.

29. Heuchert, K.R., "Refuse Sack Collection System Study", IN Arctic Waste Disposal - Social Program, Northern Pipelines, Task Force on Northern Oil Development, Report No. 74-10, pp. 1-22, 1974.

30. Stanley Associates Eng. Ltd., "Final Report on Community Services Improvement Program, Yukon Territory", prepared for: Dept. of Local Government, Government of the Yukon Territory, Whitehorse, 292 pp., 1974.

31. Lindstrom, C.R., "Clivus-Multrum System: Composting of Toilet Waste, Food Waste and Sludge within the Household", IN: Rural Environmental Engineering Conference on Water Pollution Control in Low Density Areas, September 26-28, 1973. Warren, Vt., Published by University Press of New England, Hanover, N.H., pp. 429-444, 1975.

32. Gamble, D.J. and Janssen, C.T., "Evaluating Alternative Levels of Water and Sanitation Services for Communities in the Northwest Territories", Can. J. of Civil Eng., 1(1): 116-128, 1974.

33. Ryan, W.L., "Village Sanitary Problems", In: Environmental Standards for Northern Regions, June 13-14, 1974. D.W. Smith and T. Tilsworth, eds., Inst. of Water Resources, Univ. of Alaska, pp. 315-320, 1975.

34. Village Sanitation in Alaska - Inventory. Office of Environmental Health, U.S. Public Health Service, Anchorage, Alaska.

35. Alaska Department of Environmental Conservation, "Waste Oil/Water Quality Problem Description" (Draft Report), Juneau, Alaska, November 1977.

36. Associated Engineering Services Ltd., "Waste Management for Northern Work Camps", Environment Canada, Northern Technology Centre, Edmonton, April 1978.

37. W.O. Wardrop and Associates Ltd., "Burning Practices in the Northwest Territories", (Draft Report), Regina, March 1978.

38. Zaidi, A. and Curran, B., "Open Pit Incinerator", Report of Saskatchewan District, Environmental Protection Service, Northwest Region, Environment Canada, Regina, April 1978.

39. Doulton, B., "Water and Sanitation Operation and Maintenance Costs - A Consolidation of Historic Information", prepared for the Dept. of Local Govt., Government of the Northwest Territories, Yellowknife, 1978.

SECTION 14

ENERGY MANAGEMENT

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14 ENERGY MANAGEMENT

14.1 Basic Considerations

A community requires energy for heating buildings, for lighting, for operating appliances and for domestic hot water. Transportation energy needs are not supplied by utilities. Industrial energy needs can be supplied by utilities, but they are identified and added separately and are not considered in this manual.

The energy requirements for heating depend on the climate and vary with the season. Based on the pertinent climate design information, the requirements can be estimated. Climatic information is also used for the design of thermal protection for utility lines.

The strong seasonal variation in heating requirements and, to a modest extent, the variation in electrical requirements, namely for lighting, affect utilities and, therefore, their cost and feasibility. The utilization can be estimated and used as a basis for selection of the appropriate equipment.

14.1.1 Energy requirements

The heating requirements for buildings are controlled primarily by the outside air temperature. Wind and sun have a lesser, more temporary influence. The design and construction of a building determines its thermal efficiency, of course, and affects its annual heating requirement compared with another building. For planning purposes, typical values can be used, based on the heating index. The heating index is expressed in degree-days. The usual base in 18°C. Table 14-1 lists typical values for residential heating requirements.

TABLE 14-1. RESIDENTIAL ENERGY REQUIREMENTS

	Space heat kWh/°C d	Domestic hot water kWh/d	Lights and appliances kWh/d
Single residence houses	9	12	12-24
Multi-residence buildings	6	12	12-24

Domestic hot water requirements are nearly constant throughout the year. Table 14-1 shows typical daily requirements which may be supplied through the heating system or through electricity. With electricity, off-peak power can be used to heat water in individual accumulators. With district heating, a low baseload is provided for the summer season.

The typical lighting and appliances requirements of residences are also shown in Table 14-1. The lower values are for summer conditions; the higher values are for the winter. The difference is primarily due to lighting requirements which are near zero in the summer.

Table 14-1 does not include electrical requirements for car engine heaters, which are about 5 to 10 kWh/d per car during the cold season.

The values for electricity use are typical daily totals. The ratio of daily peak to average demand is 2 to 3 for a community. The ratio for an individual residence is much higher.

The design heating system capacity is based on the winter design temperature. The difference between the heating index base temperature and the winter design temperature gives the number of degree-days and the corresponding heating requirements per day. The daily peak load on a district heating system is influenced mainly by the effects of morning warm-up after night set-back, and by heating needs during dropping ambient temperatures, e.g., in the evening. The ratio of daily peak to average load is about 1.2.

The commercial and institutional heat and electricity requirements are summarized in Table 14-2. Electricity requirements are more cyclical with the time of day than residential requirements.

TABLE 14-2. COMMERCIAL AND INSTITUTIONAL ENERGY REQUIREMENTS

	Space heat, $Wh/m^2/°C\ d$	Lights and equipment, $Wh/m^2/d$
Schools, offices < 1500 m^2	65	600
Schools, offices > 1500 m^2	65	720
Shops and retail stores	60	850
Food stores	60	1400

14.1.2 Climate design information

Climatic design information is given in Appendix H.

The heating index is a measure of the heating requirements of buildings in a particular location. Table H-1 gives the heating index for various Alaskan communities, Table H-2 for various Canadian communities. Degree-days are Fahrenheit. For conversion to degree-days Celsius, divide by 1.8. Figure H-1 shows the heating index distribution across Alaska, Figure H-2 the distribution across Canada.

The design temperatures indicate the lowest temperatures that can be expected in a particular location and provide a measure of the needed capacity of the heating system. Table H-3 gives design temperatures for various Alaskan communities, Tables H-4 and H-5 for Canadian and Greenland communities. Temperatures are in degrees Fahrenheit. Figure H-3 shows the distribution of design temperatures across the contiguous United States.

The freezing index is a measure of below-freezing (below 0°C) weather conditions and is used for computing frost penetration into the ground. Frost penetration information is needed to define the depth of water line burial or the amount of insulation necessary for protection. Figure H-4 shows the freezing index distribution across Alaska, Figure H-5 across Canada. Values are based on degrees Fahrenheit.

The thawing index is a measure of the summer climate. When it is significantly smaller than the freezing index, the chances for permafrost conditions increase. In permafrost areas, the thawing index is used to compute the seasonal thaw penetration. Figure H-6 shows the thawing index distribution across Alaska, Figure H-7 across Canada.

The mean annual air temperature is used in conjunction with the freezing index for computing the ground frost penetration. Figure H-8 shows the mean annual temperature distribution across Alaska. Table H-6 gives temperatures for northern Canadian communities. The same table also gives ground temperatures. Ground temperatures, including permafrost temperatures, are typically a few degrees higher than the mean annual air temperatures. Alaskan ground temperatures are given in Table H-7 for various communities.

Groundwater temperatures are a good ground temperature indicator. In Alaska, the locations of many thermal wells are known, even in permafrost areas, mainly because they are artesian. It is very likely that there are many more thermal wells (non-artesian) or undiscovered aquifers.

14.1.3 System utilization and feasibility

Electric and thermal utility systems are capital intensive. For electric systems, the generating plants are the most expensive part; for thermal systems, the distribution lines are most expensive. That means, in turn, that thermal distribution systems have a smaller range of coverage than electric systems, because they are limited to higher density areas. Dispersed residential areas must use either delivered fuel or they may be able to use off-peak electricity economically, supplemented with solar heat.

To ensure economic feasibility, the system utilization must be as high as possible. That means that the amplitude of the peaks and valleys of the load curve should be minimized.

With electric systems, this goal can be achieved through various demand management techniques which shift loads from peak to off-peak periods. Heating of domestic hot water and electric storage heating are examples of deferrable demands.

With thermal systems (district heating), the loads are governed by the weather. Daily demand fluctuations are smaller than the seasonal fluctuations. Seasonal storage has not yet been shown to be feasible. The demand closely corresponds to the weather, and known climatic data can be used to estimate the anticipated plant utilization.

The intensity of the winter weather, i.e., the winter design temperature, determines the required plant capacity. The duration of the cold weather, i.e., the heating index, determines the annual plant output. The ratio of actual annual output to possible annual output (at full capacity) is the measure of plant utilization. It is expressed in hours per year of equivalent full capacity output. Full capacity is

8760 h/a (hours per annum). For a district heating system, 2000 to 2500 h/a is a feasible utilization.

The anticipated plant utilization is computed from climate information by:

$$\frac{\text{heating index} \times 24}{18°\text{C} - \text{design temperature}} \qquad (\text{h/a}) \qquad (14\text{-}1)$$

The actual utilization may be only about 90% of the value computed from equation (14-1), or less, because the system usually has excess capacity, e.g., to allow for growth and reserve.

As an example, the anticipated utilization is computed for Anchorage Alaska, and Edmonton, Alberta. From Tables H-1 and H-2 the heating index values are 10789 and 10320 °F d, respectively. The values of -25°F and -39°F from Tables H-3 and H-4 can be used for the design temperatures. The resulting values for utilization are 2877 and 2381 h/a, respectively. Using 90% to obtain the anticipated actual utilization, the following values result:

Anchorage	2590 h/a
Edmonton	2143 h/a

Figure H-10 shows a plant utilization distribution across the contiguous United States which corresponds closely to utilization values that result from the above calculation method.

A higher value for system utilization means that lower density areas may be served economically, other things being equal.

As with electric systems, it is advantageous to have a mix of baseload and peak load plants. Baseload plants are characterized by high capital but low energy cost, for example, cogenerating plants (heat and power). Peak load and reserve capacity plants have the opposite characteristics and are used only intermittently. Gas turbines (without heat recovery) are examples of peak load plants for electricity production; boiler plants are examples for heat production.

14.2 Energy Supply

Energy supply in arctic climates is similar to that in other climates. Some methods are employed to greater or lesser degrees due to arctic conditions.

14.2.1 Fuels and storage

The fuels and storage of fuels used in the arctic climate are, generally speaking, the same as in temperature climates. However, there are some special design elements which must be considered to ensure reliable operation.

14.2.1.1 Selection of fuels. The petroleum products (gasoline, diesel, etc.) used in arctic climates to power motor vehicles, trucks and air craft are identical to fuels used in temperate climates, except for possible octane levels, grades or additives which are controlled by the different petroleum producers.

The one area in which fuel use varies is in the use of diesel fuel. The one main property of fuel oil which is readily affected by the cold climate is viscosity. Viscosity is the property of a substance which makes it resist the tendency to flow. From Figure 14-1, it can be seen that fuel oil at moderate temperatures of 20°F to 60°F has a kinematic viscosity of between 9 to 3.5 centistokes. But when the temperature drops to arctic conditions of -10°F to -60°F, the viscosity of the fuel oil becomes extremely high, 25 to 500 centistokes. This high viscosity presents a problem in that the fuel oil becomes so thick that it refuses to flow. Fuel oil in above-ground tanks and piping which are exposed to arctic temperatures often becomes too thick for burner pumps to handle.

There are several solutions to this high viscosity problem. One solution is to bury the fuel piping and storage tank to avoid exposure to the cold temperatures. This is only practical for small tanks of up to 190 m^3. Another solution is the use of arctic grade diesel fuel, DF-A, which has a much lower kinematic viscosity. From Figure 14-1, it can be seen that DF-A fuel has a kinematic viscosity of 11.4 centistrokes at -30°F. This is a great improvement over other figures.

14.2.1.2 Storage and transport of petroleum fuel. The basics of fuel storage are the same as those for water storage presented in Chapter 5. The most common means of storing large quantities of petroleum products, both in temperate and arctic climates, is large above-ground steel storage tanks. The storage tanks used in both climates are generally the

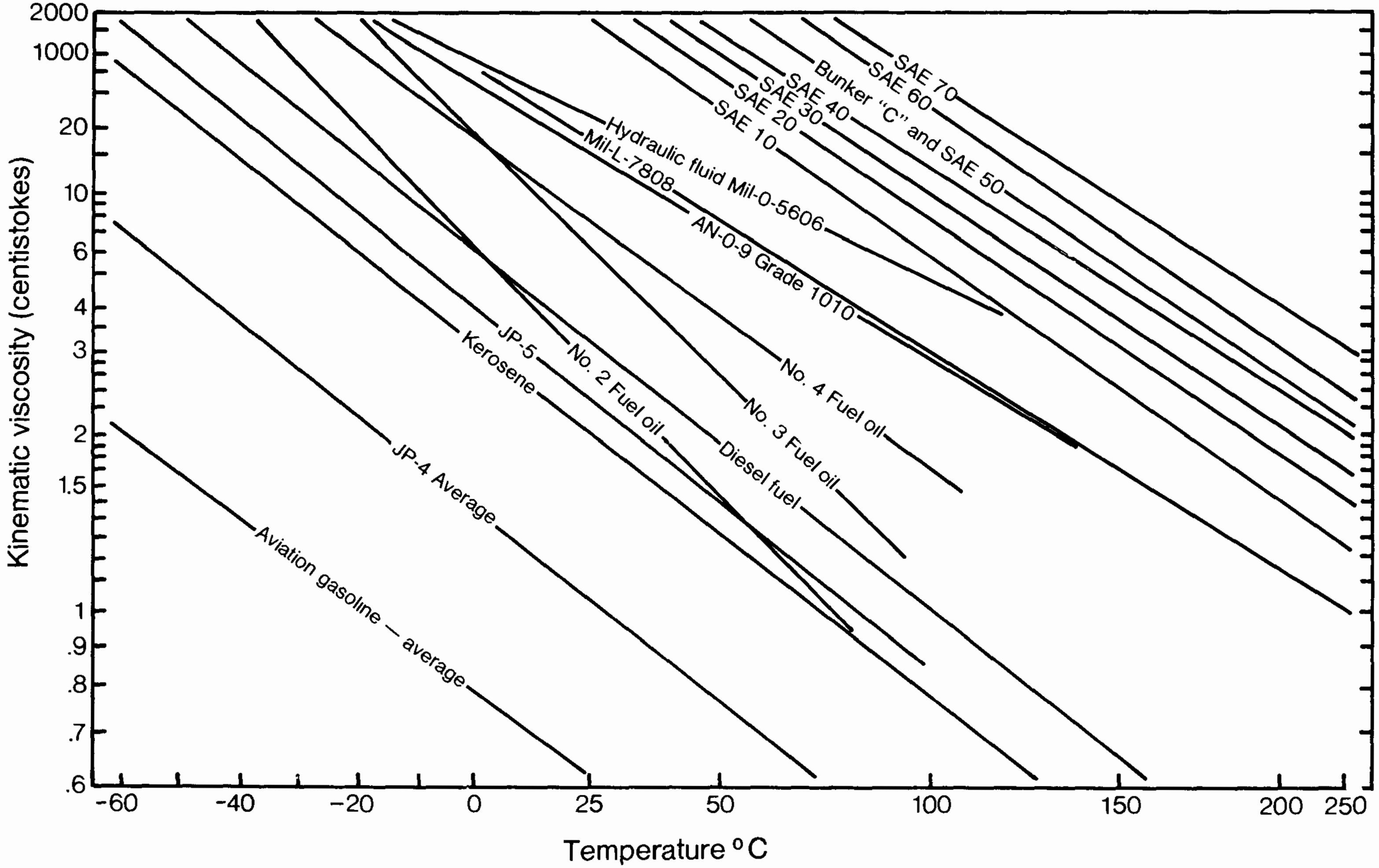


FIGURE 14-1. KINEMATIC VISCOSITY AS A FUNCTION OF TEMPERATURE FOR VARIOUS FLUIDS.

same and are constructed to the standards set by the American Petroleum Institute, Standard 650. The structural design of the tanks, in most cases, is the same unless extreme snow and ice loads are expected, in which case the structure is re-designed to carry the loads. One major difference in storage tank design in the Arctic is the steel materials used. Standard grade steel plates become less flexible and somewhat brittle at extremely cold temperatures. For this reason, a different grade of steel with good cold weather characteristics is used for tank construction. The tank appurtenances also vary from temperate to arctic climates. Water in the product is a very serious problem in any climate, but in the Arctic it presents some different problems. The water draw-off connection on the tank is used to remove the water which accumulates within the tank. Because of the arctic cold, the water draw-off valve must be a non-freeze type valve. The design of a non-freeze valve is such that the valve seat is mounted well back into the inside of the storage tank, where the temperature of the product and water is above freezing. If a conventional valve is used, the probability of water in the valve freezing and cracking it is quite high. This could create a serious problem because when the frozen, cracked valve thaws out, fuel will escape resulting in a spill.

Some storage tanks equipped with vapour-saving tank breathers also present problems. The breathers will freeze up in cold weather unless they are equipped with a flexible frost and ice resistant diaphragm material. The breather screens also have a tendency to frost shut during periods of extreme cold. Therefore, it is recommended that the screens be removed during winter.

For the most part, petroleum products are transported by pipeline, tank trucks, rail tank cars, and barges on sea and rivers, whichever proves to be the most efficient and economical. In some cases, petroleum products have to be air lifted into remote sites due to the lack of road or rail service. In these cases, the petroleum products are transported in drums or flexible bladder tanks.

Pipelines are probably the most efficient way of transporting large quantities of petroleum products. Arctic construction of a pipeline is similar to methods used elsewhere in the world. There are, however, a few problems encountered when routing a pipeline through the arctic climate and terrain. Pipelines are generally not buried in permafrost areas because the warm flow of product would melt the permafrost and the pipeline would gradually sink in the quagmire slurry produced. If a pipeline is buried some form of thermal protection must be provided for the permafrost.

Pipelines in permafrost areas are supported above-ground on refrigerated pile supports. The refrigerated piles prevent the permafrost from thawing, thus providing a solid foundation for the pipeline.

Moisture or water in petroleum products presents a very serious problem when the product is transported through pipelines or any other system where it is exposed to freezing temperatures. The water freezes and builds up by glaciering until a plug is formed. Damage to valves, pumps, and other equipment could result. Therefore, it is essential that water be removed from the product through water separators. These water separators, along with other product transfer equipment, should be enclosed in a heated shelter to protect the equipment and provide a warm working area in which to perform routine repairs and maintenance.

Transfer components, which are not enclosed in warm shelters but are used in pipelines and other systems, require cold weather considerations in their design. Control valves, flexible hoses, meters, etc., should be designed from materials and components that will stay flexible and operable at cold temperatures, such as polybuthylene flexible plastic pipe.

14.2.1.3 Storage and transport of solid fuels. The most commonly used solid fuel is coal. The storage and transport of coal is virtually the same in both arctic and temperate climates. However, unloading and storing of coal in arctic temperatures presents some problems. The coal is usually washed at the mining operation prior to loading into the rail cars. At cold temperatures, the wet coal quickly freezes into a large rail-car-shaped chunk of coal. The unloading area must be enclosed by a shed type structure built onto the power plant over the tracks. The frozen coal cars are placed in the warm sheltered area for unloading. The frozen coal is thawed and unloaded with steam probes and coal car shakers. The coal, via conveyor belt, is then stored either in the plant bins or in piles outside the plant. When coal is required from outside storage piles, steam probes, bulldozers and loaders are used to thaw and move the coal into the power plant storage bins. Once the coal is inside the plant, one would think that no other problems would exist. However, because of the mass involved, the coal is still quite cold, contains moisture and, once allowed to sit, will generally refreeze in the bins or in the coal chutes on the way to the boilers. This condition is usually remedied with shakers attached to the chutes or bins.

14.2.1.4 Storage and transport of liquified gaseous fuels. The most common fuel of this type used in the Arctic is propane gas. Propane is transported the same way in both arctic and temperate climates, in specially designed pressure tank cars and trucks. Propane is distributed and stored in small pressure vessels which serve homes and small businesses.

The one major problem with propane in the Arctic is related to its vaporization characteristics. Propane, at temperatures below −45°C, remains a liquid. This situation can become dangerous because a liquid stream of propane is sometimes allowed to pass into piping leading to utilities and appliances, causing fires and explosions. Propane tanks exposed to these cold temperatures either require thick insulation or enclosure in heated structure. If a heated enclosure is used, an additional problem arises in that the enclosure must be ventilated to prevent a build-up of explosive vapours. Another problem with propane at sub-zero temperatures is that when the gas passes through the tank regulator and valve, its expansion causes a drop in temperature, resulting in frosting and freeze up of the regulator and valve.

14.2.1.5 Reliability, maintenance, security. The reliability of petroleum product systems in the Arctic is basically the same as systems constructed in warm climates, provided that the materials and components used in the arctic construction are appropriate to the climatic conditions. If arctic design procedures are followed, there should be no problem concerning reliability. Maintenance of petroleum product systems in cold regions again does not present any serious problems.

Security of petroleum product systems in the Arctic is no different from temperate climates. Tank farms, pump stations, etc., are usually manned 24 hours a day and are enclosed with high security fencing. Pipelines are inspected regularly by vehicle or helicopter.

14.2.1.6 <u>Fuel spills and containment.</u> The probability of a fuel spill is virtually the same anywhere in the world. The largest cause of fuel spills is related to human error or negligence of operating personnel. Large spills generally start out as small leaks which can be stopped or avoided by performing regular maintenance and inspections.

Containment of large or small petroleum spills is basically the same in any climate. The most common methods of containing and collecting spills consist of dike areas around tanks, collection weirs in drainage ditches, drip pans, absorbents, etc. Dikes in cold regions are generally constructed of gravel and rock with a layer of impervious local soil as a liner. Membrane materials which remain flexible at low temperatures, such as PVC and CPE, may also be used. Concrete dikes are not always practical in the North because freeze-thaw action causes cracks in the concrete walls to the point where spilled fuel would leak out.

Some problems are encountered in dike maintenance and operation during the winter. Large snow falls are not uncommon and they are usually followed by warm thawing temperatures and rain, which creates a quick snow melt situation. This quick melt produces large quantities of water which must be drained from the frozen dikes. A sump is usually provided and a portable pump is used to pump out water which accumulates.

14.2.1.7 <u>Corrosion and grounding.</u> Corrosion of petroleum storage and transport systems in the Arctic presents virtually the same problems as found elsewhere. Arctic soil and atmospheric conditions vary from location to location, some being more corrosive than others. For instance, those systems which are located along the arctic coast are exposed to the corrosive action of salt air, whereas those systems inland are only exposed to normal conditions. Soil conditions also vary considerably from one area to another. Areas containing peat bog are usually acidic and very corrosive. Preventative measures taken against corrosive conditions in cold regions are standard measures used elsewhere in the world. Pipelines are cleaned, primed and wrapped before burial. Storage tanks are protected inside and out with special coatings, etc. Cathodic protection measures, magnesium anodes, are also used to help prevent corrosion of buried product lines.

The battle against corrosion of steel used in product storage and transfer systems is a universal problem and cold regions provide no special problems.

Grounding of petroleum product systems is very important and is required in all climatic conditions. Arctic designs are no different concerning grounding of equipment and product lines to guard against static discharge. In areas without permafrost conditions, the product systems, including storage tanks, piping, buildings, water lines, metal sewer lines, etc., are all bonded together and connected to grounding rods which are driven into the ground. In some areas of the Arctic, the ground conditions provide good grounding systems. Some areas may require several ground rods or even a grounding plate set in a salt solution.

Permafrost areas present another situation. Areas with underlying permafrost do not provide acceptable grounding conditions due to the high resistance of frozen ground. In these areas, everything is bonded together, including electrical wiring, POL piping, metal building structures, storage tanks, water and sewer lines, etc., to form one large grid network which can then be connected to a water well casing which penetrates the permafrost layer, which in turn provides an acceptable ground. If no well casing exists, then the grid system is connected to a ground rod which does not penetrate the permafrost. This will provide a common floating ground with everything at the same electrical potential. This is acceptable as long as everything is bonded to that common ground. Another practice is to place a grounding grid of cable into a lake.

14.2.2 Heat and power production

The boilers and machinery that generate heat and electricity are the same in cold regions as in temperate climates. Special considerations apply to the structures that support and contain them, their reliability, their operating characteristics, their constructibility, and other factors.

14.2.2.1 Central vs. independent generation. Electricity is generated in central plants and distributed in cold regions as in temperate climates. The reliability advantages of central plants with multiple generating units are desirable, but added consideration must be given to achieving corresponding reliability in the distribution network, which is exposed to the severe climate conditions. The same holds true for heating plants within the feasible distribution limits, even more so than in temperate climates: heating needs are greater, favouring the economic benefits of district heating; the greater reliability is a vital factor; and fire safety is enhanced by the elimination of combustion equipment in every building.

14.2.2.2 Cogeneration. Whenever heat is generated, particularly for low temperature uses such as space heating, the simultaneous generation of electricity should be considered because most electricity is generated from heat. Conversely, whenever electricity is generated, the utilization of the waste heat should be considered. The advantage of cogenerated electricity is the high fuel efficiency it attains compared with single-purpose generated electricity. The amount of cogeneration that is feasible is determined from an analysis of the thermal and electrical loads supplied by the central plants, the output characteristics of the generating equipment, and the ability to store output (e.g., heat) for load management. Typical generating efficiencies of different types of plants are summarized in Figure 14-2.

14.2.2.3 Strategic considerations. These are influenced not only by the severity of the climate and the possible difficulties with logistics due to remoteness, but also because the isolation of most installations or communities requires a greater degree of self-sufficiency than with interconnected systems. Diversity should be built into the system so that alternate fuels can be used. Redundancy of equipment as well as standby capacity must also be considered.

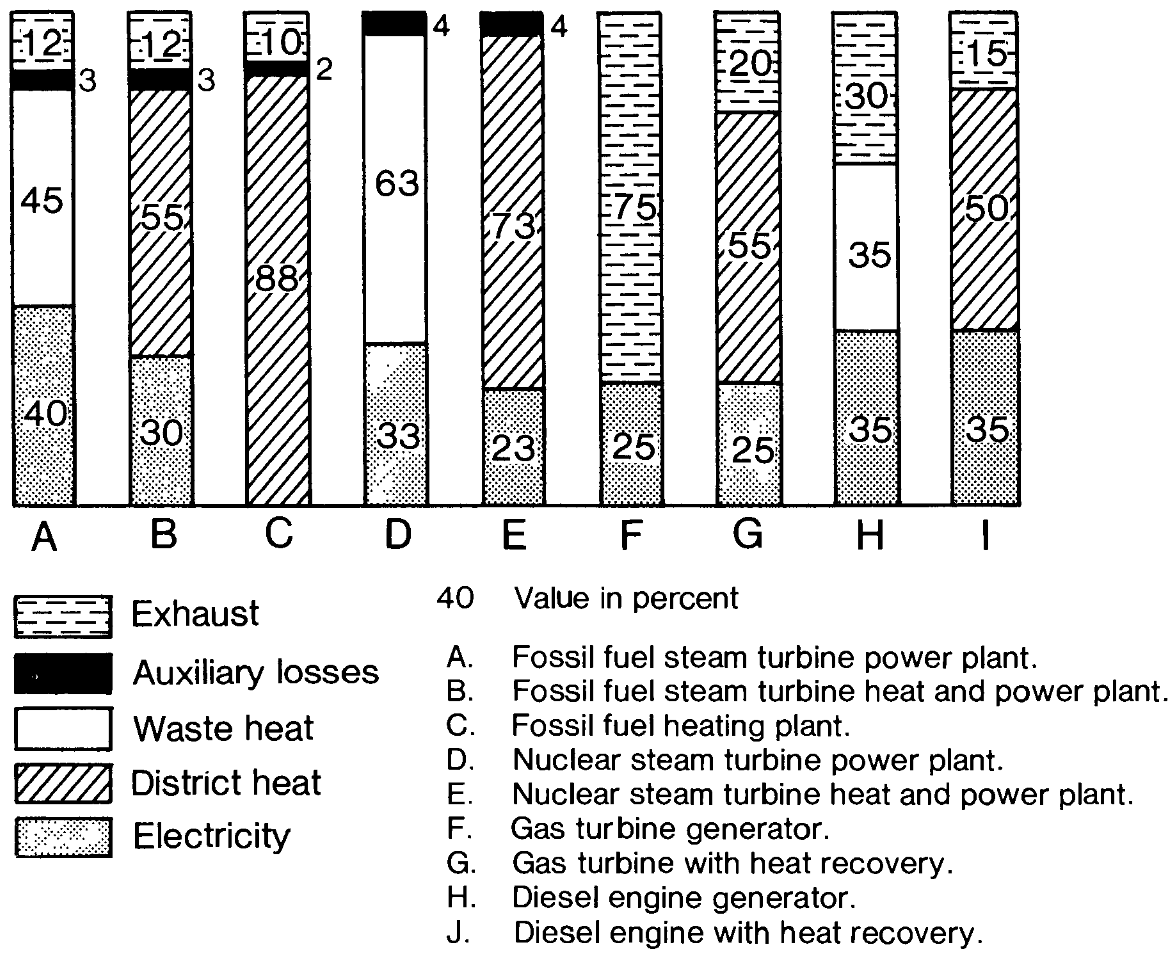


FIGURE 14-2. OUTPUT CHARACTERISTICS OF VARIOUS COMMON ELECTRIC GENERATING SYSTEMS. The output called "District Heat" represents recoverable thermal output in the temperature range of 80 to 120°C.

14.2.2.4 Electric generating plants. Hydroelectric plants are independent of fuel logistics problems and have the possible added advantage of providing pumped hydro storage in conjunction with cogeneration. They use renewable resources. In cold regions, hydroelectric plants may be limited by icing or seasonally reduced output. Large thermal electric plants are typically baseload plants; they are also likely candidates for cogeneration. Smaller units, usually for peak load and reserve, may be gas turbine or diesel engine generators. They require special consideration in the design of air intakes and filters to avoid congestion by snow. This is achieved by installing a heat exchanger in the intake plenium to sublimate the snow or melt any possible ice build-up. It is not sufficient to depend on open doors or windows in a generator building for air intake. The combustion air requirement for diesel engines is about 3 std. m^3/h per kW, and for gas turbines about 55 std. m^3/h per kW output. Use of wind energy, such as a vertical axis wind turbine, is limited by icing problems that would be encountered on the turbine blades.

14.2.2.5 Heating plants. Fuel burning heating plants, also called boiler plants, are low cost plants but the heat output is relatively expensive because the cost of the fuel is high (fuel oil or natural gas), and because electricity is not co-produced to offset the fuel cost. Therefore, boiler plants are typically peak load and reserve plants. Figure 14-3 shows how the overall cost is minimized by combining a baseload plant with high first cost but low operating cost with a peak load plant with lower first cost but higher operating cost. The baseload plant is efficient at high utilization rates (above 4000 h/a in the example), the peak load plant at low utilization rates. Boiler plants burning coal, peat, or solid waste have lower fuel costs but higher first costs. They are more like baseload or intermediate load plants.

When an indigenous source of low-temperature heat is available for utilization through heat pumps, it offers an alternative with the important advantage of independence, particularly when the electricity used for the heat pumps is also generated from renewable resources. Examples of low-temperature sources are ocean water, with year-round

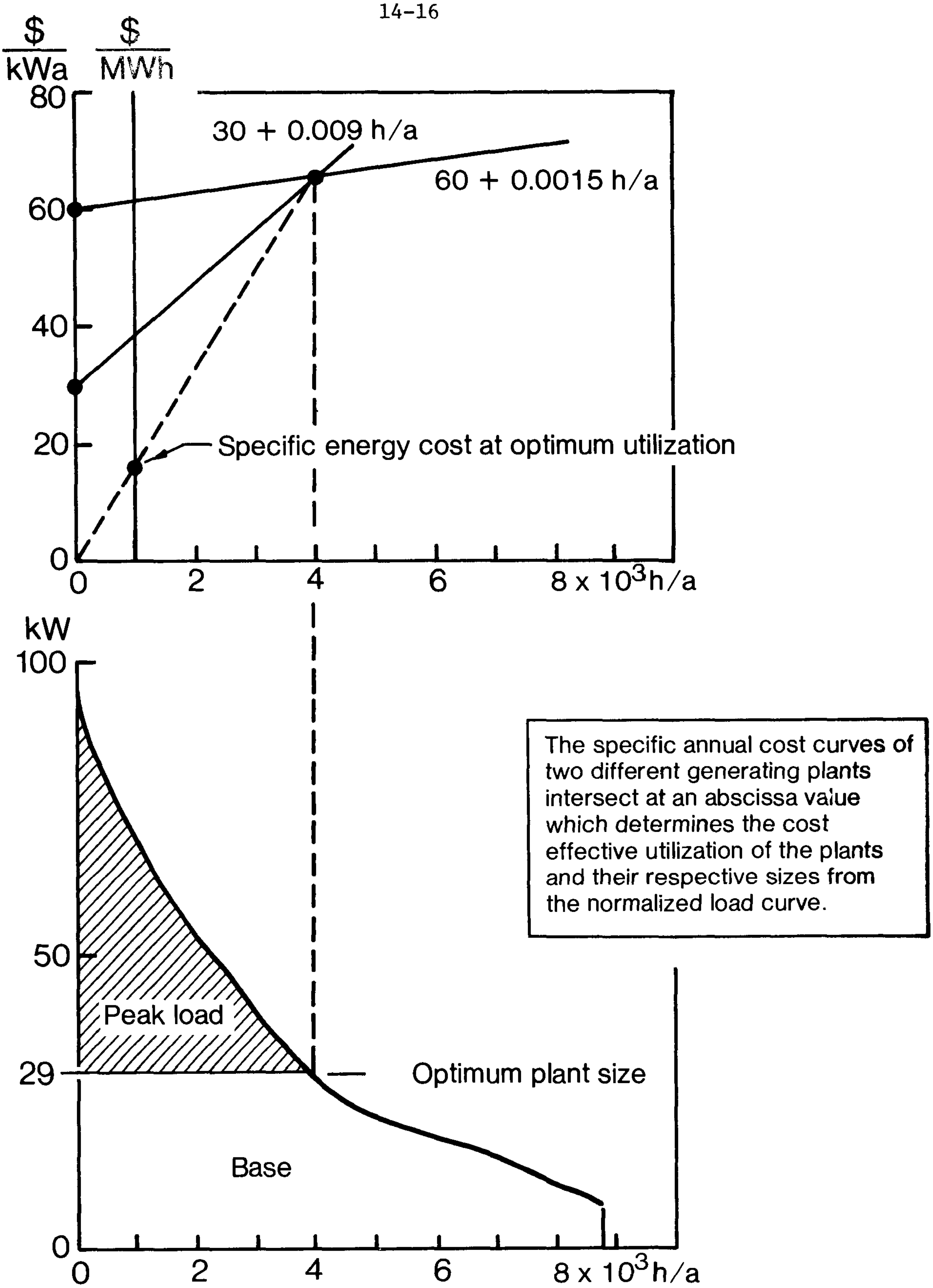


FIGURE 14-3. DETERMINATION OF OPTIMUM COST AND PLANT SIZE FOR BASE AND PEAK LOAD GENERATING PLANTS. The specific annual cost curves of two different generating plants intersect at the abscissa value which determines the cost-effective utilization of the plants and their respective sizes from the normalized load curve.

temperatures of at least about 5°C, and groundwater (hydrothermal sources), with those same minimum temperatures. Higher source temperatures are advantageous because the coefficient of performance depends also on the temperature of the heat output; lower output temperatures permit a higher coefficient of performance. For example, with a source water temperature of 10°C and a delivery water temperature of 60°C, a coefficient of performance of about CP = 2.6 can be expected. That means that for each unit of electric energy used to drive the heat pump, 2.6 units of thermal energy are delivered, while 1.6 units of thermal energy are extracted from the source. If only 50°C is required or, if instead the source temperature is 20°C, then the coefficient of performance approaches CP = 3.0. Suitable sea water temperatures are found along the coast of eastern Alaska (east of Valdez) and the west coast of Canada (see Figure 14-4). Suitable ground water temperatures are found in southwestern Canada.

14.2.2.6 Alternate energy sources. Alternative indigenous sources of heat and electrical power generation are being seriously considered for many northern locations. Although the benefits in terms of economics and self-sufficiency are attractive, the technical and climatic limitations are often greater in northern locations. For example, the use of solar energy is limited by the shortness or absence of daylight hours during the winter. Also, the use of wind generators may be limited by icing conditions.

14.2.2.7 Storage. Hot water accumulators for heat distribution, providing load management capability and reserve capacity, are feasible in relatively larger sizes in cold regions than in temperate climates because heating loads are greater and because greater reserve capacity requirements are desirable. Figure 14-5 illustrates a storage accumulator. Large insulated accumulator tanks do not have to be inside buildings but the connecting lines and valves must be sheltered and protected to reduce the danger of freezing.

14.2.2.8 Waste heat. All electricity generated from heat has also "waste" heat as a byproduct, as stated by the Second Law of Thermodynamics. This waste heat is unavailable to the process and

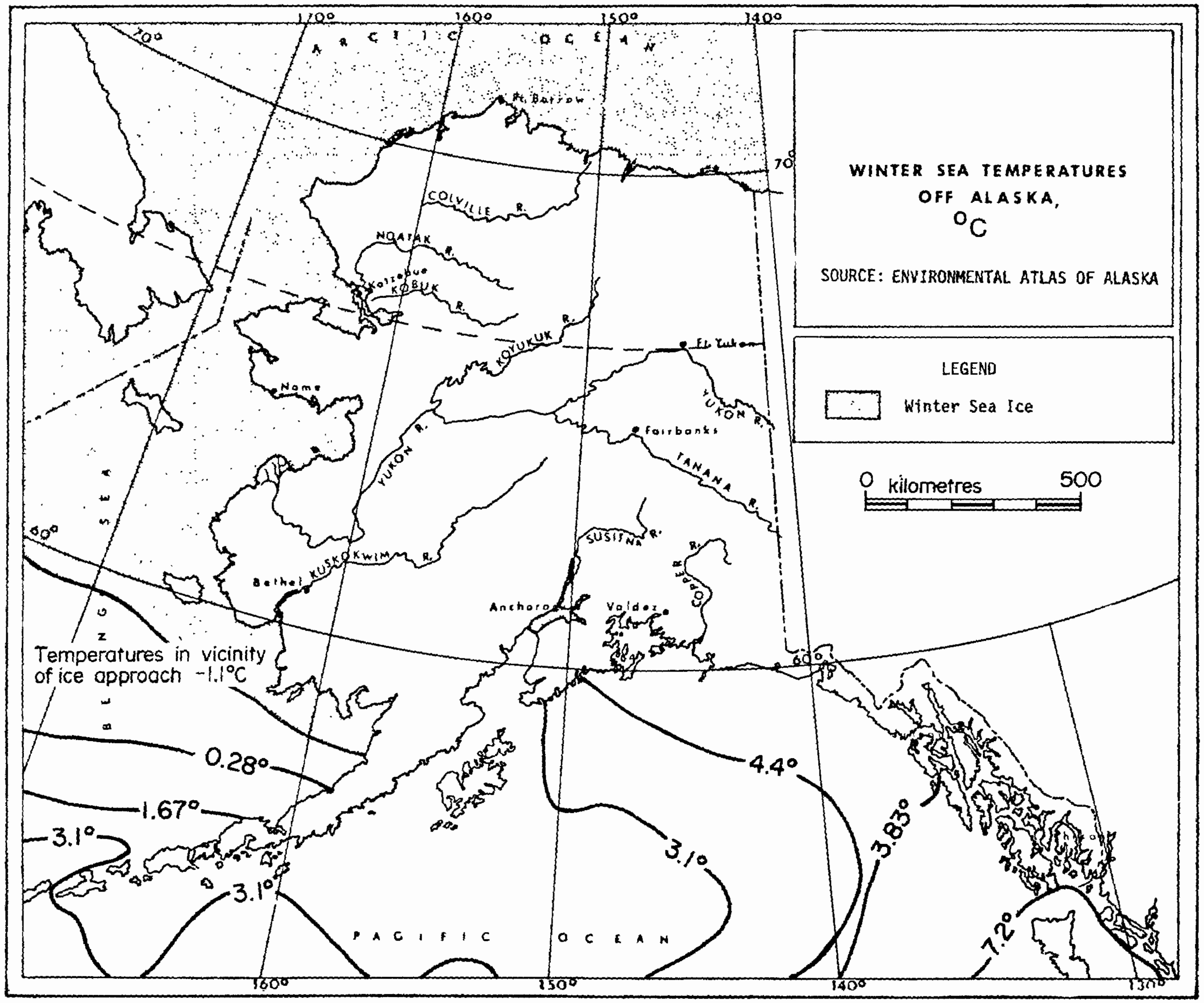


FIGURE 14-4. WINTER SEA TEMPERATURES OFF ALASKA

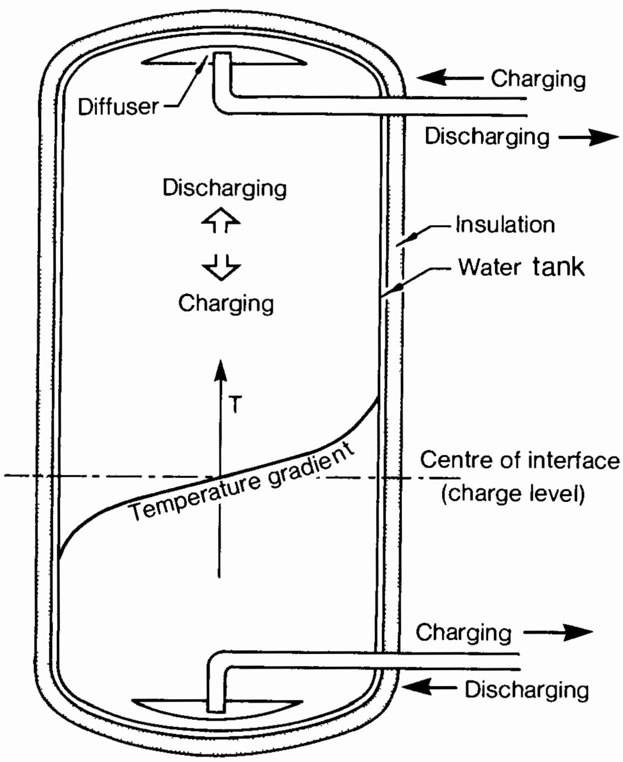


FIGURE 14-5. HOT WATER ACCUMULATOR FOR THERMAL STORAGE SHOWING TYPICAL INTERFACE CHARACTERISTICS

represents usually about twice as much energy as that converted to electricity (Figure 14-2). In case of a steam turbine, the condenser heat is produced at a temperature which is too low for space heating. If a higher back pressure is used or steam is extracted before the last stages, then it is less a case of waste heat utilization than a modification for cogeneration.

Gas turbines provide heat from compresser intercooling and from exhaust gases (after recovery for air preheating) at temperatures which are suitable for district heating. Diesel engines provide heat from jacket cooling and exhaust gases which is also suitable for district heating. In these cases, cogeneration is possible using rejected "waste" heat without process modification.

Heat is recovered from exhaust gases from producing hot water or steam with an economiser. This is basically a water tube boiler without combustion chamber. Frequently, a boiler has an economiser built to its back end for feed water preheating. When the economiser is combined with a gas turbine or diesel engine, the engine serves as combustion chamber and the economiser is the boiler. Jacket heat recovery from the diesel engine is with a water-to-water heat exchanger connected to the engine cooling loop. Such heat recovery boilers and heat exchangers are standard equipment.

To recover heat from exhaust gases from a boiler or a gas turbine for preheating combustion air, gas-to-gas heat exchangers are available in the form of plate or tubular air preheaters, or Ljungstrom rotating cylinder air preheaters.

The low-temperature heat, at 20 to 30°C, from a typical steam turbine condenser is useable for such applications as municipal water supply heating, including storage, and sidewalk, street or runway heating for snow and ice control. The advantage of using low-temperature heat is its low cost (low economic value) and frequently its great abundance.

Waste heat which cannot be used must be dissipated. The equipment required to dissipate waste heat represents a cost which must be considered when evaluating the cost of equipment for utilizing it. Also, the environmental impact of the waste heat must be considered.

14.2.2.9 Environmental impact. The thermal modification of a river or a lake due to condenser heat dissipation from a steam power plant may be either detrimental or beneficial to aquatic life. In any case, it will cause more open water during the winter, and increased fog formation. The same results from artificial cooling ponds. Open water cooling is restricted in cold climates, even when abundantly available, and cooling towers must be used. Wet cooling towers will also frequently cause fog problems; therefore, dry cooling towers or wet/dry cooling towers must be used. Cooling towers are more expensive than taking available water from a stream and usually more expensive than constructing a cooling pond.

Wet cooling towers are smaller and less expensive than dry towers but dry towers have no adverse environmental impact.

Fog and air pollution problems are greatest in low lands or valleys, particularly river valleys. Therefore, a power plant is best located away from a valley or at least downstream from a community to avoid contributing to air pollution problems. When a power plant must be located in a low area, its chimney must be especially high to lift the exhaust gases above the inversion and fog levels that occur normally during the winter. A concentric chimney and cooling tower (i.e., chimney inside of cooling tower) can improve lofting of the pollutants and reduce the visible smoke plume.

14.2.2.10 Foundations. Permafrost presents special requirements for foundations, different from those in seasonal frost areas. Foundations of buildings containing machinery must also take into account vibration in the design. Since foundations can shift in permafrost or severe seasonal frost areas, the following measures should be taken:

a) Each boiler should be on a rigid slab with provisions for levelling.
b) Turbine and generator or engine and generator units should be on a common rigid slab with provisions for levelling.
c) Ducts and pipes should be routed overhead in the structure and suspended to provide freedom for independent movement.
d) Points of transit of ducts, pipes and conduits through building walls should be flexible so that swing movement is possible on both sides of the wall.
e) Floor drains should lead into appropriate containments for separation of water from oils, etc.

Where earthquake resistant designs are necessary, such design features are basically compatible with and similar to the above requirements.

14.3 Energy Distribution

The distribution of various energy forms in the Arctic is similar to methods in other climates. However, many problems which are unique to the Arctic require use of special equipment and techniques.

14.3.1 Electric power distribution

The distribution of electric power in arctic and subarctic regions is generally similar to those practices which have also proven safe and economical in temperate climates. The specific environmental considerations related to extreme low temperatures, snow, ice, wind, and permafrost are the important factors that the designer, contractors, and maintainers of electrical distribution systems must be concerned with.

14.2.1.1 Distribution methods. Both aerial and underground methods of electrical distribution have been successfully used. Wood pole lines, and both self-supporting and guyed metal towers have been used for high voltage transmission and distribution lines. The design of foundations for these structures in localities where seasonal frost and active layers vary is of prime consideration. Foundation soils must be carefully evaluated. Underground distribution methods must employ means to stabilize, equalize, and protect buried cables from mechanical damage. Non frost-susceptible materials must be used in all pads, foundations, and trenches for electrical distribution systems. Utilidors and duct bank systems, if used, must be reinforced to withstand structural displacement. Prime consideration should be given to placing structural gravel and non frost-susceptible material pads on top of the active freeze-thaw layer, effectively burying cables above the existing or surrounding ground level. Surface laid wood utilidors placed on gravel pads have also been used successfully.

14.3.1.2 Aerial. Aerial electrical distribution systems should be selected and designed for the basic economic factors that normally dictate standard voltage, conductor, transformer, and substation sizes. Increased safety factors which consider the extremes of the climate are the important parameters to consider. Extreme wind chill factors make routine repairs "slow". Simplicity of construction is essential.

Additional structural, conductor, and apparatus strengths are required where severe wind, snow, ice loads, and low temperatures are anticipated.

Indoor/outdoor modular apparatus designs are desirable where severe weather conditions are anticipated. Cable terminal buildings, substations, and power transformers should be designed to protect equipment from the elements. Snow sheds, frost shields, and windbreaks are desirable features wherever possible. Localized heated compartments within larger structures in substations are helpful and provide the necessary ambient temperatures for standard apparatus.

In aerial distribution construction, wood poles have been set into the permanently frozen soils during the cold season when the top active zone is also frozen. This permits easier construction on and across tundra, swamp, and small pond/lake areas. Specifications for pole depth settings have generally used the gravelly soils criterion of 10 percent pole length plus another additional four feet (e.g., 50-ft poles set 9 ft). These wood pole structures were in the average range of 50 feet, classes 2 to 4.

Consideration can also be given to "tripod" pole configuration without pole burial; gravel-filled oil drums or rock-filled cribbing will provide stability. For camp distribution systems, masts supported on the buildings can serve to distribute secondary power, a common practice in Europe.

14.3.1.3 Underground. Underground electric power distribution systems should be selected and designed with the same economic factors relevant to the aerial system, i.e., voltage, ampacity, and loss considerations. In addition, the flexibility of cable insulations and jackets are important factors where extreme low temperatures are found.

Both primary (above 600V) and secondary cables must be installed so that bends, tensions, splices, and terminations are properly made. Underground distribution standards that cover such items as the grounded neutral insulation ratings, basic impulse levels (BIL), and corona extension levels, etc., are available to the designer. Construction may warrant special conditions and additional safety factors. Lines should be placed below the seasonally active depth. Table 14-3 provides a comparison of rubber and plastic compounds. Figures 14-6 and 14-7 illustrate items considered of prime importance for both underground and overhead aerial systems.

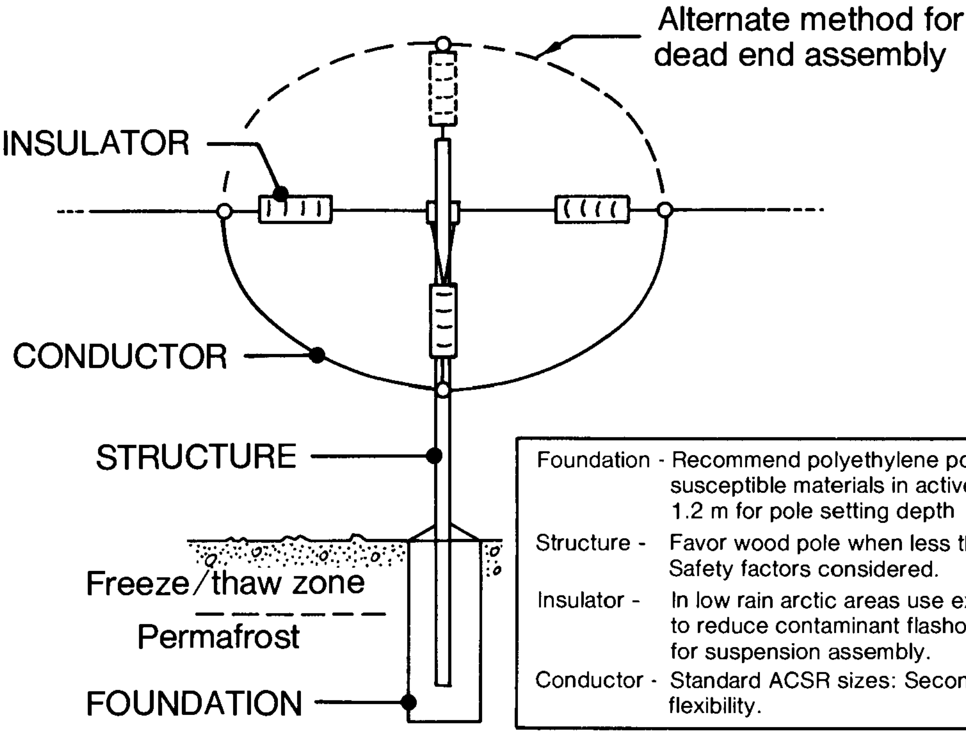
TABLE 14-3. RUBBER AND PLASTIC COMPOUNDS COMPARISON

Rubber Insulation	SBR (Styrene Butadiene)	Natural	Syn- thetic Natural	Poly- buta- diene	Neo- prene	Hypalon (Chloro- sulfo- nated Poly- ethylene	NBR (Nitrile or Buta- diene Acrylo- nitrile)	EPR Ethylene Propy- lene Rubber	Butyl	Silicone
Oxidation Resistance	F	F	G	G	G	E	F	G	E	E
Heat Resistance	F-G	F	F	F	G	E	G	E	G	O
Oil Resistance	P	P	P	P	G	G	G-E	F	P	F-G
Low Temperature Flexibility	F-G	G	E	E	F-G	F	F	G-E	G	O
Weather, Sun Resistance	F	F	F	F	G	E	F-G	E	E	O
Ozone Resistance	P	P	P	P	G	E	P	E	E	O
Abrasion Resistance	G-E	E	E	E	G-E	G	G-E	G	F-G	F
Electrical Properties	E	E	E	E	F	G	P	E	E	O
Flame Resistance	P	P	P	P	G	G	P	P	P	F-G
Nuclear Radiation Resistance	F-G	F-G	F-G	P	F-G	G	F-G	G	P	E
Water Resistance	G-E	G-E	E	E	G	G-E	G-E	G-E	G-E	G-E
Acid Resistance	F-G	F-G	F-G	F-G	G	E	G	G-E	E	F-G
Alkali Resistance	F-G	F-G	F-G	F-G	G	E	F-G	G-E	E	F-G
Gasoline, Kerosene, Etc. (Aliphatic Hydrocarbons) Resistance	P	P	P	P	G	F	E	P	P	P-F
Benzol, Toluol, Etc. (Aromatic Hydrocarbons) Resistance	P	P	P	P	P-F	F	G	F	F	P
Degreaser Solvents (Halogenated Hydrocarbons) Resistance	P	P	P	P	P	P-F	P	P	P	P-G
Alcohol Resistance	F	G	G	F-G	F	G	E	P	E	G

Plastic Insulation	PVC (Poly- vinyl Chloride)	Low- Density Poly- ethylene	Cellular Poly- ethylene	High- Density Poly- ethylene	Poly- propylene	Poly- urethane	Nylon	Teflon
Oxidation Resistance	E	E	E	E	E	E	E	O
Heat Resistance	G-E	G	G-E	E	E	G	E	O
Oil Resistance	E	G-E	G-E	G-E	E	E	E	O
Low Temperature Flexibility	P-G	G-E	E	E	P	G	G	O
Weather, Sun Resistance	G-E	E	E	E	E	F-G	E	O
Ozone Resistance	E	E	E	E	E	E	E	E
Abrasion Resistance	F-G	F-G	G	E	F-G	O	E	G-E
Electrical Properties	F-G	E	E	E	E	P-F	F	E
Flame Resistance	E	P	P	P	P	P	P	O
Nuclear Radiation Resistance	P-F	G	G	G	F	G	F-G	P-F
Water Resistance	E	E	E	E	E	P	P-F	E
Acid Resistance	G-E	G-E	G-E	G-E	E	F	P-F	E
Alkali Resistance	G-E	G-E	G-E	G-E	E	F	E	E
Gasoline, Kerosene, Etc. (Aliphatic Hydrocarbons) Resistance	G-E	P-F	P-F	P-F	P-F	F	G	E
Benzol, Toluol, Etc. (Aromatic Hydrocarbons) Resistance	P-F	P	P	P	P-F	P	G	E
Degreaser Solvents (Halogenated Hydrocarbons) Resistance	P-F	P	P	P	P	P	G	E
Alcohol Resistance	G-E	E	E	E	E	P	P	E

P = poor F = fair G = good
E = excellent O = outstanding

These ratings are based on average performance of general purpose compounds. Any given property can usually be improved by the use of selective compounding.



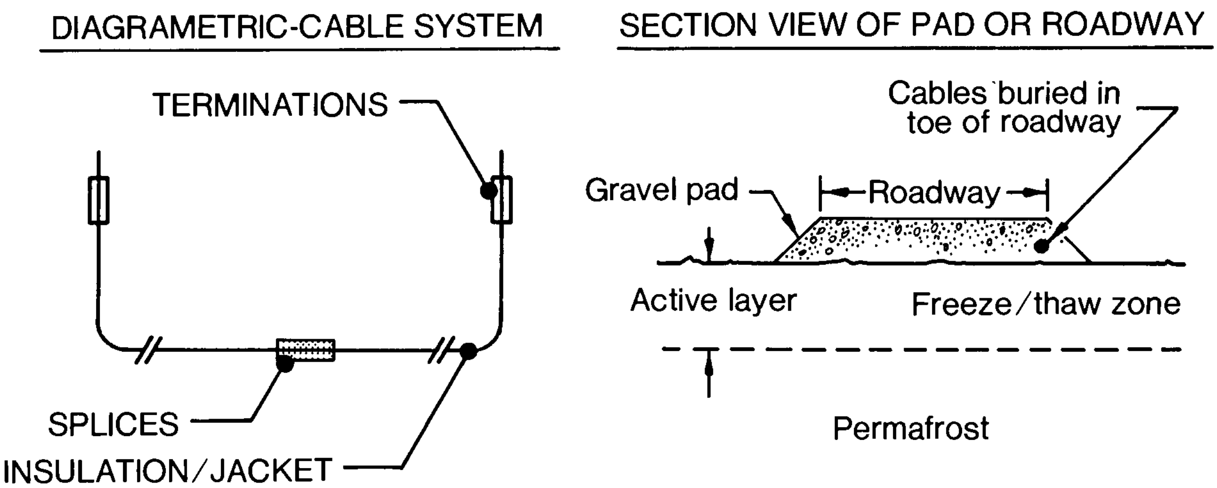
Foundation - Recommend polyethylene pole "blanket" and/or non-frost susceptible materials in active zone. In permafrost, 10% + 1.2 m for pole setting depth

Structure - Favor wood pole when less than 60 ft. for helicopter setting. Safety factors considered.

Insulator - In low rain arctic areas use extra dead end suspension bells to reduce contaminant flashover. Recommend tongue and clevis for suspension assembly.

Conductor - Standard ACSR sizes: Secondary insulated/low temperature flexibility.

FIGURE 14-6. OVERHEAD AERIAL



Recommendations

Insulation/Jacket - Low temperature flexibility favor solid dielectrics, and ethylene propolene types.

Splices - Manufacturers kits, instant slip-on terminators to eliminate pouring hot compounds, and building taped stress cones in field.

Terminations - Taped stress cones in field.

FIGURE 14-7. UNDERGROUND CABLE GUIDELINES

14.3.1.4 Special considerations. There are certain special considerations and problems that pertain to construction of electric distribution utilities in cold regions. These are not necessarily impossible to solve but require care and thought in the selection of materials, methods of installation, and followup maintenance.

A general list of items is as follows:

1) Nylon jacketed conductors (types THWN). When used at low ambient temperatures, the insulation tends to separate from the jacket.
2) Cold weather starting of gaseous discharge lighting. Mercury vapour type is especially hard or impossible to start. Ballast low-temperature ratings must be checked for minimum starting temperatures; otherwise luminaries must remain energized continuously during extreme lows or provided with integral thermostats to start luminaries when the temperature drops below -30°C, the present low limit of ballast manufacturers' ratings.
3) Molded case circuit breakers and stored potential switches are not 100 percent dependable at extreme low ambient temperatures. The alternative use of fuses and an adequate supply of spares must be evaluated, or supplemental heat provided to raise the ambient temperature of the equipment enclosure.
4) Pole jacking occurs when frost heaves and soil freeze/thaw conditions displace alignment of overhead pole lines. Polyethylene pole blanket sleeves have been specified and used for some utilities. A pole sleeve of 10 mil black polyethylene can be slipped over the base of the pole and sealed moisture tight. This permits seasonal frost heaving without pole jacking. The plastic double-walled sleeve prevents frost bonding to the wood pole surface.
5) The resistance of grounding electrodes and earth grounds in frozen soils varies according to the temperature. Arctic

research papers by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) have treated this subject [1].

6) Cold-temperature special alloy steel is being specified for transformers, circuit breakers, and other exterior electrical distribution apparatus and specifications for equipment subject to extreme low temperatures is described in reference [2].

7) Aerial conductor vibrations, aoelian and galloping. Arctic environments, especially near coastal regions, present unpredictable storm combinations that make normal service access impossible. The extreme low temperatures mandate critical evaluation of mission objectives. Power interruptions of several hours may result in building freeze-ups. Added safety factors must be applied. Consideration should be given to the use of steel conductors to provide melting of ice on conductors, or the use of strain gages on conductors to sense critical ice loading and sound an alarm or pre-schedule line "short-circuiting" to melt ice. All deadend primary insulators should be tongue and clevis type. Reliance on cotter keys alone is inadequate. All pole-mounted hardware should be nut and cotter key to nut and "pal" lock-nut.

   Aeolian vibration control is covered in Stockbridge [3], and dumbell torsional dampers plus armor rods should be used at all primary cable conductor supports. Cataclismic failures are not associated with aeolian vibrations. Frequent conductor inspection is required to identify areas of severe conductor fatigue to prevent conductor failure.

   The "galloping" conductor phenomenon is endemic to all areas. In general, conductor spacing must allow for elliptical loop dancing in the single conductors to prevent short circuit phase-to-phase faults. Mechanical considerations, however, present the greatest area of challenge. It is not possible with the present state-of-the-art to eliminate "galloping". In severe galloping areas, conductors should be dead-ended at each pole, or preferably the transmission line should be rerouted or an underground cable routing selected. Dense cold winds from glaciers and ice fields have been known to reach velocities of over 300 km/h near the sea, coincident with 152 mm of radial ice [4]. Catastrophic mechanical damage to towers, insulators, and hardware can be minimized by the use of slack spans in relatively short runs of 90 m or midspan spacers in longer runs of up to 300 m.

In general, cold regions do not always have a recorded history of meteorological data upon which to base a pole/tower line design. For this reason conservative design must be used.

14.3.1.5 Reliability, maintenance, and security. Reliability of electric power distribution is the norm rather than the exception. If the major items offered in the previous paragraphs on special considerations are acknowledged and the weak links are eliminated, then reliability is measured further by adoption or use of the following individual job features: dual feeders, loop/radial circuits, parallel transformers, dual busses, additional switchgear and generation units. These all add up to planned reliability.

Maintenance is enhanced by enclosing complex apparatus in modules or enclosures where the cost of such structures warrant their use. Consideration should also be given to providing "line-men" weather shelters with emergency survival gear in inaccessible areas. Helicopter access is not predictable and ground crews in all-terrain vehicles may be required to make emergency repairs in nonflying weather conditions. During helicopter operations, rather than use standby time, options are usually for return pick up. Sudden weather changes have isolated line crews for as long as a week [4]. Buried multiplate steel culvert storerooms have been considered expedient in instances where fast, efficient helicopter supported crews must work many miles from larger warehouses. If an area is a severe environmental hazard or has a low safety factor then, for example, spare insulators, hardware, and accessories may be kept locked and secure from the elements.

Security is usually handled with scheduled maintenance and inspection trips. "Flying the line" or overland inspection trips are considered most expedient where daylight in the Arctic is reduced. When darkness prevails, operation, maintenance and security lighting becomes an important factor. Vehicles equipped with inspection lights and/or banks of auxilliary lighting and standby generators for power are considered important. Small helicopters equipped with high intensity spot/flood lights are being used for security and maintenance purposes.

14.3.1.6 Communications lines. Design, construction, operation and maintenance of communications lines in cold regions are considered standard practices of 'outside plant work'. Until recently long haul communications in the Arctic have been via tropospheric radio and microwave methods. Satellite communication is now being used for some remote military and civil bush communications links. Communications at remote sites, villages, military encampments, experimental and operation stations are normally handled by telephone or radio telephone equipment. In these locations standard local telephone exchange equipment practices are used. Outside plant overhead and underground installations are usually constructed during the summer months. Protection of overhead lines and underground communications systems from failure presents the same mechanical/electrical environmental problems as with electric distribution.

14.3.2 Heat distribution

Heat distribution networks in cold regions require particular attention to the seasonally restricted conditions for construction, and the influence of frost on operation and maintenance. The greater heating needs in cold regions enhance the feasibility of providing district heating. Minimum density limits of 15 to 25 MWh/km^2 are typical of

Swedish district heating experience. This corresponds to about four residences per acre. The lowest densities can be served economically where they are an expansion of an existing system or where a residential area is adjacent to a trunkline leading to another large area being served. Another factor influences the feasible density limit: a coastal climate location with a long heating season but without extremely cold weather will provide a greater system utilization (more equivalent full load hours) than a continental climate location with its greater temperature extremes and will, therefore, make lower load densities feasible. For example, in Sweden and Finland, the typical system utilization is 2000 to 2500 h/a; in Iceland, it is nearly 4000 h/a.

14.3.2.1 Temperatures and fluids. It is principally advantageous to use the lowest practical fluid temperatures for heat distribution because losses and total costs are minimized. The temperatures required inside the building for heating purposes are usually no more than 80°C during the coldest weather, and less during milder weather. Heating systems requiring supply temperatures not exceeding 50°C and even less are being built. Temperatures over 100°C are only needed in special situations such as in buildings with process heat requirements. These may be met more economically with auxiliary heating equipment than by using high temperature distribution throughout the whole system.

Water has important advantages over steam for heat distribution. Low distribution temperatures are possible; both temperature and flow rate can be varied to permit almost infinite delivery modification; the ability to operate with low temperatures minimizes heat losses and permits more pipe material alternatives; thermal storage facilities can be readily incorporated into the system because water itself is an efficient storage medium.

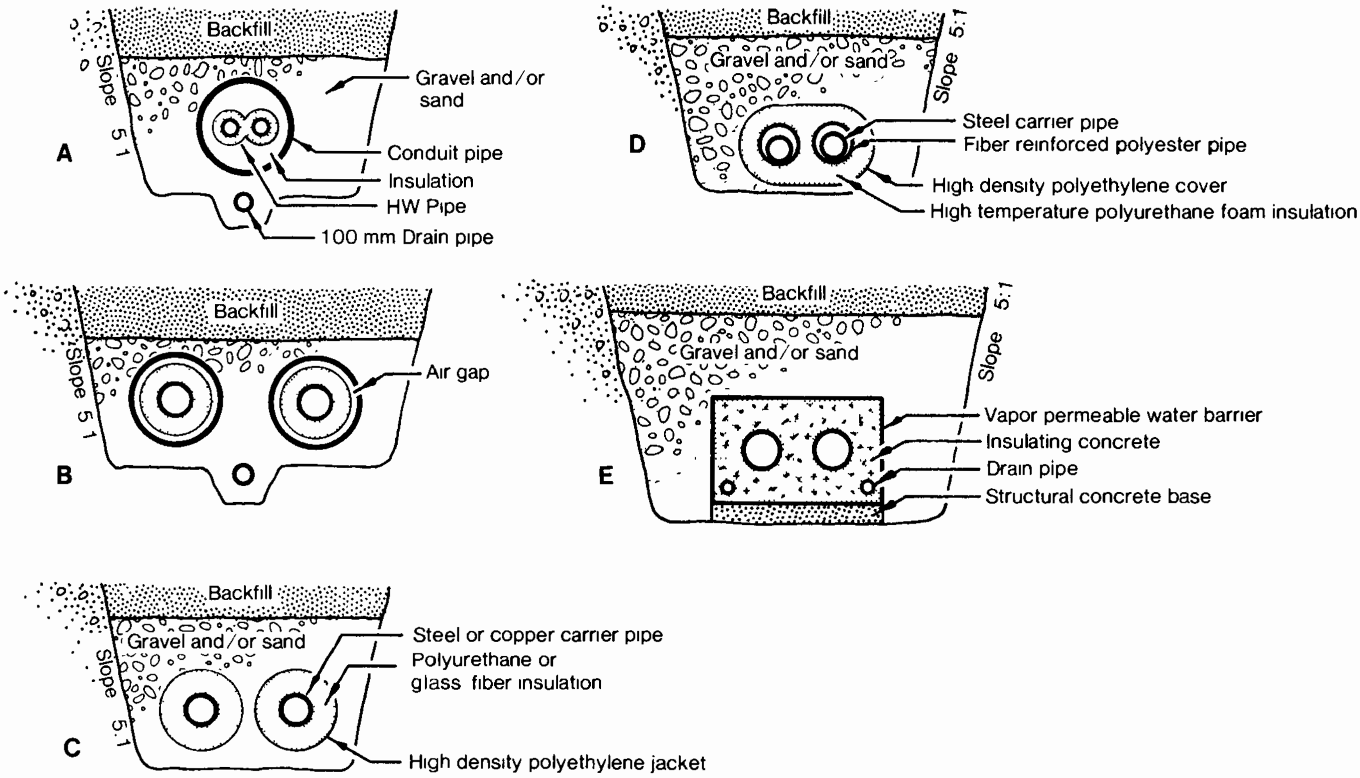
A glycol-water solution can be used instead of plain water for freeze-prevention, e.g., in an intermittently operating system. The disadvantages of the glycol solution are greater viscosity and lower specific heat than water, resulting in greater pipe size, fluid cost and pumping power requirements.

14.3.2.2 Buried distribution piping. This concerns directly buried, insulated piping. A wide variety of insulating methods or pre-insulated pipe systems are being used. Figure 14-8 shows examples of the principal types of systems being used. Their selection and applicability depends somewhat on the soil moisture conditions. Directly buried piping is less expensive to install than piping in conduits but its service life expectancy is also less.

The primary distinction is between installations in seasonal frost areas and permafrost areas. Within these areas there are considerations based on the frost-susceptibility of the soils. Peat, clay and silt are frost-susceptible soils; they retain large amounts of water. Sand, gravel and rock are non frost-susceptible; they drain the water. Frost penetration is deepest in the least frost-susceptible soils and under snow-free areas.

In seasonal frost areas it is always safe to place the piping below the seasonal frost depth (Figure 14-9A). Shallow burial is less expensive. In non frost-susceptible soils it can be accomplished without special measures (Figure 14-9B). In frost-susceptible soils a frost shield must be added (Figure 14-9C) to prevent heaving and rupture of the lines. Installation on grade is less expensive than burial and is efficient where it causes no interference. The soil cover provides protection (Figure 14-9D). The frost shield protects from heaving in frost-susceptible soils and from excessive cooling in non frost-susceptible soils. Elevated construction may be necessary in some areas where obstacles, high groundwater or other reasons make it necessary (Figure 14-9E).

The purpose of the frost shield is to prevent the soil under the pipes from freezing and heaving. The water in the pipes themselves is hot and protected, as opposed to cold water pipes, which are not insulated themselves, and depend on the shield for protection. The heat dissipation from the insulated hot water pipes is greater than from bare cold water pipes. Therefore, more extreme frost conditions can be encountered than with cold water pipes. In fact, cold water pipes can be protected by co-location with the heat distribution pipes. The most



A. Pipe-in-pipe system. Supply and return service lines in common conduit pipe.

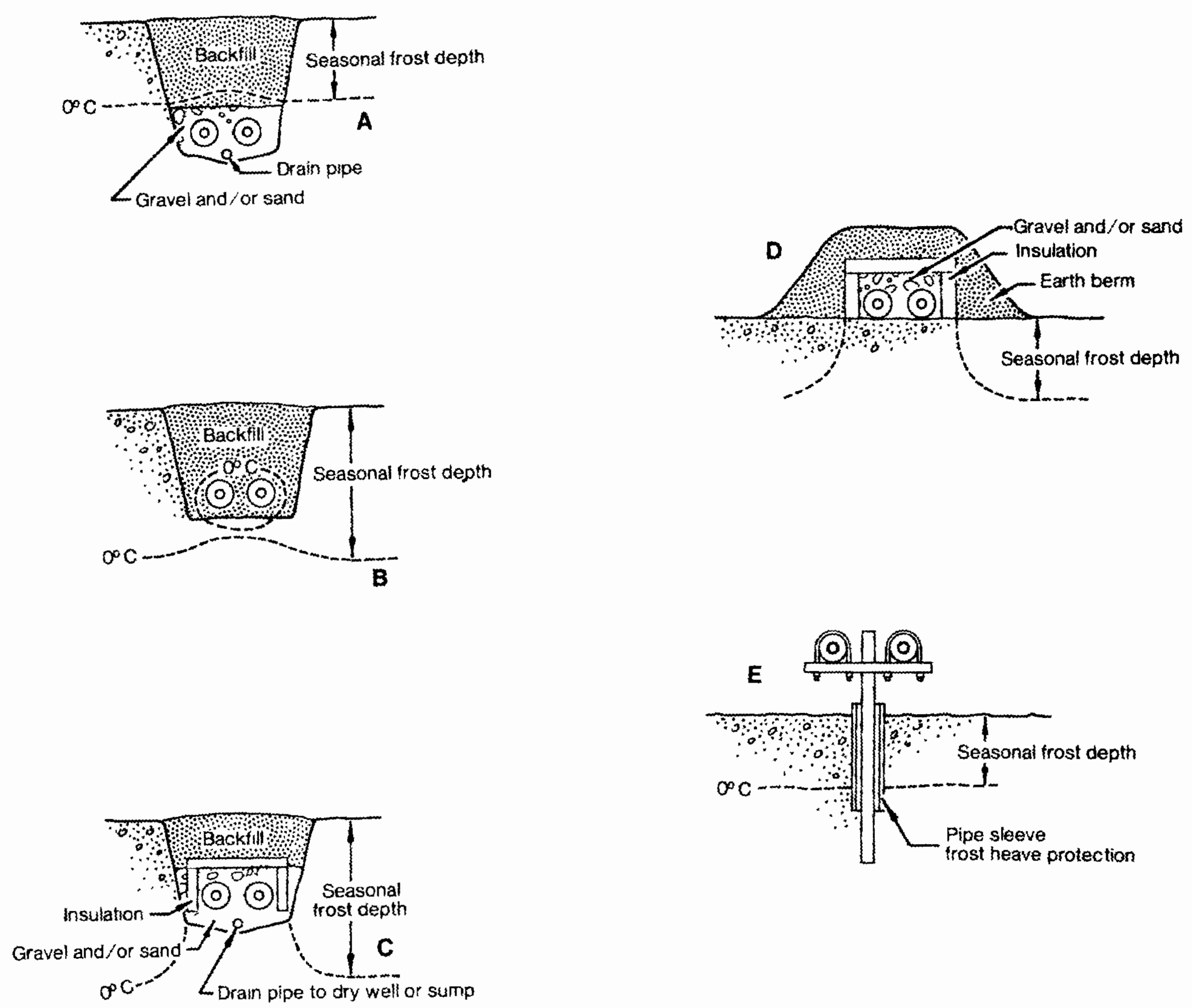
B. Individual pipe-in-pipe main distribution lines.

C. Pre-insulated distribution piping with integral extruded jacket.

D. Pre-fabricated insulating culverts for slip-on assembly.

E. Cast-in-place insulating concrete block.

FIGURE 14-8. DIRECTLY BURIED HOT WATER DISTRIBUTION PIPING



A. Deep burial in frost-susceptible and non frost-susceptible soils.

B. Shallow burial in non frost-susceptible soils.

C. Shallow burial in frost-susceptible soils.

D. On-grade installation with earth cover.

E. Elevated installation over all soils.

FIGURE 14-9. INSTALLATION OF HEAT DISTRIBUTION LINES IN SEASONAL FROST AREAS severe exposure is in the case of pipes on grade under a berm (Figure 14-9D) because it is desirable to keep the berm height to a minimum. The dimensions of the U-shaped frost shield can be determined by the method given by Gundersen [5] and illustrated in Figure 14-10. The determination is based on soils of sand and gravel which experience greater frost penetration than clay and silt. Figure 14-10 applies only to non frost-susceptible soils.

In permafrost areas, direct burial is possible in non frost-susceptible soils. A thaw zone develops around the pipes (Figure 14-11A). A drain pipe is necessary if burial is shallow so that the seasonal thaw depth reaches the thaw zone around the pipes, permitting surface water to drain into it. In frost-susceptible soils a thaw shield is necessary to avoid instability problems (Figure 14-11B). Trenching in permafrost requires appropriate equipment for cutting. This cost is avoidable where on-grade installation is acceptable. A thaw shield is necessary to avoid soil thaw instability and water accumulation (Figure 14-11C). The soil cover provides protection. Elevated construction is possible where necessary in all soils, as in seasonal frost areas (Figure 14-11D).

14.3.2.3 Distribution piping in conduits. Conduits include all kinds of utilidors, culverts and ducts, whether below or above-ground. They are discussed in Section 8. The piping is installed in the conduit on supports using either preinsulated pipe or insulating it separately after installation. The installation is basically the same as inside a building. There must be fixed-point supports and also sliding supports to allow movement due to thermal strain of the pipes, as well as for movement of the conduit due to frost (or seismic) action. In large, walk-through utilidors the piping is accessible for installation and maintenance at all times. Smaller buried ducts are only open during installation with normal access subsequently limited to manholes. Elevated ducts can be made with removable side panels for later access or installation of additional lines. A buried duct with its top at ground level can be made accessible through removable cover plates; the top surface can serve as a walkway.

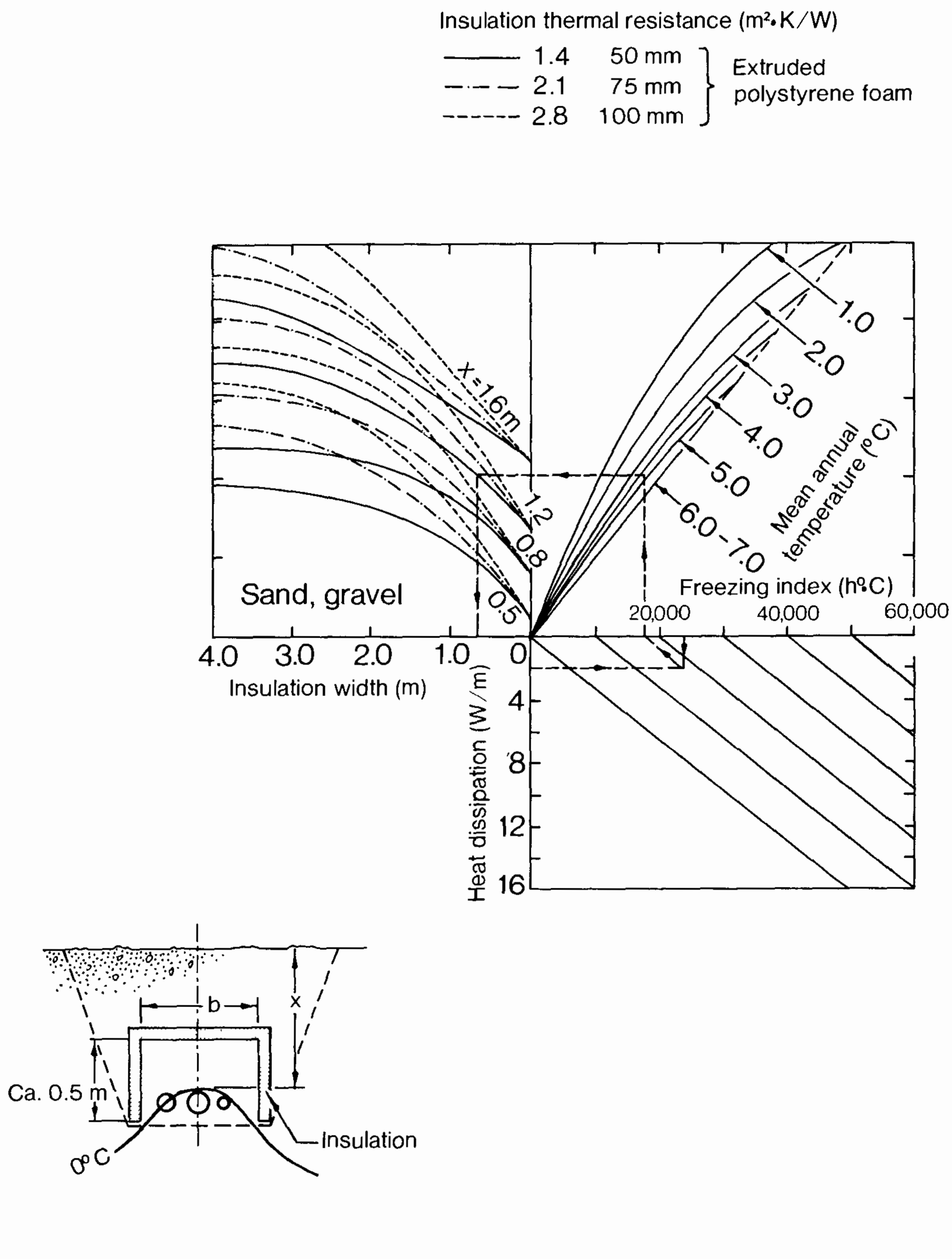
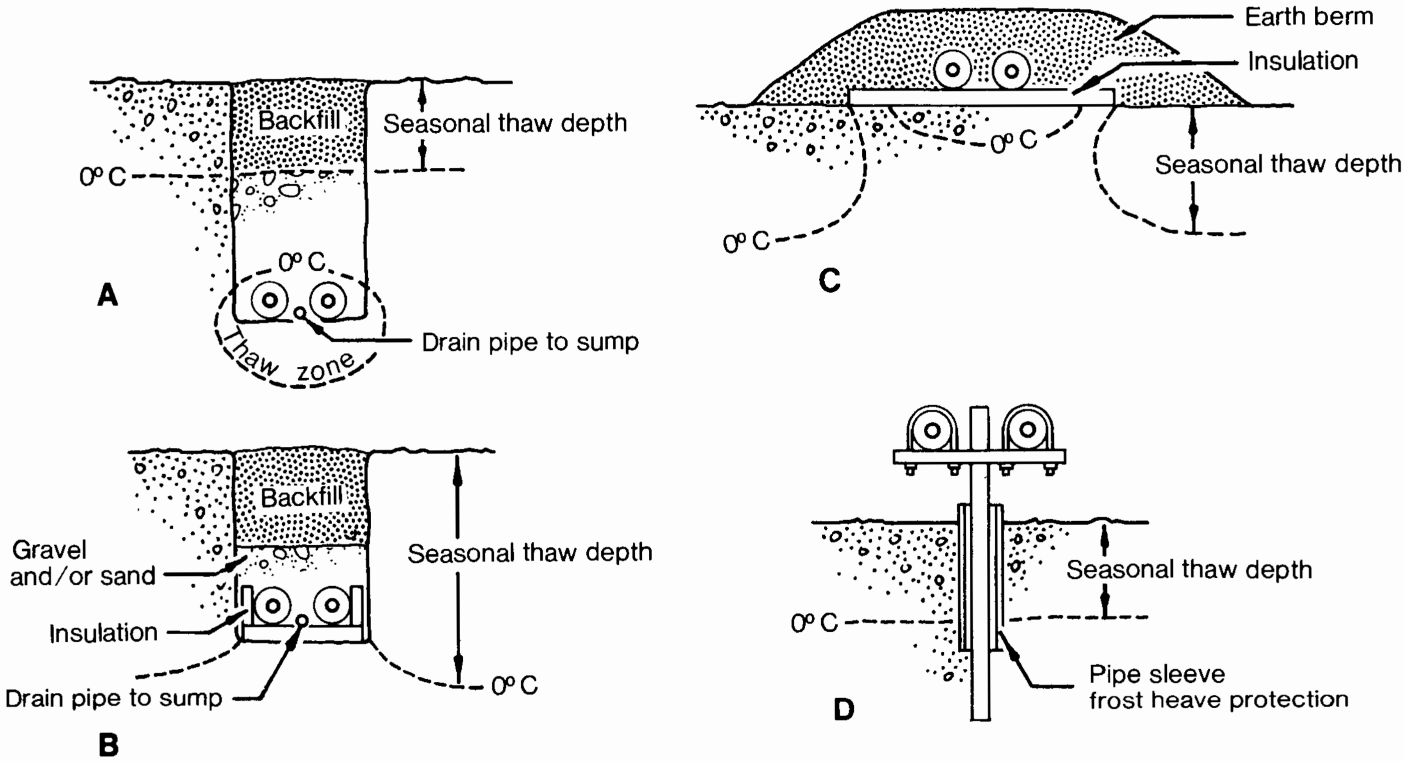


FIGURE 14-10. DIAGRAM FOR DETERMINING THE REQUIRED INSULATION FOR FROST PROTECTION OF SOILS AND PIPELINES
Source: P. Gundersen, Norwegian Building Research Institute [5].



A. Deep or shallow burial in non frost-susceptible soils.

B. Shallow or deep burial in frost-susceptible soils.

C. On-grade installation with earth cover on frost-susceptible and non frost-susceptible soils.

D. Elevated installation over all soils.

FIGURE 14-11. INSTALLATION OF HEAT DISTRIBUTION LINES IN PERMAFROST AREAS

For the design and construction of the conduits, the considerations for frost are the same as for directly buried piping. Heaving as a result of freezing and instability due to thaw must be avoided. Inside the conduit, water from leaks or infiltration must be able to drain freely to sumps with pumps at low points of the route. The conduits also should have vent pipes extending above-ground at intervals of not more than 50 m for venting and drying with suction blowers or compressed air. In areas with severe or bad water conditions in the ground, drain tiles should be placed under the conduit leading to a dry well or sump with pump at low points of the route.

The conduit does not need to be heated but its cover should be insulated to prevent condensation followed by dripping on the pipe insulation. When sewer lines or uninsulated cold water lines are placed in the same conduit, its walls should be insulated and heating can be provided by reducing or eliminating the insulation on the return pipe of the heat transmission line so that the temperature in the conduit remains above freezing. For conduits above-ground the heating requirements can be calculated from the heat transmission factors ("U" values) of the conduit walls and the anticipated ambient air temperatures. For buried conduits, the heating requirements can be determined from information given by Gundersen [5].

14.3.2.4 Reliability, maintenance, security. The distribution network is the most expensive and vulnerable part of the utility system. The consequences of failure are more severe in cold climates than under temperate conditions. The reliability of a distribution network can be increased by interconnecting adjacent service areas, and by forming a ring of trunk lines so that a pipe failure or shutdown can be isolated and loss of service can be avoided as much as possible. The maintenance of lines is easiest in large walk-through utilidors but these are only feasible for trunk lines, particularly where several utilities use the same utilidor. Buried ducts are less maintainable than elevated ducts or box utilidors but their security is greater. The duct with its top cover at ground level is a good compromise for these diverging characteristics.

14.3.2.5 Corrosion and grounding. Insulated buried pipes are isolated from the ground by dry insulation so that corrosion on the outside of the pipe is seldom a problem. When the outer pipe or the conduit is of metal, corrosion must be considered in cold regions as elsewhere. A special problem arises in permafrost where grounding is complicated by the presence of ice. The conduit may be coated and a parallel grounding wire may be installed (e.g., zinc wire).

Internal corrosion of the pipes is controlled by the addition of rust inhibitors to the closed circulating water systems. Steam distribution systems have a characteristic corrosion problem in the condensate return pipes because air enters the system and supports the oxidation of steel pipes. One solution is to use (fiber reinforced) plastic pipes for condensate return lines.

14.3.6 New product developments. There is a need for materials and products to make the installation of individual service lines more economical because they are the relatively most expensive part of the whole network. Pre-insulated piping in lengths up to 25 m is becoming available for this purpose, including pre-insulated T-pieces and bends. The tube is copper or steel, the insulation is plastic foam or glass wool, and the continuous outer jacket is HD polyethylene. The solder or braze joints are covered with insulation shells and a heat shrink sleeve for tightness. Installation is by direct burial in a simple trench.

Another development uses a flexible, corrugated tube, plastic foam insulation, flexible, corrugated outer tube and extruded plastic jacket. This "cable-pipe" is produced in long continuous lengths and supplied on large reels. Installation is extremely fast; the pipe can also be pulled through conduits (currently available in Europe).

A plastic insulating culvert that is becoming popular is used as a loose fitting sleeve over bare steel pipes. Standard 2 m long lengths are slipped over the pipes and joined with heat shrink sleeves.

14.3.3 Gas distribution

Design and construction of gas distribution systems in arctic and subarctic regions (regions underlain with permafrost) must deal with special problems not encountered in other areas. The basic engineering principles governing design of gas distribution systems in temperate climates also apply in cold regions. The special problems encountered are discussed in the following paragraphs.

14.3.3.1 Scope. The gas distribution system consists of the piping, supports, valves, meters, and all such necessary appurtenances from the gas transmission line (or other primary source) to the gas piping at the buildings.

14.3.3.2 Locations. The gas piping may be buried, installed at ground level, or may be an overhead distribution system, depending upon the site conditions and the overall concept and usage of the installation. The type or types of soil at the site, depth and structure of the permafrost, water content, surface drainage, etc., must be known. The method to be used to preserve site stability is determined by other disciplines. The type of gas distribution system to be designed must be consistent with the overall concept. For example, if a thick insulating gravel pad is to be provided for the construction site, a direct burial system may well be selected.

14.3.3.3 Direct buried systems. Where soil types and the natural drainage patterns permit, the direct buried gas distribution system is most desirable from standpoints of economics, security, and area utilization. The soils must be non frost-susceptible, and seasonal moisture must readily drain from the area. Where soils consist of frost-susceptible mateials, and where surface water stands without draining away, the gas piping should not be direct buried. Metal and plastic piping is used for gas distribution systems. If piping is installed in soil which is frost-susceptible or water saturated, the water can freeze to the pipe, forming ice anchors. A section of piping secured between two ice anchors can fail (usually at the connecting points) due to axial stress from further temperature reduction.

Where direct buried gas piping must cross road and traffic lanes, the piping should be installed in a protective sleeve or culvert. The piping within the sleeve should be provided with supports or spiders which will position the gas pipe concentric with the sleeve. Where the ends of the sleeves are buried, the ends should be sealed tightly to the gas pipe with flexible boots and drawbands or clamping devices. Several types of these boots are available. Where the ends of the sleeves extend to daylight due to area grading or to road elevation, the ends may be left open. The sleeve or culvert should be pitched slightly to ensure proper drainage of moisture.

The design and installation of the gas distribution system must include provision for the expansion and contraction of the piping caused by changes in temperatures of the soil and/or the gas. Where the system supply is obtained from an above-ground transmission line, the product temperature may range from 27°C to -50°C. The range of ground temperature, of course, is less. It also changes more slowly. Flexibility may be worked into the system layout, making use of ell-shaped and zee-shaped runs, with properly located anchors. On long straight runs, expansion loops must be provided. Legs of the loops should be encased in suitable resilient material to allow space for pipe movement when required. It is recommend that the loops be pre-stressed when installed, and adjusted so that the loop will be in the neutral position at minimum design temperature.

Drip pockets for moisture or gas condensate accumulations with blow-off pipes and valves are required at all low points in the system and at the base of risers. Natural gas in cold regions may have a sufficient water or moisture content to require dehydrating. This, of course, is done at the well heads or at a collecting point in the gas fields. Dehydration is accomplished with diethelyne glycol, triethelyne glycol, or alcohol process. In each process, there is a carry-over which collects at the system low points and must be removed periodically. For buried piping systems, a small diameter (13 mm) return bend from the drip leg, with a pipe extension to above-ground level, and terminated with a blow-off valve will serve to remove accumulated liquids at the drip collection points. The blow-off pipe should extend well above the expected snow level, and should be protected from physical damage by a guard post.

14.3.3.4 Ground level systems. A gas distribution system installed just high enough above the ground to be exposed to the normal snow level is called a ground level system. It is the most simple and economical system, but is vulnerable to damage and its use must be carefully considered. In general, the concept can only be employed in areas requiring a limited number of service connections and where the piping can be routed to avoid the planned traffic patterns.

Holes for support posts should be made with a drill or soil auger. The diameter of the hole should be approximately 8 cm larger than the diameter of the greater axis of the support member. Depth of the hole should extend sufficiently into the permafrost to ensure sufficient anchor, when re-frozen, to resist the lifting force of seasonal thawing and freezing. The required depth will depend upon the climate, the soils and the permafrost conditions at the particular site, and should be determined by soil experts assigned to the project. As a rule, the required depth of penetration into the permafrost will be approximately two-and-a-half times the depth of seasonal thaw. The void space around the support member in the hole should be filled with a slurry prepared from suitable water and fine soil. The water should be free of minerals and acid so that the freeze point will not be depressed. The soil should be a fine sandy type. The slurry should be poured or ladled into the hole up to grade level and allowed to freeze in place. Freezing time in the permafrost strata will vary somewhat with the temperature of the permafrost and with the ambient temperature, but generally should be between two and seven days.

Supports must be spaced at intervals which will prevent excessive sag and stress in the piping. The load on the pipe consists of the weight of the pipe, the ice and frost build-up (up to 5 cm thick), and the wind loads.

Tops of the support posts should be trimmed as required to provide proper grading of the gas piping. The piping should be supported on or by the posts in a manner to restrain longitudinal movement but permit free axial movement caused by expansion and contraction of pipe. On wooden posts, a two-piece clamp, similar to an offset pipe clamp serves very well. Legs of the clamp may be secured to the post with thru-bolts or lag screws. On steel posts, a wall bracket hanger may be bolted or welded in place and the pipe supported from clevis-type hangers and hanger rods. Hanger rods should be as short as possible to minimize pipe sway due to wind pressure.

Expansion loops must be supported in a manner to preclude additional stress on the piping and permit proper function of the loop. The loops should be designed and installed in such manner that the loop stresses occur at maximum design temperature and will move toward the un-stressed or neutral position as the pipe temperature decreases. Expansion loops are usually considered to be on a horizontal plane. Where it is to the advantage of the system design or layout, vertical loops may be best. Vertical loops should be sized at least as required for allowable stress in the piping, and may be oversized if the loop is to be used for a pedestrian or vehicle passageway. Drip pockets and blow-off valves should be provided at the base of the vertical legs of the loop. Supports for the vertical loops must be designed for ice and wind loads as well as for piping loads.

Anchors, for controlling pipe expansion, must be properly located at the time of design. Where possible, the anchors and loops should be uniformly spaced to minimize unbalanced thrusts on the anchors. Commercial type anchor clamps may be adapted to the support posts, whether of wood or of steel, or field-fabricated anchors may be designed.

Slip-type expansion joints or couplings are not recommended for use in gas distribution systems in cold regions. At extremely low temperatures, the seals of the joints harden and lose the elasticity required for the sealing effect. The use of slip joints or couplings can be avoided by proper use of bends, loops or offsets, eliminating an unnecessary risk of system failure.

14.3.3.5 Overhead Distribution Systems. An overhead system, as discussed herein, is a system in which the gas piping is installed a minimum of 2 m above the finished grade of maximum snow line. The purpose of such a system would be to permit free use of all the area for pedestrian or low vehicle (snowmobile) traffic. Higher clearances may be provided across streets and roads for passenger cars and trucks. An overhead system is most expensive. It is also the most vulnerable to damage from traffic and from storms.

Support for the overhead system are designed and installed as described for ground-level systems, with due consideration given to wind and ice loads. Where long pipe spans are required, such as at road and street crossings, a cross-beam must be provided from which the pipe can be suspended. The beam may be of open-web bar joist design, or wood beam suitable for the span. Traffic signal arches of tubular construction should also be considered.

14.4 References

1. U.S. Army CRREL/Alaska District, "Electircal Groundings of Power and Communications Facilities for Tactical Operations in Arctic Regions". Hanover, New Hampshire, February 1973.

2. Special Alloy Steel for Extreme Low Ambient Conditions. British Petroleum and Westinghouse Street Corp.

3. Stockbridge, G. H. "Overcoming Vibration in Transmission Cables". Electrical World. (Dec. 26, 1925) Vol. 86, No. 26.

4. Alaska District Corps of Engineers and Alaska Electirc Light and Power Company experience with 'Taku' winds in the Juneau, Alaska area.

5. Gundersen, D., "Frost Protection of Buried Water and Sewer Pipes", Draft translation TL666, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, 1978.

SECTION 15

THERMAL CONSIDERATIONS

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15 THERMAL CONSIDERATIONS

15.1 Introduction

Cold regions utility systems must function under severe climatic conditions. Since thermal considerations are as important, or more important than, the hydraulic and structural features, they must be included in the selection and design of materials, components, and processes [1,2,3]. Thermal analyses are necessary to design for freeze-protection, foundation stability, thermal stress and economy. In this section the major emphasis is on the thermal design of piped water and sewer systems. Thermal aspects are discussed, and simple equations and illustrative examples are presented solving some of the thermal problems encountered in utility system design. Cold regions building design and foundation considerations are only briefly considered; other references must be consulted for detailed design information on these subjects.

15.1.1 Site considerations

Climatic and geotechnical site information is necessary for thermal analysis and design. Adequate air temperature data, which include the range, mean and various indices, are usually available from nearby weather stations or from published charts and reports [4,5,6], but the local micro-climate will modify these values (see Appendix H). Local ground temperatures are often not available, and extrapolations are inadvisable since they can vary significantly with the air temperature, snow cover, vegetation, drainage, topography, and soil properties. The most reliable approach is to obtain long term actual site measurements. Limited data must be modified to estimate the extreme climatic conditions, or to make allowances for surface changes resulting from construction and development.

Geotechnical conditions are frequently highly variable within a small area and site-specific surveys consistent with the thermal and structural design considerations are imperative. Of primary concern is movement and possible failure due to the freezing and thawing of the surface. Therefore, the maximum thickness of the active layer and the soil thermal properties and frost-susceptibility must be determined. In permafrost areas, particularly in high ice content soil, the soil survey must extend to the maximum range of anticipated major thermal effects, and surface conditions and drainage patterns must be noted.

15.1.2 Design considerations

The primary areas of concern in the design of utilities in cold regions are failure of pipes due to freezing of water, thaw-settlement or heaving of foundation soil, thermal strain and associated stress, and economical operation.

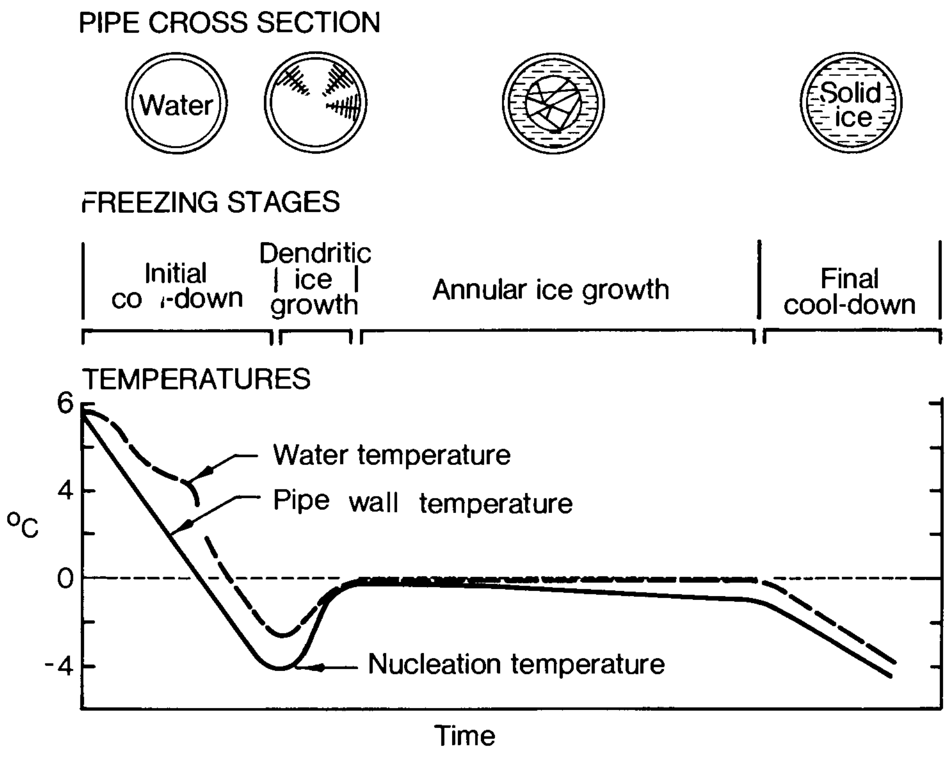
Utility systems in cold regions are thermally designed with a conservative safety factor, and often the worst conditions that could occur simultaneously are considered. This is justified by:

a) simplifications and assumptions within the thermal equations and models;
b) limited data and random nature of the climatic and physical site conditions; and
c) variations and assumptions in the physical and thermal properties of materials such as insulation, soils and pipes.

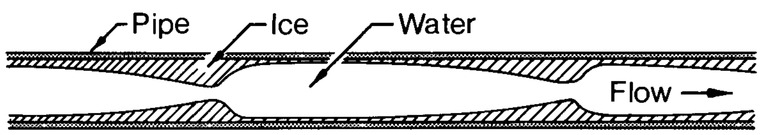
Although the thermal characteristics may be precisely defined, the application and control is complicated. In practice, it is often the unexpected or unforeseen conditions that result in damage or failure. Thermal design must consider more than the precise thermal analysis. Experience and judgement are also essential.

15.2 Freezing of Pipes

Freeze damage to containers of fluid, including pipes, occurs due to the expansion of water changing to ice [7]. This imposes a pressure on the still unfrozen liquid that can reach hundreds of atmospheres. Failure is caused by hydrostatic pressure, not by the ice expanding directly on the walls [8]. The freezing of quiescent water in pipes occurs in stages as illustrated in Figure 15-1(a) [9]. Water must always supercool, typically -3° to -7°C in quiescent pipes with slow cooling, before nucleation and freezing produces dendritic ice growth. Further cooling results in the growth of an annulus of ice inwards from the pipe walls.



(a) The stages in the freezing of a quiescent water pipe [9].



(b) Ice bands formed during the freezing of flowing pipe [10].

FIGURE 15-1. THE FREEZING OF WATER PIPES

Dendritic ice formation increases the start-up pressure required to reinstate flow, particularly in small-diameter pipes and slow fluid cooling rate, and can effectively block the pipe in much less time than that required for the pipe to become blocked by annular growth of ice [9].

The freezing process for fluid flowing in pipes is not simply by annular growth and such an oversimplification can lead to false conclusions and errors in design. Gilpin [10] observed that for flowing pipes ice does not grow as a uniform thickness along the pipe but occurs as cyclical ice bands of a tapered flow passage (Figure 15-1(b)). Further cooling will freeze off the narrow neck, arresting flow, and subsequent freezing can result in pipe breaks between each ice band. No ice formation in pipes can be safely tolerated and fluid temperatures should not be allowed to drop below 0.5°C.

As soon as the water temperature drops to freezing, ice formation may start somewhere in the system, usually on metal valves and fittings. Ice plugs formed in this manner can prevent start-up or draining of the pipes long before the entire system freezes. The recommended design freeze-up time is only the time available before water in an inoperative system reaches the freezing point. This time period must be sufficient to permit repairs or to drain the system, and depends upon the availability of maintenance personnel and equipment. Understandably, the design freeze-up time may have to be several days in small communities, while in larger centres the time may, with caution, be reduced to less than one day. The shortest freeze-up time and the largest number of freeze-ups are associated with small-diameter service lines. The maximum safety factor freeze-up time is the time necessary for the fluid to drop to -3°C, the nucleation temperature. No portion of the latent heat for complete pipe freezing should be included in freeze-up calculations. (See Figure 15-13, Example 15.9).

Gravity pipelines or open channels may also freeze by icing up. The initial filling of water or sewer pipelines is often a critical period with respect to freezing in this manner. Additionally, frosting and icing may occur in the crown of uninsulated sewer lines when the heat input is low; however, this may melt out when the flow is increased.

15.2.1 Freeze-protection

The design freeze-up time can be increased by higher operating temperatures, increased insulation, and locating pipes where ambient temperatures are warmer. Excess temperature increases heat loss, introduces inefficiency, and is expensive. Utility systems that are highly insulated are preferable, since they require less heating and provide a longer freeze-up period. A similar argument applies to buried systems as compared to exposed pipes. Insulation only retards freezing, and whenever ambient temperatures are below freezing, heat loss from pipelines must be replaced. With respect to freeze-protection, insulation can be less important than the addition of warmer water and the maintenance of flow.

Small-diameter pipes, such as service connections, have less specific and latent heat available and the design freeze-up time is usually only a matter of minutes or a few hours. They are particularly vulnerable to any interruptions in flow, and freezing usually occurs in them first. Thawing capability is therefore mandatory for small-diameter pipes.

Buried insulated piping will not usually significantly affect the ground temperatures, but bare or high-temperature pipes will have a warmed and thawed zone around them. This should not be relied upon to increase the freeze-up time, since soil texture and moisture content vary significantly, and the freezing temperature of moisture in soils is often below 0°C, particularly in cohesive soils [11]. Therefore, the deliberate thawing of ground is not recommended.

Water intakes and sewer outfalls which have intermittent or low flows and wells that have static water levels within the freezing zone may require freeze-protection. This can be accomplished with insulation and heat tracing or circulating raw unheated water (see Figure 3-8). Alternatively, air pressure has been used to lower the static water level in small-diameter pipes to below the ice or frost level when not in use [12].

Since fire protection may be a major function of piped water systems, freeze-protection of fire hydrants is imperative. Conventional hydrants on buried piping within frozen ground may not drain; therefore, they must be pumped out after use and can be filled with a non-toxic anti-freeze mixture such as propelene glycol. In-line hydrants (see Figures 6-22, 6-23 and 8-5) or hydrants located within manholes (see Figure 6-24) are preferred since the water within the pipe to conventional offset hydrants will be static and must be freeze-protected.

Where the demand is very low or intermittent, it may be more economical to fill and operate a pipeline as required and drain it between uses, than to incorporate measures to prevent the freezing of its contents. Such systems usually require pre-heating and post-heating of the pipeline during an operating cycle. This principal is the basis of a long water supply line to a small arctic community [13], and a proposed water distribution system to buildings equipped with water storage tanks [14]. For both of these situations, uninsulated surface pipelines have been utilized during the summer, then drained and not operated during the winter. Storage and intermittent discharge has also been used to prevent the icing-up of low flow or long sewer lines or outfalls [15].

Independent back-up systems should be provided for critical components, such as circulation pumps. Systems with heating cables should prevent freezing even if flow ceases, provided of course that electricity to operate these is available. In cold regions, all utility system components must be capable of being conveniently and quickly drained. If freezing is imminent, pipelines should be manually flushed or drained through hydrants or special fittings judiciously located at low points in the system [16]. Wherever practical, water and pressure sewer systems should be sloped to central draining facilities. Compressed air [12,17] or "pigs" [18] may be used to force the fluid from small-diameter lines.

Some flexible pipe materials, such as polyethylene and small-diameter copper lines, may not rupture upon freezing but the expansion depends upon the manner of freezing and, at present, no pipe should be relied upon to provide service after freeze-thaw cycles. Various methods to prevent or limit the freeze damage of pipelines have been proposed [7]. These provide additional thermal resistance at convenient, pre-determined locations where the hydrostatic pressure that occurs with freezing can be dealt with by a pressure relief valve, bursting diaphragm, expandable section, or other device, or else that short section of pipe can be sacrified.

15.2.2 Thawing of frozen pipes

It is prudent and often mandatory to provide for the thawing of all water and sewer pipes and wells that may freeze. Remote electrical thawing methods which must be incorporated into the original design include skin effect, impedence, and various resistance wire and commercial heating cable systems. Frozen wells have been thawed by applying a low voltage from a transformer to a copper wire located inside the drop pipe [19]. Once a small annulus is melted, the flow can be reinstated and it will thaw the remaining ice in the pipe. A common approach to thawing frozen small-diameter metal pipes is to pass an electrical current from a welder or transformer through the pipe [20]. This operation is greatly facilitated if readily accessible thaw wire connections are provided. A frozen pipe can also be thawed by passing warm water through a small-diameter pipe which is installed on the exterior surface of the pipe. This thaw tube system can also be used as a carrier pipe for electric heat tracing, a return line for recirculation, or a bypass of the main line. The capital cost of this system is much lower than electric heat tracing but it requires manual operation. Utilidors that incorporate pipe heat tracing can be thawed, provided that these heating lines use an antifreeze solution or they were drained prior to freeze-up. Exposed pipes may also be thawed with warm air. Injection thawing with steam or hot water can be used to thaw water and sewer lines if adequate access and room for hoses, equipment and personnel is provided at manholes. Small-diameter water lines of any material can also be quickly thawed by pumping warm water into a smaller-diameter plastic hose that is inserted into the frozen pipe [21]. These thawing methods are detailed in Appendix F.

The energy required to thaw a frozen pipe is largely the heat necessary to melt the ice. Knowing the heat that must be supplied and the energy output of a thawing system, the time to melt the ice can be calculated. In practice, an opening that permits a flow to commence may be all that is necessary to thaw the remaining ice, provided that the flushing water is warm. Long lengths may be thawed this way in stages. In many cases, heat tracing systems are sized to thaw or reopen the line in a reasonable length of time and not just to supply the heat loss necessary to prevent freezing.

15.3 Heat Loss From Pipes

The thermal design must prevent the freezing of water and wastewater within pipes or tanks that are exposed to below-freezing temperatures, and provide for economical operation. The primary and complementary methods are by reducing and replacing heat losses. Heat loss is proportional to the difference between the fluid and the ambient temperatures, and the thermal resistance of the intervening materials. Measures that provide a more favourable environment, such as buried pipes, and measures that increase the thermal resistance, such as insulation, will reduce the rate of heat loss. These methods do not eliminate freezing, rather they retard it; therefore, heat losses must be replaced by removing the cooled water before it freezes, or by heating the fluid or the pipe surface.

Estimates of the maximum rate of heat loss are required to determine the freeze-up time and to design heaters, circulation pumps and heat tracing systems. Annual heat loss estimates are necessary to determine total energy requirements and assess methods of reducing these. Solutions to these thermal problems are outlined in Section 15.9.

15.3.1 Pipe environment

The freeze-up time and the total heat loss are dependent upon the temperatures encountered in the pipe environment. Above-ground piping systems must be thermally designed for the lowest expected air temperatures, perhaps -40°C to -60°C. For reliable and economical operation during the winter, exposed piping must be completely insulated and usually a flow must be maintained. Some heating of water is necessary.

Extreme air temperatures are significantly moderated by the ground surface conditions, primarily snow cover and vegetation, and the thermal properties of the soil. Of importance to heat loss and the design of buried pipes are the minimum ground temperatures and the maximum depth of freezing or thawing. Surface temperature variations are attenuated with depth, depending upon the thermal diffusivity (thermal inertia) and latent heat (moisture content) of the soil. While air temperatures may have an annual range of 90°C, the temperature at a depth of 2 m may vary from 2°C in saturated organic soils in undisturbed areas, to as much as 25°C in exposed dry soils or rock. At a depth of 10 m, seasonal temperature fluctuations are usually negligible. Daily air temperature fluctuations are negligible below aproximately 0.5 to 1.0 m of bare soil or ice or 0.5 m of undisturbed snow. Air temperature fluctuations are moderated with depth and their influence is felt some time later. The lag time depends upon the surface conditions and soil thermal properties, and at a depth of 2 m may be one to five months. Therefore, minimum ground temperatures and maximum frost penetration may occur when the extreme winter temperatures have long passed. Frost penetration will be greatest in rock or bare, dry soils. Undisturbed snow cover itself may reduce the depth of frost by an amount equal to its own thickness [22]. Locating utility lines away from travelled, plowed areas, such as at the back of lots rather than under roadways, may significantly reduce heat loss and increase the freeze-up time, but years with little snowfall, snowdrifting and man-induced changes must be considered.

Conventional municipal piping can be installed below the maximum depth of seasonal frost. In cold regions, the frost penetration is often greater than the common pipe depths of 2 to 3 m, and may be 6 m or more in exposed dry soil or rock. Deep frost penetration, high groundwater, hilly terrain, rock or other factors may make it more practical and economical to install all or portions of the utility system within the frost zone [23,24,25]. In these cases, the degree of freeze-protection necessary will depend upon the ground temperatures at the pipe depth. Where pipes are only intermittently or periodically within frost, conventional bare pipes may be adequate, provided a minimum flow can be maintained by circulation, bleeding or consumption. Frost-proof appurtenances, stable backfill and some heating may also be necessary. Even in these marginal cases, insulating pipes in shallow or low temperature areas will greatly increase the reliability of the system and is highly desirable. Heat loss and freeze danger are significantly reduced by insulating the pipes. This is illustrated in Figure 15-2.

Insulated pipes can be installed in shallow trenches or within berms at the ground surface. In these cases, there is often little thermal advantage in deep bury, but the minimum desirable cover should be such that daily temperature fluctuations are not "felt". This is 0.5 to

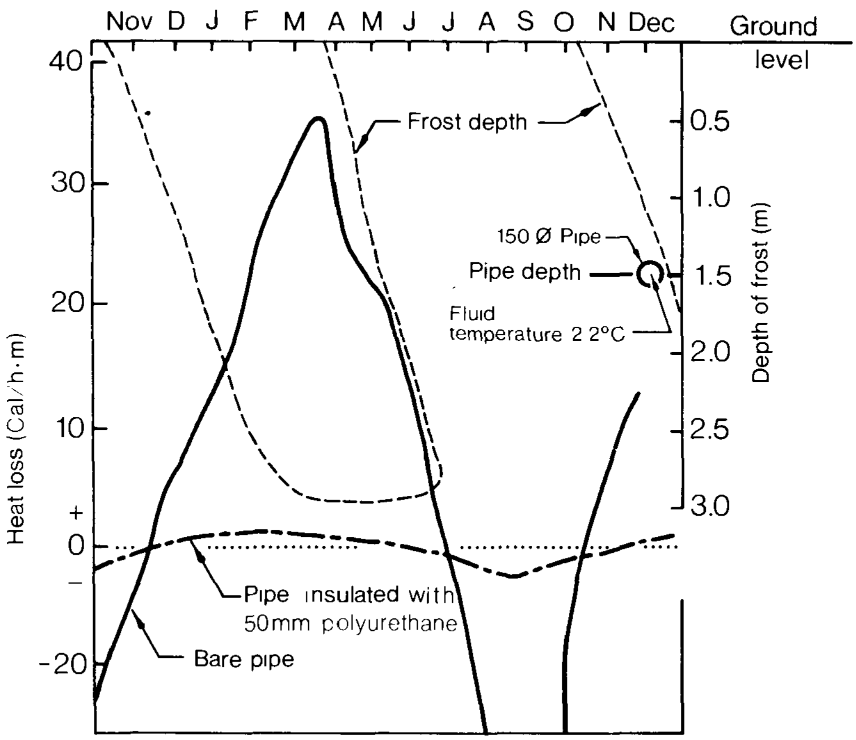


FIGURE 15-2. FROST PENETRATION AND HEAT LOSS FROM BARE AND INSULATED PIPES WITHIN SEASONAL FROST [27]

1.0 m for exposed surfaces. The minimum depth of cover is also governed by the ability of the insulation and pipe to withstand anticipated traffic loads, and this depth is usually approximately 1 m. Other factors which will influence the average and local depth of bury are the pipe grade and terrain; frost heaving problems, which are greater for shallow pipes; and access for maintenance. In some cases, it may be possible to balance the reduction in excavation cost with the cost of insulation and other freeze-protection measures necessary for shallow buried pipes within the seasonal frost zone [23,24,25].

Buried pipes within seasonal frost can be pre-insulated, usually with polyurethane, or a layer of insulating board, usually polystyrene, can be placed above the pipe (Figure 15-3). The latter method uses bare pipes and fittings and the board insulation is often less expensive; however, the installation cost will be higher and the effectiveness of the insulation is lower than direct insulation of the

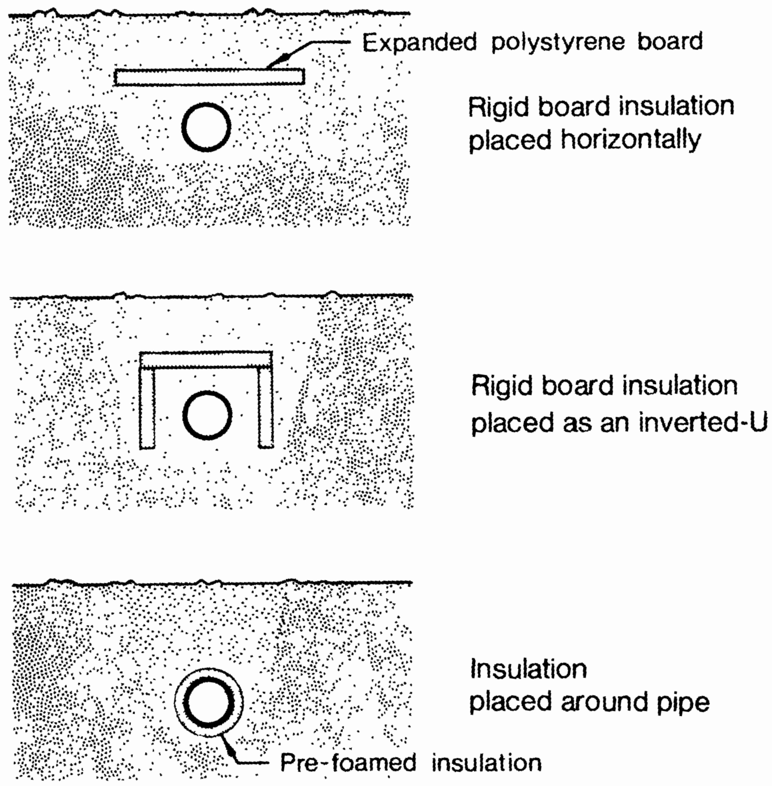


FIGURE 15-3. METHODS OF INSULATING BURIED PIPES

pipes. The board method has been used where the soils underlying the pipe are frost-susceptible, since frost penetration beneath the pipes can be prevented by an insulating board. The necessary thickness and width of the board increases for shallower pipes and deeper frost penetration, such as in dry soils or rock. The relative economics, compared to separately insulated pipes, is improved when pipes are placed in a common trench under a board and when warm sewer or central heating lines are included. Design information on this method is available from descriptions of its use in Scandinavia [27,28], and an example is shown in Figure 14-10.

Generally, the insulation should be a minimum of 1.2 m wide for a single pipe, and the thickness determined by the proposed depth of bury and the expected or calculated frost penetration. In terms of reducing frost penetration, 5 cm of polystyrene foam insulation ($k = 0.035$ W/m•K) is roughly equivalent to 1.2 m of sand or silt or 1.0 m of clay cover over the pipe [29]. The heat loss and trench width can be reduced by placing the insulation in an inverted U.

Buried pipes at any depth in permafrost areas must be protected from freezing, and pipes and appurtenances must be insulated. Deeper pipes will experience less extreme ambient temperatures, lower maximum rates of heat loss and longer freeze-up times. However, the heating period will be longer and pipes installed below the seasonally thawing active layer may require freeze-protection and heating all year. The total annual heat loss is relatively constant with depth. The most important function of soil above buried insulated pipes is in reducing the ground temperature amplitude by its thermal inertia and latent heat. The thermal resistance of the soil is often insignificant (see Example 15.3). Depth-of-bury considerations in permafrost areas are similar to those for pipes within seasonal frost, with the possible additional problems associated with the thawing of ice-rich permafrost.

15.3.2 Physical methods of reducing heat loss

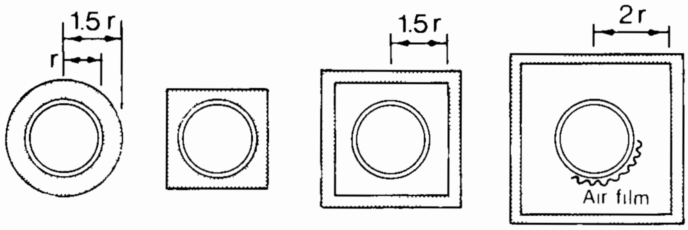
The primary physical method of reducing heat loss is insulation. It is impractical to prevent ground moisture, humidity or water from pipe failures from reaching the insulation and, since moisture content is a key factor in determining the thermal performance of insulations, only near-hydrophobic insulations should be used. Even these insulations will usually require some physical and moisture protection.

Systems that are liberally insulated are generally preferred since they require minimum heating and circulation, provide a longer freeze-up period, and have less influence on the ground thermal regime. An economic analysis to balance heating and insulating costs should be performed to determine the minimum amount of insulation that is required (see Example 15.11). Other factors, such as the freeze-up time, the maximum rate of heat loss and practical dimensional considerations, must also be considered in the selection of insulation thickness.

Heat loss estimates for piped systems must adequately allow for poorly insulated or exposed sections of pipes, joints and appurtenances, and thermal breaks such as at pipe anchors. A 150-mm gate valve has a surface area equivalent to 1 m of bare pipe. If this valve were left exposed it would lose as much heat as about 60 m of 150-mm pipe insulated with 50 mm of polyurethane insulation and freezing will occur at the valve first. Therefore, the thermal resistance around appurtenances should be 1.5 times that required around connecting pipe lengths. This illustrates the danger of restricting thermal analysis and design to straight sections of piping and the importance of fully insulating the piping system.

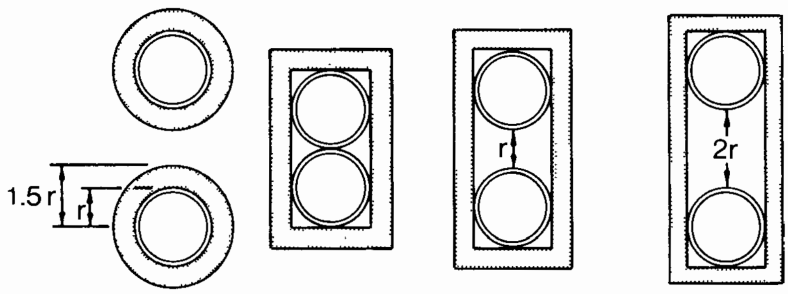
Heat loss and the volume of materials can be reduced by minimizing the perimeter and exposed surface area. This is most important for above-ground pipes and facilities. Insulation is most effective when it is placed directly around the source of heat. These characteristics are illustrated by simple shapes in Figures 15-4 and 15-5. Where there is an air space, the thermal resistance of the pipe air film can be quite significant and must be considered. For a single pipe, insulation is best applied in an annulus directly around the pipe. Heat loss from pipes in a utilidor is less than that of separate pipes insulated with the same total volume of insulation, if the utilidor is compact. This is often not possible. The spacing requirements for pipes, appurtenances, installation and maintenance, particularly for central heating lines, often make it necessary to design utilidors with large air spaces and these utilidors will be thermally less efficient than separately insulated pipes. Heat supplied from warm sewer pipes, central heating lines or heat tracing may make utilidors thermally attractive. Pipes within utilidors may also have a longer freeze-up time because of the larger heat source available compared to separate pipes. This is particularly important for small-diameter pipes. Heat loss can also be reduced and freeze-protection improved by installing one water pipe inside of a larger one, rather than using two separate pipes. This technique is applicable for freeze-protection of small-diameter recirculation pipes used to maintain a flow in supply lines, or dead ends within a water distribution system.

Heat loss can also be reduced by lowering the operating temperature of water pipelines, but the benefits of this are only significant where the ambient temperatures are just slightly below freezing. The heat loss from insulated storage tanks and pipes is

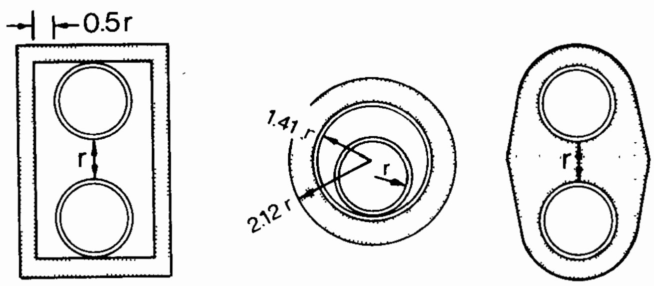


With air film	1.0	N/A	1.5	1.9
No air film	1.0	1.1	2.8	4.6

FIGURE 15-4. RELATIVE HEAT LOSS FROM SINGLE PIPES INSULATED WITH SAME VOLUME OF INSULATION



With air film	1.0	0.64	0.78	0.93
No air film	1.0	0.78	1.0	1.25



With air film	0.93	0.50	0.80
No air film	1.25	0.50	0.80

FIGURE 15-5. RELATIVE HEAT LOSS FROM TWO PIPES INSULATED WITH SAME VOLUME OF INSULATION

often small compared to the energy requirements to raise the source water to the system operating temperature. Therefore, lower operating temperatures may significantly reduce energy requirements for preheating rather than heat losses within the piping system. Because of the greater relative reduction in heating requirements, utility systems in the subarctic are often operated nearer freezing than those in arctic regions. Any reductions in heat loss and preheating requirements must be balanced with the reduction in freeze-protection when systems are operated nearer the freezing point.

15.4 Heat Loss Replacement

Heat loss cannot be completely prevented. If ambient temperatures are below freezing, it is simply a matter of time before freezing will occur unless heat is added to the fluid or it is replaced with warmer fluid. Heat can be added either continuously or at point sources.

15.4.1 Fluid replacement

Freezing will not occur if the liquid residence time in the pipeline is less than the time necessary for it to cool to the freezing point. The quantity and temperature of the replacement water (i.e., the total heat available) must be sufficient and the flow must be reliable. Operation without additional heating is restricted to situations where relatively warm water supplies, such as groundwater, are used and/or where the flow rate is reliable and high, such as in some water supply pipelines or trunk mains. Bleeding of water has been used to maintain or enhance the flow in service lines, dead ends and intermittent flowing pipelines but the wasting of large quantities of water can be inefficient and lead to water supply and wastewater treatment problems. Recirculation will maintain a flow and a uniform temperature within the system, and prevent premature freezing at locations with lower than average ambient temperatures or at poorly insulated sections. However, the water temperature will decline unless warmer water is added or the recirculating water is heated.

15.4.2 Point sources of heat

Water may be heated at the source, treatment plant, pumping stations and/or along the pipeline or within distribution systems as required. Heat is commonly obtained from fuel oil fired boilers; however, simple electric water heaters have been used where the heat requirements are very low. The heating of water can be a practical use for low-temperature waste heat, such as from electric power generation, and this should always be investigated in order to reduce energy costs. The heating capacity required to replace heat losses is based on the maximum rate of heat loss expected; whereas annual heat loss energy requirements are calculated from the cumulative heating index (see Example 15.3). Where the raw water temperature is too low and must be raised to a specified operating temperature, the required heating capacity is determined by the maximum flow rate, and the annual energy requirements are determined by the total water demand during the heating period.

There must be sufficient flow within the piping system to distribute the heat which is added. If the normal water demand is too low or is intermittent, then bleeding or recirculation is necessary. A minimum water temperature can be maintained within the piping system by increasing either the flow rate or the input water temperature while keeping the other parameters constant, or by adjusting them simultaneously. High temperatures enhance heat loss and introduce inefficiency. As a general rule, the temperature drop along a pipeline should always be kept to less than 5°C, and preferably less than 2.5°C, by insulation, higher flow rates, or intermediate heating along the pipeline or within the system. However, there is usually little reduction in heat loss by limiting the temperature drop to less than 0.5°C. By the same analogy, velocities greater than 0.1 m/s for 150-mm pipes and 0.5 m/s for 50-mm pipes are of little benefit in reducing total energy input to maintain a specified minimum water temperature. Higher velocities, such as for pitorifice systems that require a minimum velocity of 0.75 m/s, must be balanced with the electrical energy requirements for pumping (see Example 15.10).

Sewer lines are generally warmer than water mains, but freezing can occur where flows are intermittent or low. In these cases, a flush tank can be used to periodically discharge wastewater or warm water into the sewer line (see Section 7.2.3.2). Bleeding water directly into the sewer lines also adds heat but this practice is usually only recommended as a temporary measure. Direct heating of wastewater is not practised.

15.4.3 Pipe heat tracing

Heating requirements to replace heat losses and to maintain a minimum temperature (i.e., prevent freezing) can be supplied by pipe heat tracing systems. Such systems are more commonly used in multi-pipe utilidors but have been used for single pipes. Heat is provided by warming air spaces by convection, and in some cases by conduction. The pipe heat tracing system may be part of a central heating system, or designed only to heat a utilidor. In the former case, for above-ground utilidors some of the high-temperature pipe insulation may have to be removed (typically 0.25 m every 10 m) to provide enough heat to prevent freezing at the lowest ambient temperatures. The heat source cannot be manipulated and when the ambient temperature increases, inefficient and undesirable overheating of the utilidor and water main occur (see Example 15.5). Freezing of pipes can result from thermal stratification in large utilidors or the shielding of small-diameter heat tracing pipes [30].

For pipe heat tracing, low-temperature fluids, generally between 80°C and 98°C, are much simpler to use than either steam or high-temperature water, and the fluid mixture can be adjusted to depress the freezing point to the lowest expected ambient temperatures. The use of an antifreeze solution protects the heat trace piping, allows start-up during winter and provides a means of thawing frozen pipes. The viscosity of low freezing point glycol and water mixtures is greater than that of water; therefore, the required pumping capacity and friction losses will be higher. The heat transfer characteristics are also poorer than for water. For example, a 50% mixture of glycol and water would require a 14% increase in flow rate to achieve the same heat transfer. Design information on these heating systems is available from the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) [31,32]. It should be remembered that ethylene glycol is toxic and cross-contamination must be prevented. Alternatively, propylene glycol, which is non-toxic, can be used. These solutions are corrosive to zinc and they can leak through joints and pump seals that will not leak water at the same pressures. Mechanical seal pumps should be utilized. Some boiler manufacturers void their warranty if glycol solutions are used. Special organic fluids can also be used instead of water-glycol mixtures.

15.4.4 Electric heat tracing

Electric heat tracing systems are relatively easily installed and controlled. They may be installed continuously on water and sewer pipelines, or only at low ambient temperature, freeze-susceptible or critical locations, such as road crossings, service connections or at appurtenances such as fire hydrants. Because of the relatively high cost of electrical energy, these systems are usually installed for freeze-prevention in the event of operating upset, such as a prolonged no-flow condition, rather than as the primary method of maintaining a minimum operating temperature or to heat up the fluid. The capability and ease of remote thawing is also important in many situations. The designer must weigh these advantages against the risks, costs of electric heat tracing systems, and alternate freeze-protection methods. They are more attractive where the freeze-up time is short and where the lines cannot be blown clear or drained.

A variety of electric heat tracing systems and products are available [33]. Resistance-type cables and wires are available for installation within pipes or for exterior tracing [34]. Small-diameter metal pipes, such as service lines, can be heated or thawed by induction heating from an alternating current in a wire wrapped around the pipe which induces eddy currents within the pipe [35]. Skin-effect current tracing, which requires only one source of power and control, may have application for long steel pipelines [36]. The most common electric heat tracing systems used are zone-parallel and self-limiting continuous parallel heating cables and strips [37]. They contain separate conductor wires and resistance buss wires or conducting material in the same casing so they produce a constant heat output per unit length, and can be conveniently cut to the desired length. Maximum lengths are usually 75 m to 200 m, depending on the type and heating capacity, although a 400-m, 13 W/m-cable is available. One type has a carbon-filled polymeric heating element with self-adjusting properties that decreases heat output as the temperature increases. This cable will not burn itself out or overheat plastic pipes, and the heat output modulates, to some extent, with temperatures along the pipe.

For maximum heat transfer efficiency, heating cables can be installed within pipes. The coating and joints of only a few cables, such as mineral insulant (M.I.) resistance cable, are approved for installation within pipes or for submerged conditions. In-line cables are more practical for long water supply pipelines or similar applications because valves and other such fittings must be bypassed. They may be subject to vibration damage when fluid velocity is greater than 1.2 m/s [38], and the cables must be removed to clean the pipes and when some types of pipe repairs are made. Heating cables are more conveniently and commonly located on the pipe surface. The capacity of such heating cables should be increased by a factor of 1.5 for insulated metal pipes [38], unless flat or wide heating strips or adequate contact between the cable and the pipe, preferably with heat transfer cement, is maintained. Since the thermal resistance of plastic is significant (125 times that of steel), the heat tracing capacity for plastic pipes must be increased. Hence, Schedule 40 pipe up to 150-mm diameter and Schedule 80 pipe up to 75-mm diameter typically require 1.4 times the exterior heat tracing capacity of a steel pipe with the same volume of insulation [39]. Exterior cables for pre-insulated pipe are commonly installed within a raceway or conduit attached to the pipe surface, which facilitates fabrication, installation, removal and replacement. In this configuration, the air space and poor contact of the heating cable with the pipe can further reduce the heat transfer efficiency, and for plastic pipes the heat input may need to be two to six times that for a heating cable within the pipe [40]. It is difficult to make the joints in the exterior heating cable channel watertight, as is required for most cables and/or their joints when used underground.

The location of the heating cable is not significant for insulated water pipes, unless it is loose within a channel, in which case placing it on top will improve the contact and heat transfer efficiency. For above-ground pipes, heating cables are placed in the bottom quadrant for mechanical protection. The cable is usually located on top of buried water pipes for easier access [41] but for partially full sewer lines the cable is best located in the bottom quadrant.

Plastic pipes, insulation and the electric heat tracing system itself must be protected from overheating unless the self-limiting heating cable is used. For conventional cables, a high-temperature thermostat cut-off is usually installed and set at about 30°C, and the sensor is placed on the surface of the heating cable. For plastic pipes, heating cables with an output over 12 W/m are not advisable unless manufacturers of pipe and cables concur.

To provide freeze-protection, automatic control systems must activate the electric heat tracing system at a set point above 0°C to provide some lead time and allow for variances in the temperature detection sensitivity of the thermostat and sensor. To provide economical operation, the controls also cut off the power supply when heating is not required. These controls are often a major cause of malfunction and wasted energy. Mechanical thermostats with capillary tube sensing bulbs are limited to about 5 m in length and temperature control is only possible within a few degrees. Electronic thermostats are much more sensitive but they are expensive. The resistance sensors they use can be located any practical distance from the controller and the system can be selected to maintain fluid temperatures within 0.1°C. This type of system, which is commonly used in Greenland [38], allows the utility system to be reliably operated at near-freezing temperatures, which reduces or eliminates the raw water pre-heating requirements, the utility system heat losses, and the need for recirculation. The sensors must be located with care to provide proper control, freeze-protection, and prevent the waste of energy. To accurately measure the fluid temperature, they should be put in a pipe well or attached to the pipe surface with heat transfer cement, particularly for plastic pipes. They should be located where the lowest pipe temperatures within the section being controlled are expected, such as at exposed windswept areas or shallow sections.

Sometimes heating cables are installed without thermostat controls and they are manually operated. They can be left on throughout the period when freezing can occur but this wastes energy. In some situations manually operated heating cables are used for thawing only. For complex piping or temperature conditions, primarily industrial operations, a single ambient temperature sensor and thermostat control have been used.

The electric heat tracing must maintain at least 0°C at the lowest ambient temperature conditions. The minimum capacity required must compensate for the pipe or utilidor heat loss and heat transfer inefficiencies, and include a safety factor. In some cases, the capacity will be increased to shorten the time required to thaw the pipe or pipes if they become frozen. The performance of various heating cables within a service connection utilidor are illustrated in Figure F-3. Commonly used capacities are 8 W/m for service connections and 12 to 25 W/m for mains. Typical installed cost for heating cables and controls is $30/m.

15.4.5 Friction

The amount of heat generated by friction depends on the flow rate, fluid viscosity, and the pipe size and roughness. Friction heating is negligible for smooth (new) pipes with fluid velocities less than 2 m/s, which is about the desirable upper limit for flow in pipes, but for high fluid velocities it may be significant [42]. Since this energy is supplied by pumping, deliberately increasing the velocity (friction) is a very inefficient method of heating. Equations for friction heat input are presented in Figure 15-13.

15.5 Utility Systems

Many thermal considerations must be based on the characteristics of the total utility system rather than any single pipeline, cross section, or portion of the system. Some of these considerations include: the efficient integration of freeze-protection of service lines and the less freeze-susceptible mains; the identification of trunk and subdivision pipelines that require recirculation to maintain a flow; and the decisions related to the necessity, timing, and location and method of heat input. These considerations must be assessed in conjunction with alternatives and factors that influence the thermal design including: the location of pipes above or below-ground, under roadways or at the back of lots; the depth of bury; the selection of insulation thickness, if any; and alternatives such as non-gravity sewer systems and non-fire flow water systems. Some of these options are only appropriate for certain physical or climatic conditions. Large utility systems may combine various strategies or use different alternatives within the serviced areas as is economical or necessary.

The thermal design must also be a part of the physical planning and staging of development. This is particularly important for recirculation systems, which must be looped, to avoid stretches of pipeline without connections, and temporary connections or over-building (see Sections 2.4.3 and 6.5).

15.5.1 Thermal analysis

Thermal analysis of a large water distribution system with many loops, recirculation pumps and intermediate heating is much more complex than the analysis at one cross-section or for a single pipeline or loop in a recirculating system. For large systems, simultaneous hydraulic and thermal analyses must be performed to determine the flows and water temperatures at junctions and within each pipe length under various water demand and ambient temperature conditions. This analysis lends itself to computer solution [43,44]. Features such as circulation pumps and check valves require rather sophisticated hydraulic models which can be combined with the analogous thermal equations to estimate flow and temperature patterns. Of particular concern is the identification of locations or sections of the system that experience little or no flow, flow reversals, low-temperature and short freeze-up times. The benefits and strategic location of circulation pumps and heat input can be quickly assessed. Large systems are usually best operated with different temperature zones, and many pipes, such as trunk mains, will have sufficient demand flow and freeze-up time that recirculation and/or heating will not be necessary.

15.5.2 Operation

The design of the utility system, including storage, distribution, circulation and heating, must allow for maximum operating flexibility and adjustments, based on actual operating requirements and experience. Procedures for emergency situations such as prolonged power failure, freeze-up, and start-up during the winter, as well as heating, circulation, draining, thawing and other cold regions characteristics must be clearly outlined in an operator's manual [45]. Regular surveillance, monitoring and recording of flows, heating, and fluid and ambient ground or air temperatures must be conducted to maintain and improve the thermal performance, and to indicate potential problems. In some cases, soil and pipe movements may be measured.

Temperatures can be remotely measured with sensors such as thermocouples, resistance temperature detectors (RTD) and thermistors [46,47]. The latter are commonly used because the lead wires can be of practically unlimited length, and the off-the-shelf accuracy of 0.1°C to 0.25°C can be improved by simple calibration if desired. They are rugged, but must be protected from moisture. A multi-cable can be used to carry the wires from many sensors. Heat flux transducers that measure heat loss directly are available. These various sensors can be monitored with portable or fixed meters, or recorded on strip charts, printout or magnetic tape. Frost penetration is indicated by a colour change in a 0.01% solution of methyl blue in a clear plastic tube inserted into a casing in a bore hole.

15.6 Foundations for Pipelines

Frost heaving and thaw-settlement are more significant foundation considerations than the foundation load-carrying capacity. Frost heaving and thaw-settlement may have conflicting solutions. In some cases, above-ground piping may be necessary but buried utilities are usually preferred (see Section 2.5.5.4). The method of installing utilities can be selected after careful study of the local conditions, in conjunction with geothermal analysis of installation alternatives.

15.6.1 Buried utilities in permafrost areas

Heat loss from buried warm pipelines and thermal disturbances resulting from their installation will cause thawing that is greater than the natural thawing in undisturbed areas. Possible thaw-settlement of ice-rich foundation soils requires that special attention be given to the thermal regime and the stability of the soils and piping. The degree of concern and countermeasures depends upon the thermal sensitivity and ice content of the permafrost. For example, at locations where the mean annual ground temperature is just below freezing (-2°C to 0°C), it is often impractical to prevent complete thawing of permafrost once the surface vegetation has been disturbed. For this reason, utilities in the discontinuous permafrost zone are usually designed for thawing and possible settlement [48,49]. In the high arctic, ground temperatures are colder and thawing is more easily prevented. In considering buried utilities, a distinction must be made between the relatively small and cool water and sewer pipes, and large utilidors or high-temperature heating pipes. With the latter, the foundations of nearby structures can be adversely affected. It must also be kept in mind that thaw-settlement is only significant where permafrost contains ice lenses and excess ice content and the following considerations should not be applied to other permafrost conditions.

Measures to prevent unacceptable settlement are: reducing the thermal influence; replacing ice-rich foundation soils; anchoring pipes; and freezing foundation soils [50].

The thermal influence of water and sewer pipes can be controlled by placing insulation around or below them. Insulation will reduce the rate of thawing and the settlement of pipes in ice-rich permafrost. This is indicated by the results of a test loop which are illustrated in Figure 15-6. With practical thicknesses of insulation, the heat loss can be reduced such that it is no longer the criterion for the practicality of installing buried utilities in ice-rich permafrost. For large or hot conduits in warm permafrost, the insulation requirements for complete permafrost protection tend to become excessive, but moderate amounts of insulation result in a significant reduction in the rate of thaw [52]. Heat loss and thermal influence can be reduced by minimizing the surface area of insulated pipes and utilidors, lowering the operating temperature of the water pipes, and restricting the temperature of wastewater discharges. The placement of pipes further from the depth of maximum thaw will also reduce thawing. The relative effects of insulation and depth of bury, which can be estimated for simple conditions from equations in Section 15.9, are illustrated in Figures 15-7 and 15-8.

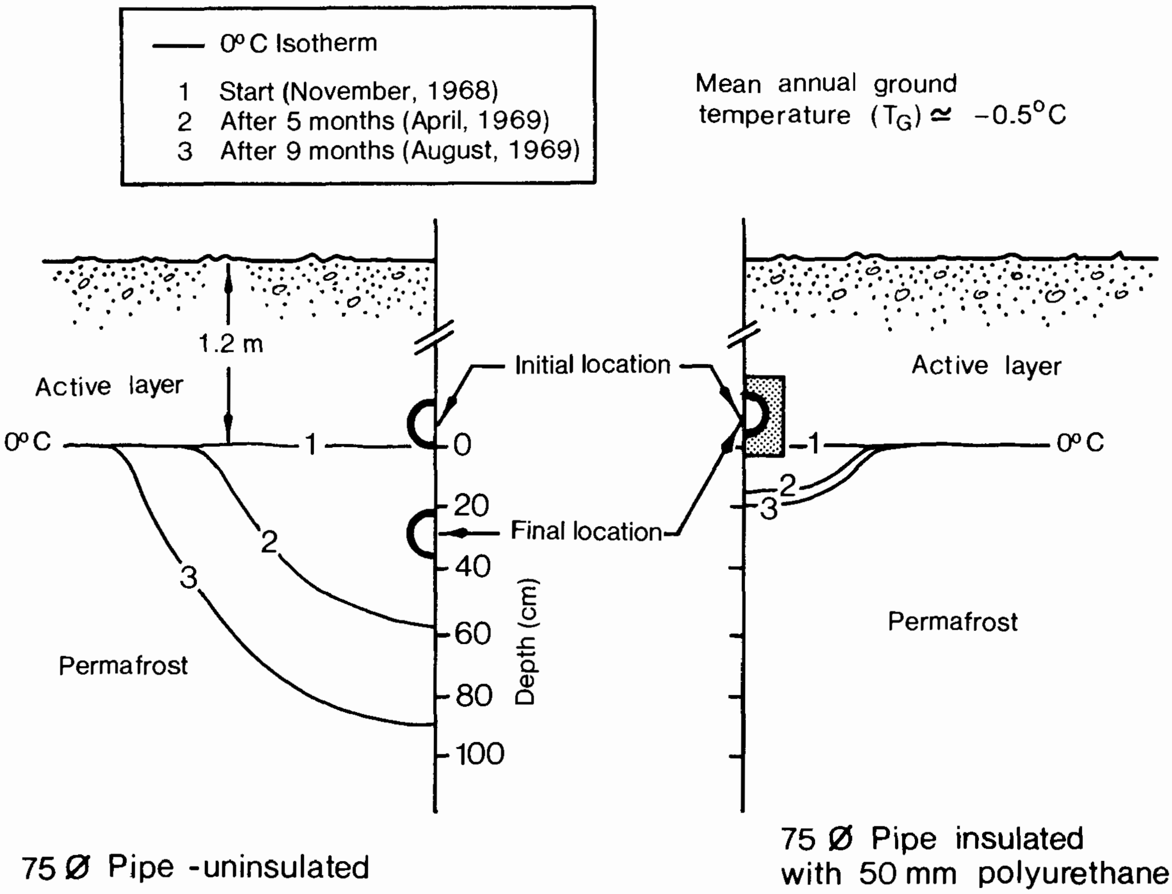


FIGURE 15-6. THAWING AND SETTLEMENT OF BURIED PIPE TEST LOOP IN ICE-RICH PERMAFROST, BETHEL, ALASKA [51]

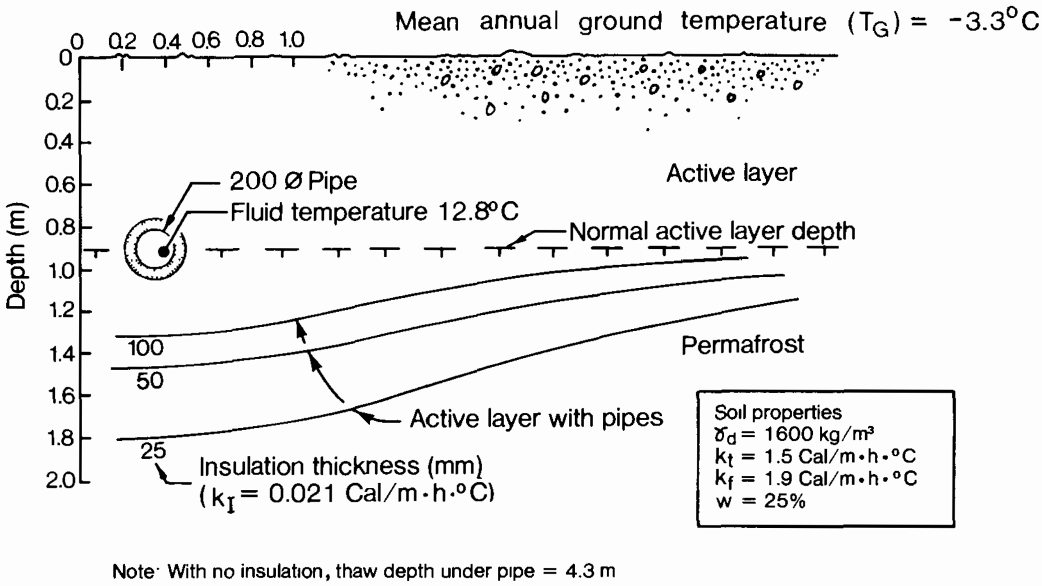


FIGURE 15-7. EFFECT OF INSULATION THICKNESS ON THAW PERTURBATION [50]

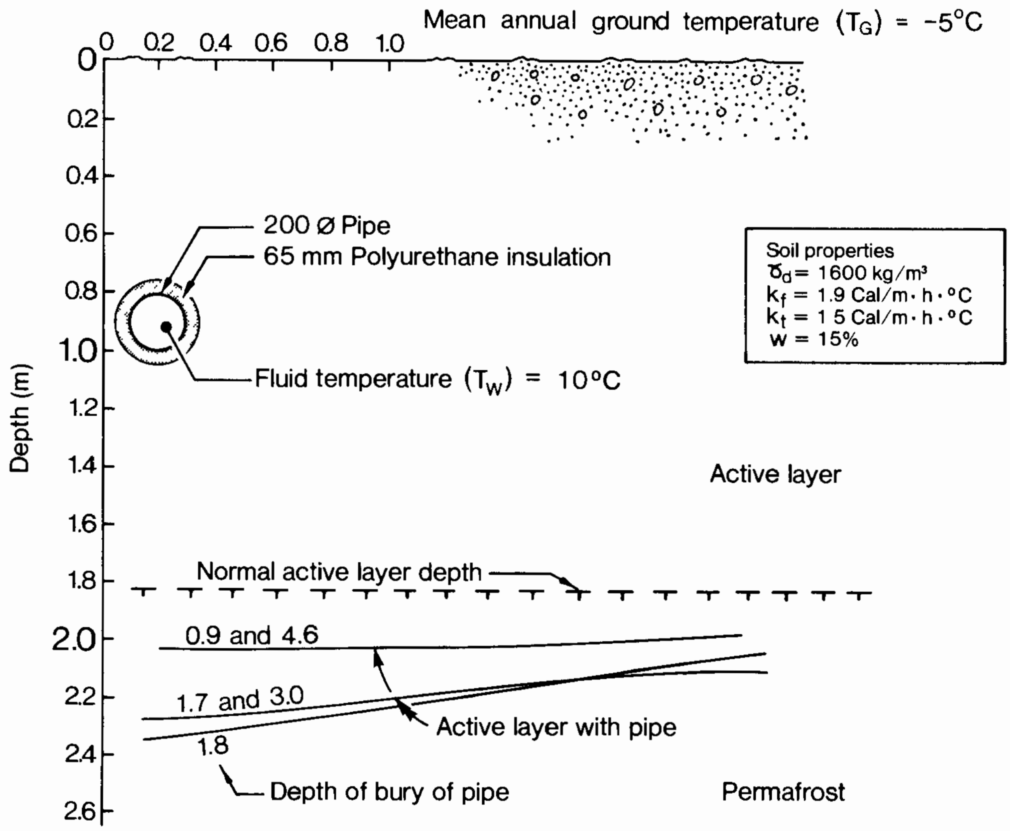


FIGURE 15-8. EFFECT OF DEPTH-OF-BURY ON THAW PERTURBATION [50]

The effects of changes in surface conditions, groundwater movement, and soils due to the installation of utilities and other developments are more complex and difficult to predict. Sophisticated computer programs can be helpful [53,54]. It may be necessary to install utilities only during periods when the air temperature is below freezing in order to reduce the thermal disturbance, including heat input from backfill and open excavations. Groundwater and fluid from breaks flowing along a trench can increase thawing and, in pervious soils, impervious backfill or cut-off walls every 50 to 200 m may be required [11,55].

Ice-rich foundation soils must be pre-thawed or replaced to the maximum depth of expected thaw. Natural or artificial pre-thawing may be used in the discontinuous permafrost zone, usually as part of the overall development strategy. More commonly, soils are mechanically excavated and replaced with compacted unfrozen soil.

Limited thawing can be tolerated if buried rigid pipes or utilidors are anchored to the permafrost. Pile supports [2] or horizontal beams [56] can be used. These must extend beyond the maximum thaw bulb and into the permafrost sufficiently to ensure anchorage. These alternatives must consider the thermal disturbance created by their installation, and frost-heaving and overburden stresses on the piping between the supports.

Refrigeration of the foundation is possible but it is complex [52, 57]. In Russia, some large utilidors with central heating networks are ventilated during the winter to refreeze and cool the foundation soils that thawed the previous summer [58]. A major problem with these open utilidors is groundwater infiltration and movement along the trench [59].

In most cases, some thawing and differential settlement must be anticipated, and the pipe and joints should be selected with this in mind. Brittle pipe materials such as asbestos cement must not be used. Strong ductile pipes, such as welded steel, which can tolerate considerable deformation without rupture, have been successfully used [60].

15.6.2 Frost effects

Frost heaving effects must be considered for pipes and appurtenances located within the seasonally freezing and thawing zone in both seasonal frost and permafrost areas. The two primary methods to reduce heaving effects on pipes are deeper burial, and over-excavation and replacement with non frost-susceptible soils within the trench. Where adequate backfill material is not available, it may be necessary to construct utilities above-ground. Flexible pipes and joints may be necessary where differential movement is expected, such as at building connections (see Figures 7-13 and 7-14). To reduce the heaving force, appurtenances such as fire hydrants, which protrude through the freezing zone, can be encased in an oil and wax collar (see Figure 6-16), wrapped with polyethylene, and/or backfilled with non frost-susceptible soil. At Norman Wells, NWT, where frost heaving is severe, metal manholes were fabricated in an inverted cone shape to reduce heaving forces [61].

Frost penetration significantly increases earth loading on buried pipes [62,63] and coupled with live loads, can cause beam breaks where pipe bedding is not uniform or the pipe has inadequate strength and ductibility.

15.6.3 Above-ground pipes

Above-ground utilities have been used where access is necessary, where excavation or backfill material would be costly, and where disturbance of permafrost is potentially hazardous. Piping can be installed at the ground surface within berms, on gravel pads, or on posts or piles. The design of piles is similar to building foundations but, because of the light loads, except perhaps for thrust blocking, the major design criterion is to provide sufficient anchorage to resist frost heaving. In permafrost areas, piles of 4 to 12 m may be required, the shorter piles being used where the active layer is thinner [64]. Unanchored surface piping must allow for ground movements due to frost heaving. Surface drainage must be considered since ponding and erosion can adversely affect the thermal regime, frost heaving and the foundation soils.

15.7 Materials

Unsuitable materials are a significant cause of failure and these often relate to their thermal performance or characteristics. Of concern are: the thermal expansion with temperature change and freezing; the change in thermal properties with moisture and freezing; the effects of freeze-thaw cycles; and, the influence of temperature on strength and durability. Other considerations are essentially similar to those in warmer climates. Composite structures, such as pre-insulated pipes and utilidors, and appurtenances must be compatible. Since environmental and design conditions are varied and often opposite properties are desirable, no material is universally applicable. General data on materials is available from manufacturers, but comparisons are often difficult and those characteristics which are important to cold regions may not be emphasized or available.

15.7.1 Piping materials

Although some northern engineers prefer certain types of pipe, virtually every type of pipe used for watermains and sewers elsewhere has been used in cold regions. The generally desirable qualities of northern piping materials are: low thermal conductivity, low thermal expansion coefficient, high thermal inertia; resistance to freezing damage and freeze-thaw cycles; fire resistance; ease of heating and thawing; convenience in applying insulation; low sensitivity to deformation of foundation soils; good transportability; and low weight. As not all of these characteristics are available in one type of pipe, the selection must be based upon the best material for the specific job, keeping in mind that it is desirable to standardize for maintenance purposes. The characteristics and properties of pipe materials are presented in Appendix A.

Some pipe materials, such as wood stave pipe, which were used in the past have largely been supplanted by modern plastics. The ability to withstand movement due to thaw-settlement or frost heaving is a major reason for the use of ductile iron and steel pipes. Plastic pipe is attractive because of its light weight, which eases shipping and installation. For service connections, copper is very popular, in part because it can be electrically thawed.

The thermal conductivity of metal pipes is insignificant and although the thermal resistance of polyethylene is about 125 times greater than that of steel, its insulating value is usually not very important when pipes are insulated (see Example 15.1). The heat capacity of the pipe is not usually considered in temperature change and freeze-up calculations but materials with low heat capacity, such as aluminum, would be an advantage for pipelines designed for intermittent flow [15].

Thermal stress and strain result from changes in the pipe temperature. The worst conditions often occur during the installation and initial filling of pipes, or if the lines are drained and allowed to cool when the ambient temperatures are at a minimum. The maximum ambient temperature range is naturally higher for above-ground piping. The calculations required are: the change in length ($\Delta l = l \cdot u \cdot \Delta T$); stress ($\sigma = E \cdot u \cdot \Delta T$); and the load ($P = A \cdot \sigma$), where: l = length of pipe; Δl = change in length; u = coefficient of thermal expansion; ΔT = change in temperature; E = Young's modules; σ = stress; P = load; and A = cross-section area of pipe (see Example 15.12).

For rigid pipes with high coefficients of thermal expansion, such as metal and fibreglass, it is impractical to restrain movement because the load would be very high. Movement can be accommodated by flexible joints, expansion joints, expansion loops, or by allowing pipe movement. In-line expansion compensation mechanisms do not perform as well at low temperatures and when coated with ice. In these conditions, free-flexing bellows which have no sliding parts generally provide better service [65].

The expansion of flexible pipe, such as plastics, is greater than for rigid pipes, but their low tensile strength makes it possible to restrain this type of pipe to eliminate movement. This can be done by: fixing the pipe to stationary anchors; encasing the pipe within rigid insulation or casing, provided that the insulation shear strength and bond are adequate; or by burial, provided that the soil friction and weight are adequate.

15.7.2 Insulation

Insulation of piping and structures in cold regions is usually necessary. The appropriate type and thickness must be selected. The thickness may be determined from economic analysis (see Example 15-11), or other considerations such as freeze-up time or building comfort. Common insulating materials are plastics, minerals and natural fibers, or composite materials. For design purposes, the structural and thermal properties for the worst conditions should be used. These conditions occur after aging, compaction, saturation and freeze-thaw cycles. Other selection considerations are ease of installation, vapour transmission, burning characteristics, and susceptibility to damage by vandals, animals, chemicals and the environment.

The insulating value of a material depends more or less directly on the volume of entrapped gas in the material. If the material becomes wet and the voids filled with water, the insulating properties are lost since the thermal resistance of air is about 25 times that of water and 100 times that of ice. This is the case when peat moss or similar materials are used around underground pipes [66]. In the past, the lack of a near-hydrophobic insulation made the design of piping in moist environments very difficult [11], and is a major reason for the development of above-ground utilidors [3]. The advent and availability of rigid closed-cell plastic foam insulations with low thermal conductivity and high resistance to water absorption has dramatically influenced northern utility systems. They have limitations and knowledge of their properties is essential.

Polyurethane foam is used extensively in cold regions to insulate pipes and storage tanks, and is also used in some buildings and foundations. Urethane will bond to most materials. Piping or other components can be pre-insulated or polyurethane can be applied on-site from the raw chemicals, which are about 1/30th the final volume. Field applications are restricted by climatic conditions, and the density and thermal conductivity will often be higher than values attainable under factory conditions (see Section 5.2.2). The foam must be protected from ultraviolet radiation during shipping and use. Only a metal skin has proven effective to prevent "aging" (the loss of entrapped heavy gas), which increases the thermal conductivity by about 30% above the theoretical minimum value [67]. Depending upon the formulation, urethanes can have a higher flame-spread rating than other building materials, but they are combustible and a flame-protective barrier is usually required by building insurers and some building codes. If ignited, plastic foams release smoke and toxic gases. Densities over 100 kg/m^3 are essentially impermeable, but lighter foams, which are better insulators, require coatings to prevent water absorption, since freeze-thaw cycles of the moisture can lead to deterioration of the insulation.

Extruded polystyrene, particularly the high density products (50 kg/m^3), suffer the least from moisture absorption and freeze-thaw [68], but the outer 5 mm of unprotected buried insulation should be disregarded in thermal analyses. Molded polystyrene will absorb some moisture and should not be used in moist conditions. Polystyrene is available in board stock or beads. The former has been extensively used to reduce frost penetration. Beads are useful for filling voids in utilidors while retaining easy access to pipes (see Figure 8-1B). Although the thermal conductivity of polystyrene is higher than urethanes, the volumetric cost is usually less (Table 15-1).

Glass fiber batt insulation is the most common building insulation, primarily because it is fire-resistant and relatively inexpensive. Its insulating value is significantly reduced when wet, and is reduced by half if 8% by volume is water. For this reason, glass fiber should not be used underground but may be considered wherever dry conditions can be ensured. Cellular glass is very water-resistant but is

TABLE 15-1. COMPARISON OF INSULATION PROPERTIES OF VARIOUS MATERIALS

Material	Thermal Conductivity (1) Cal/h·m·°C	Density kg/m³	Compressive Strength at 5% Deflection kg/m² x 10⁻⁴	Effect of Moisture Content (w) on Thermal Conductivity (k)	Relative Volumetric Cost
Polyurethane					
New	0.014	30	2	Negligable	4 to 6.5
Aged	0.02	30	2	Negligable	
High Strength	0.07	65	7	Nil	
Expanded Polystyrene	0.025-0.030	15-45	2-3	Negligable	3.5
Molded Polystyrene	0.026-0.033	15-30	0.7 - 1.8	Absorption, w= 3% max.	2
Sulfur Foam	0.036	175	3.2	Absorption, w= 2% max.	
Insulating Concrete	0.09 - 0.52	300-1500	7 - 60	Non-repellent	
Glass Fiber	0.03 - 0.045	25-55		Deterioration at w= 8%, k= 0.06	1
Glass Foam	0.05	150-200	7 (Ultimate)	Nil	
Vermiculite	0.06	200		Deteriorates	
Sawdust (dry)	0.05-0.08	150-250		Deteriorates	
Fine Grained Soil					
Moisture 10% (Frozen)	0.9 (0.9)	1600		Increases	
Moisture 30% (Frozen)	1.5 (2.0)	1600			
Coarse Grained Soil					
Moisture 5% (Frozen)	1.4 (1.0)	1750		Increases	
Moisture 15% (Frozen)	1.8 (2.6)	1750			
Water	0.50	1000			
Ice	1.90	900			

(1) Cal/h·m·°C x 1.1622 = W/m·k

seldom used because it is brittle, difficult to work with, and deteriorates with freeze-thaw cycles. Lightweight insulating concrete made with polystyrene beads, pumice or expanded shale can be formulated with relatively high strength and thermal resistance. It can be poured in place around piping but should be protected from moisture to prevent freeze-thaw deterioration.

Many other insulating materials, including new products such as sulphur foam and UREA-Formaldehyde, may also find specific applications in cold regions engineering.

15.7.3 Soils

Soil thermal properties are discussed in many reports [69,70,71, 72,73,74] and in this manual they are only considered in general terms. These include the thermal conductivity, volumetric heat capacity, thermal diffusivity, latent heat and strength. These properties are necessary to determine the depth of seasonal freezing or thawing, and variation in ground temperatures due to surface temperature fluctuations. They are also important in determining heat loss from buried pipes and in foundation design. In the field, soil composition can vary drastically within short distances and profile, and may be altered by development. Thermal properties derived from limited samples and indirect measurements must be used with caution. Satisfactory estimates may often be obtained by assuming the worst soil properties or conditions.

In general, the soil thermal properties relate to the moisture content, the state (frozen or thawed), the size and shape of the mineral particles, and the temperature. When water changes to ice, its thermal conductivity increases by a factor of 4; its volumetric specific heat decreases by one-half; and it releases enough heat to change the temperature of an equal volume of rock by 150°C. Water content plays a prominent role in soil thermal considerations because of this behaviour [73]. For fine-grained soils (silts and clays), not all the soil moisture freezes at 0°C, although for practical purposes all moisture is frozen by -20°C (Figure 15-9). In this range, particularly 0°C to -5°C, thermal-related properties are in transition.

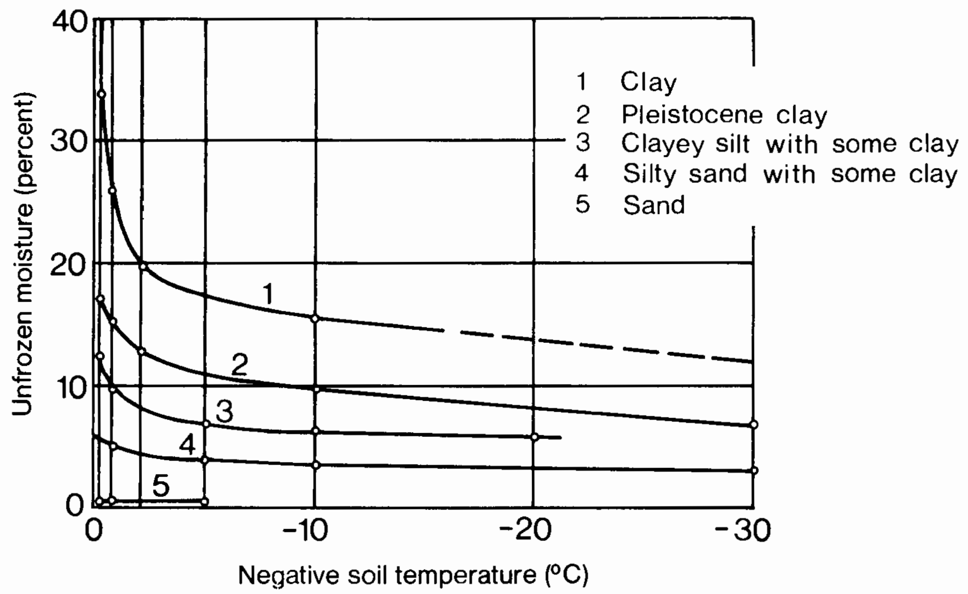


FIGURE 15-9. UNFROZEN MOISTURE CONTENT IN SOILS [72]

The specific heat capacity of a substance is the ratio of the heat capacity of a substance to the heat capacity of water and is therefore dimensionless. The volumetric heat capacity (C) is a measure of the heat required to raise the temperature of a unit volume of material by one degree. The value for soils is the aggregate of the constituents, water and mineral, and since these are relatively consistant, the soil heat capacity is determined by their proportion. The only unknown is the moisture content.

For thawed soil:

$$C_t = \gamma_s \left[C_{ms} + C_{mw} \frac{w}{100} \right] \tag{15-1}$$

and for frozen soil:

$$C_f = \gamma_s \left[C_{ms} + C_{mi} \frac{w}{100} \right] \tag{15-2}$$

where: C = volumetric heat capacity ($J/m^3{\bullet}°C$),

γ_s = dry unit weight (kg/m^3),

C_m = mass heat capacity ($J/kg{\bullet}°C$),

C_{ms} = 837 $J/kg{\bullet}°C$ for dry soil (mineral matter),

C_{mw} = 4184 $J/kg{\bullet}°C$ for water,

C_{mi} = 2092 $J/kg{\bullet}°C$ for ice.

The soil thermal conductivity (k) is a measure of the rate at which heat moves through a medium under a unit thermal gradient. A satisfactory formula is not available in terms of the aggregate of the constituents to account for thermal conductivity. Values can be determined by direct measurement, but they are more commonly approximated from tables or graphs based on the soil type and moisture content (see Appendix C). Thermal conductivity increases with soil moisture, density and on freezing. For example, undisturbed dry sand is several times better an insulator than moist compacted sand, while the thermal conductivity of silt is about half that of coarse-grained soil and several times greater than rock.

Thermal diffusivity (α) is a measure of the rate at which a temperature change spreads through a material and is:

$$\alpha = k/C \ (m^2/s) \tag{15-3}$$

$$= k/C_m{\bullet}\gamma_s$$

Temperature propagation is most rapid in materials with high thermal conductivity and low heat capacity, such as rock, dry soils or insulations. Soils of higher moisture content have decreasing thermal diffusivity; therefore, saturated soils will change temperature slower than dry soils.

The volumetric latent heat of fusion (L) is the heat which is required to thaw (or is liberated on freezing) a unit volume of soil. It depends on the moisture content of the soil and is:

$$L = \gamma_s \left(\frac{w}{100}\right) \quad (J/m^3) \qquad (15\text{-}4)$$

Where: L = volumetric latent heat of fusion of soil (J/m^3),

L_w = volumetric latent heat of fusion of water,

= 334720 J/kg.

The latent heat of soil is important in calculating the depth of freezing or thawing.

The physical properties of frozen soil depend almost entirely on the amount of ice the soil contains and the soil temperature, particularly when it is just below freezing ("plastic frozen") and unfrozen moisture is present. In terms of stability, the soil temperature is usually more important than the load. Settlement associated with the thawing of frozen soil can be estimated from the moisture content and the dry unit weight of the soil [75]. If the rate of thawing and generation of water exceeds the soil drainage capacity, excess pore pressures are generated, the bearing capacity is drastically reduced, and failure can occur [76].

Frost heaving results primarily from the siphoning or vapour movement of groundwater (moisture) to a freezing front where it forms ice lenses. Only a minor amount of the heaving is caused by the volume expansion of freezing water. The potentially damaging mechanisms are the heaving and progressive frost-jacking of objects within the freezing zone, as well as settlement and softening (loss of bearing capacity) of the soil upon thawing. The frost-susceptibility of soils is primarily a function of the size of the soil particles but a uniformly accepted criterion does not exist. Non-cohesive materials such as crushed rock, gravel and sand are non frost-susceptible. Soils with greater than 3% passing sieve size 200 (0.074 mm) should be treated as frost-susceptible unless laboratory testing proves otherwise.

15.8 Building and Structures

The functional and structural design of buildings and structures that are part of cold regions utility systems are similar to conventional requirements. Many design aspects are covered by local or national codes. Northern characteristics, such as transportation requirements or the lack of skilled tradesmen, must be considered to ensure appropriate and economic design. Building thermal design considerations differ from temperate areas only in degree, while foundations in permafrost areas require unique solutions.

15.8.1 Thermal design

The shape of buildings, tanks or other structures cannot always be adjusted, but the designer should bear in mind that compact cubes or cylinders have the lowest heat loss of all practical shapes. Windows have very high heat loss, even with double or triple thermopane, and they should only be installed where they are of significant benefit or required. The insulation thickness requirements can be determined from an economic analysis. For building walls, a minimum of 150 mm of glass fiber or equivalent insulation should be used. Air infiltration, which usually accounts for a significant portion of heating requirements, should be reduced through design and good workmanship. A double door entrance reduces air and heat loss. Humidity can be a severe problem and hazard in utility buildings particularly those with open aerated water surfaces, but these can sometimes be covered or enclosed. Vapour barriers must be meticulously installed to prevent air leakage and moisture penetration into the insulation.

Buildings are often prefabricated to some degree. Walk-in type freezers with urethane foam-insulated metal panel walls have been used for small pumphouses or truck water fill points (see Figure 6-4).

15.8.2 Foundations

Utility buildings and structures such as treatment plants and storage tanks can be very heavy and deformations must be limited because of the piping and equipment. Conventional bearing and frost heave considerations apply in non-permafrost areas. In permafrost areas, the foundation must be designed for the thermal and mechanical interaction due to construction and operation, and allowances must be made for physical and thermal changes which may occur as a result of future development or other operations. The primary concerns are: the possible settlement due to thawing of ice-rich permafrost; frost heaving; and, for heavy structures on warm permafrost, creep must also be considered. The two general methods of permafrost foundation design are: the active method, which uses the foundation in the thawing or thawed state; and the passive method, which maintains the permafrost. The applicable strategy depends upon the thermal and physical characteristics of the structure and the permafrost. In thaw-unstable soils, the most commonly used approach is to ensure preservation of the permafrost [77].

Active designs may entail: the replacement of ice-rich soils; natural or artificial thawing and compaction prior to construction (usually only in permeable, thaw-stable soils); and, allowing thawing during construction and use, provided that the estimated settlement is acceptable. These solutions are recommended when bedrock or stable soils are at shallow depths; where settlement is tolerable; in discontinuous permafrost where soils are plastic frozen (warmer than -1.5°C); or if the retention of the frozen state is not technically feasible, such as under a reservoir.

Passive designs include: putting buildings on piles to isolate them from the ground; building on top of gravel pads that may include foam insulation to reduce foundation heating or be ventilated with ducts through which cold winter air is forced or naturally flows; or the foundation can be cooled either by artificial refrigeration or the use of thermal piles.

The design of bases and foundations in permafrost is not dealt with in detail in this manual, and other references [64,70,71,72,73,74,77,78,79] and specialists with a thorough understanding of geotechnical and thermal geotechnics should be consulted.

15.9 Thermal Calculations

Unfortunatly, many of the thermal problems that are encountered in practice either do not have exact mathematical solutions or other complexities make precise solutions impossible. The second-order differential equation which describes the conduction of heat, the diffusion equation, succumbs to a limited number of closed-form solutions, and these generally relate to geometrically simple boundaries, relatively homogenous materials, and steady state conditions [80]. However, such solutions are useful since their explicit nature allows for relatively easy numerical computation and encourages quantitative insight into thermal problems.

The analytical thermal equations presented in this Section imply severe idealizations. The analyst must assess their applicability for particular problems and use the results as a guide to engineering design. The analyst is advised to consider various models and a range of values for physical and temperature conditions. More accurate results are obtained when reliable data is available. In many cases, the analyst must be content with approximate solutions and it will be necessary to assume a large safety factor and/or the worst conditions to arrive at conservative estimates.

It should be noted that boundary temperatures in the field vary continuously with both random and periodic components, and are often a result of very complex heat exchange effects. The materials encountered in practice frequently represent rather poor approximations of homogenous, isotropic media. Soil, for example, is a complex, multi-phase, heterogenous medium, the behaviour of which is further complicated by the water component, which undergoes phase transitions in the temperature regime of concern. Some of these physical and thermal complexities may be taken into account by using strictly numerical techniques to solve the appropriate differential equations [53,54,81]. Even the most sophisticated computer programs still incorporate many restrictive approximations, particularly with respect to determining the ground surface temperatures and the near-surface ground thermal regime [81]. Further, because of the associated high manpower and computing costs, such numerical methods may often only be utilized for design projects of a considerable magnitude.

Portions of this section, including time-independent, steady-state problems of heat flow in this section are adapted from Thornton [82]. As well, equations to calculate ground temperatures and depth of freezing and thawing are included. The symbols used are defined in Table 15-2, and the thermal conductivity of some common materials are presented in Table 15-3. Solutions to a number of utility system problems are presented to illustrate the computational procedures and typical results.

15.9.1 Steady-state pipeline solutions

Figure 15-10 deals with heat flow from: a bare pipe; an insulated pipe; a single pipe in an insulated box; and, a utilidor carrying multiple pipes. In each case, some of the major approximations, in addition to the implied time-independent steady-state assumptions, are indicated. Some comments intended to facilitate application of the formulae are also included. Where applicable, expressions are presented for relevant thermal resistance, rates of heat flow and insulation thicknesses.

Figure 15-11 gives similar information for uninsulated and insulated buried pipes. In each of these two cases, the presence of thawed ground around the pipe is considered, and formulae are included which indicate the dimensions of the resulting thaw cylinder.

Figure 15-12 contains expressions for the thermal resistance of various shapes and bodies from which heat loss can be calculated. Formulae are given in Figure 15-13 for estimating the temperature drop (or gain) along a pipeline system, and simple expressions relating to freeze-up times under no-flow conditions are included.

To ease the process of computation, numerical values for certain variables in some of the calculations may be read directly from Figures 15-14, 15-15 and 15-16. These curves summarize information pertaining to the thermal resistance of a hollow cylinder (insulation shell or pipe), the thermal resistance of a soil mass covering a pipe, and the physical dimensions of a thaw cylinder around a pipe buried in permafrost.

Steady-state thermal influences in isotropic, homogenous soils can be summed and geometric modifications and approximations can be made

TABLE 15-2. LIST OF SYMBOLS

List of Symbols	List of Subscripts
A = Amplitude	A - refers to Air
A = Thaw factor = T' arccosh H_p/r_p	C - refers to Conduit
B = $\sqrt{\pi C_f/k \cdot p}$	E - refers to Exterior casing (of utilidor)
c = $\sqrt{H^2 - r^2}$, m (ft)	f - refers to Frozen soil
C_m = Mass heat capacity, J/kg· (BTU/lb·°F)	g - refers to Ground freezing index
C = Volumetric heat capacity, J/m^3·K (BTU/ft^3·°F)	G - refers to Ground
d & t = Thickness, M (ft)	h - refers to Heating index
D = Scaling parameter, m (ft)	I - refers to Insulation
E = Young's modulus, kg/m^2 (lb/ft^2)	j - denotes 1,2,3,....
F = arccosh (H/r)	L - refers to Thermal lining (of utilidor)
h = Thermal film coefficient (or surface conductance), W/m^2·K (BTU/h·ft^2·°F)	m - refers to Mean
H = Depth of bury, m (ft)	0 - refers to (Zero) Freezing point of water
I = Freezing or thawing index, °K·s (°F·h)	P - refers to Pipe
k = Thermal conductivity, W/m·K (BTU/h·ft·°F)	S - refers to Soil
ℓ = Length, m (ft)	t - refers to Thawed soil
L = Volumetric latent heat, J/m^3 (BTU/ft^3)	U - refers to Utilidor
p = Period, S(h)	W - refers to Water (fluid) within a pipe
P = Perimeter (mean), m (ft)	x - refers to Depth
q = Fluid flow rate, m^3/s (ft^3/s)	Z - refers to Zone of thaw
Q = Rate of heat loss per unit longitudinal length, W/m (BTU/ft·h)	
r = Radius, m (ft)	
R = Thermal resistance of unit logitudinal length, K·m/K (h·ft·°F/BTU)	
t = Time, s(h)	
T = Temperature, K (°F)	
$T^* = (T_I - T_G)/(T_0 - T_G)$	
u = Coefficient of thermal expansion, m/m·K - m/m·K (ft/ft·°F)	
w = Moisture content by dry weight, %	
V = Velocity, m/s (ft/h)	
x = Depth	
X = Depth to freezing (0°C) plane, m (ft)	
α = Thermal diffusivity, m^2/s (ft^2/h)	
γ = Unit weight (density), kg/m^3 (lb/ft^3)	
a, μ, λ = Coefficients in modified Berggren equation	

TABLE 15-3. THERMAL CONDUCTIVITIES OF COMMON MATERIALS [1]

Material	Unit Weight (dry) kg/m^3	Specific Heat Capacity	Thermal Conductivity cal/ cm·s·°C	Cal/ m·h·°C	W/m·K	BTU/ ft·h·°F
Air, no convection (0°C)		0.24	0.057	0.020	0.024	0.014
Air film, outside, 24 km.h wind (per air film)			2.10	0.75	0.86	0.50
Air film, inside (per air film)			0.58	0.20	0.24	0.14
Polyurethane foam	32	0.4	0.058	0.021	0.024	0.014
Polystyrene foam	30	0.3	0.086	0.031	0.036	0.020
Rock wool, glass wool	55	0.2	0.095	0.034	0.040	0.023
Snow, new, loose	85	0.5	0.20	0.07	0.08	0.05
Snow, on ground	300	0.5	0.54	0.20	0.23	0.13
Snow, drifted and compacted	500	0.5	1.7	0.6	0.7	0.4
Ice at -40°C	900	0.5	6.36	2.29	2.66	1.54
Ice at 0°C	900	0.5	5.28	1.90	2.21	1.28
Water (0°C)	1000	1.0	1.40	0.50	0.58	0.34
Peat, dry	250	0.5	0.17	0.06	0.07	0.04
Peat, thawed, 80% moisture	250	0.32	0.33	0.12	0.14	0.08
Peat, frozen, 80% ice	250	0.22	0.42	0.15	1.73	1.0
Peat, pressed, moist	1140	0.4	1.8	0.60	0.70	0.40
Clay, dry	1700	0.22	2.2	0.8	0.9	0.5
Clay, thawed, saturated (20%)	1700	0.42	3.9	1.4	1.6	1.0
Clay, frozen, saturated (20%)	1700	0.32	5.0	1.8	2.1	1.2
Sand, dry	2000	0.19	2.8	1.0	1.1	0.06
Sand, thawed, saturated (10%)	2000	0.29	7.8	2.8	3.2	1.9
Sand, frozen, saturated (10%)	2000	0.24	9.7	3.5	4.1	2.4
Rock typical	2500	0.20	5.2	1.9	2.2	1.3
Wood, plywood, dry	600	0.65	0.42	0.15	0.17	0.10
Wood, fir or pine, dry	500	0.6	0.28	0.10	0.12	0.07
Wood, maple or oad, dry	700	0.5	0.42	0.15	0.17	0.10
Insulating concrete (varies)	200 to 1500		0.17 to 0.40	0.16 to 0.50	0.07 to 0.60	0.04 to 0.35
Concrete	2500	0.16	4.2	1.5	1.7	1.0
Asphalt	2000		1.72	0.62	0.72	0.42
Polyethelene, high density	950	0.54	0.86	0.31	0.36	0.21
PVC	1400	0.25	0.44	0.16	0.19	0.11
Asbestos cement	1900		1.56	0.56	0.65	0.38
Wood stave (varies)			0.62	0.22	0.26	0.15
Steel	7500	0.12	103	37	43	25
Ductile iron	7500		125	45	50	30
Aluminium	2700	0.21	490	175	200	115
Copper	8800	0.1	900	325	375	220

(1) Values are representative of materials but most materials have a variation in thermal properties.

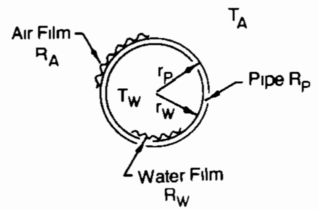
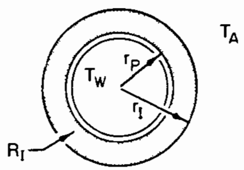
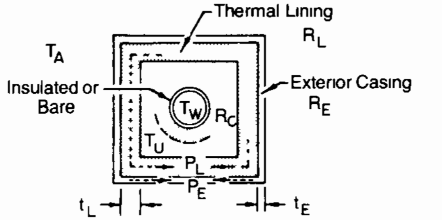
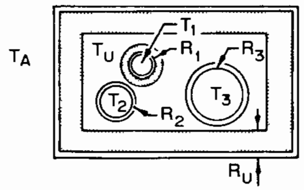
	(a) Bare Pipe	(b) Insulated Pipe	(c) Single Pipe in a Box	(d) Multiple Pipe Utilidor
Sketch				
Assumptions	Thin walled pipe (i.e. $r_P \le 2 r_W$) R_W is negligible $R_P \le R_A$	All thermal resistances but that of the insulation are neglected.	Convection ensures the temperature inside the utilidor, T_U, is uniform. Utilidor air films neglected.	Same as (c).
Thermal Resistance	$R_P = (r_P - r_W)/(r_P + r_W)\ \pi k_P$ $h_A = N\left(\frac{T_W - T_A}{r_P}\right)^{0.25} W$ $R_A = 1/2\pi r_P h_A$ $R_C = R_P + R_A$ $N = 0.23\ \mathrm{Btu/h\cdot ft^{\frac{7}{4}}\cdot °F^{\frac{5}{4}}}$ $W = \sqrt{12.5V + 1}$ for V = miles/h $N = 1.12\ \mathrm{J/s\cdot m^{\frac{7}{4}}\cdot °C^{\frac{5}{4}}}$ $W = \sqrt{0.56V + 1}$ for V = m/s	$R_C = R_I = \frac{\ln(r_I/r_P)}{2\pi k_I}$ $\approx \left(\frac{r_I - r_P}{r_I + r_P}\right)/\pi k_I$ if $r_I \le 2r_P$ Or given r_I/r_P and k_I, read off R_I from graph	Calculate R_C, the thermal resistance of the interior conduit by: using (b) if insulated or using (a) if bare and replacing T_A in the formula for h_A by **an estimate** for T_U ($\le T_W$) $R_L = t_L/P_L k_L$ $R_E = t_E/P_E k_E$ $R_U = R_L + R_E$ $R = R_C + R_U$ $T_U = \frac{(T_W/R_C) + (T_A/R_U)}{(1/R_C) + (1/R_U)}$ If bare pipe, iterate T_U	Calculate R for each pipe as in (c) to get R_J, (J = 1, 2, 3, ...) Calculate R_U as in (c) $T_U = \frac{\sum_J (T_J/R_J) + (T_A/R_U)}{\sum_J (1/R_J) + (1/R_U)}$ If bare pipes present, iterate T_U
Rate of Heat Loss	$Q = (T_W - T_A)/R_C$	$Q = (T_W - T_A)/R_I$	$Q = (T_W - T_A)/R$	$Q_J = (T_J - T_U)/R_J$ (per pipe) $Q = \sum_J Q_J = (T_U - T_A)/R_U$
Insulation Thickness (given Q)	N/A	$r_I - r_P = r_P\{\exp[2\pi k_I(T_W - T_A)/Q] - 1\}$ $= \pi k_I(T_W - T_A)Q$ if $r_I \le 2r_P$ Or given R_I and k_I, read off r_I/r_P from graph	Obtain R_E and R_C as above $t_U = P_L k_L\left[\frac{(T_W - T_A)}{Q} - R_E - R_C\right]$ If bare interior pipe, iterate T_U, R_C and hence t_L	Given acceptable Q_J, calculate R_J as above and evaluate $T_U = T_J - R_J Q_J$ **for each pipe for which Q_J is known.** Using the **maximum** T_U found, calculate new Q_J as above Using these Q_J and the same T_U, evaluate $t_L = P_L k_L\left[\frac{T_U - T_A}{\Sigma Q_J} - R_E\right]$ If bare pipes present, iterate T_U, R_J and hence t_L
Comments	Often, for metal pipes, R_P may be neglected. If R_P is significant, the expression above for h_A will generate an overestimate of Q. If $T_A > T_W$ switch T_A and T_W in the expression for h_A.	The neglected thermal resistances given in (a) may be included if desired. Estimate a value for the insulation surface temperature and calculate h_A and R_A. Interate	The value of h_A, and hence R_A, is fairly insensitive to the choice of T_U, and so one iteration on T_U is usually sufficient. Often R_E may be neglected. Similar calculational procedure may be performed for pipes and utilidors of different cross-section.	as (c) If it is clear that one pipe dominates the heat loss process, (c) may be used to estimate T_U. It is wise to consider the heat loss from the various pipes if certain other pipes cease to function.

FIGURE 15-10. STEADY-STATE THERMAL EQUATIONS FOR ABOVE-SURFACE PIPES [adapted from 82]

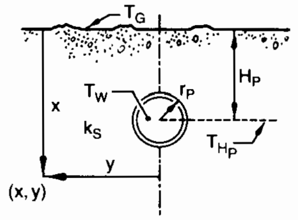
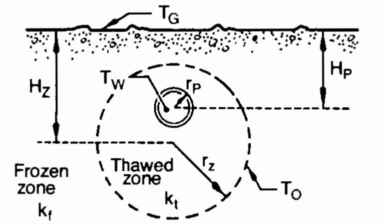
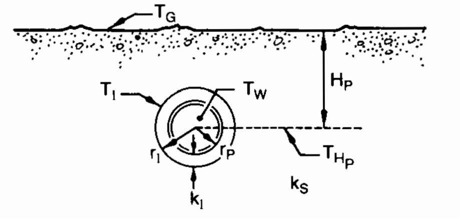
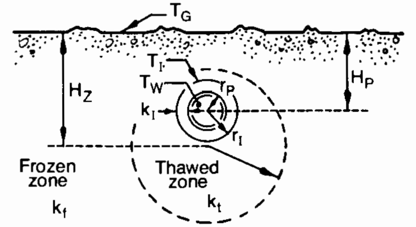
	(a) Bare, No Thaw	(b) Bare, With Thaw Zone	(c) Insulated, No Thaw	(d) Insulated, With Thaw Zone
Sketch				
Assumptions	Neglect all thermal resistances except that of the soil.	Same as (a), but accounting for the different conductivities of thawed and frozen soil	Neglecting all thermal resistances except those of the soil and insulation Outer surface of insulation assumed to be isothermal. $r_I - r_P \ll H_P$	Same as (c) but accounting for the different thermal conductivities of thawed and frozen soil.
Thermal Resistance and Thaw Zone Parameters	$R_S = \frac{\text{arccosh}(H_P/r_P)}{2\pi k_S}$ $= \frac{\ln\left[(H_P/r_P) + \sqrt{(H_P/r_P)^2 - 1}\right]}{2\pi k_S}$ $\simeq \frac{\ln(2H_P/r_P)}{2\pi k_S}$ if $H_P \geq 2r_P$ Or: Given H_P/r_P and k_S; Read off R_S from Figure 15 15	$T'_W = \frac{k_t}{k_f}(T_W - T_O) + T_O$ $T' = \frac{T_O - T_G}{T'_W - T_G}$ $c = \sqrt{H_P^2 - r_P^2} \simeq H_P$ if $H_P/r_P \geq 7$ $A = T'\ \text{arccosh}(H_P/r_P)$ $\simeq T'\ \ln(2H_P/r_P)$ if $H_P \geq 2r_P$ Or Given H_P/r_P, Read off arccosh (H_P/r_P) from Figure 15.15 $H_Z = c\ \coth A$ $\quad r_Z = c\ \text{csch}\ A$ Or, Given A; Read off H_Z/c and r_Z/c from Figure 15.16 (if $A < 0.2$, use $H_Z/c \simeq r_Z/c \simeq 1/A$) R_t, R_f and R_S $(= R_t + R_f)$ as given in (d), but with r_I replaced by r_P.	R_I as given in Figure 15.10 (b) R_S as given in (a), but with r_P replaced by r_I $T_I = T_W - \frac{R_I(T_W - T_G)}{R_S + R_I}$ For known T_W, T_G, and R_S, the minimum insulation thickness to prevent thaw (ie. $T_I = T_O$) is given by: $R'_I = \frac{T_W - T_O}{T_O - T_G} R_S$	R_I as given in Figure 15.10 (b) T'_W, T', c, H_Z, r_Z and R'_S as in (b) but with r_P replaced by r_I and using: $A = T'\ [\text{arccosh}(H_P/r_P) + 2\pi k_t R_I]$ $T_I = T_W - \frac{R_I(T'_W - T_G)}{R'_S + (k_t/k_f)R_I}$ Also: $R_t = [\text{arccosh}(H_P/r_I) - \text{arccosh}(H_Z/r_Z)] / 2\pi k_t$ $\simeq [\ln(H_P \cdot r_Z/r_I \cdot H_Z)] / 2\pi k_t$ if $H_Z \geq 2r_Z$ $R_f = [\text{arccosh}(H_Z/r_Z)] / 2\pi k_f$ $\simeq [\ln(2H_Z/r_Z)] / 2\pi k_f$ if $H_Z \geq 2r_Z$ Or. Given H_P/r_I and H_Z/r_Z; Read off arccosh (H_P/r_I) and arccosh (H_Z/r_Z) from Figure 15.15. $R_S = R_f + R_t$
Rate of Heat Loss	$Q = \frac{T_W - T_G}{R_S}$	$Q = \frac{T'_W - T_G}{R'_S}$ where $R'_S = \frac{\text{arccosh}(H_P/r_P)}{2\pi k_f}$ Or: To evaluate R'_S, use Figure 15.15	$Q = \frac{T_W - T_G}{R_I + R_S}$	$Q = \frac{T'_W - T_G}{R'_S + (k_t/k_f)R_I}$
Insulation Thickness	N/A	N/A	For no thawing outside the insulation the minimum insulation thickness is given by: $r_I - r_P[\exp(2\pi k_I R'_I) - 1]$ Or: Given R_I and k_I; Read off r_I/r_P from Figure 15.14	Given H_Z or r_Z calculate H_Z/c or r_Z/c and use Figure 15.16 to evaluate A. Then use Figure 15.15 for arccosh (H_P/r_I) $R_I = [(A/T') + \text{arccosh}(H_P/r_I)] / 2\pi k_t$ $r_I - r_P$ as in (c) but with R'_I replaced by R_I from above.
Comments	For calculations of heat loss when there is a temperature gradient in the soil and $H_P > 2r_P$, T_G may be replaced by T_{H_P}, the undisturbed ground temperature at the pipe axis depth. For an upper limit on heat loss use $k_S = k_f$, otherwise use $k_S = (k_f + k_t)/2$.	The thawed zone is a circle in cross-section	May be used to approximate (d) if $k_t \simeq k_f$ and/or $r_Z \simeq r_I$, and thaw zone parameters are not required. Use $k_S = k_f$ or $k_S = (k_f + k_t)/2$ as in (a).	Often the above expressions for R_t, R_f and R_S are not required

FIGURE 15-11. STEADY STATE THERMAL EQUATIONS FOR BELOW SURFACE PIPES [adapted from 82]

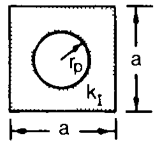
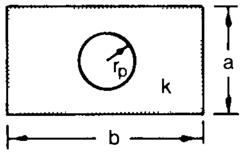
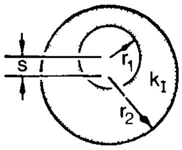
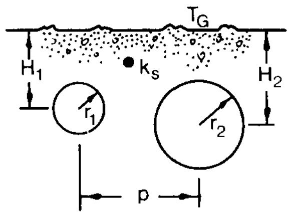
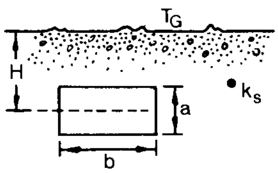
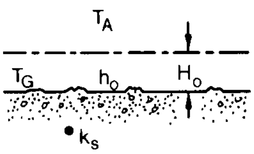
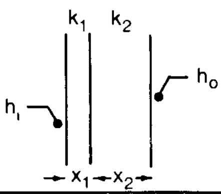
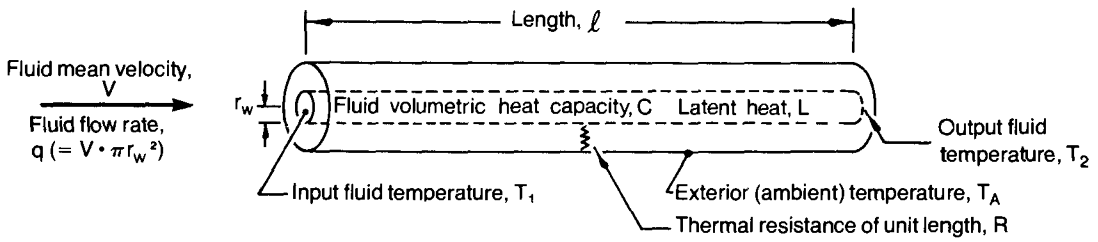
Condition	Sketch	Thermal resistance
Square insulation		$R = \frac{1}{2\pi k_I} \ln 1.08 \frac{a}{2r_p}$
Rectangular insulation		$R = \frac{1}{2\pi k} \ln\left(\frac{4a}{\pi r} - 2S\right)$ b/a S: 1.00 0.08290; 1.25 0.03963; 1.50 0.01781; 1.75 0.00816; 2.00 0.00373; 2.25 0.00170; 2.50 0.00078; 3.00 0.00016; 4.00 6.97×10^{-6}; 5.00 3.01×10^{-7}; ⋮ ⋮; ∞ 0
Eccentric cylindrical insulation		$R = \frac{1}{2\pi k_I} \ln \frac{\sqrt{(r_2+r_1)^2 - s^2} + \sqrt{(r_2-r_1)^2 - s^2}}{\sqrt{(r_2+r_1)^2 - s^2} - \sqrt{(r_2-r_1)^2 - s^2}}$ $= \frac{1}{2\pi k_I} \operatorname{arccosh} \frac{r_1^2 + r_2^2 - s^2}{2r_1 \cdot r^2}$
Two buried pipes		Where $H_1 \geq 3r_1$, $H_2 \geq 3r_2$ and $p \geq 3(r_1 + r_2)$ $R_{1-2} = \frac{1}{2\pi k_s} \cdot \frac{\ln \frac{2H_1}{r_1} \cdot \ln \frac{2H_2}{r_2} - \left[\ln\sqrt{\frac{(h_1+h_2)^2 + p^2}{(h_1-h_2)^2 + p^2}}\right]^2}{\ln\sqrt{\frac{(h_1+h_2)^2 + p^2}{(h_1-h_2)^2 + p^2}}}$ $R_{1-T_G} = \frac{1}{2\pi k_s} \cdot \frac{\ln \frac{2H_1}{r_1} \cdot \ln \frac{2H_2}{r_2} - \left[\ln\sqrt{\frac{(h_1+h_2)^2 + p^2}{(h_1-h_2)^2 + p^2}}\right]^2}{\ln \frac{2H_2}{r_1} = \ln\sqrt{\frac{(h_1+h_2)^2 + p^2}{(h_1-h_2)^2 + p^2}}}$
Buried rectangular duct		$R = \frac{1}{k_s\left(5.7 + \frac{b}{2a}\right)} \ln \frac{3.5H}{b^{0.25} \cdot a^{0.75}}$
Surface thermal resistance		Surface thermal resistance between ground and air can be approximated as the equivalent thickness of the underlying soil equal to $H_o = \frac{k_S}{h_o}$
Composite wall		$R = \frac{1}{h_i} + \frac{1}{h_o} + \frac{x_1}{k_1} + \frac{x_2}{k_2}$

FIGURE 15-12. STEADY-STATE THERMAL RESISTANCE OF VARIOUS SHAPES AND BODIES [81]

Heat Loss and Temperature Drop in a Fluid Flowing Through a Pipe | Freeze-Up Time For a Full Pipe Under No-Flow Conditions (V = o)



Comments: The above sketch is schematic. R and T_A appearing in these equations can be replaced by the thermal resistance and corresponding exterior temperature for any shape or configuration.

$D = \pi r_w^2\ V \cdot C \cdot R$

Calculate T_1 or T_2, Given R, T_1 or T_2, T_A

$T_1 = T_A + (T_2 - T_A) /\ \exp(-\ell/D)$

$\approx T_A + (T_2 - T_A) / (1 + \ell/D) \quad \text{if } \ell/D \lessapprox 0.1$

$T_2 = T_A + (T_1 - T_A)\ \exp(-\ell/D)$

Calculate R, Given T_1, T_2, T_A

$R = \ell / \pi r_w^2 \cdot V \cdot C \cdot \ln[(T_2 - T_A) / (T_1 - T_A)]$

$\approx \ell (T_1 - T_A) / \pi r_w^2 \cdot V \cdot C\ (T_1 - T_2) \text{ if } \ell/D \lessapprox 0.1$

Calculate V, Given T_1, T_2, T_A, R

$V = \ell / \pi r_w^2 \cdot R \cdot C \cdot \ln[(T_2 - T_1) / (T_1 - T_A)]$

$\approx \ell (T_1 - T_A) / \pi r_w^2 \cdot V \cdot C (T_1 - T_2) \quad \text{if } \ell/D \lessapprox 0.1$

Calculate Heat Loss (Q), Given T_1 or T_2, T_A, V, R

$Q = (D/R)(T_1 - T_A)[1 - \exp(-\ell/D)]$

$\approx (\ell/R)(T_1 - T_A) \quad \text{for } \ell/D \lessapprox 0.1$

$= D/R\ (T_2 - T_A)\ [\exp(\ell/D) - 1]$

Calculate Friction Heating, Given V, f

$Q_f = F \cdot r_w^2 \cdot V \cdot f$

Where: Q_f = BTU / h • ft
F = 0.2515 BTU / ft⁴
r = ft
V = ft / h
f = friction head loss, ft / ft length
Not significant for $V \lessapprox 2.3 \times 10^4$ ft / h

or Q_f = J / s • m
F = 3.074×10^4 J / m⁴
r = m
V = m / s
f = friction head loss, m / m length
Not significant for $V \lessapprox 2$ m / s

Freeze-Up Times; Given R, T_1, T_A

Assume that thermal resistance of the ice, as it forms, and the heat capacity of the pipe and insulation are negligible.

Design Time (Recommended)

t_D = Time for the fluid temperature to drop to the freezing point.

$= \pi \cdot r_w^2 \cdot R \cdot C \cdot \ln[(T_1 - T_A) / (T_O - T_A)]$

$\approx \pi \cdot r_w^2 \cdot R \cdot C\ [(T_1 - T_O) / (T_1 - T_A)]$

for $[(T_1 - T_O) / (T_1 - T_A)] \leqslant 0.1$
or $T_1 \lessapprox 0.11\ T_A$ (in °C)

Safety Factor Time

t_{SF} = Time for the fluid to drop to the nucleation temperature. Same as t_D but with T_O replaced by −3°C.

Complete Freezing Time

t_F = Time for the fluid at freezing point, 0°C, to completely freeze solid.

$= \pi \cdot r_w^2 \cdot R \cdot L \cdot / (T_O - T_A)$

Calculate R, Given a No-Flow Time

Design Choice

$R_D = \text{time} / \pi \cdot r_w^2 \cdot C \cdot \ln[(T_1 - T_A) / (T_O - T_A)]$

Minimum Resistance

R_{SF} = same as R_D but with T_O replaced by −3°C.

FIGURE 15-13. TEMPERATURE DROP AND FREEZE-UP TIME IN PIPES [adapted from 82]

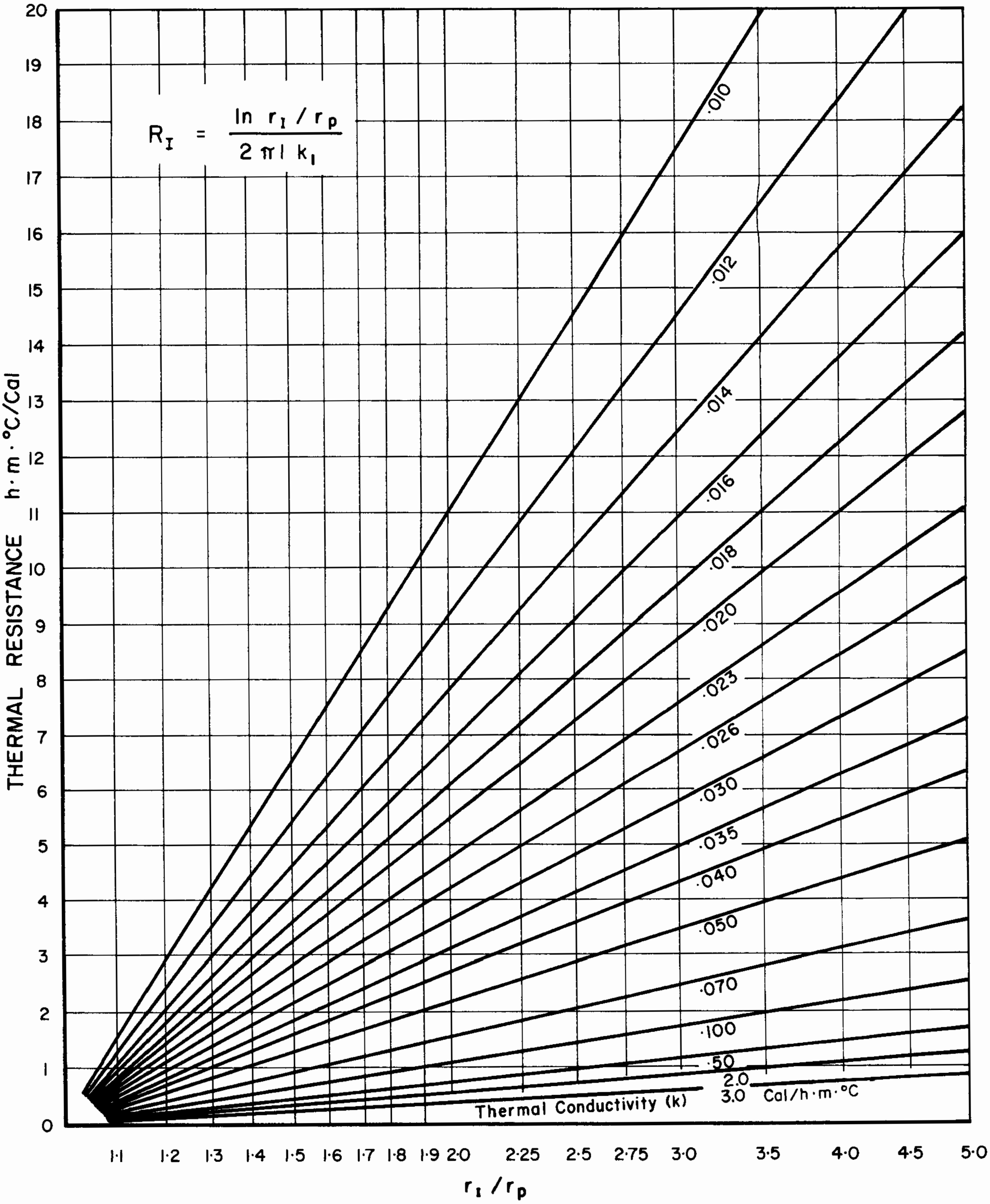


FIGURE 15-14. THERMAL RESISTANCE OF A HOLLOW CYLINDER

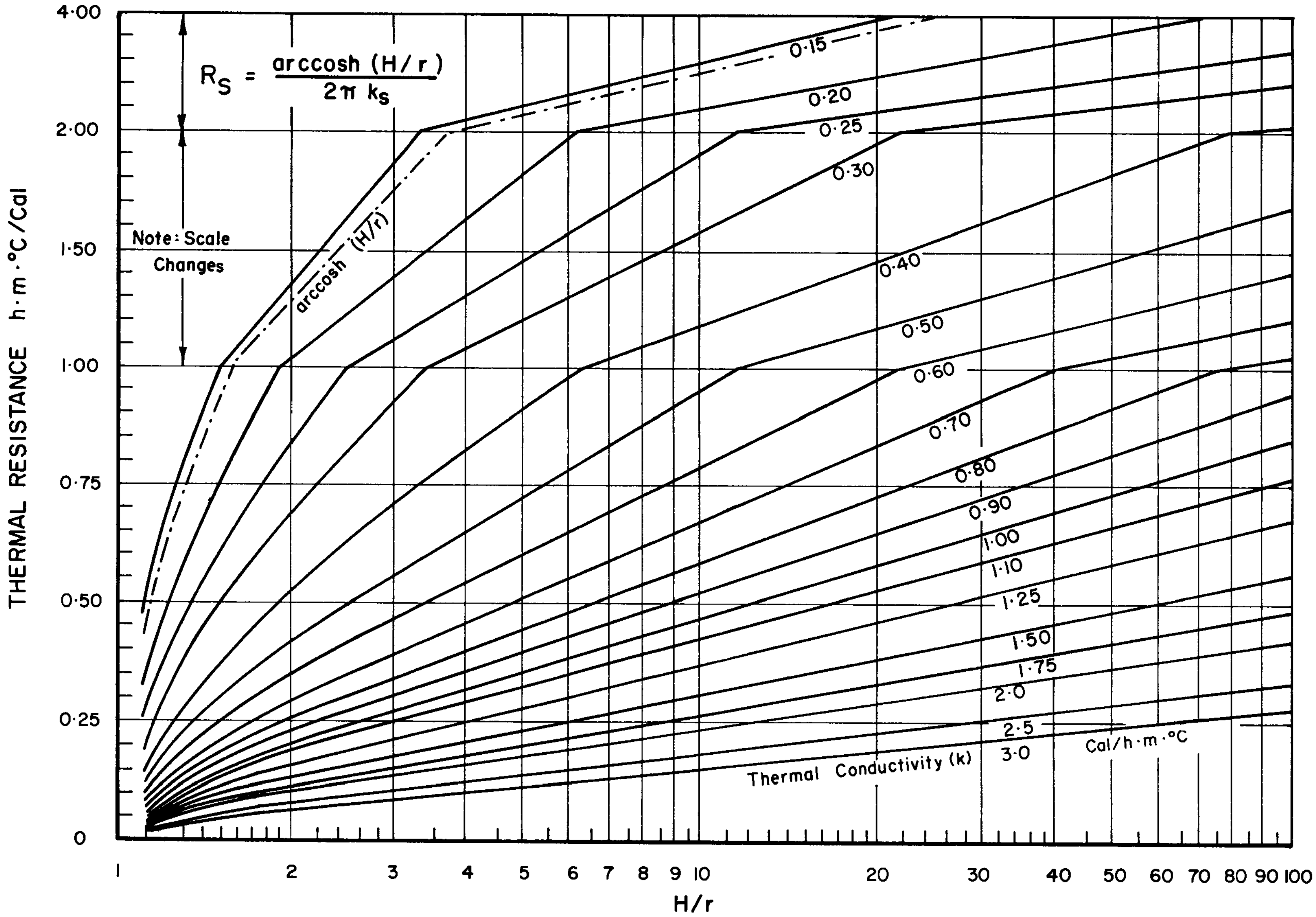


FIGURE 15-15. THERMAL RESISTANCE OF A SOIL MASS COVERING A PIPE [82]

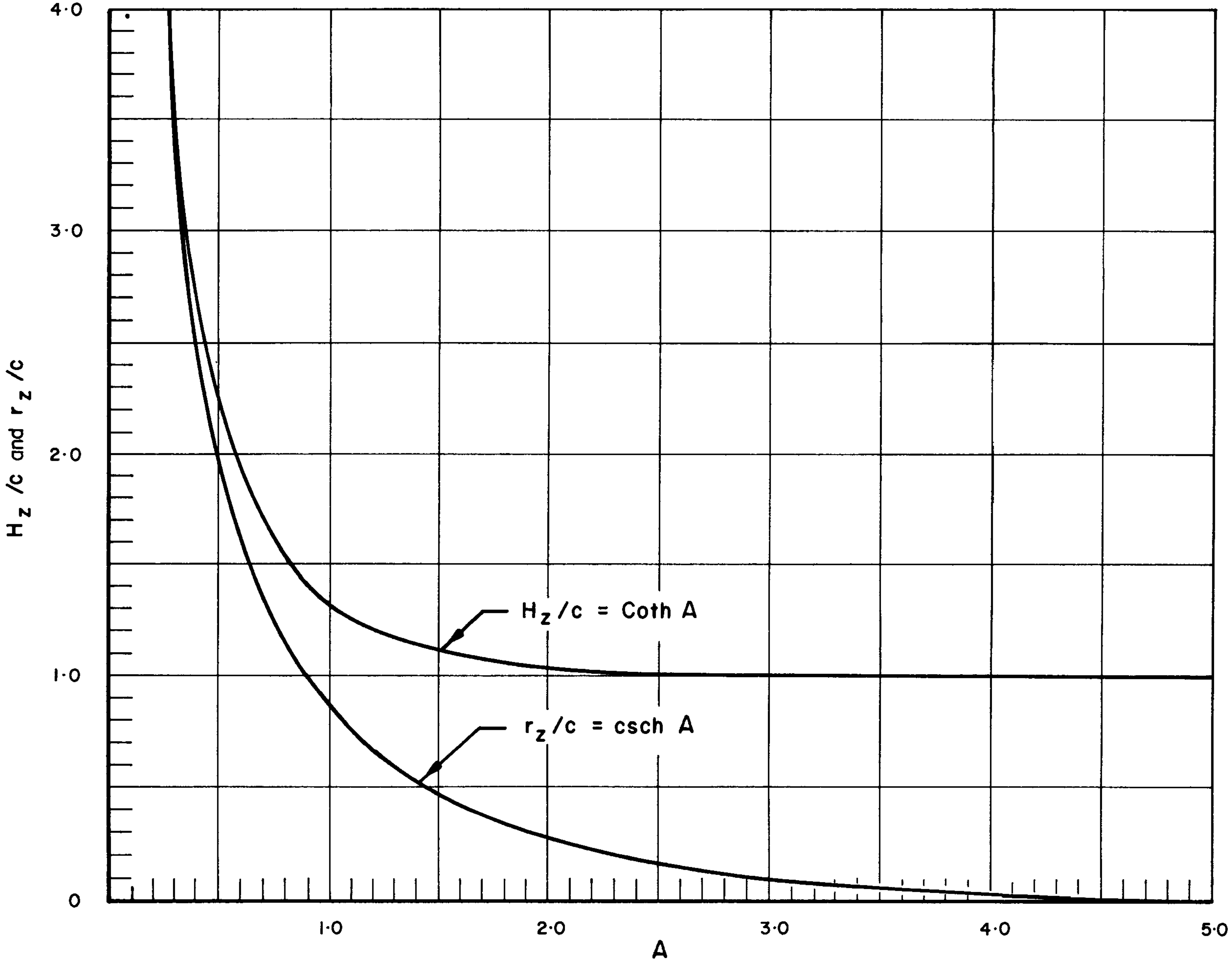


FIGURE 15-16. DIMENSIONS OF A THAW CYLINDER AROUND A PIPE BURIED IN PERMAFROST [82]

to these basic equations. For example, a layered soil can be represented by an "effective" soil thickness with the same total thermal resistance. as the layered soil.

When pipes are buried below the influence of short-term air temperature fluctuations, the ground temperatures around the pipeline resemble a slowly changing series of steady-state conditions [58]. This is ilustrated in Figure 15-17. The heat loss from deeply buried pipes can be calculated from steady-state equations for a cylinder of material around a pipe if the fluid temperature and the soil temperature at a known distance from the pipe are measured, and the soil and insulation thermal conductivities are known [84,85,86]. Heat loss from deep pipes can also be conveniently estimated by replacing the ground surface temperature in the steady-state equations with the undisturbed ground temperature at the pipe depth [24] (see Example 15.3).

Heat loss from a buried pipe over a time period can be calculated from the Heating Index during that period (see Example 15.3). This is the sum of the degree seconds (k•s) between the pipe fluid temperature and the ambient temperature. Thus:

$$\text{Heat Loss} = \frac{\text{Heating Index}}{\text{Thermal Resistance}} \quad \text{(J)} \qquad (15\text{-}5)$$

$$= \frac{\sum(\text{Pipe Temperature - Ambient Temperature})}{\text{Thermal Resistance}} \qquad (15\text{-}6)$$

15.9.2 Subsurface temperatures

Ground temperatures are determined by: the air (or ground surface) temperatures and their variations; the thermal influence of nearby water bodies, buried pipelines or other structures; heat flow from the interior of the earth; and the soil thermal properties. There are a multitude of mathematical solutions to geothermal problems which incorporate various simplifications but are useful and accurate enough for many foundation problems. Many of these solutions are of a specialized nature and application, and are not presented in this manual.

Steady-state ground temperatures beneath a building or water body can be calculated from equations [87], geometric [88], or graphical solutions [89]. The effect of a sudden change in the ground surface

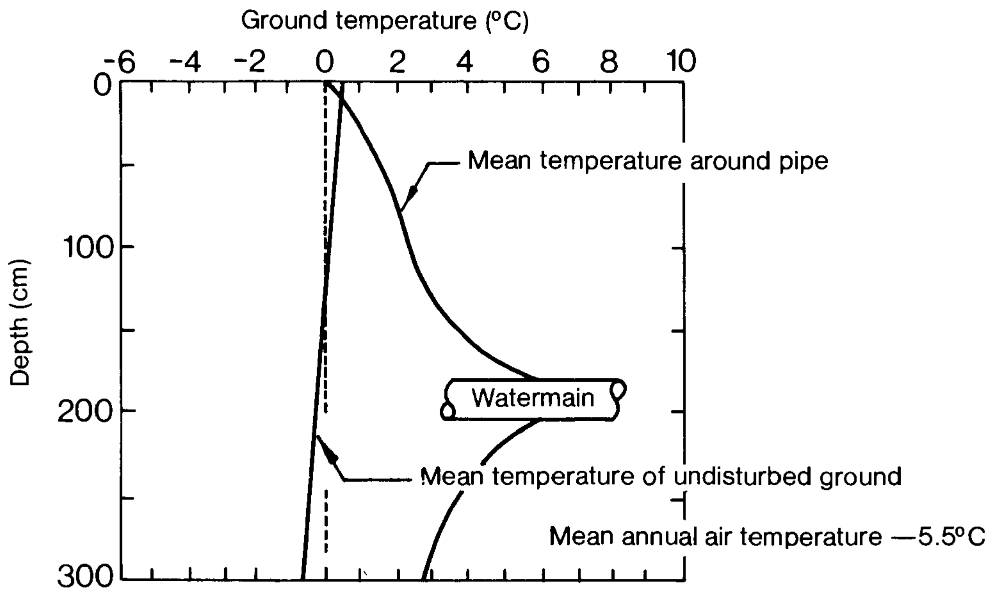
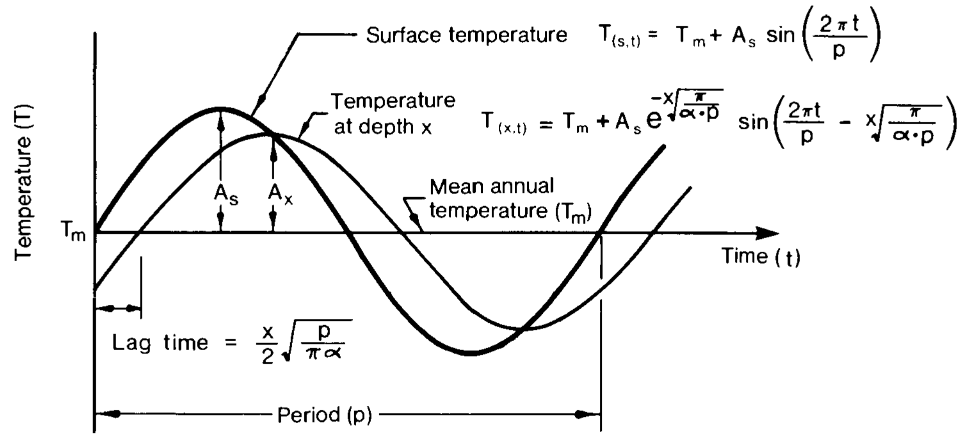


FIGURE 15-17. GROUND TEMPERATURES AROUND BURIED WATER PIPE AT YELLOWKNIFE, NWT, CANADA [66]

temperature can be simply calculated when the influence of latent heat is not involved or assumed negligible [70,80]. A similar graphical solution is available for the temperature field surrounding a cylinder (pipe) which undergoes a sudden change in temperature [90].

Air or ground temperatures can often be reasonably estimated as a sinusoidal temperature fluctuation which repeats itself daily and annually. This temperature pattern is attenuated with depth and, in a homogeneous material (soil) with no change of state, the temperature at any depth and time can be calculated from the equations in Figure 15-18. This simple solution indicates the trends found in actual ground temperatures but, in practice, they can be significantly modified by the effects of latent heat, differences in frozen and thawed soil thermal thermal properties (conductivity and diffusivity), non-homogenous materials, and non-symmetrical surface temperatures because of seasonal snow cover, vegetation, and other local climatic influences. No analytical closed-form solution which considers these effects exists, but numerical computer solutions which can take some of these factors into account are readily available (for example [52,53,54,81]).

15.9.2.1 Temperature and thawing around a buried pipe. Steady-state temperatures around a pipe (real or equivalent) can be easily determined from equations, but there is no analytical solution for a sinusoidal



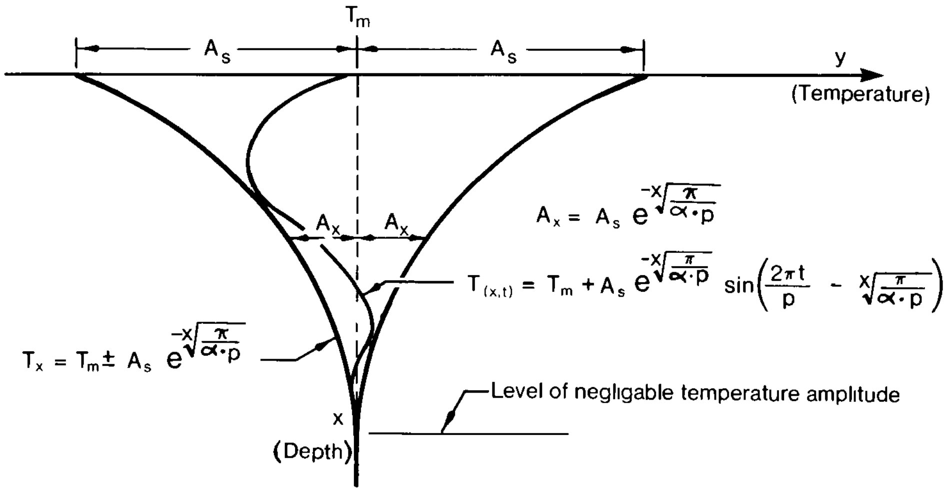


FIGURE 15-18. SINUSOIDAL AIR AND GROUND TEMPERATURE FLUCTUATIONS

surface temperature, particularly when latent heat is considered. In permafrost soils, the maximum thermal influence of the pipe can be estimated by simply adding the steady-state pipe temperatures to the maximum ground temperatures expected in the permafrost when no pipe is present. The solution can be further simplified if only the temperatures below the pipe (i.e., Y = 0), or only the maximum thaw are required. These solutions are presented in Figure 15-19. For the given conditions, these formulae will overestimate thawing, but possible transient thermal effects of the actual installation, and other factors such as subsurface water flow along the trench, are not considered.

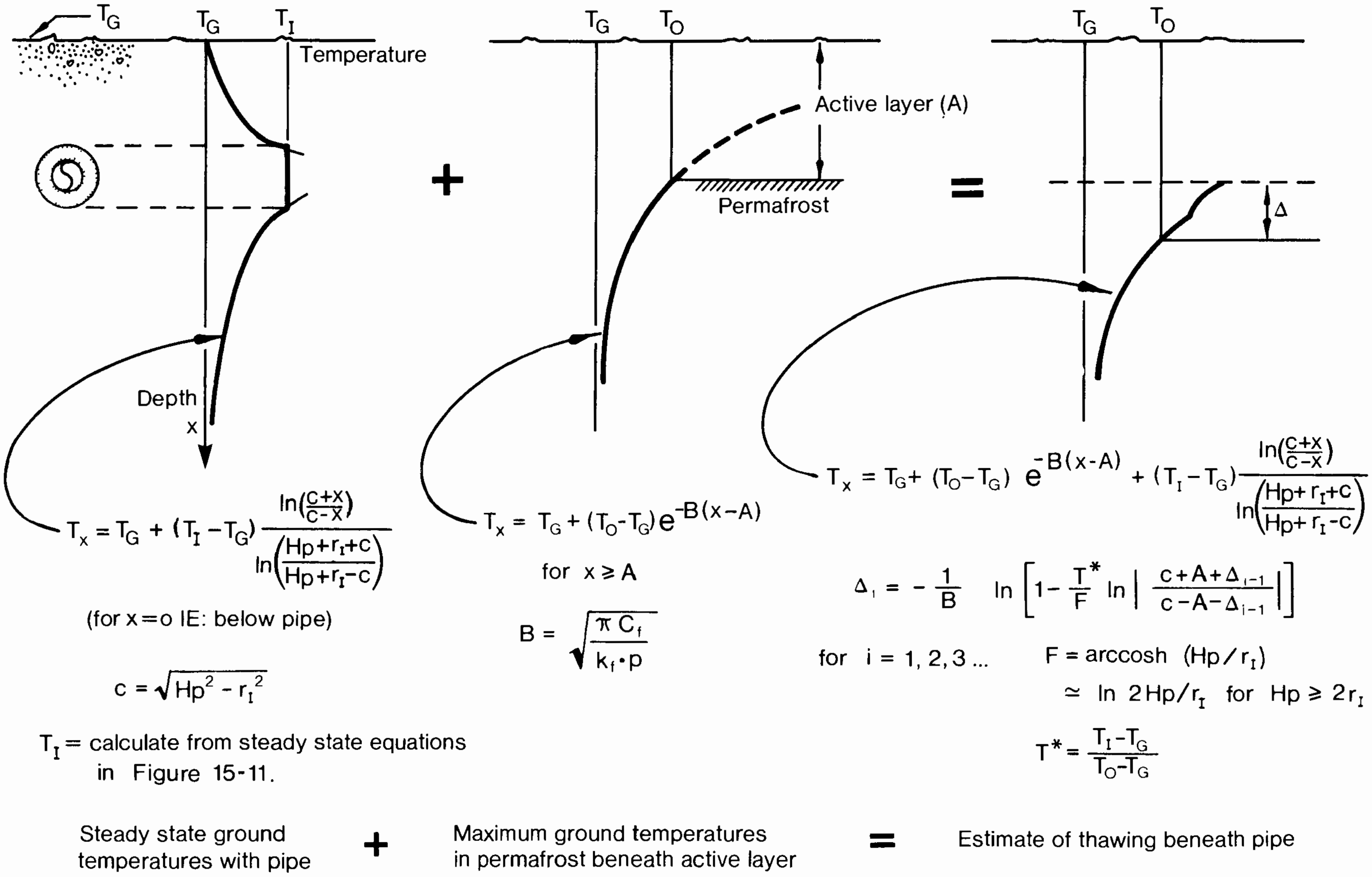


FIGURE 15-19. GROUND TEMPERATURES AND THAWING AROUND BURIED PIPES IN PERMAFROST

15.9.2.2 Depth of freezing or thawing. The depth of freezing or thawing of soil or the ice thickness on water bodies is best obtained by field measurements, but they can be estimated using one of the many analytical solutions in the literature [71,80,90,91,92,93]. Because of the assumptions necessary in these analytical solutions, such as a step change in surface temperature and/or neglecting the soil temperature changes, they generally overestimate the maximum freezing isotherm depths for the given conditions and are, therefore, useful in engineering computations. They are generally Neuman or Stephan-based solutions which have the form:

$$X = m\sqrt{I_g} = m\sqrt{t} \tag{15-7}$$

where: X = depth of freezing or thawing,
m = coefficient of proportionality,
I_g = ground surface freezing (I_f) or thawing (I_t) index (K•s),
t = freezing or thawing period (s).

The following equations incorporate various assumptions, but are accurate and handy for specific conditions.

$$X = \sqrt{\frac{2k \cdot I_g}{L}} \tag{15-8}$$

$$X = \sqrt{\frac{2k \cdot I_g}{L + C\left(T_m - T_o + \frac{I_g}{2t}\right)}} \tag{15-9}$$

$$X = \sqrt{\left(\frac{k_2}{k_1} d_1\right)^2 + \frac{2k_1 \cdot I_g - \frac{d_1^{\,2} \cdot L_1}{2k_1}}{L_2}} - \left(\frac{k_2}{k_1} - 1\right) d_1 \tag{15-10}$$

$$X = \sqrt{\frac{2k \cdot I_g}{L}} \left(1 - \frac{C \cdot I_g}{8L \cdot t}\right) \tag{15-11}$$

$$X = \lambda\sqrt{\frac{2k \cdot I_g}{L}} \tag{15-12}$$

where: k = thermal conductivity of the material above the freezing isotherm, k_f for frost penetration and k_t for thawing calculations,

L = volumetric latent heat of the material undergoing phase change (Equation 15-4),

C = volumetric heat capacity of the material above the freezing isotherm, C_f or C_t (Equations 15-1, 15-2),

T_m = mean annual site temperature,

T_o = freezing point,

d = thickness of layer of material,

λ = a correction coefficient which takes into consideration the effect of temperature change in the soil, and primarily accounts for the volumetric specific heat effects. It is a function of two parameters, the thermal ratio (a) and the fusion parameter (μ), and is determined from Figure 15-20.

$$a = \frac{\left(T_m - T_o\right)}{T_s} = \frac{\left(T_m - T_o\right)\cdot t}{I_g}$$

$$\mu = \frac{C \cdot I_g}{L \cdot t}$$

T_s = I_g/t, surface freezing or thawing index divided by the length of that period.

Subscripts f and t refer to freezing and thawing, and subscript 1 and 2 refer to the surface layer and the underlying material.

Equation 15-8 is the Stephan solution for a homogenous material with a step change in surface temperature. This is modified in Equation 15-9 to account for the temperature change in the freezing or thawing soil. Equation 15-10 is a two-layer solution of the Stephan equation which is useful for calculations involving snow cover, a gravel pad or a board of thermal insulation, in which case the surface layer has no latent heat and the equation is simplified. Equation 15-11 is a close approximation of the Neuman solution when the ground temperatures are near-freezing [92]. Equation 15-12, the modified Berggren equation, is perhaps the most commonly used solution for soils [93].

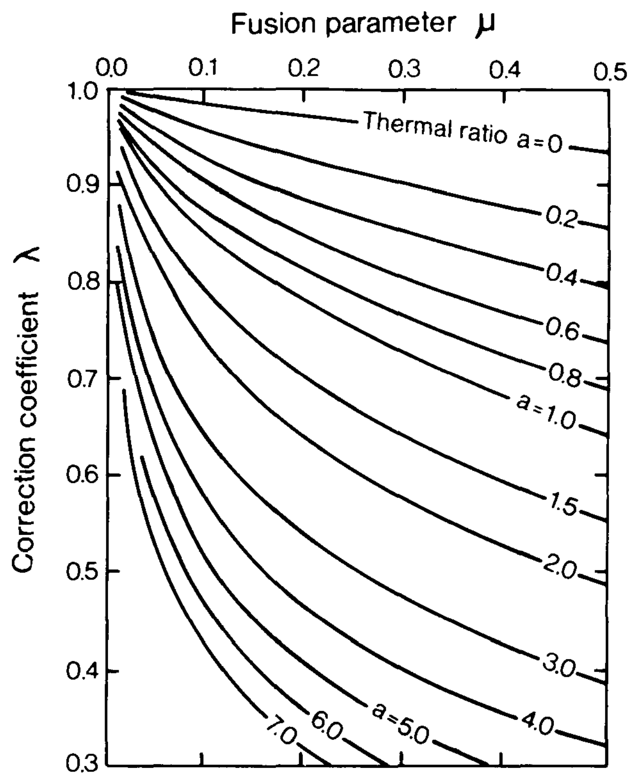


FIGURE 15-20. CORRECTION COEFFICIENT

It should be noted that, with high moisture content soils the λ coefficient approaches unity, the simple Stephan solution. In northern climates where the mean annual temperature is near or below freezing, the thermal ratio approaches zero and the λ coefficient is greater than 0.9.

In very dry soils, the soil warming or cooling can be significant and should be included [94]. Multi-layered soil systems can be solved by determining that portion of the surface freezing or thawing index required to penetrate each layer. The sum of the thicknesses of the frozen or thawed layers whose indices equal the total index is equal to the depth of freeze or thaw. The partial freezing or thawing index to penetrate the n^{th} layers is [95]:

$$I_n = \frac{L_n \cdot d_n}{2} \left(\sum_{1}^{n-1} R + \frac{R_n}{2} \right) \qquad (15\text{-}13)$$

where: I_n = the partial freezing or thawing index required to penetrate the n^{th} layer,

L_n = volumetric latent heat in the n^{th} layer;

d_n = thickness of the n^{th} layer,

λ = the coefficient based on the weighted average values for μ down to and including the n^{th} layer,

$\sum_{1}^{n-1} R$ = the sum of the thermal resistances of the layers above the n^{th} layer, and

$R_n = \frac{d_n}{k_n}$; the thermal resistance of the n^{th} layer.

The solution of multi-layered systems is facilitated by tabular arrangement of the intermediate values. The penetration into the last layer must be solved by trial and error to match the total freezing or thawing index at the site (see Example 15.13).

It is necessary to determine the temperature condition at the ground surface to determine subsurface thermal effects, including the depth of freezing and thawing. Since air temperatures are readily available, but surface temperatures are not, a correlation factor which combines the effects of radiation, and convective and conductive heat exchange at the air-ground surface is used:

$$I_g = n \cdot I_a \qquad (15\text{-}14)$$

where: I_g = ground surface freezing or thawing index,

I_a = air freezing or thawing index, and

n = n-factor, ratio of the surface and air temperature indices.

The n-factor is very significant in analytical ground thermal considerations [96]. It is highly variable and is usually estimated from published observations such as those values suggested in Table 15-4.

TABLE 15-4. SOME EXAMPLES OF n-FACTORS [97]

SURFACE	n-FACTORS THAWING	FREEZING	COMMENTS
Snow		1.0	General application
Pavement free of snow & ice		0.9	General application
Sand and gravel	2.0	0.9	General application
Turf	1.0	0.5	General application
Spruce	0.35 to 0.53	0.55 to 0.9	Thompson, Manitoba
Spruce trees, brush	0.37 to 0.41	0.28	Fairbanks, Alaska
Above site, cleared, moss surface	0.73 to 0.78	0.25	Fairbanks, Alaska
Stripped, mineral soil surface	1.72 to 1.26	0.33	Fairbanks, Alaska
Spruce	0.76		
Willows	0.82		Inuvik, NWT
Weeds	0.86		
Gravel fill slope	1.38	0.7	Fairbanks, Alaska
Gravel road	1.99		Fairbanks, Alaska
Concrete road	2.03		Fairbanks, Alaska
Asphalt road	1.74,1.96,2.70		Fairbanks, Alaska
White painted surface	0.76,0.98,1.25		Fairbanks, Alaska
Peat bales on road	1.44,1.72,2.28		Fairbanks, Aslaska
Dark gravel	1.15,1.40,1.73		Fairbanks, Alaska

Ice thickness on water bodies may be estimated from the previous depth of freezing equations or from Equations 15-7 with the m values in Table 15-5 (see Example 15.14). Snow cover has a significant insulating effect and can significantly reduce the maximum ice thickness. The ice formation can be greater th calculated if the weight of snow or the lowering of the water level causes cracks in the ice and water overflows onto the surface. This water is drawn into the snow and the mixture refreezes and bonds to th original ice. This snow ice appears white or frosty, whereas pure wat ice appears clear or black.

TABLE 15-5. SOME EXAMPLES OF m-FACTORS FOR ICE THICKNESS [98]

m-Factor $m/K^{\frac{1}{2}}\cdot s^{\frac{1}{2}} \times 10^{-5}$	Conditions
10.4 - 11.0	Practical maximum for ice not covered with snow
9.3	Windy lakes with no snow
8.1 - 9.3	Medium-sized lakes with moderate snow cover
6.7 - 7.5	Rivers with moderate flow
4.6 - 5.8	River with snow
2.3 - 4.6	Small river with rapid flow

$m/K^{\frac{1}{2}}\cdot s^{\frac{1}{2}} \times 8625 = ft/°F^{\frac{1}{2}}\cdot h^{\frac{1}{2}}$

$\times 60 = m/°C^{\frac{1}{2}}\cdot h^{\frac{1}{2}}$

15.10 Example Problems

The following example problems are presented to indicate the application of thermal equations to solve some of the thermal problems encountered in utility system design.

Various units of measure are still in common usage and this can lead to some confusion and errors. Most of the equations presented in this section can be utilized with any system of units as long as the units are consistent. The analyst is encouraged to work in S.I. units and Table 15-6 lists conversion factors to S.I. units. Example problems in metric, S.I. and British units are presented.

TABLE 15-6. CONVERSIONS TO SI UNITS

To convert from:	*to*	*Multiply by:*
Area		
circular mil	m^2	5.0671×10^{-10}
$foot^2$	m^2	0.0929
$inch^2$	m^2	6.4516×10^{-4}
Density		
$pound/foot^3$	kg/m^3	16.018
$pound/inch^3$	kg/m^3	27680.
Energy and Work		
kilojoules (kJ)	J	0.001
British Thermal Unit (BTU)	J	1054.4
calorie (cal)	J	4.184
Calorie (Kcal or Cal)	J	4184
kilowatt - hour	J	3.6×10^6
horsepower - hour	J	2.6845×10^6
Flow Rate		
$foot^3$/second	m^3/s	0.028317
$foot^3$/minute	m^3/s	4.7195×10^{-4}
$foot^3$/hour	m^3/s	7.8658×10^{-6}
Imperial gallons/second	m^3/s	4.5459×10^{-3}
Imperial gallons/hour	m^3/s	1.26275×10^{-6}
U.S. gallons/second	m^3/s	3.785×10^{-3}
U.S gallons/hour	m^3/s	1.0514×10^{-6}
litres/second	m^3/s	0.001
Force		
kilogram - force	N	9.80665
pound - force	N	4.4482
Heat		
Heat capacity		
BTU/lb·°F	J/kg·K	4184
cal/g·°C	J/kg·K	4184
Cal/kg·°C	J/kg·K	4184
kJ/kg·K	J/kg·K	0.001
Latent heat		
BTU/lb	J/kg	2324.6
cal/g	J/kg	4184
Cal/kg	J/kg	4184
kJ/kg	J/kg	0.001
Thermal conductivity		
BTU/h·ft·°F	W/m·K	1.7296
BTU·in/h·ft^2·°F	W/m·K	0.14413
cal/s·cm·°C	W/m·K	418.4
Cal/h·m·°C	W/m·K	1.1622
Thermal resistance		
h·ft· °F/BTU	K·m/W	0.5782
s·cm· °C/cal	K·m/W	2.390×10^{-3}
h·m· °C/Cal	K·m/W	0.8604
Length		
inch	m	0.0254
foot	m	0.3048
mile	m	1609.3
Mass		
ounce	kg	0.02835
pound	kg	0.45359
ton (short, 2000 lb)	kg	907.18
ton (metric)	kg	1000
litre (water, 4°C)	kg	1

To convert from:	*to*	*Multiply by:*
Power		
BTU/second	W	1054.4
BTU/hour	W	0.2929
cal/second	W	4.184
cal/hour	W	1.1622×10^{-3}
Cal/second	W	4184
Cal/hour	W	1.1622
foot pounds force/second	W	1.3558
horse power (550 ft·lb/s)	W	745.70
horse power (electric)	W	746
Joules/second	W	1
Pressure or Stress		
atmosphere	N/m^2	101325
bar	N/m^2	100000
foot of water	N/m^2	2989
inch of water (4°C)	N/m^2	249.08
inch of mercury (0°C)	N/m^2	3386.4
pound-force/$inch^2$ (psi)	N/m^2	6894.8
kilogram-force/$centimeter^2$	N/m^2	98066.5
kilogram-force/$meter^2$	N/m^2	98.066
kilo pascals (kPa)	N/m^2	1000
pascal	N/m^2	1
Temperature		
Temperature interval		
°C	K	1
°F	K	5/9 or 0.5556
Temperature		
°C	K	°C + 273
°F	K	(°F + 459.7) 5/
Velocity		
foot/second	m/s	0.3048
foot/hour	m/s	8.4667×10^{-4}
miles/second	m/s	1609.3
miles/hour	m/s	0.44704
kilometers/hour	m/s	0.27778
Viscocity		
Dynamic		
pascal·second	$N{\cdot}s/m^2$	1
centipoise	$N{\cdot}s/m^2$	0.001
pound-force·seconds/$foot^2$	$N{\cdot}s/m^2$	47.880
Kinematic		
centistoke	m^2/s	1.0×10^{-6}
$foot^2$/second	m^2/s	0.0929
Volume		
acre-foot	m^3	1233.5
barrel (oil)	m^3	0.15899
$foot^3$	m^3	0.028317
gallon (U.S.)	m^3	3.7854×10^{-3}
gallon (Imperial)	m^3	4.5459×10^{-3}
litre	m^3	1000
$yard^3$	m^3	0.76455

EXAMPLE 15.1

Calculate the rate of heat loss (per unit length) from a plastic pipe of outside diameter 166 mm and inside diamter 136 mm whose thermal conductivity is 0.36 W/m • K and is encased in 50 mm of polyurethane foam of thermal conductivity 0.023 W/m • K when the pipe contains water at 5°C and the above ground pipe is exposed to an air temperature of -40°C and the wind speed is 25 km/h (7 m/s).

SOLUTION:

$r_I = (166/2) + 50 = 133$, $r_P = 166/2 = 83$

From Figure 15-14

for $r_I/r_P = 133/83 = 1.6$

and $k_I = 0.023$; Read off:

$R_I = 3.3$ m • K/W

Assume R_P = negligible

and R_A = negligible

$$Q = \frac{5-(-40)}{3.3} = 13.6$$
$$\approx \mathbf{14\ W/m}$$

From Equations in Figure 15-10(a), (b)

$$R_I = \frac{\ln(133/83)}{2 \cdot \pi \cdot 0.023} = 3.26 \text{ m} \cdot \text{K/W}$$

$$R_P = \frac{\ln(83/68)}{2 \cdot \pi \cdot 0.36} = 0.09 \text{ m} \cdot \text{K/W}$$

Estimate the insulation surface temperature (T_S) to be at -35°C, a value close to T_A.

Note: W = J/s, N = 1.12, W = 0.56, V = 7m/s

$$h_A = 1.12\left[\frac{-35-(-40)}{0.133}\right]^{0.25} \cdot \sqrt{(0.56 \cdot 7) + 1} = 6.15$$

$$R_A = 1/(2 \cdot \pi \cdot 0.133 \cdot 6.15) = 0.20 \text{ m} \cdot \text{K/W}$$

$$T_S = -40 + [5-(-40)]\,\frac{0.20}{0.20+3.26+0.09} = -37.5°\text{C}$$

Further interation gives $T_S = -37$°C and $R_A = 0.22$ m • K/W

$$R_C = 0.22 + 0.09 + 3.26 = 3.57 \text{ m} \cdot \text{K/W}$$

$$Q = \frac{5-(-40)}{3.57} = 12.6 \simeq \mathbf{13\ W/m}$$

NOTE:

The thermal resistance of the pipe and the air film could be neglected in this case of a well insulated pipe. If there was no wind, $T_S = -35$°C, $R_A = 0.43$ and Q = 11.9 W/m.

EXAMPLE 15.2

Calculate the rate of heat loss (per unit length) for the pipe in Example 15.1 if the pipe is buried at a depth of 1.22m in soil with a thermal conductivity of 2.0 W/m • K when the fluid temperature is 5°C and the (steady state) ground surface temperature is −40°C.

SOLUTION:

From Example 15.1: $R_P = 0.09$ m • K/W and $R_I = 3.26$ m • K/W

From Figure 15-16 for $H_P/r_P = 1.22/0.133 = 9.17$; obtain R_S or since $H_P \geq 2r_P$ from Figure 15-11(a):

$$R_S = \frac{\ln(2 \cdot 1.22/0.133)}{2 \cdot \pi \cdot 2.0} = 0.23 \text{ m} \cdot \text{K/W}$$

$$R_C = 0.09 + 3.26 + 0.23 = 3.58 \text{ m} \cdot \text{K/W}$$

$$Q = \frac{5-(-40)}{3.58} = 12.6 \simeq \mathbf{13\ W/m}$$

NOTE:

The thermal resistance of the soil is relatively small compared to that of the insulated pipe and in this case it could have been neglected. In practice, the main effect of the soil is to dampen out the extreme temperature fluctuations (daily or annually) at the ground surface and a mean ground surface temperature of −40°C is unrealisticallv low for buried heat loss calculations (See Example 15.3).

EXAMPLE 15. 3

Calculate the annual heat loss and the maximum rate of heat loss (per unit length) for the pipes in Examples 15.1 and 15.2 when the ambient temperatures (typical of Barrow, Alaska) are:

Mean Monthly Temperatures (°C)

	Mean Annual	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Air	−12.8	−28.4	−24.9	−24.0	−16.8	−11.7	−1.2	4.5	2.6	−0.2	−8.8	−15.2	−21.4
Depth of 1.22 m	−9.7	−14.0	−15.0	−15.0	−13.8	−10.4	−8.0	−4.9	−2.8	−2.8	−3.1	−6.7	−10.0

Minimum air temperature = −50.0°C
Minimum mean daily ground temperature at 1.22 m = −17.8°C

SOLUTION:

Heating Index = $\Sigma\,(T_W - T_A)$ for period when $T_A \leq T_O$ (When there is a risk of freezing)

For Air: $I_A = \Sigma\,[5 - (-12.8)] + [5 - (-28.4)] + \ldots\ldots$ (for each month)
$= 199.6°C \cdot \text{months} = 146000\ K \cdot h$

For Depth of 1.22 m: $I_{1.22} = \Sigma\,[5 - (-14.0)] + [5 - (-15.0)] + \ldots\ldots$ (for each month)
$= 166.5°C \cdot \text{months} = 122000\ K \cdot h$

For an above ground pipe:

From Example 15.1: $R_C = 3.57\ m \cdot K/W = 3.57\ s \cdot m \cdot K/J$

Annual heat loss = 146000 (60 • 60) / 3.57 = **$1.47 \cdot 10^8$ J/m**

Maximum rate of heat loss = [5 − (−50.0)] / 3.57 = **15.4 W/m**

and for a buried pipe:

From Example 15.2: $R_C = 3.60\ m \cdot K/W = 3.60\ s \cdot m \cdot K/J$

Annual heat loss = 122000 (60 • 60) / 3.60 = **$1.22 \cdot 10^8$ J/m**

Maximum rate of heat loss = [5 − (−17.8)] / 3.60 = **6.3 W/m**

NOTE 1:

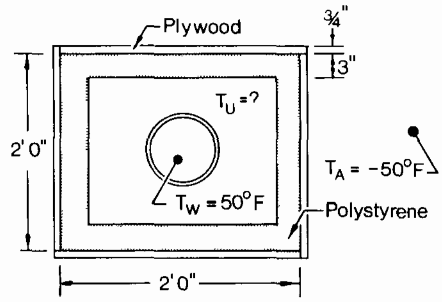
The annual heat loss from the above ground pipe is only slightly higher than a pipe buried in permafrost; however, the maximum rate of heat loss (and freeze-up risk) is much higher. The relative differences become greater in warmer areas, particularly in non-permafrost conditions. In the extreme case, the pipe may be located below the maximum frost penetration therefore heating and freezing risk are nil.

NOTE 2:

The use of the mean daily (or even hourly) temperatures would result in a more precise (and lower) estimate of the Heating Index, but this is seldom warranted.

EXAMPLE 15.4

Calculate the interior temperature and rate of heat loss (per unit length) from the plywood box sketched below which contains a 6-inch nominal diameter, Class 150 asbestos cement pipe. Assume that there is free convection, radiation is negligible and that there is no air exchange (leakage) from the box. Temperatures and dimensions are shown below.



SOLUTION:

Pipe O.D. = 7.17″ $\quad r_P = 3.58'' = 0.298$ ft

I.D. = 5.85″ $\quad r_W = 2.98'' = 0.243$ ft

$k_P = 0.375$ BTU/ft • h $\quad r_P - r_W = 0.055$ ft

$k_L = 0.02$ BTU/ft • h $\quad$ and

$k_E = 0.075$ BTU/ft • h $\quad r_P + r_W = 0.541$ ft

From Figure 15-10 (c):
Estimate T_U to be +35°F, a value between −50°F and +50°F.

$$R_P = \frac{0.055}{0.541 \cdot \pi \cdot 0.375} = 0.086 \text{ h} \cdot \text{ft} \cdot {}^\circ\text{F/BTU}$$

$$h_A = 0.23\left(\frac{50 - 35}{0.298}\right)^{0.25} = 0.613 \text{ h} \cdot \text{ft}^2 \cdot {}^\circ\text{F/BTU}$$

$R_A = 1 / (2 \cdot \pi \cdot 0.298 \cdot 0.613) = 0.872$ h • ft • °F/BTU

and $R_C = 0.086 + 0.872 = 0.959 \simeq 0.96$ h • ft • °F/BTU

$P_E = 4\,(2.0 + 0.75/12) = 8.25$ ft

$R_E = (0.75/12)\,/\,8.25 \cdot 0.075 = 0.101$ h • ft • °F/BTU

$P_L = 4\,(2.0 - 3/12) = 7.0$ ft

$R_L = (3/12)\,/\,7 \cdot 0.02 = 1.786$ h • ft • °F/BTU

$R_U = 0.101 + 1.786 = 1.887 \simeq 1.89$ h • ft • °F/BTU

$$T_U = \frac{(50/0.96) - (50/1.89)}{(1/0.96) + (1/1.89)} = 16.3 {}^\circ\text{F}$$

Interate (Use this new value of T_U and repeat the calculation)

$$h_A = 0.23\left(\frac{50 - 16.3}{0.298}\right)^{0.25} = 0.75 \text{ h} \cdot \text{ft}^2 \cdot {}^\circ\text{F/BTU}$$

$R_A = 1 / (2 \cdot \pi \cdot 0.298 \cdot 0.75) = 0.712$ h • ft • °F/BTU

and $R_C = 0.086 + 0.712 = 0.798 \simeq 0.80$ h • ft • °F/BTU

$$T_U = \frac{(50/0.80) - (50/1.89)}{(1/0.80) + (1/1.89)} = 20.3 {}^\circ\text{F}$$

Another interation gives a value of $T_U = 19.7$ °F
Hence $T_U \simeq$ **20 °F**

$$\text{and } Q = \frac{50 - (-50)}{0.80 + 1.89} = 37.2 \simeq \mathbf{37\ BTU/h \cdot ft}$$

$$\text{or } Q = \frac{20 - (-50)}{1.89} \simeq \mathbf{37\ BTU/h \cdot ft}$$

NOTE:
If the same volume of polystyrene were placed in a annulus around the pipe, the radius would be 0.79 ft and the rate of heat loss would be 13 BTU/h • ft.

EXAMPLE 15.5

The same configuration as Example 15.4, but including a 2 inch OD High Temperature Water (HTW) pipe at 250°F encased within 1.5 inches of asbestos fibre of thermal conductivity 0.04 BTU/h • ft • °F.

SOLUTION:

From Example 15.4: R_U '= 1.89 BTU/h • ft • °F;
R_P = 0.086 BTU/h • ft • °F (for water conduit)

The thermal resistance of the HTW pipe and the air film adjacent to the insulation are neglected. The thermal resistance of the HTW pipe insulation can be determined from Figure 15-15 or by equation:

r_I = (1 + 1.5) / 12 = 0.208 ft; r_P = 1.0 / 12 = 0.083 ft

$$R_2 = R_I = \frac{\ln 0.208 / 0.083}{2 \cdot \pi \cdot 0.04} = 3.65 \text{ h} \cdot \text{ft} \cdot {}^\circ\text{F/BTU}$$

From Figure 15-10 (d):

Assume T_U = 35°F since then part of the calculation has already been done in Example 15.4.
So: R_1 = 0.96 h • ft • °F/BTU

$$\Sigma T_j / R_J = 250 / 3.65 + 50 / 0.96 = 120.6 \text{ BTU / h} \cdot \text{ft} \cdot {}^\circ\text{F}$$

and $\Sigma 1 / R_j = 1 / 3.65 + 1 / 0.96 = 1.32$ BTU / h • ft • °F

$$T_U = \frac{120.6 + (-50/1.89)}{1.32 + (1/1.89)} = 50.9 \simeq 51\ {}^\circ\text{C}$$

(Further interation gives R_1 = 1.66 and T_U = 51.3 °F)

For the HTW pipe: $$Q_2 = \frac{250 - 51}{3.65} = 54.5 \simeq \mathbf{54\ BTU/h \cdot ft}$$

For the Water Pipe: $$Q_1 = \frac{50 - 51}{1.66} - 0.6 \simeq \mathbf{0\ BTU / h \cdot ft}$$

For the Box: $$Q_B = \frac{51 - (50)}{1.89} = 53.7 \simeq \mathbf{54\ BTU / h \cdot ft}$$

NOTE 1:
If the air film of the HTW pipe insulation had been included the temperature at the surface of the insulation must also be estimated and an interative analysis performed. This results in an interior temperature of approximately $T_U \simeq 45$°F, which is quite close to the previous simple analysis.

NOTE 2:
If the HTW pipe ceases to function, the rate of heat loss from the water pipe becomes that calculated in Example 15.4 (37 BTU/h • ft).

NOTE 3:
If the outside air temperature increases to 20°F, then $T_U \simeq 70$°F and the heat gain by the water pipe is ≃ 22 BTU/h • ft. If flow stops, the quiesent water temperature will initially increase at a rate of $(23 / \pi\ (0.243)^2 \cdot 62.4 \cdot 1) \simeq 2$°F/h and after a long period of time it will equal the interior temperature when only the HTW pipe is present which is :

$$T_U = \frac{250/3.65 + 20/1.39}{1/3.65 + 1/1.89} \simeq 98^\circ\text{F}$$

EXAMPLE 15.6

A metal pipe of outside diameter 6 inches is buried 4 ft below grade in a clay soil with thawed and frozen thermal conductivities of 0.60 and 1.0 BTU/h • ft • °F respectively. Calculate the mean size of the thawed zone and the average rate of heat loss if the mean ground surface temperature is 27.5°F and water at 45°F is circulated through the pipe.

SOLUTION:

R_P = negligible

$r_P = 6/(2 \cdot 12) = 0.25$ ft

$T'_W = (0.6/1.0)(45 - 32) + 32 = 39.8$

$T^* = (32 - 27.5)/(39.8 - 27.5) = 0.398$

$c = \sqrt{4^2 - 0.25^2} \simeq 4$

$H_P/r_P = 4/0.25 = 16$

From Figure 15.15 for H/r = 16,

read off: arccosh 16 ≃ 3.5

$A = 0.398 \times 3.5 = 1.4$

From Figure 15.16 for A = 1.4

read off:

$H_Z/c \simeq 1.13$

$r_Z/c \simeq 0.5$

$H_Z = 1.13 \cdot 4 = \mathbf{4.5\ ft}$

and $r_Z = 0.5 \cdot 4 = \mathbf{2\ ft}$

From Equations in Figure 15-11(a):

$A = 0.398 \ln 2 \cdot 4/0.25$

$= 1.38$

$H_Z = 4 \coth 1.38$

$= 4 \cdot 1.135$

$= \mathbf{4.54\ ft}$

and $r_Z = 4 \operatorname{csch} 1.38$

$= 4 \cdot 0.473$

$= \mathbf{1.89\ ft}$

Hence, under steady state conditions a thawed zone will be present within a cylinder parallel to the pipe, of radius 2 ft and with its axis approximately 0.5 ft below the pipe axis.

From Figure 15.15 with H/r = 16

and k (= k_f) = 1.0 BTU/h • ft • °F,

read off:

$R'_S = 0.55$ h • ft • °F/BTU

$$Q = \frac{39.8 - 27.5}{0.55} = 22.4 \simeq \mathbf{22\ BTU/h \cdot ft}$$

From Equations

$R'_S = [\text{arccosh}(4/0.25)]/2\pi \cdot 1.0$

$\simeq [\ln(2 \cdot 4/0.25)]/2\pi \cdot 1.0$

$= 0.55$ h • ft • °F/BTU

$$Q = \frac{39.8 - 27.5}{0.55} = 22.4 \simeq \mathbf{22\ BTU/h \cdot ft}$$

EXAMPLE 15.7

A metal pipe of external diameter 0.152 m is buried in permafrost (k_f = 1.73 W/m • K) with its axis 1.22 m below the ground surface whose mean temperature is −2.5°C. (Same as Example 15.6). What is the minimum thickness of polyurethane foam insulation (k_I = 0.024 W/m • K) which will maintain the soil in a frozen state (on average) if water is flowing through the pipe has a mean temperature of 7.2°C? What is the average rate of heat loss if this insulation thickness is used?

SOLUTION

To evaluate R_S use Figure 15-15

with H/r = 1.22/0.076 = 16

and k_S (= k_f) = 1.73 W/m • K

Then $R_S = 0.32$ m • K/W

$$R'_I = \frac{(7.2 - 0)}{0 - (-2.5)} \cdot 0.32 = 0.92 \text{ m} \cdot \text{K/W}$$

From Equations in Figure 15-11(c):

$$R_S = \frac{\ln 2 H_P/r_P}{2\pi k_S} = \frac{\ln 2 \cdot 1.22/0.076}{2\pi \cdot 1.73}$$

$= 0.319$ m • K/W

For no thawing

$$R'_I \geqslant \frac{T_P - T_f}{T_f - T_S} R_S = \frac{7.2 - 0}{0 - (-2.5)} \cdot 0.319$$

$= 0.919$ m • K/W

To evaluate r_I/r_P use Figure 15.14

with $R_I = 0.92$ m • K/W

and $k_I = = 0.024$ m • K/W

Then $r_I/r_P \simeq 1.15$

$r_I - r_P = (1.15 - 1) \cdot 0.076 = 0.011 \text{ m} \simeq \mathbf{10\ mm}$

$$Q = \frac{7.2 - (-2.5)}{0.92 + 0.32} = \frac{9.7}{1.24} = \mathbf{7.8\ W/m}$$

$r_I - r_P \geqslant r_P [\exp(2\pi k_I R'_I) - 1]$

$= 0.076 [\exp(2\pi \cdot 0.024 \cdot 0.919) - 1]$

$= 0.011$ m

$\simeq \mathbf{10\ mm}$

NOTE 1:
In Example 15.6 for the same conditions the bare pipe (not insulated) had a heat loss of 22.4 BTU/h • ft (= 21.5 W/m) which is 2.75 times that calculated with 11mm (0.5 inches) of insulation.

NOTE 2:
To design for the worst conditions, in order to minimize the thaw zone during the fall when the soil is relatively warm, see Example 15.8.

NOTE 3:
To estimate the maximum rate of heat loss, use the **minimum** temperature attained by the undisturbed soil at the pipe depth of bury, rather than the mean surface temperature, T_G. (See Example 15.3)

EXAMPLE 15.8

For the buried insulated pipe in Example 15.7, estimate the maximum thawing under the pipe (in the fall) if the maximum thaw depth (A = active layer) is 1.22 m and the volumetric heat capacity of the frozen soil is 420 Cal / m³ • °C

SOLUTION:

From Example 15.7 for no thawing:
$r_I = 0.076 + 0.011 = 0.087$ m
$k_f = 1.73$ W/m • K = 1.48 Cal/m • h • °C
$T_I = 0.0$°C (for no thawing in steady state analysis)

From Equations in Figure 15-19:

$$B = \sqrt{\pi \cdot 420/1.48 \cdot (365 \cdot 24)} = 0.319$$
$$F = \text{arccosh}\ 1.22/0.087 \simeq \ln 2 \cdot 1.22/0.087 = 3.334$$
$$c = \sqrt{1.22^2 - 0.087^2} = 1.217$$
$$T^* = \frac{0.0 - (-2.5)}{0.0 - (-2.5)} = 1.0$$

$$\Delta_1 = -\frac{1}{0.319} \ln \left[1 - \frac{1.0}{3.334} \ln \left| \frac{1.217 + 1.22 + \Delta_0}{1.217 - 1.22 - \Delta_0} \right| \right]$$

Estimate $\Delta_0 = 1$ m gives $\Delta_1 = 1.44$ m
Iterate with $\Delta_0 = 1.44$ m gives $\Delta_2 = 1.10$m

Further iterations give $\Delta = $ **1.24** $\simeq$ **1.2 m**

NOTE 1:
This equation overestimates thawing for the given conditions; however, it does not include other factors that may increase thawing such as: surface disturbances; moisture movement in the active layer and pipe trench; and initial transient effects from trenching and backfill.

NOTE 2:
With 50mm insulation, $T_I = -1.8$°C (mean) and $\Delta = 0.6$m.

EXAMPLE 15.9

Calculate the Design Freeze-Up Time and the Safety Factor Time and the Complete Freezing Time for the pipe design used in Example 15.1 if the water ceases to flow.
(For water: $C = 1000$ Cal/m³ • K; $L = 80{,}000$ Cal/m³)

SOLUTION:

From Example 15.1 $R_C = 0.09 + 3.26 + 0.22 = 3.57$ m • K/W = 4.15 m • h • °C/Cal

$r_W = 0.068$ m; $T_W = 5°C$; $T_A = -40°C$

From Equations in Figure 15-13

$$\text{Design Time} = \pi\,(0.068)^2 \cdot 4.15 \cdot 1000 \ln \frac{5-(-40)}{0-(-40)}$$

$$t_D = 7.10\ \text{h} \simeq \mathbf{7\ h}$$

$$\text{Safety Factor Time} = \pi\,(0.068)^2 \cdot 4.15 \cdot 1000 \ln \frac{5-(-40)}{-3-(-40)}$$

$$t_{SF} = 11.8\ \text{h} \simeq \mathbf{12\ h}$$

$$\text{Complete Freezing Time} = \pi\,(0.068)^2 \cdot 4.15 \cdot 80000 \,/\, [0-(-40)]$$

$$t_F = 120.5\ \text{h} \simeq \mathbf{120\ h}$$

EXAMPLE 15.10

Calculate the input temperature and the rate of heat loss (heat input) for a 3000 m recirculating water system for various flow rates if the buried pipe is the same as Example 15.2 and the water temperature is to be maintained at a minimum of 5°C when the ground temperature at the pipe depth is $-10°C$.

SOLUTION

From Example 15.2

$r_W = 0.068$ m ; $R_C = 3.58$ m • K/W (s • m • K/J) ; $C_W = 4.184 \times 10^6$ J/m³ • K

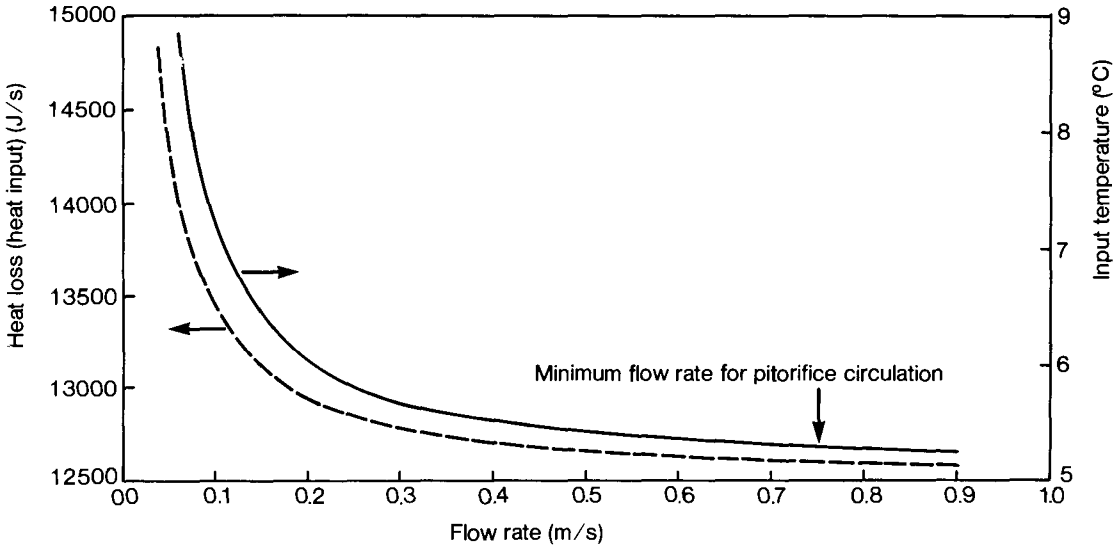
From Equations in Figure 15-13

$$D = \pi\,(0.068)^2 \cdot V \cdot 4.184 \times 10^6 \cdot 3.58 = 217600\ V$$

$$T_1 = -10 + \frac{5-(-10)}{\exp(-3000/217600\ V)}$$

$$\text{and } Q = \frac{217600\ V}{3.58}\,[5-(-10)]\,[(\exp 3000/217600\ V) - 1]$$

Thus T_1 and Q can be evaluated for various values of V. These are plotted below:



NOTE:
Heat loss and input temperature are lower at high flow rates, however, there is little benefit from flow rates greater than 0.1 m/s. A pitorifice system would require a minimum flow rate of approximately 0.75 m/s.

EXAMPLE 15.11

Determine the economical thickness of insulation for an above ground 6.625 inch OD steel water pipe that is maintained at 41 °F for the temperature conditions given in Example 15.3. The cost of fuel oil, which has a heat content of 140,000 BTU/US gallon, is $0.75/US gallon and the efficiency of the heating plant is 85%. The installed cost of polyurethane foam insulation (k = 0.014 BTU/ft • h • °F) for various available thicknesses are given below. The economic life is 20 years and the cost of capital (discount rate) is 8% net of inflation.

SOLUTION

The economical thickness of insulation has the lowest sum of the initial cost (capital plus installation) and the present value of the annual operating (heat) cost.

Cost of heat = 0.75 / 140000 x 0.85 = 6.30×10^{-6} \$/BTU

Neglecting air film and the pipe:

$$R_C = R_I = \frac{\ln (r_I/0.276)}{2\pi \times 0.014} = 11.37 \ln (r_I/0.276)$$

From Example 15.3, the Heating Index for an above ground pipe is: I_A = 146000 K • h = 262800 °F • h

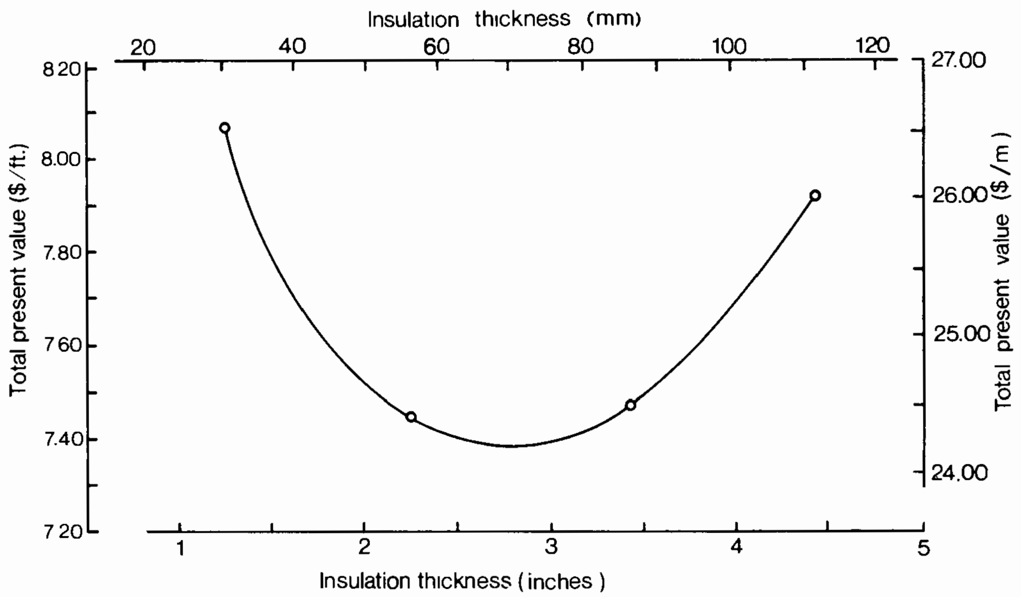
Present Value Factor = $[(1.08)^{20} - 1] / 0.08 (1.08)^{20} = 9.818$ (can also be obtained from tables)

$$\text{Present Value of annual cost of heat} = \frac{262800}{11.37 \ln (r_I/0.276)} \cdot 6.30 \times 10^{-6} \cdot 9.818$$

$$= 1.43 / \ln (r_I/0.276)$$

For the following available insulation thickness and costs:

Insulation Thickness Nominal (inches)	r_I (ft)	Installed Cost ($/ft)	PV of annual heating cost ($/ft)	Total PV ($/ft)
1	0.380	3.60	4.47	8.07
2	0.464	4.70	2.75	7.45
3	0.552	5.40	2.06	7.46
4	0.635	6.20	1.72	7.92



These results, which have been plotted above, indicate that the most economically attractive thickness of insulation is approximately **2.75 inches.**

NOTE:
Other factors such as the freeze-up time, the maximum rate of heat loss (heating system capacity), and practical dimensional consideration must also be considered in the selection of insulation thickness. The sensitivity of results to the assumptions, including the discount rate and energy costs, should also be checked.

EXAMPLE 15.12

Calculate the expansion and load for 100 m lengths of 150 mm diameter steel and polyethelene pipes which undergo a temperature change of 50°C.

SOLUTION:

For steel pipe: r_p=0.084m; r_w=0.077m;
μ=3.5 • 10^{-6}m/m per °C; E=2.1x10^{10}kg/m^2

Change in length if unrestrained:

$\Delta\ell$ = 100 • 3 • 5x10^{-6} • 50
= 0.0175 m
= **18mm**

Load if restrained:

P = $\pi(0.084^2-0.077^2)$. 2.1x10^{10} • 3.5 x 10^{-6} • 50
= **13000 kg**

For high density polyethelene pipe: r_p=0.133m; r_w=0.083m;
μ=4x10^{-5}m/m per °C; E=4.2x10^7 kg/m^2

Change in length if unrestrained:

$\Delta\ell$ = 100 • 3.9x10^{-5} • 50
= 0.195 m
= **200 mm**

Load if restrained:

P = $\pi(0.133^2 - 0.083^2)$ • 4.2x10^7 • 4 x 10^{-5} • 50
= **900 kg**

NOTE:

Although the thermal expansion of the plastic pipe is much more than the metal pipe,the load to restrain thermal expansion is considerably less

EXAMPLE 15.13

Estimate the frost penetration depth for a snow covered sand embankment overlying a silty soil when the air freezing index is 60000°C • h, the mean annual temperature is -5°C, and the duration of the freezing period is 225 days (5400 h). The characteristics of the materials are:

		Snow	Sand		Silt	
	Given					
k_t	(Cal/h•m•°C)	—	2.0	}2.1	1.2	}1.4
k_f	(Cal/h•m•°C)	0.2	2.2		1.6	
γ_d	(kg/m³)	300	2000		1600	
w	(%)	—	5		20	
d	(m)	0.1	1.0		indefinite	
	Calculated					
L	(Cal/m³)	—	8000		25600	
C_t	(Cal/m³•°C)	—	500	}475	640	}560
C_f	(Cal/m³•°C)	60	450		480	

SOLUTION:

Assume the surface factor for snow cover, n=1.0; therefore, I_g=60000°C • h. The results using the modified Berggren solution for a multilayered system (Equations 15-12 and 15-13) are tabulated below. The frost penetrates the snow and sand layers with 10544°C•h and successive trials of thicknesses of the underlying silt (0.5, 1.5 and 1.0m) are estimated until $\Sigma I_n \simeq I_g$. In this case the total frost penetration below ground level is **X=2.0 m.**

Trial	Layer	d	Σd	γ_d	w	k	C	L	C • d	ΣC • d	c	L • d	I
1	Snow	0.1	0.1	300	—	0.2	60	—	6	6	6	—	—
2	Sand	1.0	1.1	2000	5	2.1	475	8000	475	481	432	8000	7273
3a	Silt	0.5	1.6	1600	20	1.4	560	25600	280	761	475	12800	13000
3b	Silt	1.5	2.6						840	1321	508	38400	17846
3c	Silt	1.0	2.1						560	1041	496	25600	16000

Continued

Trial	Layer	μ	λ	λ²	R_n	ΣR	$\Sigma R + \frac{1}{2} R_n$	I_n	ΣI_n
1	Snow	—	—	—	0.5	—	0.25	—	—
2	Sand	0.65	0.75	0.56	0.476	0.5	0.738	10544	10544
3a	Silt	0.41	0.81	0.65	0.357	0.976	1.155	22745	33289
3b	Silt	0.32	0.83	0.69	1.071	—	1.512	84146	94690
3c	Silt	0.34	0.83	0.69	0.714	—	1.333	49462	60006

$$a = \frac{(-5-0)\,5400}{60000} = 0.45 \qquad \mu = \frac{C \cdot 60000}{L \cdot 5000} = 11.11 \bullet \frac{C}{L}$$

$$\mu_2 = 11.11\,\frac{432}{7273} = 0.65 \qquad I_2 = \frac{8000 \cdot 1.0}{0.56}(0.738) = 10544$$

$$\mu_{3a} = 11.11\,\frac{516}{19096} = 0.30 \qquad I_{3a} = \frac{25600 \cdot 0.5}{0.65}(1.155) = 22745$$

$$\mu_{3b} = 11.11\,\frac{508}{17846} = 0.32 \qquad I_{3b} = \frac{25600.1.5}{0.69}(1.512) = 84146$$

$$\mu_{3c} = 11.11\,\frac{496}{16000} = 0.34 \qquad I_{3c} = \frac{25600 \cdot 1.0}{0.69}(1.333) = 49462$$

EXAMPLE 15.14

Calculate the expected maximum ice thickness for a medium sized lake with moderate snow cover when the annual air freezing index is 90000 °C • h.

SOLUTION:

From Table 15.5: m-Factor ≃ $5.25 \cdot 10^{-3}$

$$\text{Ice thickness} = 5.25 \cdot 10^{-3}\sqrt{90000} = 1.575 \simeq \mathbf{1.6\ m}$$

Alternatively, for no snow cover, from the Stephen Equation (Eqn. 15-8):

Where: k_{ice}=1.9 Cal/m•h•°C

L_w= 80000 Cal/m^3

$$X = \sqrt{\frac{2 \cdot 1.9 \cdot 90000}{80000}} = 2.07 \simeq \mathbf{2.1\ m}$$

If the lake has an average snow cover of 0.1m with thermal conductivity 0.3 Cal/h • m • °C; the maximum ice thickness is:

From Eqn. 15-10 with $L_1 = 0$.

$$X = \sqrt{\left(\frac{1.9}{0.3} \cdot 0.1\right)^2 + \frac{2 \cdot 1.9 \cdot 90000}{80000}} - \left(\frac{1.9}{0.3} - 1\right) 0.1$$

$$= 1.629 \approx \mathbf{1.6m}$$

15.11 References

1. Alter, A.J. "Water Supply in Cold Regions", U.S. Army, Cold Regions Research and Engineering Laboratory, Monograph 111-C5a, Hanover, New Hampshire, 1969.

2. Alter, A.J. "Sewage and Sewage Disposal in Cold Regions", U.S. Army, Cold Regions Research and Engineering Laboratory, Monograph 111-C5b, Hanover, New Hampshire, 1969.

3. Lukomskyj, P. and Thornton, D., "Piping Systems", IN: Permafrost Engineering Manual - Design and Construction, National Research Council of Canada, Ottawa, Ontario (In preparation).

4. Johnson, P.R. and Hartman, C.W., "Environmental Atlas of Alaska", Institute of Water Resources, University of Alaska, Fairbanks, Alaska, 1969.

5. Canada Department of Transport, "The Climate of the Canadian Arctic", Meteorological Branch, Air Services, Department of Transport, Toronto, Ontario, 1967.

6. National Research Council "Climatic Information for Building Design in Canada", National Research Council, Ottawa, Ontario, NRC No. 11153, 1970.

7. McFadden, T. "Freeze Damage Prevention in Utility Distribution Lines", IN: Utilities Delivery in Arctic Regions, Environmental Protection Service, Environment Canada, Report No. EPS 3-WP-77-1, pp. 221-234, Ottawa, Ontario, 1977.

8. Houk, J. "Freeze Damage in Water Containers", The Northern Engineer 6(2):4-6, 1974.

9. Gilpin, R.R. "A Study of Pipe Freezing Mechanisms", IN: Utilities Delivery in Arctic Regions, Environmental Protection Service, Environment Canada, Report No. EPS 3-WP-77-1, pp. 207-220, Ottawa, Ontario, 1977.

10. Gilpin, R.R. "The Morphology of Ice Structure in a Pipe at or Near Transition Reynolds Numbers", presented at: 18th National ASME/AIChE Heat Transfer Conference, San Siego, California, August, 1979.

11. Churakov, B.H. "Installation of Sanitary Engineering Utilities in Permafrost", National Science Library, Ottawa, Ontario, 1959.

12. Anderegg, J.A., Hubb, G.L. and Eaton, R.R., "Ice Water on Tap for the Arctic", Waterworks Engineering, 113 (7):632-634, 1960.

13. Foster, R.R. "Arctic Water Supply", Water and Pollution Control, 3(3):24-28, 1975.

14. James, W. and Suk, R. "Least Cost Design for Water Distribution for Arctic Communities", McMaster University, Faculty of Engineering, Hamilton, Ontario, 1977.

15. Stephenson, D.G. "Design of Exposed Sewer Pipes for Intermittent Use Under Freezing Conditions", Division of Building Research, National Research Council of Canada, Ottawa, Ontario, Internal Report No. 166, 1959.

16. Ryan, W.L. "Design and Construction of Practical Sanitation Facilities for Small Alaskan Communities", North American Contribution Permafrost Second International Conference, 13-28 July, 1973, Yakutsk, U.S.S.R., National Academy of Science, Washington, D.C., 1973.

17. Grainage, J.W. "Arctic Heated Pipe Water and Wastewater Systems", Water Research, Permagon Press, Vol. 3, pp. 47-71, 1969.

18. Ryan, W.L. and Rogness, D.R. "Pressure Sewage Collection Systems in the Arctic", IN: Utilities Delivery in Arctic Regions, Environmental Protection Service, Environment Canada, Report No. EPS 3-WP-77-1, pp. 523-552, Ottawa, Ontario, 1977.

19. Eaton, E.R. "Thawing of Wells in Frozen Ground by Electrical Means", Water and Sewage Works, 3 (8):350-353, 1964.

20. Bohlander, T.W. "Electrical Methods for Thawing Frozen Pipes", Journal of the American Water Works Association, 55(5):602-608, 1963.

21. Nelson, L.M. "Frozen Water Services", Journal of the American Water Works Association, 68(1):12-14, 1976.

22. Legget, R.F. and Crawford, C.B. "Soil Temperatures in Water works Practice" Journal of the American Water Works Association, 44(10):923-939, 1952.

23. Nyman, F. "Insulation vs Deep Trenching for Alaskan Water Mains" Civil Engineering, American Society of Civil Engineers, 35(3):40-41, 1965.

24. Janson, L.R. "Water Supply Systems in Frozen Ground", IN: Proceedings, Permafrost International Conference, Lafayette, Indianna, National Academy of Science, National Research Council, Washington, D.C., pp. 403-433, 1966.

25. Aldworth, G.A. and Petrie, A.W. "Some Recent Developments in Shallow-Buried Water and Sewage Systems", Presented at: American Water Works Association, Atlantic Canada Section Conference 1977, 19-21 September, 1977.

26. Associated Engineering Services Ltd. "Freeze Protection Analysis for the Water Distribution System in Buffalo Narrows", Prepared for: Department of Northern Saskatchewan, Prince Albert, Saskatchewan, 1978.

27. Gunderson, P. "Frostproofing of Pipes", U.S. Army, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, Draft Translation TL497, 1975.

28. Gunderson, P. "Frost Protection of Buried Water and Sewer Pipes", U.S. Army, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, Draft Translation TL666, 1978.

29. Gerritsen, E.D. "Northern Ontario Water Distribution Systems", Journal of the American Water Works Association, 69(5):242-244, 1977.

30. Reed, S. "Field Performance of a Sub-arctic Utilidor", IN: Utilities Delivery in Arctic Regions, Environmental Protection Service, Environment Canada, Report No. EPS 3-WP-77-1, pp. 448-468, Ottawa, Ontario, 1977.

31. ASHRAE, "ASHRAE Handbook of Fundamentals" American Society of Heating, Refrigeration and Air-Conditioning Engineers Inc., (latest edition).

32. ASHRAE, "ASHRAE Guide and Data Book", American Society of Heating Refrigeration and Air-Conditioning Engineering Inc., (latest edition).

33. Chapman, F.S. and Holland, F.A. "Keeping Piping Hot - Part II, By Heating", Chemical Engineering, January 17, pp. 133-144, 1966.

34. Cheriton, W.R. "Electrical Heating of a Water Supply Pipeline under Arctic Conditions", Engineering Journal, 49(9):31-35, 1966.

35. Klassen, H.P. "Water Supply and Sewerage System at Uranium City", Engineering Journal, 43(9):61-65, 1960.

36. Carson, N.B. "Pipeline Heating with Electrical Skin Current", Engineering Digest, pp. 23-25, March, 1976.

37. O'Brien, E.T. and Whyman, A., "Insulated and Heat Traced Polyethylene Piping Systems: A Unique Approach for Remote Cold Regions", IN: Utilities Delivery in Arctic Regions, Environmental Protection Service, Environment Canada, Report No. EPS 3-WP-77-1, pp. 309-339, Ottawa, Ontario, 1977.

38. Gronlands Techniske Organisation, "Guide for Carrying Out Electrical Pipe Heating Works" Gronlands Techniske Organisation, Copenhagen, Denmark, (n.d.) (In Danish).

39. Chemelex Division, Raychem Corporation, "Thermal Design Guide", Redwood City, California, 1978.

40. Hsin, J. "A Study of the Auto-Trace Heaters Application in the Sclaircor Piping System", Chemelex Division, Raychem Corporation, Redwood City, California, 1978.

41. Kardymon, V.F. and Stegantsev, V.P. "The Positioning of Heating Cable for Protecting Water Supply Lines from Freezing", Translated from Russian for: Northern Technology Unit, Environmental Protection Service, Environment Canada, Edmonton, Alberta, 1972.

42. Anon. "Plastic Foam Insulates Yukon Waterline", Engineering and Contract Record, March, p. 29, 1966.

43. Srouji, G.A. "Thermal Analysis of Heated Recirculating Water Distribution Systems in Northern Regions", proceedings of Conference on Applied Techniques for Cold Environments, Anchorage, Alaska, May 17-19, 1978, Volume II, American Society for Civil Engineers, New York (in press).

44. Hull, J. "Thermodynamic Analysis of Water Distribution System in Inuvik, N.W.T.", Presented at Symposium on Utilities Delivery in Northern Regions, March 19-21, 1979, Edmonton, Alberta, Environmental Protection Service, Environment Canada, Ottawa, Ontario, (in preparation).

45. Squires, A.D. "Preparation of an Operations and Maintenance Manual", IN: Utilities Delivery in Arctic Regions, Environmental Protection Service, Environment Canada, Report No. EPS 3-WP-77-1, pp. 256-265, Ottawa, Ontario, 1977.

46. Johnston, G.H. (1973). "Ground Temperature Measurements Using Thermocouples," IN: Proceedings of a Seminar on the Thermal REgime and Measurements in Permafrost, National Reserach Council of Canada, Ottawa, Technical Memorandum 108, pp. 1-12, 1973.

47. Judge, A.S. "Ground Temperature Measurements Using Thermistors", IN: Proceedings of a Seminar on the Thermal Regime and Measurements in Permafrost, May 1972, National Research Council of Canada, Ottawa, Ontario, Technical Memorandum 108, pp. 13-25, 1973.

48. Stanley, D.R. "Water and Sewage Problems in Discontinuous Permafrost Regions", IN: Proceedings of the Canadian Regional Permafrost Conference, National Research Council of Canada, Ottawa, Ontario, Technical Memo 86, pp. 93-105, 1965.

49. Klassen, H.P. "Public Utilities Problems in the Discontinuous Permafrost AReas", IN: Proceedings of the Canadian Regional Permafrost Conference, National Research Council of Canada, Ottawa, Ontario, Technical Memo 86, pp. 106-118, 1965.

50. Cameron, J.J. "Buried Utilities in Permafrost Regions", IN: Utilities Delivery in Arctic Regions, Environmental Protection Service, Environment Canada, Report No. EPS 3-WP-77-1, pp. 151-200, Ottawa, Ontario, 1977.

51. Ryan, W.L. "Design Guidelines for Piping Systems - Panel Discussion", IN: Utilities Delviery in Arctic Regions, Environmental Protection Service, Environment Canada, Report No. EPS 3-WP-77-1. pp. 243-255, Ottawa, Ontario, 1977.

52. Jahns, H.O., Miller, T.W. Power, L.D. Rickey, W.P., Taylor, T.P. and Wheeler, J.A., "Permafrost Protection for Pipelines", IN: North American Contribution Permafrost Second International Conference, July 13-28, Yakutsk, U.S.S.R., National Academy of Science, Washington, D.C. pp. 673-684, 1973.

53. Kent, D. and Hwang, C.T., "Use of a Geothermal Model in Northern Municipal Projects", Presented at Symposium on Utilities Delivery in Northern Regions, March 19-21, 1979, Edmonton, Alberta, Environmental Protection Service, Environment Canada, Ottawa, Ontario, (In preparation).

54. Goodrich, L.E. "Some Results of a Numerical Study of Ground Thermal Regimes", IN: Proceedings of the Third International Conference on Permafrost, July 1978, Edmonton, Alberta, National Research Council of Canada, Ottawa, Ontario, pp. 29-34, 1978.

55. Yastrebov, A.L. "Engineering Utility and Sewage Lines in Permafrost Soil", U.S. Army Foreign Science and Technology Center, Charlottesville, Virginia, FSTC-HT-23-1392-73, 1972.

56. James, F.W. "Buried Pipe Systems in Canada's Arctic", The Northern Engineer, 8(1):4-12, 1976.

57. Giles, S. "A Proposed System of Utility Piping Installation in Snow, Ice, and Permafrost", U.S. Naval Civil Engineering Research and Evaluation Laboratory, Port Hueneme, California, Technical Note N-261, 1956.

58. Prokhaev, G.V. "Underground Utility Lines", National Research Council of Canada, Ottawa, Ontario, Technical Translation TT-1221, 1959.

59. Orlov, V.A. "The Problems of Heat Supply in Settlements in the Permafrost Regions", IN: Problems of the North, No. 10, National Research Council of Canada, Ottawa, Ontario, 1966.

60. Zenger, N.N. "Ways in Which to Improve the Economics of Water Supply in the Northern Regions", IN: Problems of the North, National Research Council of Canada, Ottawa, Ontario, No. 9, 1965.

61. Irwin, W.W. "New Approaches to Services in Permafrost Areas - Norman Wells, NWT", presented at Symposium on Utilities Delivery in Northern Regions, March 19-21, 1979, Edmonton, Alberta, Environmental Protection Service, Environment Canada, Ottawa, Ontario (In preparation).

62. Smith W.H. "Frost Loadings on Underground Pipe", Water Technology Distribution Journal, December: pp. 673-674, 1976.

63. Monie, W.D. and Clark, C.M., "Loads on Underground Pipe due to Frost penetration", Journal of the American Waterworks Association, 66(6): 353-358, 1974.

64. Sanger, F.J. "Foundations of Structures in Cold Regions.", U.S. Army, Cold Regions Research and Engineering Laboratory, Hanover, N.H., Monograph 111-C4, 1969.

65. Gilpin, R.R. and M.G. Faulkner "Expansion Joints for Low-temperature Above-Ground Water Piping Systems", IN: Utilities Delivery in Arctic Regions, Environmental Protection Service, Environment Canada, Report No. EPS 3-WP-77-1, pp. 346-363, Ottawa, Ontario, 1977.

66. Copp, S.S., Crawford, C.B. and Grainge, J.W. "Protection of Utilities Against Permafrost in Northern Canada", Journal of the American Water Works Association, 48(9):1115-1166, 1956.

67. Shirtliffe, C.J. "Polyurethane Foam as a Thermal Insulation: A Critical Review", Division of Building Research, National Research Council of Canada, Ottawa, Ontario, Building Research Note No. 124, 1977.

68. Kaplar, C.W. "Moisture and Freeze-thaw Effects on Rigid Thermal Insulations", U.S. Army, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, TR 249, 1974.

69. Kersten, M.S. "Thermal Properties of Soils", University of Minnesota, Minneapolis, Minnesota, Bulletin No. 28, 1949.

70. Jumikis, A.R. "Thermal Soil Mechanics", Rutgers University Press, New Brunswick, New Jersey, 1966.

71. Jumikis, A.R. "Thermal Geotechnics", Rutgers University Press, New Brunswick, New Jersey, 1977.

72. Tsytovich, N.A. The Mechanics of Frozen Ground, Translation from Russian, Edited by G.K. Swinzow, McGraw-Hill Book Company, New York, New York, 1975.

73. Anderson, O.B. and Anderson, D.M., Geotechnical Engineering for Cold Regions, McGraw-Hill Book Company, New York, New York, 1978.

74. Gold, L.W. and Lachenbruch, A.H., "Thermal Conditions in Permafrost: A Review of North American Literature", IN: North American Contribution Permafrost Second International Conference, 13-29 July 1973, Yakutsk, U.S.S.R., National Academy of Sciences, Washington, D.C., pp. 3-23, 1973.

75. Cory, F. "Settlement Associated with the Thawing of Permafrost", IN: North American Contribution Permafrost Second International Conference, 13-28 July 1973, Yakutsk, U.S.S.R., National Academy of Sciences, Washington, D.C., 1973.

76. Morgenstern, N.R. and Nixon, J.F., "One-dimensional Consolidation of Thawing Soil", Canadian Geotechnical Journal, 8(4):558-565, 1971.

77. Linell, K.A. and Johnston, G.H., "Engineering Design and Construction in Permafrost Regions: A Review", IN: North American Contribution Permafrost Second International Conference, 13-28 July, Yakutsk, U.S.S.R., 1973, National Academy of Sciences, Washington, D.C., pp. 553-575, 1973.

78. Vyalov, S.S. and Porkhaev, G.V. (eds), "Handbook for the Design of Bases and Foundations of Buildings and other Structures on Permafrost", National Research Council of Canada, Ottawa, Ontario, Technical Translation NRC/CNR TT-1865, 1975.

79. National Research Council "Permafrost Engineering Manual - Design and Construction", National Research Council of Canada, Ottawa, Ontario (In preparation).

80. Carslaw, H.S. and Jaeger, J.C., "Conduction of Heat in Solids", Oxford University Press, 2nd edition, 1959.

81. Goodrich, L.E. "Computer Simulations", Appendix to "Thermal Conditions in Permafrost - A Review of North American Literature" by Gold, L.W. and Lachenbruch, A.H. IN: North American Contribution Permafrost Second International Conference, July 13-28, 1973, Yakutsk, U.S.S.R., National Academy of Science, Washington, D.C., pp. 23-25, 1973.

82. Thornton, D.E. "Calculation of Heat Loss from Pipes", IN: Utilities Delivery in Arctic Regions, Environmental Protection Service, Environment Canada, Edmonton, Alberta, Report No. EPS 3-WP-77-1, pp. 131-150, Ottawa, 1977.

83. Okada, A. "A Rough Estimation Method of Heat Loss in Buried Underground Pipes", Society of Heating, Air Conditoning and Sanitary Engineers, Japan (SHASA), Transactions, Vol. II, pp. 46-52, 1973.

84. Saltykov, N.I. "Sewage Disposal in Permafrost in the North of the European Portion of the U.S.S.R.", Academy of Sciences, Moscow, U.S.S.R., 1944, Translated for St. Paul District, Corps of Engineers, U.S. Army, 1944.

85. Page, W.B. "Arctic Sewer and Soil Temepratures", Water and Sewage Works and Sewage Works, 102(8):304-308, 1955.

86. Page, W.B. "Heat Loss from Underground Pipelines", IN: Science in Alaska - Proceedings, Fourth Alaskan Science Conference, Sept. 28-Oct. 3, 1953, Juneau, Alaska, Alaska Division, American Association for the Advancement of Science, pp. 41-46, 1956.

87. Cameron, J.J. "Waste Impounding Embankments in Permafrost Regions: The Sewage Lagoon Embankment, Inuvik, NWT", IN: Some Problems of Solid and Liquid Waste Disposal in the Northern Environment, Northwest Region, Environment Canada, EPS 4-NW-76-2, pp. 141-230, Edmonton, 1976.

88. Brown, W.G. "Graphical Determination of Temperature Under Heated or Cooled Areas on the Ground Surface", Division of Building Research, National Research Council of Canada, Ottawa, Ontario, Technical Paper No. 163, 1963.

89. Jumikis, A.F. "Graphs for Disturbance - Temperature Distribution in Permafrost Under Heated Rectangular Structures", IN: Proceedings, Third International Conference on Permafrost, July 10-13, 1978, Edmonton, Alberta, National Reserach Council of Canada, Ottawa, Ontario, pp. 589-596, 1978.

90. U.S. Department of the Army "Calculation Methods for Determination of Depths of Freeze and Thaw in Soils", Department of the Army, Washington, D.C., Technical Manual No. 5-852-6, 1966.

91. Moulton, L.K. "Prediction of the Depth of Frost Penetration: A Review of Literature", West Virginia University, Morgantown, West Virginia, Report No. 5, 1969.

92. Nixon, J.F. and McRoberts, E.C., "A Study of Some Factors Affecting the Thawing of Frozen Soils", Canadian Geotechnical Journal, 10(3): 439-452, 1973.

93. Aldrich, H.P. and Paynter, H.M., "Analytical Studies of Freezing and Thawing of Soils", U.S. Army, Arctic Construction and Frost Effects Laboratory, Technical Report No. 42, 1953.

94. Janson, L.E. "Frost Penetration in Sandy Soil", Royal Institute of Technology, Stockholm, Sweden, Transaction No. 231, 1964.

95. Aldrich, H.P. and Paynter, H.M.," Depth of Frost Penetration in Non-Uniform Soil", U.S. Army, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, Monograph 111-C5b, 1966.

96. Lunardini, V.J. "A Correlation of n-Factors", IN: Proceedings, Applied Techniques for Cold Environments, May 17-19, 1978, Anchorage Alaska, American Society of Civil Engineers, New York, New York, pp. 233-244, 1978.

97. McRoberts, E.C. "Ground Thermal Regime", IN: Recent Advances in Permafrost Engineering - Lecture Notes and Reference List, Department of Civil Engineering, University of Alberta, Edmonton, Alberta, n.d.

98. Zarling, J.P. "Growth Rates of Ice", IN: Proceedings, Applied Techniques for Cold Environments, May 17-19, 1978, Anchorage, Alaska, American Society of Civil Engineers, New York, New York, pp. 100-111, 1978.

ABBREVIATIONS

ABS	- acrylonite-butadiene-styrene
AC	- alternate current
ADEC	- Alaska Department of Environmental Conservation
Ak	- Alaska
ASTM	- American Society for Testing Materials
AWWA	- American Water Works Association
BOD	- biochemical oxygen demand
BOD_5	- five-day biochemical oxygen demand
Btu	- British thermal unit
°Cd	- degree-days celsius
°Ch	- degree-hours celsius
cfm	- cubic feet per minute
COD	- carbonaceous oxygen demand
CPE	- chlorinated polyethylene
CSA	- Canadian Standards Association
m^3	- cubic metre
DC	- direct current
DEW	- Defense Early Warning
DFC	- Dominion Fire Commission
DO	- dissolved oxygen
DOT	- Department of Transporation
DWV	- non-pressure drainage, waste and vent work
EPA	- Environmental Protection Service (Canada)
FC	- fecal coliform
°Fd	- Degree-days Fahrnheit
F/M	- food to microorganism ratio
gpcd	- U.S. gallons/capita day
gpm/ft^2	- U.S. gallons per minute per square foot
gpd	- U.S. gallons per day
h/a	- hours per annum
hp	- horse power
kWh/d	- kilowatt hour per day

kg/ha	-	kilogram per hectare
kg/d	-	kilogram per day
kPa	-	kilopascal
kg/m^3	-	kilogram per cubic metre
Lpm	-	litres/minute
lb/cu.yd.	-	pounds per cubic yard
mg/L	-	milligram per litre
mgd	-	million U.S. gallons per day
mH/day	-	manhours per day
MJ/h	-	megajoule per hour
MJ/kg	-	megajoule per kilogram
MLSS	-	mixed liquor suspended solids
m^3/h	-	cubic metre per hour
MW/km^2	-	megawatt per square kilometre
NWT	-	Northwest Territories
NBC	-	National Building Code
O&M	-	operation and maintenance
O.S.H.A.	-	Occupational Health and Safety Authority (U.S.)
O.D. PVC	-	outer diameter polyvinyl chloride
PHS	-	Public Health Service (U.S.)
PVC	-	polyvinyl chloride
psi	-	pounds per square inch
SSU	-	saybolt universal seconds
std.m^3 per kW	-	standard cubic metres per hour per kilowatt
SDR	-	sidewall diameter ratio
TDS	-	total dissolved solids
TOC	-	total organic carbon
TKN	-	total Kjeldahl nitrogen
USA CREEL	-	U.S. Army Cold Regions Research and Engineering Laboratory
WHO	-	World Health Organization
ULC	-	Underwriters Laboratory

GLOSSARY

Active construction:	method of construction in which perennially frozen soil (permafrost) is thawed and kept thawed. Thaw unstable soil or permafrost with excess ice is often excavated and replaced by sand and gravel.
Active layer:	the layer above the permafrost which freezes and thaws annually as seasons change (also called seasonal frost).
Alluvia:	clay, silt, sand, gravel or similar material deposited by running water.
Anadromous fish:	fish that journey up rivers from the sea at certain seasons for breeding (salmon, shad, etc.).
Anchor ice:	see ice.
Arctic:	regions where no mean monthly temperature is greater than 10°C and where at least one month has a mean monthly temperature of 0°C or colder.
Arctic circle:	where at least one day the sun doesn't set in the summer or rise in the winter (latitude 66° 31 'N).
Aufeis:	ice that is formed as water flows over a frozen surface.
Beaded streams:	streams that contain enlargements or "beads" that are caused by the melting of blocks of ground ice along its course.
Bentonite:	a clay type substance used as a drilling mud, which has the ability to expand when water is added to it.
Black water:	wastewater which contains only human toilet waste and a small amount of flushing water, as used in vacuum toilet systems.

Bleeding:	the continuous running of water through taps to maintain a flow in the main service lines and sewers to prevent freezing of pipes.
BOD:	biochemical oxygen demand; a measure of the amount of oxygen required by bacteria to oxidize waste aerobically to carbon dioxide and water.
BOD_5:	the amount of oxygen required by bacteria during the first five days of decomposition (at 20°C).
Bog:	a wet peatland which is extremely nutrient-poor, acidic, and has a tree cover of less than 25% of its area.
Bog soils:	a wet spongy soil composed of decayed mass and other vegetable matter. (Soil in its thawed state has almost no bearing strength.)
Brackish water:	saline or mineralized water with a total dissolved solids concentration of about 1000 mg/L to 10 000 mg/L.
Breakup:	the melting time at which a) ice on rivers breaks and starts moving with the current, b) lakes can no longer be crossed on foot, and c) previously frozen mud is soft and most of the snow is gone.
Cat trains:	trailer trucks or large sleds hitched together in a train-like manner which are then pulled by a snow plow or tractor.
Central facility:	a community facility where one or more sanitary services (washrooms, laundry, showers, etc.) are available.
Central water points:	a potable water supply centrally located within a community where hand-carried containers and/or water trucks are filled.

Coastal ice:	see ice.
COD:	chemical oxygen demand; a measure of the amount of oxygen required to reduce the chemical concentration (such as nitrogen) in the effluent waste.
Cold climate:	the climate experienced in the arctic and subarctic regions of the United States and Canada.
Coliforms:	nonpathogenic fecal bacteria; crude sewage may contain hundreds of thousands of fecal coliforms per cubic centimetre, but only a few pathogens; used as indicators of the water's purity; survive longer in cold clean water than in warm polluted water.
Continuous permafrost:	an area underlaid by permafrost with no thawed areas except under large lakes and rivers that never freeze solid.
Degree-days:	a quantity expressed as the product of "degrees variation from a base" and "time in days". Example: If the temperature averages 5°C for 10 days, there is an accumulation of 50 degree-days of "thaw". (Base for freezing and thawing degree-days is 0°C and base for heating degree-days usually is 18°C.)
Demurrage charges:	the payment rates for detaining a freighter beyond a reasonable time for loading and unloading.
Discontinuous permafrost:	an area underlain mostly by permafrost but containing small areas of unfrozen ground, such as on south facing slopes.
DO:	dissolved oxygen; the amount of oxygen dissolved in water.

Evapotranspiration:	to pass water as a vapour into the atmosphere through the processes of evaporation and transpiration.
Faculative lagoon:	a lagoon that treats wastes aerobically and/or anaerobically.
Fill point:	refers to the truck haul system. This is the location where a water truck fills its water tanks; also refers to the point on individual houses where ice/water is delivered to/through.
Floatation tire:	a large tire that is bloated with air; allows wheeled vehicles to stay on top of the snow.
F/M ratio:	the ratio of the food (organic matter) to microorganisms by weight.
Frazil ice:	see ice.
Freeze-rejection concentrate:	the natural process whereby water slowly freezes, excluding impurities and forming crystals of pure water; impurities rejected from the ice are concentrated in the remaining liquid.
Freeze up:	the time when hardened mud no longer sticks to boots, a traveller can cross rivers and lakes on ice, and sleds can be used on the ground.
Freezing index:	the integrated number of degree-days colder than the freezing point in a winter session.
Frost creep:	a gradual movement usually downhill of soil, clay or loose rock due to alternate freezing and thawing.
Frost-heaving and jacking:	the expansion of soil due to the growth within it of extensive ice whose volume is greater than the (thawed) voids-volume of the soil.

Frost mounds:	a micro-relief of about 1 m formed by intense frost heaving in the active layer.
Frostshield:	an insulated shield that is used to deter the advancement or penetration of frost into the area in question.
Frost-susceptible soil:	a soil that retains large amounts of water, encouraging the growth of ice wedges during freezing, from which frost heaving develops; also defined as a soil passing more than 3 percent through a no. 200 sieve.
Glacial rock flour:	finely powdered rock material produced by the grinding action of a glacier on its bed.
Glacial silt:	particles of crushed rock deposited by glacial streams. The particle size of this silt lies in the range of 0.002 to 0.06 mm.
Glacering:	see icing.
Glacier:	a field or body of ice formed in a region where snow fall exceeds melting.
Glaciolacustrine sands:	the sands of a lake which come from the deposits of a melted glacier.
Grey water:	wastewater from kitchen sinks, showers and laundry, excluding human toilet wastes, as in vacuum sewer systems.
Heat capacity:	the quantity of heat required to raise the temperature of a mass one degree. Therefore, the heat capacity of a body is its mass multiplied by its specific heat.
Heating index:	the integrated number of degree-days colder than some base figure (usually 18°C) during a heating season.

Heat trace system: an electrical system having thermostats and sensing bulbs along the pipe in question, thereby keeping it from freezing.

Honeybags: a plastic or heavy paper bag tht fits into a bucket toilet.

Honeybuckets: a plastic or steel bucket that fits into a bucket toilet.

Ice

anchor: ice formed below the surface of a body of water that attaches either to a submerged object or to the bottom.

coastal: formations that, regardless of origin, exist between land and sea on the coast.

frazil: ice crystals that form in flowing supercooled water which collects on any channel obstructions; usually occurs at night because of the high rate of heat radiation away from the water.

Icebergs: huge mass of ice calved from a glacier.

Ice crypt: a sub-ice chamber or vault found in icebergs and glaciers.

Ice field: an extensive sheet of sea ice that can be several square miles in area.

Ice fog: fog composed of particles of ice, usually caused by steam released into the cold environment or by a large open body of water exposed to the air.

Icing: mass of surface ice formed by successive freezing of sheets of water that can seep from the ground, a river, or a spring. When the ice is thick and localized, it may be called an icing mound. Icing (also known as glaciering, or aufeis ice) can produce ice 3 m thick and 0.8 km long.

Ice-rich ground:	soil containing ice in excess of its thawed voids-volume.
Ice scour:	the marring effect of ice as it moves over the river or stream bed.
Ice wedges:	vertically oriented "V shaped" masses of relatively pure ice occurring in permafrost. The head of the wedge is on top and can be up to 4 m wide, while the wedge itself can be 10 m in height.
Indigeneous people:	people originating in and characterizing a particular region or country.
Infrastructures:	permanent installations and facilities belonging to a community.
Insulating layer:	a layer of sand, gravel wood, or other low heat conductive material for the purpose of protecting the permafrost.
Intrapermafrost water:	groundwater within the permafrost; usually has high concentration of minerals which keeps it from freezing.
Lateral thermal stresses:	the thermal expansion of ice upon a temperature increase towards melting which causes lateral thrusting (stresses).
Leaching fields:	plot of land used for disposing of sewage and and other liquid wastes; by allowing it to percolate through the soil, treatment of the wastes is accomplished.
Lignins:	a brown dye from mosses and other organic materials.

Muskeg:	an Indian (Algonquin) word for bog or peatland.
Non frost-susceptible soil:	a soil that doesn't retain water, thereby not encouraging the growth of ice wedges.
Northern communities:	those communities that lie in the arctic and subarctic regions.
Northern temperate zone:	the northern part of the zone lying between the Tropic of Cancer and the Arctic Circle in the Northern Hemisphere.
Open burning:	uncontrolled burning of wastes in an open dump.
Organic matter:	more or less decomposed material in soil derived from ogranic sources, usually from plant remains or animal and human waste.
Package treatment plant:	a treatment system available as prefabricated "packaged" units.
Passive construction:	method of construction that preserves the permafrost for its structural value.
Pathogenic bacteria:	an organism capable of producing disease.
Peat:	highly organic soil, 50% of which is combustible, composed of partially decayed vegetable matter found in bogs (muskegs) and very frost-susceptible.
Permafrost:	soil, bedrock, or other material that has remained below 0°C for two or more years.
Permafrost table:	the dividing surface between the permafrost and active layer.
Pitorifice circulation:	continuous circulation of water through the water pipes of a house due to a pitorifice; the pitorifice, which is located in the water main and connected to the supply and return service

lines, causes a higher water pressure on one side (for the supply line) and a lower pressure on the other side (for the return line).

Polygonal ground: patterned ground with recognizable trenches or cracks along the polygonal circumference (a surface relief); produced by alternative freezing and thawing of the surface soil above the permafrost.

Potable water: water suitable for drinking.

Pressure ridges: ridge produced on floating ice by buckling or crushing under lateral pressure of wind or tide.

Reach of a river: a straight rapid-free portion of a river.

Sand spit: a narrow, sandy point of land projecting into a water body.

Seasonal frost areas: areas where ground is grozen by low seasonal temperatures and remains frozen only through the winter; in permafrost this refers to the active layer.

Self-haul system: a system where water is carried in containers from a central water point to the home for use or storage.

Service bundle: a set of service lines supplied to the house which is bundled together and is usually enclosed by a cover (see utilidette).

Shore fast ice: a wall or belt of ice frozen to the shore having a base at or below the low-water mark, which formed as a result of the rise and fall of the tides, freezing spray, or stranded ice.

Sink hole: a hole formed in soluble rock or melted permafrost by the action of water going from the surface to an underground passage.

Slump:	a depression/land slide on the land due to the removal of the natural vegetation which causes the underlying massive ground ice in the permafrost to melt.
Snowdrifts:	a mound or bank of snow formed by the wind.
Sludge:	a semiliquid substance consisting of settled sewage solids combined with varying amounts of water and dissolved materials.
Snow/ice roads:	a road made of snow and ice that exists only in winter. These roads, which melt each spring and are reconstructed each winter using the icy surface on the lakes as highways, make travel by land vehicles possible in winter.
Snow fences:	a barrier erected on the windward side of a road, house, etc., serving as protection from drifting snow.
Soil bonding:	the bonding of the individual soil grains by the freezing of water between them; if a pipe is interwoven with soil of this nature it can become locked in place.
Stick built:	an expression referring to on-site construction; all raw materials are brought to the site and the structure constructed there.
Subarctic:	regions adjacent to the Arctic in which one to three calendar months have a mean monthly temperature above 10°C and at least one month that has a mean monthly temperature of 0°C or colder.
Subpermafrost layer:	the layer below the permafrost; it may contain some permafrost islands.
Suprapermafrost layer:	the layer between the ground surface and the permafrost table; this layer contains the

	active layer, year-round thawed areas (taliks) and temporarily frozen areas (pereletoks).
Talik:	a layer of unfrozen ground between the active layer and the permafrost; also applies to an unfrozen layer within the permafrost, as well as to the unfrozen ground beneath the permafrost.
Tannins:	a bluish black or greenish black dye from plant leaves.
Thaw bulb:	a thawed section in the permafrost due to the warming effect of a house, river, lake, etc.
Thawing index:	the yearly sum of the differences between 0°C and the daily mean temperature of the days with means above 0°C.
Thermal erosion:	the undercutting of a frozen tank or shore by melting of the soil from exposure to running water and/or wave action.
Thermal inertia:	the degree of slowness with which the temperature of a body approaches that of its surroundings.
Thermal insulation:	insulation to resist the transmission of heat.
Thermal resistance:	the resistance of a body to the flow heat.
Thermal stratification:	the layering effect of temperature in an enclosed body of water or air due to lack of mixing.
Tidelands:	land alternately exposed and covered by the ordinary ebb and flow of the tide; the only vegetation present is salt-tolerant bushes and grasses.
Tundra:	term applied to the treeless areas in the arctic and subarctic; consists of mosses, lichens and small brush.

Unstable permafrost	a term used to describe permafrost that is not physically stable when melted.
Utilidette:	the enclosure for a bundle of service lines supplied to the house from the utilidor; may or may not be insulated.
Utilidor:	an above or below-ground box-shaped conduit (not necessarily insulated) that acts as an enclosed corridor for a network of pipes and cables which supply community services to individual homes.
Vehicle-haul system:	a vehicle (truck or tractor) system which transports water or ice from a source to individual buildings, and/or a vehicle system for wastewater collection.
Volumetric heat of fusion:	the amount of heat required to melt a unit volume of a substance at standard pressures.
"Warm" permafrost:	arbitrarily defined as permafrost that has a temperature of -4°C or greater.
Water wasting:	see Bleeding.
Watering point:	see central watering point.
Wetlands:	general term, broader than muskeg, to name any poorly drained tract, whatever its vegetation cover or soil.
White-out:	blowing snow so thick that you cannot see your hand in front of your face.
Windchill factor:	the cooling effect of both temperature and wind on a body, expressed as a temperature which is equivalent to the heat lost per unit of time.
Sporadic permafrost:	isolated masses of permafrost located within an area generally thawed during the summer.

APPENDIX A

PIPE MATERIALS

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A. PIPE MATERIALS

A.1 Plastic Pipes

Plastic pipe is relatively new compared to other pipe materials. Plastics that have lower modules of elasticity are more ductile at low temperatures. Plastic pipes essentially do not corrode at the temperatures encountered in water and sewer lines, but some types are sensitive to sunlight. They have a large coefficient of expansion which definitely must be taken into account in design. The properties of different plastics are given in Tables A-1 and A-2. Steam or water of over 60°C must not be used to thaw plastic pipes. Plastic pipe is light-weight, about 18 kg per length of 10 cm nominal diameter. Because it is relatively smooth it has lower head losses than any other pipe materials. The Hazen-Williams coefficient (C) for plastic pipes is 150.

A.1.1 Polyvinyl chloride (PVC)

Polyvinyl chloride type I has relatively good thermal characteristics and can be used in -40°C temperatures. It has lower impact resistance but higher chemical resistance and pressure ratings than PVC type II or polyethylene (PE) at a given temperature. Exposure to sunlight and climate conditions does no noticeable harm to it. Because of its ease of fabrication, piping systems can be fabricated by inexperienced labour in the field. Type II has higher impact resistance but a lower pressure rating for the same dimensions.

PVC is unaffected by corrosive soils or fluids, sea water, and oils at temperatures below 21°C. Pressure ratings and abrasive resistance drop off quickly at higher temperatures.

SDR is the standard pipe dimension ratio and is the ratio of pipe diameter to wall thickness. Seven standard values are 13.5, 17, 21, 26, 32.5, 41 and 64.

Hydrostatic design stress (HDS) is the maximum tensile stress in the wall of the pipe due to the hydrostatic pressure inside. The following equation rates PVC pipe:

$$\frac{2(\mathrm{HDS})}{\mathrm{P}} = (\mathrm{SDR}) - 1$$

TABLE A-1. PROPERTIES OF PLASTICS*

	Polyvinyl Chloride Type II	Polyvinylidene chloride (Saran)	TFE polytetrafluoroethylene (Teflon)	CFE polychlorotrifluoroethylene	Vinylidene fluoride	Chlorinated polyether	Polypropylene
<u>Service Temperatures</u>							
Max intermittent °C	71	82	260	227	--	159	159
Max continuous °C	60	71	232	199	159	121	121
Min continuous, °C	-18	-40	268	-196	-184	--	--
<u>Physical Properties</u>							
Specific gravity	0.135	1.7	2.2	2.1	1.7	1.4	0.90
Thermal conductivity cal/cm s°C	0.48	0.20	0.56	0.41	0.56	--	0.32
Coef. of thermal expansion m/m - °C x 10^{-5}	2.8	4.4	3.1	2.2	4.7	2.4	2.6
Specific heat, Cal/kg-°C	0.28	0.32	0.25	0.22	0.33	0.2	0.46
Water absorption (24 hr) %	0.30	0.10	Nil	Nil	0.04	0.01	0.03
Flammability	Self extinguishing	Self extinguishing	Nonflammable	Nonflammable	Nonflammable	Self extinguishing	
<u>Mechanical Properties</u>							
Tensile strength 1000 kg/cm^2	0.35-0.49	0.28-0.42	0.07-0.21	0.35-0.42	0.49	0.35-0.49	0.28-0.42
Compressive strength 1000 kg/cm^2	0.56-0.70	0.49-0.63	0.04-0.05	0.14-0.21	0.70	0.56-0.70	0.63-0.77
Flexural strength 1000 kg/cm^2	0.70-0.84	0.42-0.56	no break	0.49-0.63		0.28-0.42	0.49-0.63
Impact strength (Izod notched) N	640-694	low	160-214	214-267	214	low	53-107
Mod. of elasticity in tention kg/cm^2	0.21-0.28	53-107	0.03-0.04	0.15-0.17	0.08	53-107	0.11-0.13
Hardness, Rockwell	R105-115 6-8	R115-105 6-8	R85-95 150-250	R110-120 25-35	80 Shore D 300	R95-105 75-125	R85-95 10-20

* SI units by Manual Committee

TABLE A-1 (CONT'd)

	Asbestos-filled phenolic	Asbestos-filled furane	Glass Fibre-filled polyester	Glass Fibre-filled epoxy	ABS acrylonitrile-butadiene styrene	High Density polyethylene	Polyvinyl chloride Type I
Service Temperature							
Max Intermittent °C	177	159	135	159	82	121	177
Max continuous, °C	159	121	107	121	71	104	66
Min continuous, °C	--	--	--	--	--	--	--
Physical Properties							
Specific gravity	1.7	1.7	1.5	1.5	1.07	0.96	1.4
Thermal conductivity cal/cm s °C	0.81	0.81	0.60	0.60	0.32	0.77	0.40
Coef. of thermal expansion m/m - °C x 10^{-5}	1.1	1.7	1.5	1.4	1.8	3.9	2.06
Specific heat, Cal/kg-°C	0.3	0.3	0.3	0.3	0.32	0.54	0.25
Water absorption (24 hr) %	0.2	0.2	0.2	0.1	0.3	0.02	0.10
Flammability	Self extinguishing	Self extinguishing	Slow burning	Slow burning	Burns	Burns	Self extinguishing
Mechanical Properties							
Tensile strength, 1000 kg/cm^2	0.35-0.49	0.28-0.42	0.91-1.05	1.05-1.20	0.28-0.42	0.21-0.35	0.49-0.63
Compressive strength, 1000 kg/cm^2	0.77-0.91	0.77-0.91	1.83-1.97	183-197	0.42-0.49	Poor	0.63-0.77
Flexural strength, 1000 kg/cm^2	0.42-0.49	0.49-0.56	1.76-1.83	2.04-2.1	0.63-0.70	0.13-0.14	1.05-1.20
Impact strength (Izod notched) N	0-53	0-53	694-747	694-747	267-320	427-534	
Mod. of elasticity in tension 10^5 kg/cm^2	1.20-1.34	0.98-1.12	0.84-0.98	0.35-0.63	0.21-0.28	0.07-0.08	0.28-0.35
Hardness, Rockwell	R105-115	R105-115	M90-100	M90-100	R40-50	R40-50	R115-125

TABLE A-2. MECHANICAL PROPERTIES OF PLASTICS*

Plastic	Temp. °K	Ultimate tensile strength $kg/cm^2 x10^{-3}$	Compressive yield strength $kg/cm^2 x10^{-3}$	Young's modulus $kg/cm^2 x10^{-6}$
Teflon	295	0.14	-	0.004
(Polytetraflu-	195	0.39	-	0.018
oroethylene)	153	0.56	0.63	0.038
	77	1.05	1.29	0.052
	20	-	1.76	-
	4	-	1.90	0.07
Polyethylene	3300	0.09	-	0.001
	4	-	1.76	-
Polyvinylchlo-	293	0.54	-	0.037
ride	198	1.22	-	0.039
	77	1.38	-	0.078
Nylon	293	0.67	-	0.030
	198	1.41	-	0.039
	153	1.71	-	0.053
	77	1.96	-	0.077

* SI by Manual Committee.

where P = the pressure rating of the pipe in psi or kPa. (HDS is in psi or kPa).

The most common PVC pipe materials are:

a) Type I, Grade 1 - HDS = 13 800 kPa @ 23°C (#PVC 1120).

b) Type I, Grade 2 - HDS = 13 800 kPa @ 23°C (#PVC 1220).

c) Type II, Grade 1 - HDS = 6 900 kPa @ 23°C (#PVC 2110).

d) Type IV, Grade 1 - HDS = 11 000 kPa @ 23°C (#PVC 4116).

PVC is also available in Schedules 40, 80 and 120, which roughly correspond to iron pipe sizes and have more uniform wall thickness for different sizes within each schedule. This sizing procedure results in small diameter pipe having a much higher pressure rating than a larger pipe in the same class. Both of these general types (SDR or Schedules) are designed for pressure applications. PVC pipe designed specifically for sewer use is thin-walled and breakable and should not be used in cold regions.

PVC pipe is covered by the following American Society for Testing and Materials (ASTM) specifications:

a) PVC pipe and fittings (SDR classes) in D-2241

b) PVC pipe and fittings (Sch. 40, 80, 120) in D-1785

c) PVC sewer pipe and fittings in D-3034

A.1.2 Acrylonite-butadiene-styrene (ABS)

Acrylonite-butadiene-styrene has also been used for sewer mains, service lines, and drainfield installations. This pipe is not as readily available as PVC is some sizes. In general, it has a higher impact strength than PVC in the more common types but it requires a thicker wall to be equivalent to PVC in pressure rating. Ratings and nomenclature for different type of ABS pipe are basically the same as those for PVC.

ASTM standard specificatons covering ABS pipe are as follows:

a) ABS pipe and fittings (SDR classes) in D-2282

b) ABS pipe and fittings (Sch. 40, 80, 120) in D-1527

c) ABS sewer pipe and fittings in D-2751.

Recommended design information is available from manufacturers and should be followed closely. Advantages, disadvantages and recommended joints are basically the same as for PVC. ABS pipe is used quite extensively for building plumbing. It is more susceptible to sunlight and the atmosphere (ozone) than PVC.

A.1.3 Polyethylene (PE)

Polyethylene is flexible and impact resistant even at low temperatures, particularly for the higher molecular weight materials. It comes in various molecular weights.

Pre-insulated PE pipe has become quite popular in cold regions. One significant advantage of high molecular weight PE (HDPE) is that it ca go through several freeze cycles without damage to the pipe. If successful, this would be a definite advantage to cold regions.

It can be joined using compression type fittings or clamps, or i can be butt fused (essentially welded) together.

By itself, it is not rigid enough under most conditions to hold proper grades in a gravity sewer line. It does gain rigidity when it is covered with urethane insulation and then an outer covering of PE or metal culvert.

A.2 Metal Pipes

The greatest disadvantages of metal pipes are probably the lack of corresion resistance and the weight of the pipe. Sewer pipes are usually epoxy or cement-lined and also coated on the outside. The advantages of metal pipes include high strength and rigidity but because o this they will split when frozen solid. Bedding does not have to be as carefully done as with other types and they can tolerate some movement. They can be thawed electrically, but for large diameter pipes, such as those used in sewers, this is a very slow and expensive method of thawing (see Apppendix F).

Some of the characteristics of various metal pipes are presented below.

Cast Iron:

1) A 6-m section of 100-mm pipe weighs about 227 kg.
2) Do not use it unlined.
3) It will crack or break if mishandled (dropped, etc.).
4) $C \approx 125$.
5) The Handbook of Cast Iron Pipe, published by the Cast Iron Pipe Research Association contains detailed information on cast iron pipe.

Ductile Iron:

1) It is a little lighter than cast iron.
2) It is cast iron pipe whose structure has been changed to make it more ductile and flexible.
3) $C \approx 125$.

Although other types of joints are available, bell and spigot joints with rubber gaskets are generally the best choice for cast and ductile iron. The pipes are covered by the following ASTM standard specifications:

- Cast Iron and Ductile Iron Pressure Pipe - in A-337,
- Cast Iron Soil Pipe and Fittings - in A-74,

American National Standards Institute specifications for ductile iron pipe are A21.51 for the pipe and material, A21.6 for the pipe coating, A21.4 for the cement lining, and A21.11 for Tyton type gaskets.

Steel:

1) It is less corrosion resistant than either ductile or cast iron.
2) It is somewhat lighter than either ductile or cast iron and it is more flexible. It should be lined with cement or epoxy linings.
3) It can be welded to make it self-supporting.
4) $C \simeq 125$.

A.3 Asbestos-Cement Pipes

Asbestos-cement (AC) and concrete pipes are brittle and should not be used where any movement can occur. Damage can also occur during shipping. It is only available in short lengths and AC pipe weighs about 8.6 kg/m for 100-mm pipe. Cement pipes are also subject to corrosion by sewer gases. Testing with air pressure may not be accurate with concrete because of the concrete porosity.

A.4 Wood Stave Pipes

An advantage of wood stave pipe in cold regions is that it can usually take freeze-thaw cycles with little damage. Also, the thick wood walls offer a degree of insulating valve.

It is relatively corrosion free except for the spirally wound wire on the outside which must be coated if it is exposed to corrosive conditions. It is relatively expensive and is only available in short lengths. It has a C coefficient of about 140 which doesn't change significantly with time.

A.5 Pre-insulated Pipes

The U.S. Public Health Service has developed an insulated pipe, shown in Figure A-1, with the following characteristics.

1) It is on the U.S. Federal Supply Schedule (Contract #GS-10S-34039).

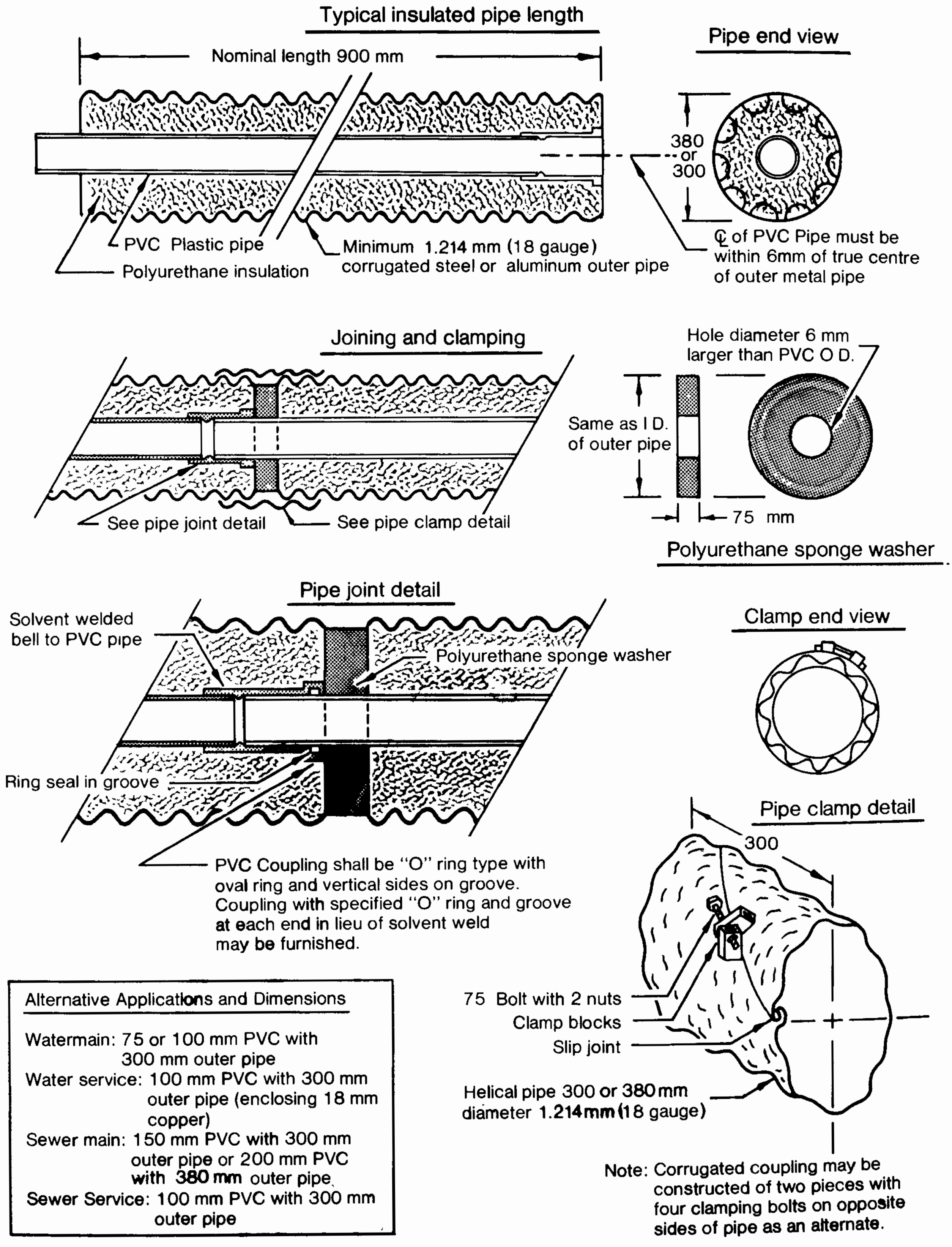
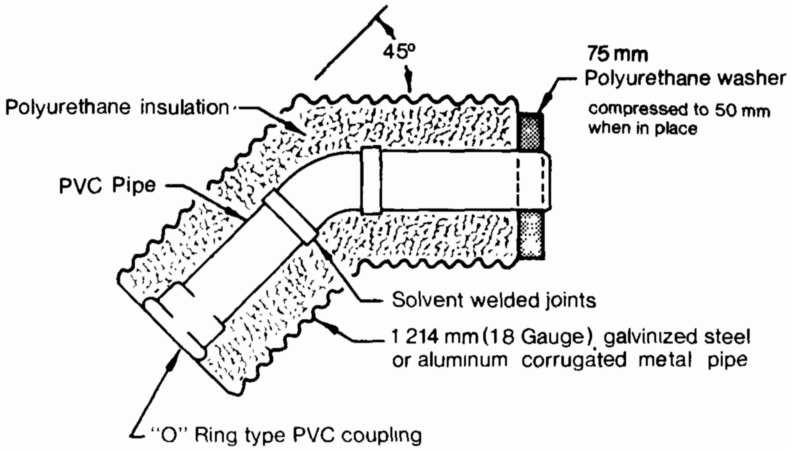
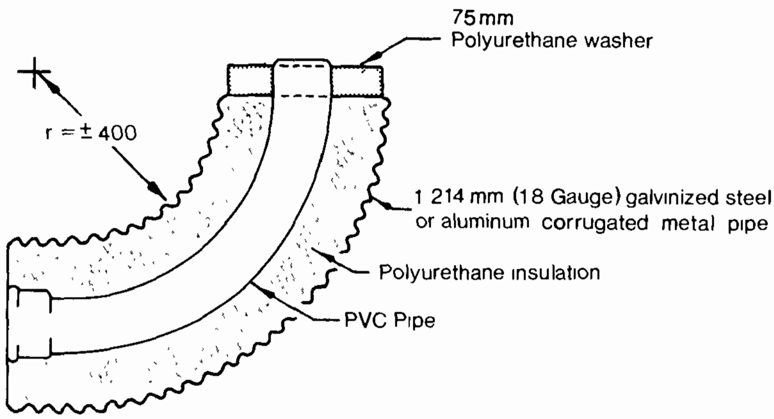


FIGURE A-1. ARCTIC CONDUIT PRE-INSULATED PIPE

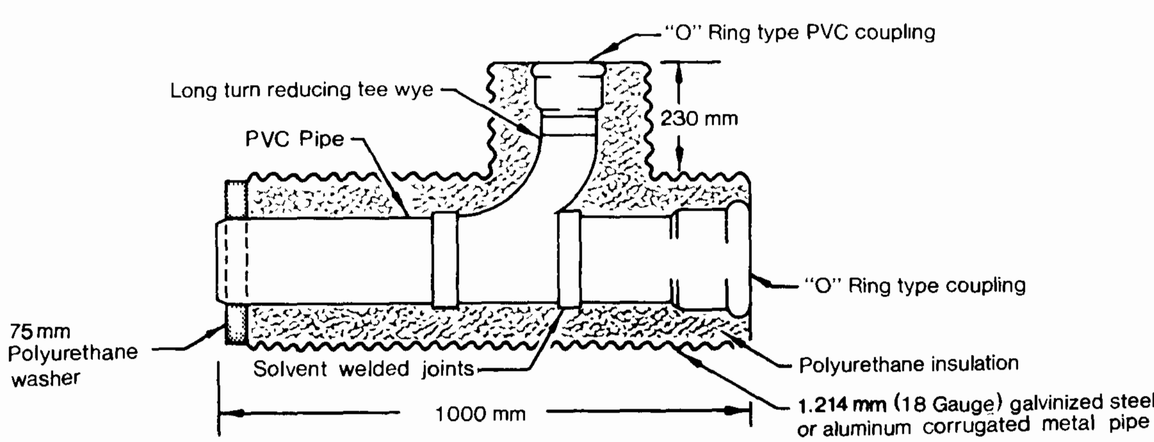
2) It can be obtained with several prefabricated fittings, some of which are shown in Figure A-2.
3) Heat loss for a 100-mm pipe within a 300-mm metal outer pipe with -12°C ambient temperatures and 4.4°C water temperature, is approximately 2.4 W/m. This represents a temperature drop of approximately 0.1°C/km of pipe if water is circulated and is flowing at a rate of 6.3 L/s.
4) The plastic pipe has a high coefficient of expansion, but this system has an expansion joint each 6 m. For a temperature change of 67°C, the pipe length changes about 25 cm per 100 m. This is about three times greater than copper.
5) The polyurethane sponge washer is designed to fill the entire space between the two pipe lengths even with contraction and expansion. This keeps moisture out. The band on the culvert prevents lengths from pulling apart.
6) If desired, the inner pipe (carrier pipe) and/or outer pipes can be steel, PE or other material. Also, other types of joints could be used with modifications to the design.



Prefabricated 45° bend



Prefabricated 90° long sweep bend



In-line sewer service wye

FIGURE A-2. INSULATED FITTINGS FOR ARCTIC CONDUIT

APPENDIX B

WATER CONSERVATION ALTERNATIVES

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B WATER CONSERVATION ALTERNATIVES

The benefits of water conservation, whether philosophical or economical, will vary with the local conditions and utility system. Generally, utilities delivery system costs are higher in cold regions, and the benefits and need for conservation can be greater. Water and concomitant energy conservation considerations in a northern setting are summarized in this Appendix from a review by Cameron and Armstrong [1].

B.1 Benefits of Water Conservation

Water conservation will reduce the total and peak demands on community water and sewer systems. This reduces the necessary capacity and cost of these systems, and hydraulically designed wastewater treatment facilities. Alternatively, water conservation may extend the life of present facilities and/or allow the servicing of more consumers. Variable operating costs, such as for pumping, heating, chemicals and labour, for all utility systems, will be reduced. In locations with a limited water supply, water conservation is imperative.

Trucked systems have a relatively high and constant unit price, and water conservation is essential to make this system viable and competitive with piped systems. For buildings individually served by wells and septic field systems the benefits are site-specific. In locations with a limited water supply, the efficient use of water is imperative.

The consumer will benefit from reduced utility system capital and operating costs through lower bills, even though the unit price may be higher in order to return the necessary revenue to the utility operators. The individual will also benefit from reduced hot water consumption through lower energy bills and the convenience of increased capacity from existing hot water heating systems. Water conservation in existing buildings served by trucked systems may reduce the need for frequent servicing. For both trucked and piped systems, many water conservation methods and devices will increase the reliability and quality of service. Agencies that subsidize energy production and/or water and sewer services, either directly or indirectly, may receive part or all of the economic benefits of reduced consumer water demand.

B.2 Water Use

The method of water distribution and wastewater collection is very significant in establishing water consumption. Communities in the North with individual-haul or delivery to houses without plumbing use only about 10 L/person/d. Water consumption increases dramatically in houses which are equipped with pressurized hot and cold water plumbing systems including bathtubs, showers, toilets and sinks, and where a community utility system exists. A household of four persons on a trucked systems with full conventional plumbing can be expected to consume approximately 95 L/person/d. For a similar household on a piped system consumption is about 225 L/person/d. Lower water use for the trucked households can be attributed to a lower internal water pressure obtained from the individual pressure pumps, and a general consciousness of a limited water supply, resulting in changes in water use habits and installation of some water conserving devices.

Figure B-1 illustrates the mean values of several studies which measured piped household water distribution. Naturally, there may be significant variations within individual households.

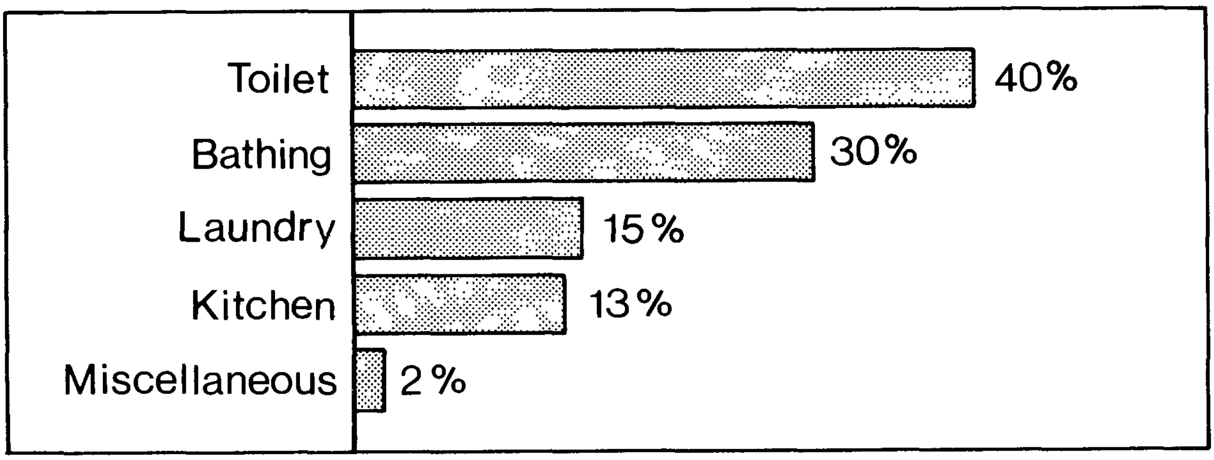


FIGURE B-1. HOUSEHOLD WATER USE DISTRIBUTION

B.3 Water Use Influences

Water demand is dependent upon many factors, including the type of utility system, building plumbing, number of occupants or building function, socio-economic status, climate and price. Other factors peculiar to northern locations include the practices of bleeding of water to prevent freezing of water and sewer lines, and overheating water in the mains, which wastes a considerable volume of water because of attempts to obtain a cold supply.

For the individual household, total water use increases as the number of persons living in the house increases, but the per person consumption decreases. This is partly because there is a quantity of water used to perform certain household tasks regardless of the number of occupants. The socio-economic level of the household also influences water use and may be indicative of a different type or level of water and sewer service. The climate mainly influences only the outdoor water usage. Outdoor uses in northern regions are often minimal because of the short summers and fewer lawns.

The rate structure and pricing policy can be used to manipulate water consumption. The various rate structures that have been used include: flat rate (constant price per month); uniform rate (constant price per litre); declining block rate (decreasing price per litre); increasing block rate (increasing price per litre); demand and peak load rates; and seasonal pricing.

Without metering, the same flat rate is charged regardless of consumption and there is no incentive, economic or otherwise, for the consumer to reduce water use. Consumers who pay a flat rate usually utilize 30% to 50% more water than metered customers. With all of the other rate structures, water consumption can be influenced to some degree.

Consumer response to changes in the price of water will depend on the present uses of water, the existing price level, the portion of consumer income spent on water, and the availability and cost of methods or technology to substitute or reduce the requirements for water. This is only true if water is metered and the consumer is charged accordingly.

With the notable exception of a flat rate, any unit price scheme can equitably return adequate revenue while encouraging efficiency. The unit price should reflect the actual cost of service, particularly the marginal unit price. For piped systems, this is typically a decreasing unit price due to economy of scale and minimum sizing for fire protection. For trucked systems, the unit cost is relatively constant, since variable costs such as labour and fuel are significant. Administrative practicalities and subsidies will distort, or even dictate, the pricing scheme and price.

B.4 Water Conservation Technology

Cultural attitudes and the users' personal biases must be considered when encouraging or implementing water conservation. Utility operators or subsidizing agencies interested in reducing water use should initiate a public information and education campaign that involves the consumers. Changes in wasteful attitudes and behavioral practices, combined with knowledge of simple water conservation hints and an awareness of the benefits of water conservation, can produce a reduction in total water demand. Water conservation devices can further reduce waste and conveniently increase the efficiency of water use.

In some situations, existing plumbing codes may impede the use of water conservation devices, but they have also been successfully used to reduce consumption.

Toilets use more water than any other single fixture within the home. Conventional toilets, which typically use 20 L/flush, can be easily modified by the homeowner to reduce water consumption during flushing. Various toilet modifications are described in Table B-1 and range from simple homemade devices, such as weights or plastic bottle inserts, to inexpensive manufactured dams or dual flush attachments. A more expensive modification, applicable for piped systems, replaces the reservoir tank with a small pressure tank.

There are also a number of low water use toilets available. The lowest use flush tank toilet unit is the 3-L model manufactured in Sweden. The lowest use fresh water flush toilets are the recirculating toilets. These require an initial charge of water and chemicals or other additives. A number of toilet alternatives that do not require any water are also available. These toilets, along with the low water use types, are summarized in Table B-2. It is important to note that not

Table B-1 Toilet modification alternatives

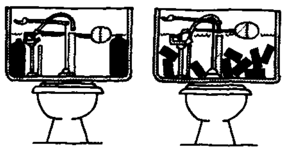
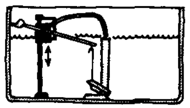
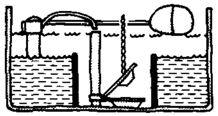
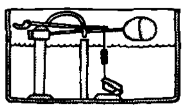
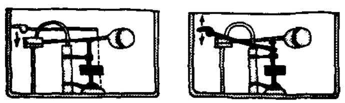
	Principle of operation	Advantages	Disadvantages	Hookups required	Consumption	Approximate cost	
						Capital	Operating
Bricks or plastic bottles 	Bricks or plastic bottles filled with water and weighted with small stones or completely filled with sand or gravel are inserted into the toilet tank. For each flush they displace and, therefore, save water equal to their volume.	Inexpensive, easily installed homemade devices usually consisting of discarded household items. If inadequate flushing results, plastic bottles can be cut reducing the size until the toilet flushes satisfactorily	Bricks deteriorate in water and particles will clog water jets and lodge under the flush valve causing a continuous leak. They can also crack the tank if dropped or fall over, and multiple bricks will inhibit the flow of water around them. Bricks are not recommended Plastic bottles can shift and interfere with the flushing mechanism and if filled with sand and not properly sealed, escaping sand can lodge under the flush valve resulting in a continuous leak	None	Depends on size. Two bricks or two plastic bottles will save approximately 2 litres or about 10% per flush.	Low to none for homemade.	None
Improved float assemblies 	Replaces existing conventional float ball and fill valves, allowing water levels to be lowered and adjusted to use exactly the minimum amount of water necessary for efficient flushing.	Improves flushing efficiency and some will facilitate the detection of leaks Potentially more durable than conventional replacement equipment due to less wear. Valve on leak signaling type is always in fully open or closed position, therefore, is quieter than slow closing conventional ballcocks.	Water savings are essentially limited to the elimination of leaks. Slightly higher cost than conventional replacement equipment.	Connects to toilet water line.	Depends on existing mechanism, therefore, savings can vary from none to significant. Very little data is available on how much water is lost due to leakage.	\$6. - \$10.	None
Dams 	Plastic or metal wall is inserted into toilet tank in a verticle position and sealed against the sides and bottom of tank. Some types encircle the flush valve outlet, but all prevent the lower portion of water from draining out of the tank when the toilet is flushed.	Easy to install and will reduce water usage more than homemade devices. Will not Interfere with static head or flush mechanism Types made of metal and rubber are potentially more durable than those made of plastic.	Some types are not adjustable to allow only the minimum amount of water for efficient flushing to be released. Due to the age and design of some toilets they may not give an adequate flush.	None	Saves approximately 35% or about 7 litres per flush.	\$4. - \$8.	None
Weights 	Attached to the ball-chain or rod. After the desired amount of water is flushed the flush handle is released, and the weight immediately forces the stopper back into the flush valve seat, and flow stops	Nearly as effective as dams in reducing water consumption and can be used in conjunction with dams to maximize savings Can be homemade.	Negates the normal operation of the toilet flush mechanism and user must hold down handle for both solid and liquid waste until the desired quantity of water has been released. Commercial types have no advantage over homemade varieties.	None	Saves an average of approximately 30% or about 6 litres per flush.	\$ 80 - \$8. None for homemade	None
Dual-flush mechanisms 	Single action type can be a counterweight, floating cylinder or air bleeder mechanism which manipulates the flush valve stopper. When toilet is flushed normally, only a portion of flush water is released. For a full tank flush, the flush handle is held down. Double action types replace existing flush valve assembly. The flush handle moves in one direction for low volume flush (liquid wastes) and in the opposite direction for full flush (solid wastes).	Allow for user choice in flush quantities. Can be used in conjection with dams.	Single action types require handle to be held for full tank volume flush Air bleed types could become clogged with water deposits or dirt. The double action flush mechanism is difficult to install and since it is not adjustable, it may not give an adequate flush in all toilets	None	Saves approximately 50% for low volume flush resulting in an average total saving of approximately 30% or 6 litres per flush.	\$3 - \$15.	None
Replacement tanks 	Mounts on existing toilet bowl replacing the whole reservoir tank with a pressure tank cartridge and cover. Water entering the empty tank compresses the air inside, stopping when water and air pressure are equal. When toilet is flushed, compressed air and gravity force water into the bowl.	Uses about half the water used by a conventional toilet tank.	Expensive and more difficult to install than other devices. Somewhat noisy at high pressure and may not work adequately on systems with water pressure less than 240 kPa.	Mounts on standard toilet bowl and must be connected to water line.	Uses approximately 9.5 to 11.5 litres per flush, therefore, saves approximately 50%.	\$65. - \$95.	None

Table B-2 Toilet alternatives

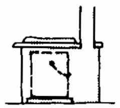
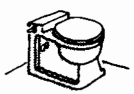
	Principle of operation	Advantages	Disadvantages	Hookups required	Consumption	Approximate cost	
						Capital	Operating
Outhouse 	Wastes biodegrade in pit and seep into soil Pit gradually fills and outhouse must be moved.	Easy, inexpensive, no pipes, no water required, no moving parts	Unpleasant odors, cold in winter, inconvenience of access, can contaminate water sources. Not applicable for use in developed communities or in areas with permafrost Must be periodically moved to new site.	None	None	\$0-\$150	\$0
Bucket 	Wastes drop directly into bucket with deodorizing chemical or into plastic "honeybag " Bucket is dumped and recharged periodically or "honeybag" is removed for pick-up and replaced with fresh bag	Inexpensive, simple, no water required, no moving parts.	Little more than an indoor outhouse. Removal of wastes from the building and the collection and disposal is often unsanitary. Collection should be 5 times per week.	Vent only	None	\$25-\$100	Varies, but is low. Some require chemicals and/or plastic bag inserts (5¢/bag).
 Conventional	Wastes are syphoned through a trap by a sudden rush of water from the tank reservoir.	Sanitary, odorless, relatively easy to repair and inexpensive to buy.	Uses large quantities of water to transport small quantities of wastes Ultimate disposal of sewage is a problem. Requires pressure water supply and piped gravity sewage collection system.	9 5mm water 75mm waste	15-30 litres/flush avg 20 litres/flush	\$60-\$240 Some as high as \$500	Depends on cost of water; family of four would use approximately 400 litres per day for flushing.
Shallow trap	Same as above, except has a shallower trap and smaller reservoir tank.	Same as above, except toilet water use is approximately 33% less than conventional	Same as above except uses less water	same as above	13-16 litres/flush avg 14 5 litres/ flush	\$80-\$200	Same as above except family of four would use approximately 290 litres per day for flushing.
 European 6L	Wastes are syphoned through a trap by a sudden rush of water. Has shallow trap and smaller reservoir tank than conventional Models with 9 litre flush available	Sanitary, odorless, toilet water use is approximately 70% less than conventional	Sewer pipe connection is centred at back of toilet therefore may present retrofit problems. Performance not as good as conventional North American toilets, particularly for non-human waste materials.	9 5mm water 75mm waste	6 litres/flush	\$170-\$225	Depends on cost of water, family of four would use approximately 120 litres per day for flushing.
European 3L	Same as above with smaller trap and water mirror.	Same as above, except toilet water use is approximately 85% less than conventional.	Same as above but connection must be to a ground tank, not a piped sewage collection system Several recommendations for installation with respect to sewer pipe size, slope and maximum distance. These may inhibit use as retrofit.	same as above	3 litres/flush	\$220	Same as above except family of four would use approximately 60 litres per day for flushing.
Flush valve 	Handle releases high velocity water injection producing swirl effect to syphon wastes through a trap	Eliminates need for bulky reservoir tank and generally have a shorter pre-fixed cycle and quicker recovery time. Toilet bowl is well cleaned by flushing action	Depend on water line pressures and will be affected by pressure changes due to use of other fixtures Requires 25 mm water service line, therefore, is not applicable for household use.	25mm water 75mm waste	8 5-16 litres/flush	\$100-\$175	Depends on cost of water; family of four would use approximately 170-320 litres per day for flushing.
Air pressure 	Wastes and flush water drop from bowl into a secondary chamber where an air charge is induced to pressurize and eject water and waste materials into discharge line.	Uses little water and will retrofit into conventional plumbing system. Same air compressor can be used on multiple toilet installation. Does not have reservoir tank	Requires air compressor or compressed air bottle and operation is relatively complex. High capital cost plus power requirement for air compressor or recharging of air bottle.	9 5mm water 75mm waste compressed air at 410 kPa or electricity for compressor.	2 litres/flush	Vitreous China \$600-\$675 Stainless Steel \$800-\$875 Air Compressor \$400	Cost of water and electricity. Family of four would use approximately 40 litres per day for flushing and 15 kW·h per year to run compressor.

Table B-2 Toilet alternatives (continued)

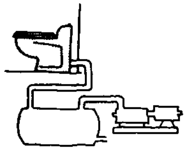
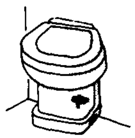
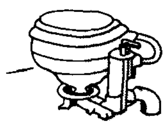
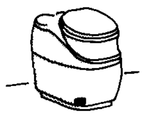
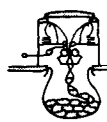
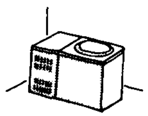
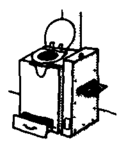
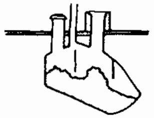
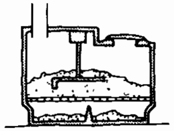
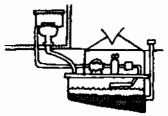
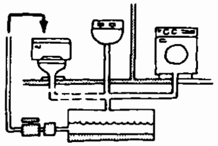
	Principle of operation	Advantages	Disadvantages	Hookups required	Consumption	Approximate cost: Capital	Approximate cost: Operating
 Vacuum	Vacuum toilet connected to special valve mechanism and discharge piping. Utilizes an air pressure differential created by partially evacuating the air from the pipe network to transport slugs of wastewater through small diameter piping to central collection vacuum tank.	Uses little water and toilet does not have reservoir tank. Collection system uses small diameter plastic pipe which can be installed relatively independent of grade. Vacuum mains can be laid in same trench as watermains and have less heat loss due to lower volumes of fluid transported. Can be connected to multiple units within the same building or community.	Relatively complex operation and high capital cost. System requires back-up pumps and power. Installation requires qualified personnel	9.5mm water 38mm waste electricity at collection tank for vacuum pump	1 litre flush	Individual building approx. $3500 Community systems vary.	Cost of water and electricity to run vacuum pump.
Mechanical seal 	Pedal or handle opens valve in bottom of bowl and actuates swirl of fresh water to rinse bowl. Also, portable models with detachable holding tank for dumping of waste.	Fresh water flush but very low water use. No chemicals or re-circulating. Can be used as portable unit with holding tank.	Sewer lines will clog due to low volume flush, therefore should only be used when there is a relatively straight drop into a holding tank. Portable unit must be dumped and recharged.	Varies from none to 9.5 mm water to 75 mm waste to holding tank.	.5 litres/flush	$75–$175	Depends on cost of water. Family of four would use about 10 litres per day for flushing. Portable model requires deodorizing chemical
Marine 	Hand or electric pump brings water into bowl. Valve is turned, same pump ejects wastes. Can pump wastes uphill.	Relatively low water usage. Can pump its waste uphill. Pumps its own water and could be used as a recirculating toilet.	Clogs relatively easily. Relatively complicated to use. Power consumption for electric models	19 mm water 38 mm waste 120V or 12V for electric models	1 litre/flush, electricity for some models	$100–$400	Depends on cost of water and nominal power for electric models
Recirculating 	Hand and/or electric pump swirls filtered, chemically treated waste-water from holding chamber to flush and rinse bowl. When full, unit must be dumped and recharged with chemical and water. Portable or fixed models available.	Uses very little water. Fixed units can be used with conventional plumbing, usually discharge to holding tank.	Relatively complex and some larger commercial models expensive to buy. Requires dumping and recharging with chemicals every five days for family of four.	Varies from no hook-ups to 120V or 12V, 9.5 mm water; and/or 75 mm waste to holding tank or sewer.	0 2 litres fresh water/flush, electricity for some models	$90 (portable) $350 (fixed) Up to $3000 for public washroom system.	Depends on cost of water and nominal power for 12V elecric models. Family of four would use 4 litres per day. Chemical cost approx. $ 50 per charge or $0.10 per day for a family of four.
Packaging 	Wastes drop into plastic lined bowl. The continuous tube of plastic is drawn down through the bowl and is heat sealed to form a series of "sausages." Plastic bag under toilet collects "sausages" which must be periodically removed.	Handling of waste is improved. Odors and breakage of bags is minimized by isolating small quantities of waste in separate "sausages."	Expensive to buy and use. Requires plastic liners, collection bags and electricity. Collection and ultimate disposal of bags must be organized and can create problems.	120V electricity	Electricity, no water	$500–$1000	Manufacturer claims electrical consumption is 1 kW·h per 3400 uses. Costs for regular changing of collection bags and liners
Freezing 	Wastes drop into plastic bag in a small freezing compartment. When full, bag is removed for pick-up and replaced with new bag.	Freezing prevents decomposition, odors and handling of waste is much easier and more sanitary and acceptable.	Relatively expensive to buy, requires plasticized bags, and electricity. Power failure or defrosting reactivates decomposition. Collection and ultimate disposal of bags must be organized and can create problems.	120V electricity	Electricity, no water	Approx. $400	Costs for 120 watt compressor and collection bags.
Incinerating 	Wastes are incinerated in timed cycle after each use. Ash must be removed periodically. Models use electricity or gas.	No liquid waste generated and very little ash to dispose of. Reduces pollution.	Uses considerable energy. Some models require use of paper bowl liner with each use. Relatively complex mechanism. Must be vented.	120V or 220V (recommended) electricity, or optional 9 5 mm gas with 120V or 12V optional, 100 mm vent	Electricity or gas, no water	Approx. $650 – $1000	Depends on cost of energy. Uses approx. 0.1 cubic meters gas or 1 kW·h per use. Also, bowl liners and odour control catalyst.

Table B-2 Toilet alternatives (continued)

	Principle of operation	Advantages	Disadvantages	Hookups required	Consumption	Approximate cost	
						Capital	Operating
Composting (large) 	Kitchen garbage and human wastes are digested by microorganisms, producing fertilizer.	End product, compost, can be used as fertilizer Reduces pollution No water, sewer or electrical hookups required No moving parts Little maintenance	High initial cost for unit and installation Unit is very large, requiring considerable basement space.	150 mm vent	none	$1500-$2500	None, some value created in fertilizer
Composting (small) 	Same as above, except compact and uses forced air circulation and heat to speed process	No water or sewer hookups required. Unit is relatively small and can be installed in conventional washroom. End product, compost, can be used as fertilizer. Reduces pollution.	Expensive to buy and relatively complex to maintain and operate properly. Requires significant energy input and can not handle shock loading of organic and liquid wastes.	120V electricity 100 mm vent	Electricity, no water	$500-$1000	Power requirement of 1 2 to 8.75 kW·h per day for fan and heating element.
Synthetic fluid 	System utilizes special chemical fluid or mineral oil as flushing medium Waste materials settle out in holding tank and fluid is filtered and recycled to conventional toilet. Waste must be pumped out about once a year	Utilizes conventional toilet and plumbing but no water Can be used in conjunction with an incinerator to destroy concentrated wastes Applicable for multiple units such as camps or public washrooms	High initial cost for unit and installation Requires significant space and is relatively complex. Requires replacement of lost fluid and addition of odor control chemicals. Energy requirement for pumps and incinerator, if used, otherwise waste must be pumped out for disposal	Connection to recycle system 9 5 mm water 75 mm waste Electricity for recycle system	Electricity, no water	$2500-$5000	Costs for replacement fluid, odor control chemical and power for electric motors.
Treatment systems (recycle) 	Recycle of treated and filtered toilet and/or other wastewater for toilet flushing. Sludge in tank must be pumped out every year or two	Uses little or no fresh water Some will accept wastewater from other fixtures	High maintenance and capital cost Requires filters, disinfectant, dye, pumps and electrical power.	Connection to treatment/recycle system 9 5 mm water 75 mm waste electricity for treatment and recycle system	Electricity, uses wastewater	$2500-$5000	Cost for disinfectant, dye, filters and electricity
Urinals 	Handle releases high velocity water injection syphoning liquid wastes through a trap	Low volume flush models use very little water compared to conventional toilet Uses conventional plumbing Commonly used in public washrooms.	Relatively expensive addition to household washroom Only handles liquid waste. Low consumer acceptance due to institutional and public image	9 5 mm water 50 mm waste	4-15 litres/use	$75-$150	Depends on cost of water

all of these toilets are applicable or appropriate to every situation. For example, a mechanical seal toilet must be located directly over a receiving tank, and a 3-L toilet should only discharge into a tank less than 25 m away through a sewer line with a minimum slope of 3%. Also, various alternatives, including some reuse systems, are beyond the operating capabilities of most individuals, particularily when located in isolated communities.

Depending on the habits of the user, showers will usually use less water than tub bathing, particularily if an inexpensive flow-restricting insert or specially designed low-flow showerhead is installed. Many low-flow showerheads will give a satisfactory or even superior shower while saving a considerable volume of water and energy required for hot water heating. Other specialty shower units or systems use very little water. Several add-on shower devices are available which will save water, and some increase user convenience, comfort and safety. Bathing alternatives are summarized in Table B-3.

Hand laundering can potentially use the least amount of water, but considerable user time and effort is required. Wringer washers are versatile and reuse of the water is easily done, but they have been largely superseded by the more convenient automatic washing machines. Numerous top loading automatic washers are available, some of which use considerably less water than others. The more efficient tumble action of the front load washer makes it the lowest hot and total water user of the automatic washers. They are, however, more expensive and consumer acceptance has been poor. Laundry alternatives are summarized in Table B-4.

In the kitchen, dishwashing uses the most water. Hand-washing can be done with very little water but may entail some inconvenience and extra effort. If an automatic dishwasher is used and always loaded to capacity for each full cycle of operation, water use will be comparable to hand-washing in a filled sink and rinsing under a free flowing stream of water. In-sink food waste disposal units are a modern convenience that, if judiciously used, will not significantly increase household water use. Other kitchen operations, such as

Table B-3 Bathing alternatives

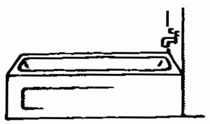
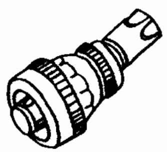
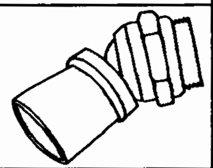
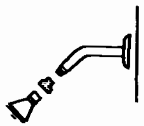
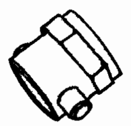
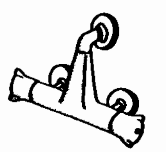
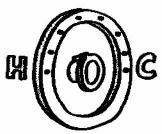
	Principle of operation	Advantages	Disadvantages	Hookups required	Consumption	Approximate cost	
						Capital	Operating
Bathtubs 	Vitreous china, fiberglass, or metal bathtub is filled with mixture of hot and cold water for bathing.	Facilitates personal hygiene and relaxation. Can be used without plumbing system and water can be reused. Level to which tub is filled need not be excessive, and water use is independent of duration of bath. Water can be left in tub to recover heat before discharge.	Uses relatively fixed volume of water per use. Large bathtubs with or without whirlpool spas, use large volumes of water. Most are not designed to conform to the shape of human body or insulated to reduce heat loss.	Varies from none to 9.5 mm H&C water and 38 mm waste.	Varies with size of tub and user habits. Approx. 150 litres/ use.	Galvanized $30–$50 Vitreous china & fiberglass $80–$250	Depends on cost of water and energy for hot water heating.
Conventional shower heads 	Blend of hot and cold water flows through a fitting with small openings to produce a water spray.	Convenient, quick method of body cleansing and rinsing. Water use can be regulated by time spent in shower.	Requires water and sewer plumbing and shower stall. Water consumption is high particularly with "massaging" type showerheads. Flow restrictors installed on some models may reduce the quality of shower to unfavorable as may low pressure systems.	9.5 mm H&C water and 38 mm waste	15–40 Lpm Typically 25 Lpm "massaging" as high as 55 Lpm. Normal shower duration is 5 mins.	Normal $5–$25 Typically $8. massaging $20–$50	Depends on costs; 5 minute shower every second day for family of four would use about 250 litres per day; ½ hot water.
Low flow shower heads 	Same as above, except water flow is restricted. Aerating types mix air with the water.	Same as above, except uses less water and energy to heat hot water for the same amount of time spent showering without sacrificing shower quality. Aerating types use less water. Most work well on low pressure systems by delivering a constant water flow regardless of pressure changes.	Generally a little more expensive than conventional shower heads and spray pattern is often narrower. Low flow may be noticeable by some, particularly for washing hair. Aerating type have non-adjustable sprays.	Same as above.	5–12 Lpm Typically 9 Lpm	$5–$25 Typically $10.	Same as above, except family of four would use about 90 litres per day, ½ hot water.
Flow controls 	Small diameter orifice which restricts the flow of water. They are either an insert that slips into the shower water supply line or an independent fitting that is coupled onto the supply line ahead of the shower head.	Inexpensive retrofit method of reducing the flow of conventional shower heads. Can be homemade, consisting of a rubber washer with small diameter opening.	May reduce shower quality of some conventional showerheads.	Attarhes, threads or inserts ahead of shower head.	8–12 Lpm Typically 10 Lpm	$1–$6.	Same as conventional, except consumption would be reduced to about 100 litres per day, ½ hot water.
Shut-off valves 	A valve installed between the shower arm and the shower head to allow turning off of the water at the shower head without adjusting other controls. Some shower heads have shut-off valve built in.	Saves water by allowing user to conveniently shut off water at the showerhead while not under spray, lathering up, washing hair, etc. Some types have a small water flow while in off position which maintains the selected water temperature.	Water temperatures in riser stem or supply lines may change while valve is turned off. User may feel chilled when shower spray is turned off.	Attaches ahead of shower head.	Varies with flow rate and user habits.	$2–$5	Depends on flow rate and user habits. Approx. 0 to 50% savings.
Thermostatic mixing valves 	Controls temperature changes from the hot and cold water supply lines by means of sensitive bi-metal spring. Two metals expand at different rates causing spring to move interior mechanism which controls the hot and cold supply lines, thus, maintaining a constant ratio of hot and cold water. Has two control knobs; one for temperature selection and the other controls the rate of water flow.	Provides constant pre-selected water temperature regardless of flow (pressure) or temperature changes in hot or cold supply lines. Increases user convenience, comfort and safety by reacting quickly to supply line temperature changes. One valve can control both shower and bath and/or other outlets.	Costs two to three times the price of conventional valves.	9.5 mm H&C water and supply line to shower head.	Not applicable, reduces waste.	Approx. $70.	None
Pressure balancing mixing valves 	Designed specifically for showers, it compensates instantly for pressure changes in either the hot or cold water supply lines, usually due to the use of other fixtures, thus, maintaining the selected flow mixture resulting in a consistent shower temperature.	Avoids discomfort and wasting of water by maintaining a consistent shower temperature.	Does not compensate for temperature changes from source unless accompanied by a pressure change. Costs about twice as much as conventional valves.	9.5 mm H&C water and supply line to showerhead.	Not applicable, reduces waste.	Approx. $50.	None

Table B-3 Bathing alternatives (continued)

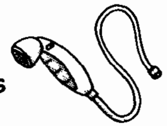
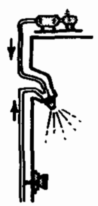
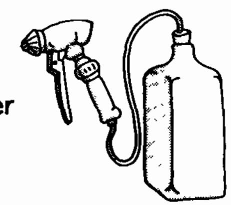
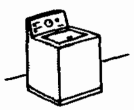
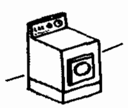
	Principle of operation	Advantages	Disadvantages	Hookups required	Consumption	Approximate cost: Capital	Approximate cost: Operating
Hand held showers 	Shower head type fitting attached to a short hose, for hand held use. Can be permanently attached for use in shower stall or connected to end of faucet on sink basin.	Increases ability to get the water spray where it is desired with a minimum of inconvenience. Available with built in flow control and on-off valve. Can be permanently clipped to wall or attached to any faucet. Can be used to compliment conventional or low flow shower head, particularly for washing hair.	Potential danger of contamination by back-syphonage. If not clipped to wall, requires use of one hand. The wetting and rinsing operation may be inconvenient to some.	Faucet or shower outlet and 38 mm waste.	4-30 Lpm greater for massage type.	$10-$30	Depends on costs and user habits. As low as 10 L/shower.
 Air assisted shower system	A small centrifugal air blower supplies air tn a special showerhead where air and water are mixed to create a fine spray.	Very low water consumption while maintaining satisfactory cleansing. Can use in-line heater, therefore, no need for hot water supply line. Main economic advantage is amount of energy saved in water heating.	High capital and installation cost. Due to length of time required to drain water in hot water supply line, in-line heater, circulation of hot water or short distance to hot water tank is necessary. Reqnires enclosed shower stall. Separate blower required for each showerhead. Unsatisfactory shower for some.	9.5 mm H&C water 38 mm waste 120V electrical for blower.	2 Lpm	$325	Depends on costs, family of four would use about 20 litres per day, ½ hot water. 25 kW·h (400 watts) per year for compressor.
Atomizer shower 	Water of the desired temperature is delivered to an atomizing nozzle which produces a very fine spray (mist). The atomized water spray removes surface cells, dirt and soap.	Uses extremely little water. Existing designs are self-contained and require no water, sewer or power hookups and are portable.	Takes a long time to have a "complete shower." Drifting of spray if not within an enclosure. May require additional system for washing hair. Technology and plumbing not fully developed for conventional houses. Unsatisfactory shower for many.	None for self-contained models.	As low as 1 L/shower	Approx. $5-$30	Negligible

Table B-4 Laundry alternatives

	Principle of operation	Advantages	Disadvantages	Hookups required	Consumption	Approximate cost	
						Capital	Operating
Hand laundering 	Beating or rubbing of articles together or rubbing on scrub-board in water filled tub or basin. Manual wringing of articles to remove excess water.	Complete user control over water quantity and temperature and number of articles laundered in same wash or rinse water. Does not require electrical hook-up or household plumbing.	Highly labor intensive requiring considerable time, inconvenience and effort. Water use depends on size of tub and user habits.	None	Depends upon user.	Low to none.	None
Wringer washer 	Agitator washing motion in user filled tub. User activates pump to drain wash or rinse water from tub. Laundered articles are manually fed through wringer to remove excess water.	User control over water quantity and temperature and number of wash loads laundered in same wash or rinse water. Can be moved to convenient storage location.	Capacity of tub varies with manufacturer. Requires time but not nearly as inconvenient or labor intensive as hand laundering. Possible to overfill or use too much water for varying wash load sizes. Wringer can be hazardous. Requires electrical hookup and storage space.	120V electrical and should be close to water supply and sewer drain.	Varies according to size of tub, manufacturers recommendations and number of reuses of wash and rinse water. Usually less than automatic washers.	\$200 - \$500	Depends on cost of water and power. Household of 4 would wash an average of 5 loads per week.
Top loading automatic washer 	Top loading agitator motion for preselected wash/rinse/spin cycles. Wash and rinse water is automatically filled and drained with excess water spun from laundered articles.	Convenient automatic wash and spin dry cycles are labor saving. Other convenience features allow for water level and temperature selection Some models offer a suds-saver attachment which will save water.	High range of water use among currently available models. Water level selection not possible on some models. Minimum wash load size may be high for small families. Temperature selection does not allow cold water rinsing on some models. Requires electrical and plumbing hookup and permanent space.	120V electrical and must be connected to water supply and sewer drain.	Total water use 140 - 260 litres Hot water only 40 - 87 litres	\$350 - \$700 average \$500	Same as above
Low water use top loading automatic washer	Same as above.	Same as above except uses less water per cycle, promoting less use of detergents and other laundry additives.	Has slightly higher cost than average of other top load models. Maximum wash load sizes may be low for some families. Requires electrical and plumbing hookup and permanent space.	Same as above.	Total water use 133 - 146 litres Hot water only 27 - 53 litres	\$575	Requires less water and laundry additives than above.
Front loading automatic washer 	Front-loading tumble wash motion for preselected wash/rinse/spin cycles. Wash and rinse water is automatically filled and drained with excess water spun from laundered articles.	Lowest water use of currently available automatic washers. Has water level and temperature selection convenience features. Uses less detergent and other laundry additives and requires less operational energy than average of top load models.	Front loading door is not preferred by many consumers. Has slightly higher cost than average of top loading models. Maximum wash load size may be low for large families. Requires electrical and plumbing hookup and permanent space.	Same as above.	Total water use 119 litres. Hot water only 20 - 40 litres.	\$650	Requires less water, operating power and laundry additives than above.

drinking and cooking, use relatively fixed and small volumes of water. Reductions in the wasting of water can be achieved by adjusting user habits, such as keeping a container of cold water in the refrigerator. There are also a number of faucets and faucet attachments that reduce the amount of water flow and wastage compared to conventional faucets. Water flow reduction at faucets also has the added benefit of energy savings since approximately 50% to 75% of the flow is heated water. Faucets and faucet attachments are summarized under miscellaneous water use alternatives in Table B-5.

Household systems are also discussed in Table B-5. These alternatives all involve some alteration in the conventional household plumbing, and provide additional water and energy savings.

B.5 Economic Analysis

There are practical and technical limitations to a comparison and economic selection of water conservation alternatives for an individual building or for a community. All capital and O&M costs associated with an alternative must be discounted to obtain their present value. Since these depend upon the unit costs for water, sewerage and energy, the number of uses or volume used, and the O&M costs, each new and retrofit situation will be different. The marginal unit costs, net of any subsidies, should be used to arrive at costs, but these are often difficult or impractical to obtain.

Despite these difficulties general recommendations can be economically justified. For piped systems there is no need for toilets to use over 15 L/flush. Low-flow showers and flow control aerators are almost universally economical. Piped systems with preheating, excessive water pressures or high treatment costs, and locations with very high electricity costs may find other devices economical.

For trucked systems with marginal economic rates of 1 to 2¢/L, more restrictive alternatives are economical for households. Mechanical flush toilets should be used wherever possible. Where the sewage holding tank cannot be located directly below the toilet, the recirculating toilets are usually the most economical, despite the chemical costs. Certainly toilets using over 6 L/flush should not be

Table B-5 Miscellaneous water conservation alternatives

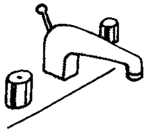
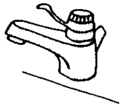
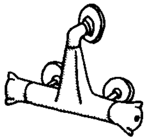
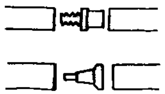
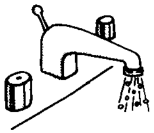
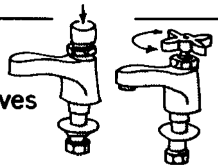
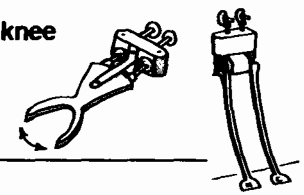
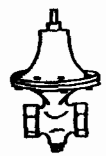
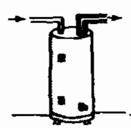
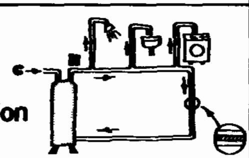
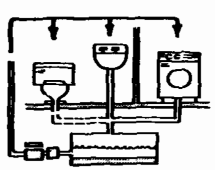
	Principle of operation	Advantages	Disadvantages	Hookups required	Consumption	Approximate cost	
						Capital	Operating
Conventional faucets 	Water flow from supply line is controlled by rubber gasket which is turned down onto a seat Gasket is connected to valve stem and operated by a handgrip Available with single spigot or separate hot and cold faucets.	Valve controls water flow rate. Washerless valves with ceramic discs instead of rubber resist water and mechanical wear and operating temperatures up to 80°C.	High unrestricted flow rates Wearing of rubber gasket type results in water loss due to leakage.	H&C water supply lines.	20 - 50 Lpm	$15 - $40 Washerless $30 - $50	Depends on cost of water and hot water heating
Mixing faucets 	Single faucet with one control handle that is used to adjust both flow rate and temperature of water.	Desired flow and temperature can be quickly selected and adjusted with only one hand, thereby reducing waste. Compact.	More expensive than conventional.	Same as above.	Reduces waste	$30 - $50	Same as above.
Spray faucets 	Single faucet which delivers water in a spray, much like a shower head. Flow rate is preset and control knob is used for on/off operation and temperature selection.	Minimum pressure requirement of 13 kPa ideal for gravity tank systems. Compact and can use small diameter water supply and drain lines. Possible to use an in-line water heater eliminating need for hot water line.	Inconvenient for filling containers due to very low flow rate. Institutional image as they are commonly installed in public restrooms. Cost slightly more than comparable conventional faucets	Same as above.	2 - 3.5 Lpm	$45	Same as above.
Thermostatic mixing valves 	Temperature changes from the hot and cold water supply lines are controlled by means of sensitive bi-metal spring. Two metals expand at different rates causing spring to move interior mechanism which controls the hot and cold supply lines, thus, maintaining a constant ratio of hot and cold water. Has two control knobs; one for temperature selection and the other controls the rate of water flow.	Provides constant pre-selected water temperature irregardless of flow (pressure) or temperature changes in hot or cold supply lines. Increases user convenience, comfort and safety by reacting quickly to supply line temperature changes. One valve can control multiple water fixtures.	Expensive and generally used to supplement other faucets.	9.5mm H&C water and supply line to faucet.	Savings are up to 40% of that used by conventional faucets.	Approx. $70	None
Flow controls 	Reduce water flow rate by means of small diameter orifice in the supply lines ahead of fixtures or on end of spigot Are either an insert or a threaded fitting. Most will compensate for pressure changes in water supply line to produce a constant flow rate.	Reduces flow rate where they are higher than desired or needed. Inexpensive and usually easily installed as retrofit. Some faucets have them built in. Available with various maximum flow rates.	May require cutting of existing water lines to install in-line type. Some users may feel flow rate is too low. Takes longer to fill and no water savings when filling containers such as a glass or bathtub.	Threads or inserts into supply line.	8 - 12 Lpm Typically 10 Lpm	$1 - $6	None
Aerators 	Attaches to end of spigot and gives appearance of larger flow than actually present by breaking up flow and introducing air bubbles into the stream of water.	Restricts flow a little, however, main advantage is water use is reduced due to illusion of larger flow. Aerated flow feels gentle and greatly reduces splashing. New faucets generally equipped with an aerator but are in expensive and easily installed on end of spigot of existing faucets. Some aerators have built in flow control increasing water conservation.	May not fit all old style faucets without an adaptor. Reduces flow rate slightly.	Threads onto end of faucet.	10-25 Lpm	$1 - $5	None
Self closing valves 	Spring loaded valve type, simply shuts off water supply immediately upon release. Timer valves are usually a single faucet with preset flow rate and temperature which automatically close due to accumulated water pressure.	Reduces waste since on only for time actually needed and ensures it will not be left on unattended or after use. Can be used with thermostatic mixing valve.	Do not operate unattended and therefore generally not practical for households. Separate spring loaded hot and cold faucets are inconvenient and warm water can only be obtained by mixing in bowl or container. Do not have temperature or flow rate selection.	H&C water supply lines.	Reduces waste	$30 - $40	Depends on cost of water and hot water heating.

Table B-5 Miscellaneous water conservation alternatives (continued)

	Principle of operation	Advantages	Disadvantages	Hookups required	Consumption	Approximate cost: Capital	Approximate cost: Operating
Foot or knee valves 	Faucet valve is activated by depressing a foot or knee lever and when released automatically returns to off position.	Reduces waste since water is on only when activated. Does not require hands to operate, therefore is convenient and sanitary.	Initial cost and modifications to existing equipment is expensive. Some do not allow temperature or flow rate selection. Must be attended to operate.	Mounting on floor or cabinet and controls to H&C water supply lines.	Reduces waste	\$75 - \$120	None
 Pressure regulator	Adjustable spring is used to change pressure on a rubber diaphragm which in turn maintains the building water pressure at a preset value below the water main pressure.	Used where excessive water main pressures could burst fittings or cause excessive noise, vibration and leakage. Reduces water use and waste since maximum flow rate is reduced. Provides constant water pressure to building.	Lower pressure and therefore flow rate will increase time to obtain fixed volume of water.	Connects to building water supply line.	Saves water in all water outlets.	\$30	None
Water pipe insulation 	Insulation is placed or wrapped around water lines, usually hot water only, to reduce heat loss and help maintain temperature level of water in pipes.	Reduces heat loss and rate of cooling of water in pipes thus reducing wasting of water left standing in lines.	May be difficult, expensive and/or impractical to add to some existing water systems.	None	Approx. savings of 7.5 L/person·d	\$1.50 - \$3 per meter	None
Water circulation 	Water pipes in the building or particular area are looped back to hot water tank and a small pump circulates water within the loop. Buildings with individual water systems only need a return line from each faucet to the cistern and a valve to allow draining. Faucets or other water outlets tap off of the loop. Usually only done for hot water pipes.	Eliminates need to waste cooled water standing in line between the heater and faucet before hot water is available. Provides hot water instantly since supply loop is maintained at hot water heater temperature. Circulation pump can be put on timer or thermostatic control to reduce heat loss and pump operating time.	Retrofitting existing systems may be impractical. Increased heat loss particularly for un insulated pipes and where circulation pump is not on a timer. Circulation of water requires a pump.	Circulation pump (electricity) and return piping.	Reduces waste	\$100 pump \$25 plumbing	Nominal power for pump.
Recycle systems 	Household wastewater is collected and treated for reuse. Some systems only recycle greywater and may not recycle for drinking and cooking purposes. Treatment methods may include biological, chemical precipitation, filtration, carbon adsorption, reverse osmosis, distillation, disinfection and/or others.	Reduces total water requirements to zero or minimal. Building can be independent of water and sewer systems.	Very high capital and operating cost. Complex and high technology beyond most householders capabilities to maintain. Recycle of wastewater, except for toilet flushing, is a health hazard and is not aesthetically acceptable by many. Requires energy, chemicals and scheduled servicing by qualified personnel. Takes up space and may require alternative system for emergencies.	Electrical for treatment system and pumps, recycle piping and standby system.	Depends on system.	\$2500 - \$5000	Cost of chemicals and power requirement. Cost of recommended monthly servicing. Cost for fresh and makeup water.

installed. Low-flow showers, hand-held showers, flow control aerators, mixing faucets and a method to reduce hot water pipe flushing such as insulation, circulation or a return line, will be economical. Front load laundry machines will be economical for new installations and high water users.

Where utility cost are very high and/or water supply is limited, more severe steps are necessary. Even non-gravity piped sewer systems will not allow the control over water use that is inherent with trucked systems and central facilities. In addition to the trucked system recommendations above, devices such as spray and self-closing faucets, specialty shower systems, and timers on showers should be used. Water conservation is still usually more economical than greywater reuse. This alternative should only be considered for central facilities and where other considerations such as autonomy or zero pollution are paramount. Reuse must be approached with caution due to the complex treatment systems and controls that are necessary.

B.6 References

1. Cameron, J. and Armstrong B.C., "Water and Energy Conservation Alternatives for the North", Utilities Delivery in Northern Regions, 19-21 March, 1979, Edmonton, Alberta, Environmental Protection Service, Environment Canada (in preparation), 1979.

B.7 Bibliography

Bailey, J.R., R.J. Benoit, J.L. Dodson, J.M. Robb and H. Wallman, "A Study of Flow Reduction and Treatment of Wastewater from Households", Water Pollution Control Research Series, Environmental Protection Agency, Washington, D.C., 1969.

Chan, M.T., J. Edwards, M. Roberts, R. Stedinger and T. Wilson, "Household Water Conservation and Wastewater Flow Reduction", Office of Water Planning and Standards, U.S. Environmental Protection Agency, Washington, D.C., Contract No. 68-02-2964, U.S. Department of Commerce, National Technical Information Service, Publication No. PB-265 578, 1976.

Cohen, S. and H. Wallman, "Demonstration of Waste Flow Reduction from Households" National Environmental Research Centre, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio, EPA-670/2-74-071, 1974.

Grima, A.P., "Residential Water Demand; Alternative Choices for Management", University of Toronto, Department of Geography, Research Publications, University of Toronto Press, 1972.

Linaweaver, F.P. (Jr.), J.G. Geyer and J.B. Wolff, "Report V on Phase Two of the Residential Water Use Research Project, Final and Summary Report", Department of Environmental Engineering Science, the John Hopkins University, 1966.

Milne, M., "Residential Water Conservation", California Water Resources Centre, Report No. 35, University of California/Davis, 1976.

Orr, R.C. and D.W. Smith, "A Review of Self-contained Toilet Systems With Emphasis on Recent Development", Utilities Delivery in Arctic Regions, Edmonton, Alberta, March 16-18, 1976, D.W. Smith, ed., Environmental Protection Service Report No. EPS 3-WP-77-1, Ottawa, pp. 266-305, 1974.

Rybczynski, W. and A. Ortega, "Stop the Five Gallon Flush! A survey of Alternative Waste Disposal Systems", Minimum Cost Housing Group, School of Architecture, McGill University, Montreal, 1973.

Sharpe, W.E. and P.W. Fletcher (eds.), "Conference on Water Conservation and Sewage Flow Reduction with Water-Saving Devices", April 8-10, 1975, Institute for Research on Land and Water Resources, The Pennsylvannia State University, Information Report No. 74, 1975.

Washington Suburban Sanitary Commission, "Final and Comprehensive Report, Cabin John Drainage Basin Water-Saving Customer Education and Appliance Test Program", Washington Suburban Sanitary Commission, Hyattsville, Maryland, 1973.

Washington Suburban Sanitary Commission, "A Customer Handbook on Water-Saving and Wastewater-Reduction", The Washington Suburban Sanitary Commission, Hyattsville, Maryland, 1976.

APPENDIX C

THERMAL PROPERTIES

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TABLE C-1. THERMAL PROPERTIES OF VARIOUS MATERIALS

Material	Unit Weight (kg/m^3)	Thermal Conductivity K [Cal/(m)(hr)(°C)]	Heat Capacity C (Cal/kg)
Asbestos sheets, 1 to 5 mm thick	900	0.15	0.20
Asphalt	1800	0.65	-
Basalt, at 20°C	2400-3100	1.44	0.20
Ash, Timber, air-dry	450-500	0.1-0.13	0.18
Cinder, dry	700-1000	0.06-0.25	0.18
Clay, at 0°C	1800-2600	2.83	0.224
Concrete, T = 70°C	-	0.77	0.156
Cork plates, natural	250	0.06	0.50
Felt, technical	150-250	0.04-0.05	0.45
Glass wool	200	0.05	-
Granite, T = 20°C to 100°C	2650-2700	7.32	0.20
Ice	900	1.90	0.50
Ice, -20°C	900	2.00	0.505
Mineral wool	200	0.06	-
Moss, sphagnum, air-dry	135	0.04	0.40
Peat Moss plates, air-dry	170-250	0.05-0.06	0.50
air-dry	800-1000	0.26-0.40	0.39-0.87
Peat, pressed, moist	1140	0.59	0.39
Plywood	600	0.15	0.65
Sawdust, air-dry	150-250	0.05-0.08	0.60
Sand	1600-1800	1.70-2.10	0.20
Snow, loose	300	0.20	0.50
Snow, dense	500	0.50	0.50
Tarpaper	600	0.15-0.20	0.36
Topsoil	1800	1.00	-
Water	1000	0.50	1.00

From: Jumikis, A.R., Thermal Soil Mechanics, Rutgers University Press, New Brunswick, New Jersey, 1966.

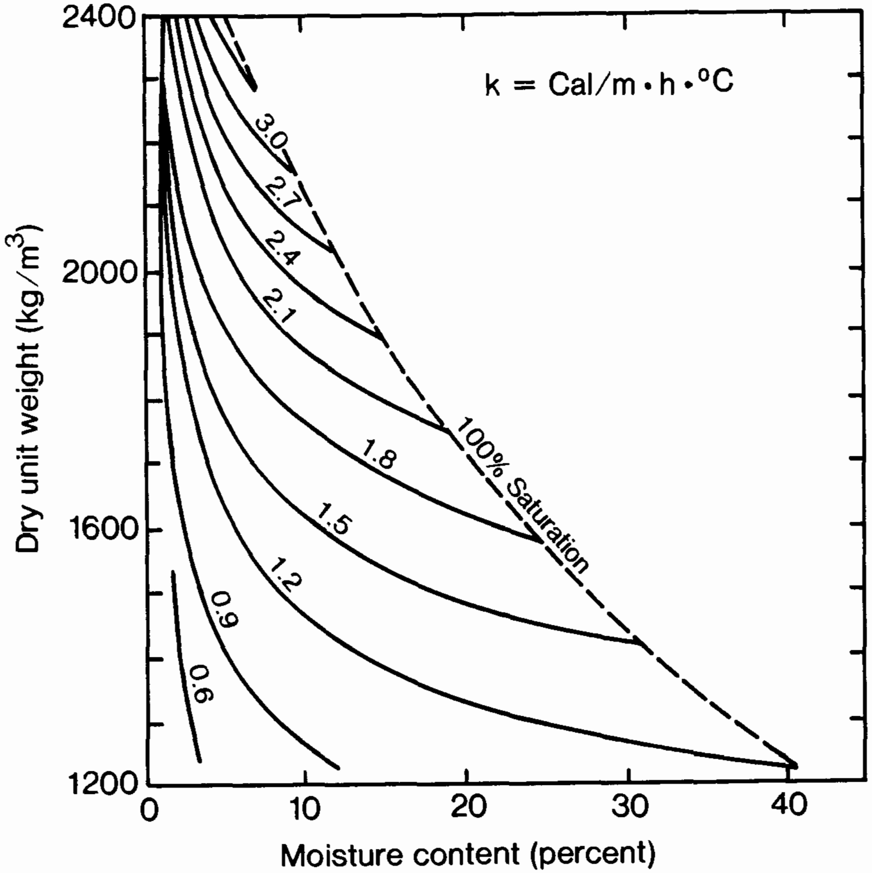

FIGURE C-1. AVERAGE THERMAL CONDUCTIVITY OF SANDY SOIL, THAWED (Kersten, M.S., "Thermal Properties of Soils", University of Minnesota, Inst. of Technology, Bulletin No. 28, Minneapolis, 1949)

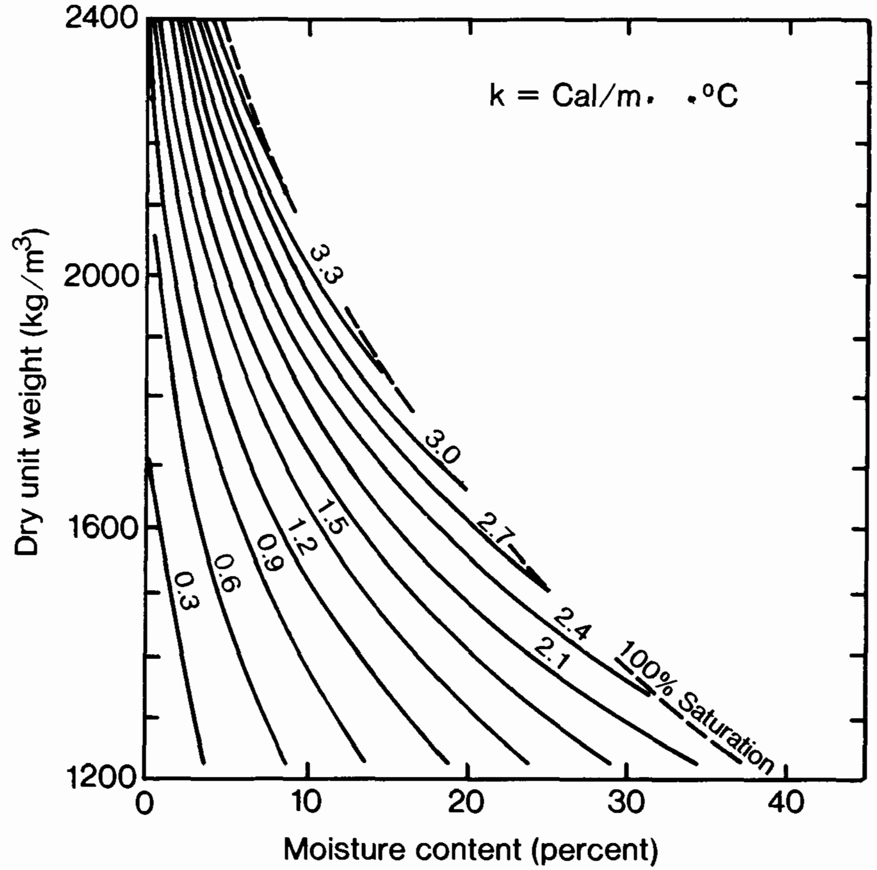

FIGURE C-2. AVERAGE THERMAL CONDUCTIVITY OF SANDY SOIL, FROZEN (Kersten, 1949)

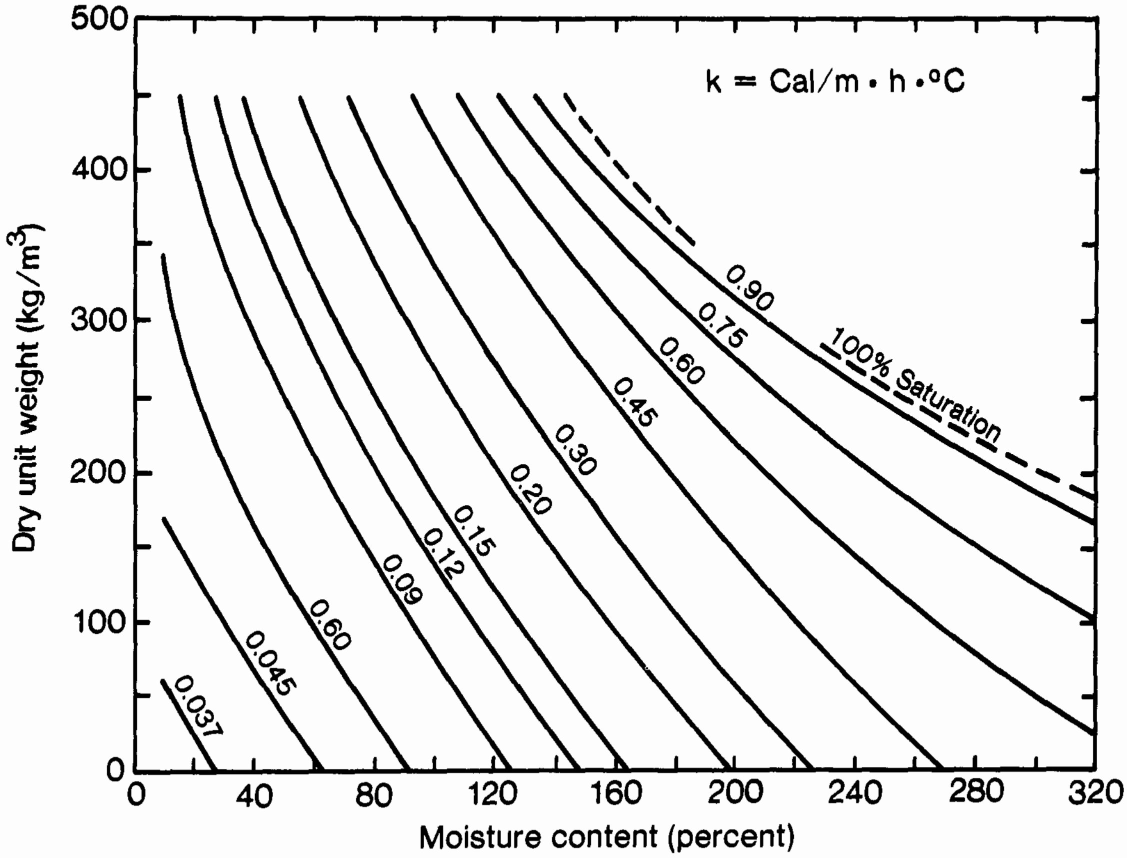

FIGURE C-3. AVERAGE THERMAL CONDUCTIVITY OF PEAT, FROZEN (Kersten, 1949)

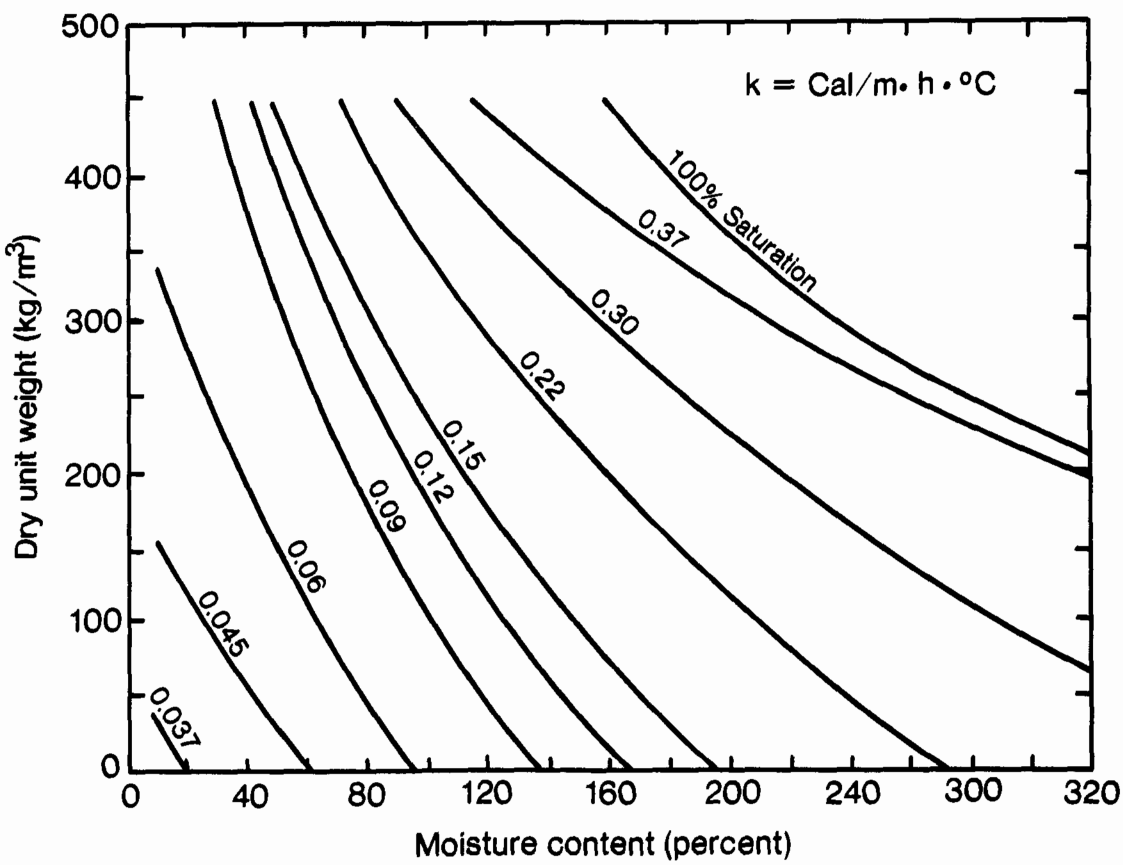

FIGURE C-4. AVERAGE THERMAL CONDUCTIVITY OF PEAT, THAWED (Kersten, 1949)

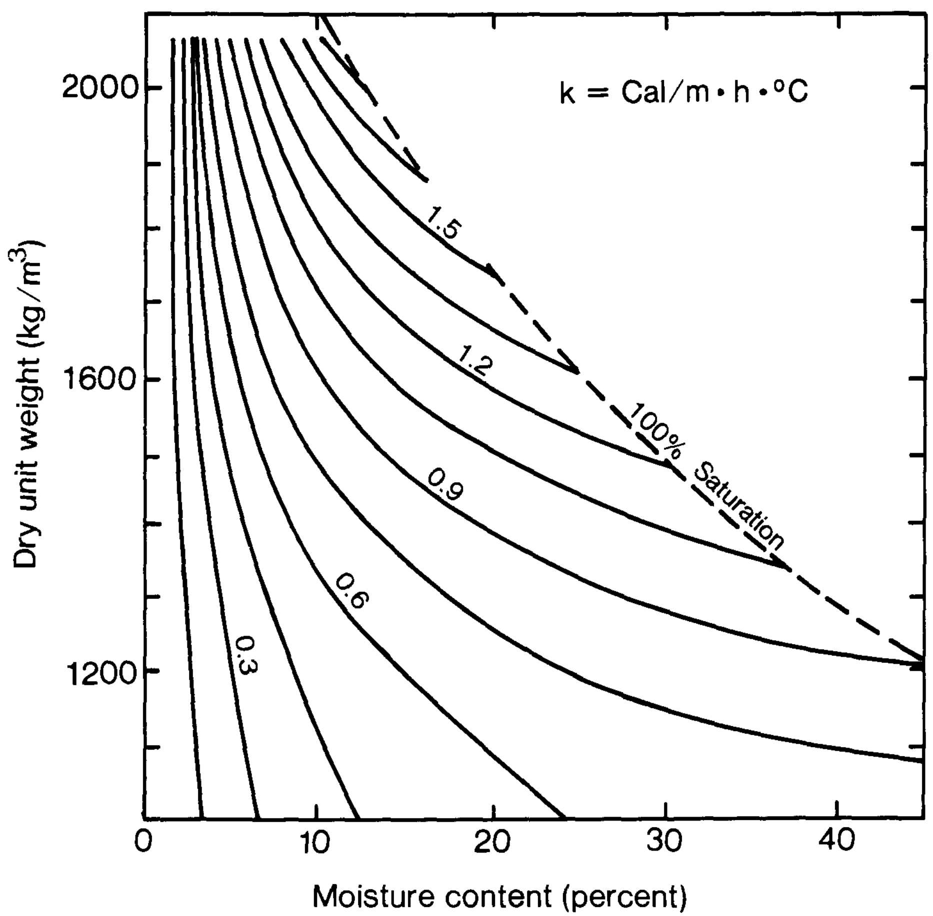

FIGURE C-5. AVERAGE THERMAL CONDUCTIVITY OF SILT AND CLAY SOILS, THAWED (Kersten, 1949)

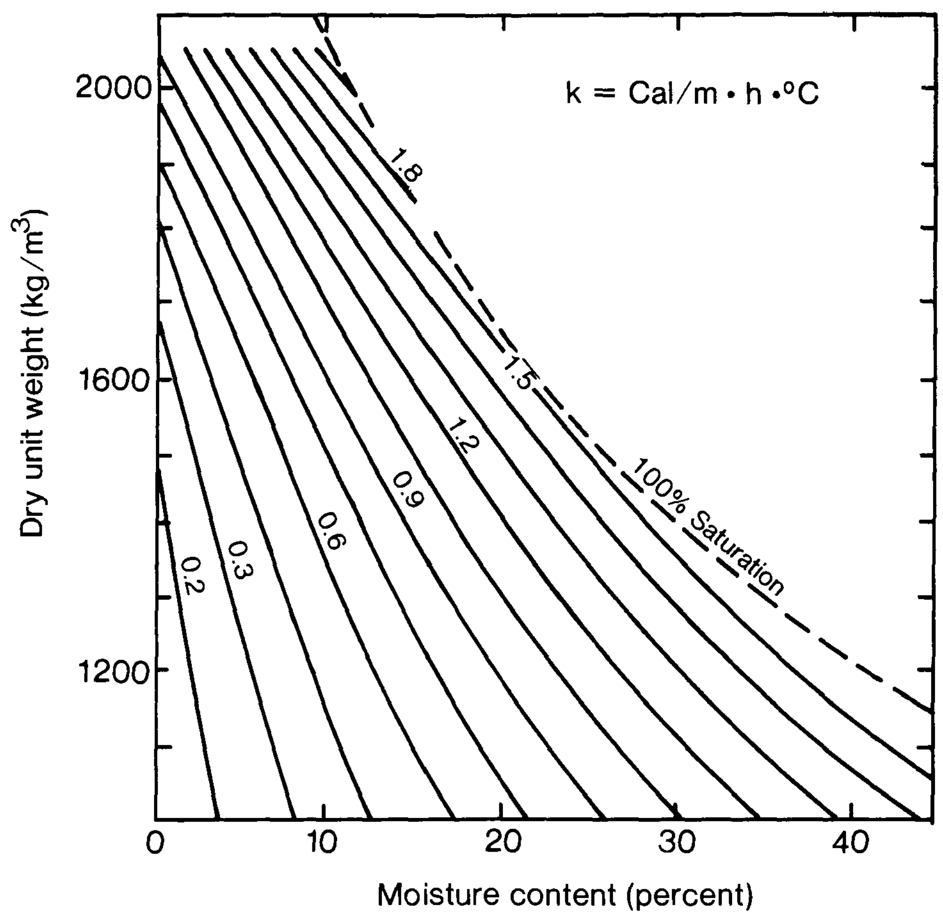

FIGURE C-6. AVERAGE THERMAL CONDUCTIVITY OF SILT AND CLAY SOILS, FROZEN (Kersten, 1949)

APPENDIX D

TRUCKED SYSTEMS

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D TRUCKED SYSTEMS

D.1 Trucked System Analysis

This appendix presents a detailed and simplified method of analyzing the characteristics and associated costs of trucked water delivery, sewage pump-out, honeybag collection and garbage collection systems for a particular community. It is abstracted from procedures developed by the Department of Local Government. Government of the N.W.T. [1], based on work by Gamble and Janssen [2].

Each system is basically the same and can be analysed using the same general equations. To help illustrate the model, a brief description of the water delivery procedure follows.

The vehicle must load up its tank at the source, travel to the community, deliver the water house-to-house by filling up the individual tanks until the vehicle tank is empty, and then return to the source. This is repeated until all the houses have had their water tanks filled. The entire process is repeated as soon as the house water tanks are emptied by the occupants.

The time involved in performing the above task can be represented by equations which quantify the characteristics of the delivery system.

Beginning at the source, the time to fill the vehicle tank can be expressed as the time for the pump to fill the tank plus the time required to start the pump, hook and unhook the hoses, etc. Then there is travelling time between the community and the source of water, and analogous time going from house to house filling the water tanks and hooking up the hoses. The time spent servicing the houses is multiplied by the number of dwellings serviced per truck tank load.

As one can appreciate, precisely the same steps are also required for the sewage pump-out, honeybag and garbage collection systems, although the system parameters such as tank sizes, travelling times, etc., are different.

D.1.1 General equations

The following system of equations applies for a particular year under consideration, and for a particular set of community, building and vehicle characteristics. The costs are based on equivalent annual costs.

(1) Circuit time

a) $CT = CST + CSTT + CBT$

where: CT = estimated time to service a defined group of buildings once (hours),

CST = estimated time to turn around, hook/disconnect, pump, etc., at source or disposal point (hours),

CSTT = estimated time to travel to and from the community and the source/disposal point (hours),

CBT = estimated time to travel and service the buildings within the community (hours).

b) $$CSTT = EL \times NB \times \left[\frac{C \times CSF}{VS \times VUF}\right] \times \frac{2D}{S}$$

where: EL = estimated efficiency of labour. Recognizing the fact that only five effective hours would normally be used in a 7½-hour day, the theoretical circuit for each system must be multiplied by 1.5 to calculate the estimated actual circuit time, i.e., EL will normally equal 1.5,

NB = the number of buildings in the defined group to be serviced, e.g., commercial, residential, full plumbing houses, etc.,

C = average container size for the buildings, e.g., water tank, garbage barrel, etc.,

CSF = container safety factor to ensure that the circuit time accounts for under-utilization of the container size, e.g., the water delivery truck will refill the tank before the building runs out of water (usually taken to be 0.85),

VS = vehicle size, e.g., 4500-L water truck, 5-m^3 garbage truck, etc.,

VUF = vehicle use factor for under-utilization of the vehicle container volume, e.g, usually 0.95 for water trucks and 0.80 for garbage trucks,

D = travel distance to and from source or treatment/ disposal point (kilometres),

S = speed of vehicle to and from source or treatment/ disposal point (kilometres).

c) $$CST = EL \times NB \times \left[\frac{C \times CSF}{VS \times VUF}\right]\left[\frac{VS}{60 \times R} + \frac{TT}{60}\right]$$

where: R = rate of filling or emptying the vehicle container at the source or disposal point (litres per minute),

TT = turn-around time at source or disposal point, i.e., time required to hook-up, disconnect, turn around, etc., exclusive of time occupied by emptying or filling the vehicle (minutes).

d) $$CBT = EL \times NB \times \left[\frac{DB}{1000 \times SB} + \frac{C \times CSF}{60 \times RB} + NTB \times \frac{TTB}{60}\right]$$

where: DB = average distance between building hook-ups (metres),

SB = average speed that the vehicles travel between the buildings (kilometres/hour),

RB = rate of filling or emptying the vehicle container while servicing the buildings in the community (litres per minute),

TTB = average turn-around time while servicing each building (filling or emptying time not included) (minutes),

NTB = number of vehicle visits or trips to service each building container,

NTB = 1 if $\frac{C \times CSF}{VS \times VUF} \leq 1$, i.e., building container is smaller than the vehicle,

$= \frac{C \times CSF}{VS \times VUF}$ if $\frac{C \times CSF}{VS \times VUF} > 1$.

e) Therefore, the Circuit Time equation becomes:

$$CT = CST + CSTT + CBT$$

$$= EL \times NB \times \left(\left[\frac{C \times CSF}{VS \times VUF}\right] \times \left[\frac{2D}{S} + \frac{VS}{60 \cdot R} + \frac{TT}{60}\right] + \frac{DB}{1000 \times SB} + \frac{C \times CSF}{60 \times RB} + \frac{TTB}{60} \times NTB\right)$$

(2) Frequency. The servicing cycle must be repeated as soon as the building containers have been emptied or filled. Assuming a certain consumption or generation rate, the servicing frequency is given by:

$$F = \frac{NOPB \times VPCD}{C \times CSF} \times 365$$

where: F = the number of circuits required per year to adequately service the buildings.

NOPB = average number of persons per building (real or equivalent),

VPCD = the volume of water consumed or waste generated per capita per day (water = litres/person/day; garbage = m^3/person/day).

NOTE: For garbage and honeybag collection, frequency is usually fixed by policy and is not a variable.

(3) Total hours. It follows that:

$$THRS = CT \times F$$

where: THRS = total hours per year required to provide the service.

(4) Number of vehicles. Knowing the time per complete delivery cycle, i.e., circuit time and the frequency with which it must be performed, allows the computation of the number of vehicles. The number of vehicles required is equal to the circuit time multiplied by the frequency and divided by the total time a vehicle is required to be available. To account for Sunday, and the fact each vehicle requires maintenance, it has been assumed that each vehicle is available for work 7.5 hours per day for 5.5 days/week.

Therefore: $$NV = \frac{CT \times F}{7.5 \times 5.5 \times 52}$$

where: NV = exact number of vehicles required.

Further: $INV = NV^{>NV}$

where: INV = The smallest integer larger than NV, i.e., simply the actual number of vehicles required.

(5) Vehicle costs. Knowing the number of vehicles required and their utilization permits the calculation of the total annual cost of each system to serve the defined group of buildings.

a) Vehicle Annual Capital Cost:

$$VACC = INV \times VRC \times VCRF$$

or $$VCC = INV \times VRC$$

where: VACC = vehicles annual capital cost (dollars),
VCC = vehicles capital cost (dollars),
VRC = current vehicle replacement cost in community (dollars),
VCRF = vehicle capital recovery factor.

and $$VRC = VC + (VW \times VTFR)$$

where: VC = current vehicle cost F.O.B. "south", e.g., Montreal, Winnipeg or Edmonton (dollars),
VW = vehicle weight (tons),
VTFR = vehicle transportation freight rate to community (dollars/ton).

and

$$VCRF = \frac{\frac{DR}{100}\left(1 + \frac{DR}{100}\right)^{VEL}}{\left(1 + \frac{DR}{100}\right)^{VEL} - 1}$$

where: VEL = vehicle economic life in years (generally 4 years),
DR = discount rate expressed as a percentage (as a general value use 8%).

b) Vehicle Annual O&M Cost:

$$VAOMC = VSC + VOC$$

where: VAOMC = vehicle annual O&M cost (dollars),
VSC = vehicle service cost, which includes painting, major repairs, overhaul (dollars),
VOC = vehicle operating cost, which includes fuel, oil, minor maintenance (dollars).

and, $$VSC = INV \times VRC \times VSF$$

where: VSF = vehicle service factor. As a general guide use:

= 0.21 for tracked water/sewage vehicles,

= 0.15 for wheeled water/sewage vehicles,

= 0.30 for garbage and honeybag vehicles,

and, VOC = VOCPH x THRS (dollars/year).

where: VOCPH = BHP (FR x FUEL + MISC)

VOCPH = vehicle operating cost per hour (dollars/hour),

FR = fuel consumption rate (litres per kilowatt hour). as a general guide use:

= 0.24 for wheeled vehicles (gasoline).

= 0.37 for tracked vehicles (gasoline).

FUEL = fuel cost (dollars/litre),

MISC = miscellaneous operating cost factor, As a general guide use:

= 0.011 for wheeled vehicles,

= 0.013 for tracked vehicles.

BHP = brake horsepower of vehicle (kilowatts). As a general value this is approximately 1/5th engine horsepower.

NOTE: VSF, FR and MISC were determined according to Canadian Construction Association cost calcuation methods [3].

c) Vehicle Total Annual Cost:

VTAC = VACC + VAOMC

where: VTAC = vehicle total annual cost.

(6) Labour Cost per Year:

LCPA = LCPH x THRS

where: LCPA = labour cost per year (dollars),

and, LCPH = [WD + WH x NH] LFB

where: LCPH = labour cost per hour (dollars/hour),

WD = hourly wage of driver (dollars/hour),

WH = hourly wage of helpers (dollars/hour),

NH = number of helpers,

LBF = labour benefits factor. This factor converts the hourly wage rate into the actual payroll

Cost of worker, i.e., workers' hourly wage plus employer's contributions to health pension and other benefits plus miscellaneous items, usually LBF = 1.2.

(7) <u>Parking Garages Cost</u>

a) Parking garage Annual Capital Cost:

$$PGCC = (PGBSF \times NCI) \times VSR \times INV \times f(INV)$$

where: PGCC = capital cost of parking garage (dollars),

PGBSF = base cost per square metre of floor space in the parking garage; it is a function of the size, i.e., the number of vehicles required (dollars/m^2), range of approximately \$300/m^2 to \$500/m^2.

VSR = vehicle space requirement (m^2); typically VSR will equal approximately 75 m^2,

f(INV) = a function of the integer number of vehicles to account for changing vehicle space requirements and cost per m^2 of space in the parking garage as the number of vehicles increases,

NCI = North Community Index, which relates base costs to specific community costs [4]. Range from 1.0 to 2.0.

and, PGACC = PGCC x PGCRF

where: PGACC = annual capital cost of parking garage (dollars per year).

PGCRF = parking garage capital recovery factor.

and,

$$PGCRF = \frac{\frac{DR}{100}\left(1 + \frac{DR}{100}\right)^{PGEL}}{\left(1 + \frac{DR}{100}\right)^{PGEL} - 1}$$

where: PGEL = parking garage economic life (years). As a general value use 10 years.

b) Parking garage Annual O&M Cost:

PGAOMC = PCGG x PGOMF

where: PGAOMC = parking garage annual O&M cost, PGOMF = parking garage O&M factor. As a general value use 0.60.

c) Parking Garage Total Annual Cost:

PGTAC = PGACC + PGAOMC

where: PGTAC = parking garage total annual cost.

(8) Associated Costs of Building Containers

ACCB = NB x CUC x C x NCI for trucked water, sewage pump-out and garbage service,

= NB x CUC x C x NCI x F for trucked honeybag service,

AACCB = ACCB x ACBCRF

where: ACCB = associated capital cost to buildings (dollars),

AACCB = associated annual capital cost to buildings (dollars/year),

CUC = container unit capital costs. It is a function of container size and type, i.e., water, sewage pump-out, garbage, honeybag (dollars per cubic metre),

ACBCRF = associated cost to buildings capital recovery factor,

and

$$ABCEL = \frac{\frac{DR}{100}\left(1 + \frac{DR}{100}\right)^{ABCEL}}{\left(1 + \frac{DR}{100}\right)^{ABCEL} - 1}$$

= 1 for honeybag collection/disposal only,

where: ABCEL = associated building container economic life.

b) AAOMCB = ACCB x AOMFB

where: AAOMCB = annual associated O&M cost to buildings (dollars/year),

AOMFB = annual O&M factor for buildings. As a general value use 0.02.

c) Total Annual Associated Costs for Building Containers:

ATACB = AACCB + AAOMCB

where: ATACB = associated total annual cost to buildings (dollars).

(9) Trucked System Total Costs

a) Total Capital Costs:

$$TSCC = VCC + PGCC + ACCB$$

$$TSACC = VACC + PGACC + AACCB$$

where: TSCC = trucked system capital costs (dollars),
TSACC = trucked system annual capital costs (dollars/year).

b) Total Annual Operations and Maintenance Costs:

$$TSAOMC = VAOMC + LCPA + PGAOMC + AAOMCB$$

where: TSAOMC = trucked system annual O&M costs (dollars/year).

c) Total Annual Costs:

$$TSTAC = TSACC + TSAOMC$$

where: TSTAC = trucked system total annual cost (dollars/year).

NOTE: By manipulating the equations the total cost can be broken down into the portions attributable to servicing the buildings and the source/disposal related costs.

(10) Cost per Unit Service

a) Water Delivery and Sewage Pump-Out:

$$CPG = \frac{(TSTAC - ATACB)}{NB \times NOPB \times VPCD \times 365}$$

where: CPG = average cost per litre (dollars/litre).

b) Garbage and Honeybag:

$$CPP = \frac{(TSTAC - ATACB)}{52 \times NB \times F}$$

where: CPP = average cost per pick-up (dollars/pickup).

NOTE: This variable may also be expressed as cost per container size; however, cost per pick-up is a more significant statistic.

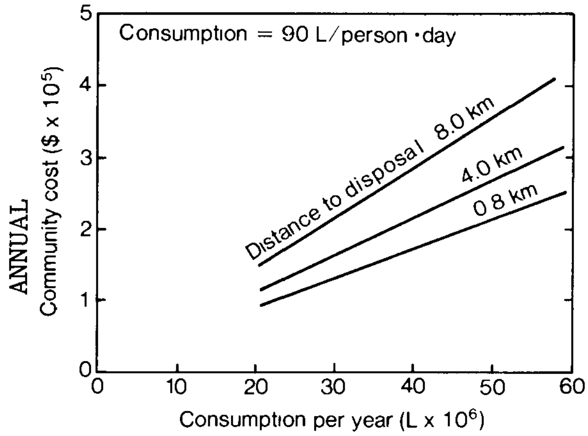
D.1.2 Application of truck system equations

The equations presented in this Appendix can be used to estimate the cost of trucked water delivery and sewage pump-out, garbage and honeybag collection services for individual or groups of buildings, or for whole communities [4]. They can also be used to optimize the design or sizing of components and equipment for a particular location. For example, various vehicle sizes, within the limitations of the road system and maneuverability requirements, can be assessed and building containers matched to provide a least-cost system. Technical improvements to increase the efficiency can also be identified.

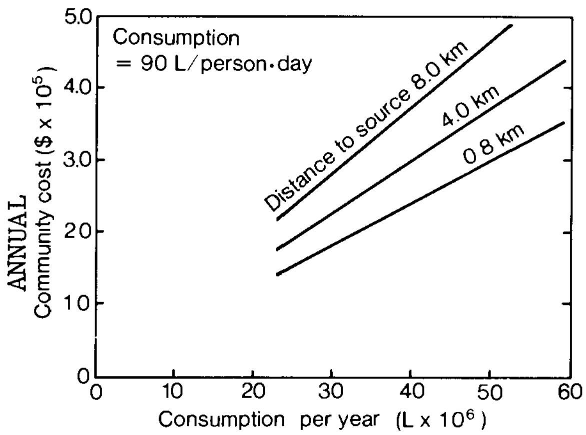
The equations and their applications are particularly suited to evaluation by computer or programmable calculator. By repeating the general equation, the cost for various building catagories within the community can be calculated and summed to a total system cost. Changes due to growth or water demand can be incorporated and costs over an economic planning horizon, say 20 years, can be obtained.

The most significant variable with respect to the cost of trucked water and sewage service is the quantities of water consumed and waste generated. The quantities necessary for sanitation and convenience must be carefully and realistically estimated. Many water conservation alternatives will be economical and should be incorporated into building plumbing (see Appendix B). Their use should be encouraged, particularly where such systems are subsidized. In many cases, it is more economical to pipe water from a distant source to a central truck fill point for distribution. The benefits of this and similar alternatives can be quickly identified by solving the general equations for the particular conditions in question. In some locations, the inherent lower water demand and storage requirements with trucked systems compared to piped systems will be a significant economic and practical advantage. Portions of communities, such as large consumers or compact or high density areas, may be more economically serviced by piped systems. Conversely, housing that is spread out, or where other conditions make it expensive to pipe service, at least during the winter, may be more economically serviced by a truck water and/or sewage system. The cost of truck servicing is relatively insensitive to housing density.

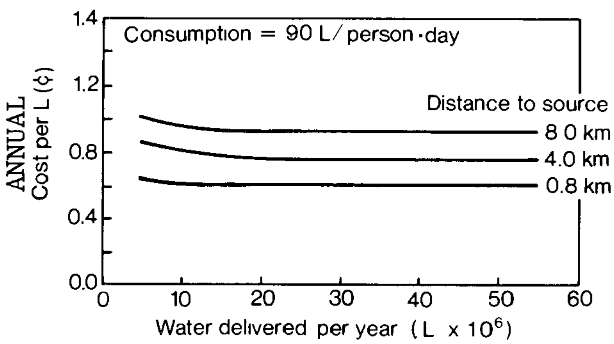
The effects of various factors on the cost of trucked system servicing are illustrated in Figure D-1 [5]. Figures D-1(a) and (b) show the effects of distance to the water source and sewage disposal on the



(a) Influence of distance to disposal on cost of sewage collection

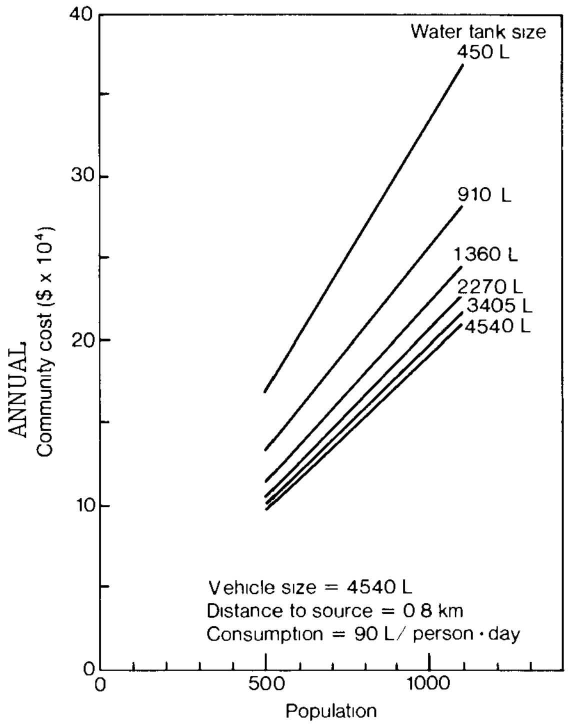


(b) Influence of distance to source on cost of water delivery

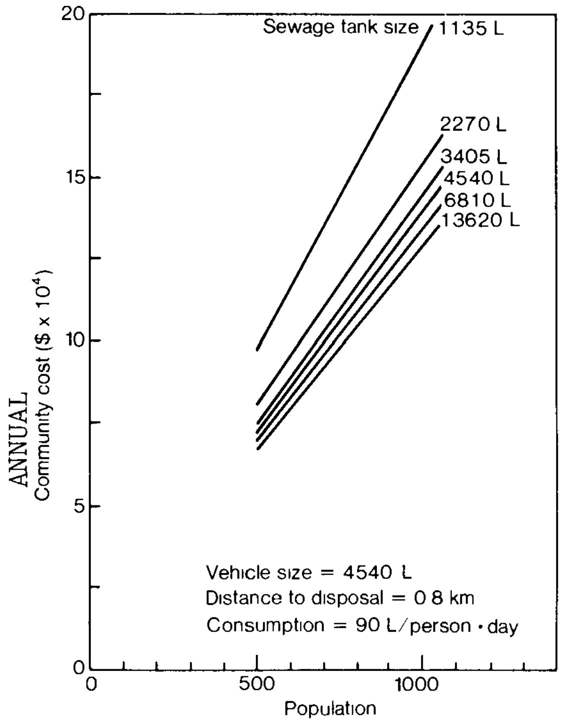


(c) Influence of distance to source on unit cost of water delivery

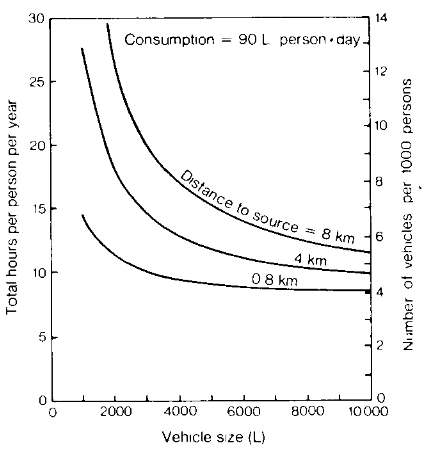
FIGURE D-1. INFLUENCE OF VARIOUS FACTORS ON COST OF TRUCKED SERVICE



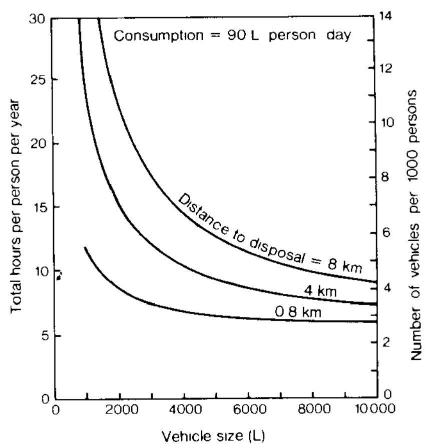
(d) Influence of household water tank size on water delivery costs



(e) Influence of household sewage tank size on sewage collection costs



(f) Influence of vehicle size on water delivery



(g) Influence of vehicle size on sewage collection

FIGURE D-1 (CONT'D)

total annual capitaland O&M costs at a discount rate of 8%. Figure D-1 (c) illustrates the influence of water source location and total annual consumption on the unit cost of water delivery. It shows that the cost per litre is relatively constant for a fixed average daily per person consumption. Figures D_1(d) and (e) show the effects of the size of the building tanks on the total costs. In this case, for a 4500-L vehicle it can be seen that there is little economic benefit of water tanks over 2250 L (five days consumption) and sewage holding tanks over 3400 l (7.6 days production). Figures D-1 (f) and (g) indicate the influence of the vehicle size on the total hours to service each person. It can be seen that vehicles larger than 4500 L are only of significant benefit when the source or disposal site is some distance from the buildings being serviced.

A breakdown of the total delivery costs of trucked water and sewage systems is presented in Table D-1. These values are for typical conditions and should only be used for preliminary estimating purposes. Typical economic rates for water delivery and sewage pump-out service inclusive are 1¢ to 2¢ per litre.

TABLE D-1. BREAKDOWN OF ANNUAL COST OF TRUCKED WATER DELIVERY OR SEWAGE PUMPOUT*

Vehicle Capital	= 14% (4-year life_
Vehicle O&M	= 25% (repairs, fueld, etc.)
Garage Capital	= 9% (construction, 10-year life)
Garage O&M	= 4% (heat, reparis, etc._
Labour	= 48% ($13/hour for two men)

* Assumes a discount rate of 8%. The cost of building tanks is included.

D.2 Data Supplement for Trucked Systems

A considerable amount of data particular to the Northwest Territories water and sanitation systems has been compiled by the Department of Local Government. It has been determined from analysis of the data that a number of parameters can be assumed to be the same for the typical vehicles being used and community conditions. Also, some parameters, such as the distance between buildings, are relatively insensitive to the total cost and reasonable values can be assumed. This data is summarized in Table D-2. It should be noted that, in certain communities, unusual local conditions or equipment may result in some parameters differing somewhat from those presented in this table. The analyst should assess the community in question to ascertain the reasonableness of the parameters.

Costs for wheeled and tracked water and sewer vehicles are presented in Table D-3. These are 1977 costs at a southern centre (e.g., Edmonton, Winnipeg, Montreal) and the transportation costs to specific communities must be added to these values. Adjustments for various options or alternatives are presented. A detailed breakdown of a steel water tank and appurtenances is shown in Table D-4.

TABLE D-2. TYPICAL VALUES FOR TRUCKED SYSTEM PARAMETERS [1]

	Trucked Water Supply Distribution	Trucked Sewage Collection & Disposal	Trucked Honeybag Collection & Disposal	Trucked Garbage Collection & Disposal
Efficiency of labour (EL)	1.5	1.5	1.5	1.5
Building container size (C)	5 days demand	7 days demand	0.03 m^3	0.2 m^3
Container utilization factor (CSF)	0.85	0.85	0.85	0.85
Vehicle Size (VS)	4500 L	4500 L	1.4 m^3	4.5 m^3
Vehicle utilization factor (VUF)	0.95	0.95	0.85	0.85
Speed of vehicle to and from source or treatment/ disposal point (S)	25 kmh	25 kmh	25 kmh	25 kmh
Rate of filling or emptying the vehicle container at the source or disposal point (R)	450 L/min	450 L/min	0.086 m^3	0.26 m^3
Turn around time at source or disposal point - emptying or filling time not included (TT)	4.0 min	4.0 min	1.0 min	1.0 min

TABLE D-2. (CONTINUED)

	Trucked Water Supply Distribution	Trucked Sewage Collection & Disposal	Trucked Honeybag Collection & Disposal	Trucked Garbage Collection & Disposal
Average vehicle speed between buildings (SB)	10 kmh	10 kmh	10 kmh	10 kmh
Distance between buildings (DB)	30 m	30 m	30 m	30 m
Rate of filling or emptying the vehicle container while servicing the buildings (RB)	180 L/min	340 L/min	0.018 $\frac{m^3}{min}$	0.085 $\frac{m^3}{min}$
Turn-around time while servicing each building - emptying or filling time not included (TTB)	3.0 min	3.0 min	0.25	0.25
Servicing cycle frequency (F)	calculate	calculate	260/yr	52/yr
Vehicle Cost (VC)	$30 500	$22 000	$12 000	$12 000
Vehicle Weight (VW)	4.3 t	4.3 t	2.5 t	2.5 t
Vehicle Economic Life (VEL)	4 yrs	4 yrs	4 yrs	4 yrs
Vehicle Service Factor (VSF)	0.15	0.15	0.30	0.30
Brake horsepower (BHP)	55 kW	55 kW	45 kW	45 kW
Fuel consumption rate per hp hour (FR)	0.24	0.24	0.24	0.24
Miscellaneous operating cost factor (MISC)	0.10	0.10	0.10	0.10
Number of helpers per vehicle - not including driver (NH)	1	1	1	2
Parking garage economic life (PGEL)	10 yrs	10 yrs	10 yrs	10 yrs
Associated building container economic life (ABCEL)	20 yrs	20 yrs	N/A	5 yrs
Residential container cost (CUC) Note: cost for non-residential buildings is not necessarily the same.	$0.40/L (installed)	$0.40/L (installed)	$0.06 per honeybag	$10.00 per container

TABLE D-3. WATER AND SEWAGE VEHICLE AND TANK COSTS [6]*

* 1977 PRICES - F.O.B. "SOUTH"

		WATER					SEWER				
	TANK SIZE	CAB & CHASSIS	INSULATED STEEL TANK	APPURTE-NANCES	TOTAL	WEIGHT	CAB & CHASSIS	NON-INSULATED STEEL TANK	APPURTE-NANCES	TOTAL	WEIGHT
	Litre	$	$	$	$	tons	$	$	$	$	tons
WHEELED 4 x 4	2250	10 000	4 240	8 750	23 000	2.9	10 000	2 900	3 600	16 500	2.9
	4500	13 000	5 750	8 750	27 500	4.3	13 000	3 400	3 600	20 000	4.3
	6800	16 000	7 750	8 750	32 500	5.4	16 000	4 500	3 600	24 100	5.4
	8200*	23 000	8 750	8 750	40 500	7.3	23 000	5 300	3 600	31 900	7.3
TRACKED	2250	27 000	5 250	8 750	41 000	5.4	27 000	5 400	3 600	36 000	5.4
	3400	55 000	6 750	8 750	70 500	8.2	55 000	6 150	3 600	64 750	8.2
	4500**	65 000	8 250	8 750	82 000	9.1	65 000	6 900	3 600	75 500	9.1

* Tandum Axle

** Larger tracked vehicles are generally impracticable.

ADJUSTMENTS TO TABLE D-3 (If Required):

1) For 4 x 2-wheeled vehicle, decrease the cost by $3 000.

2) For a non-insulated steel water tank, decrease the insulated steel tank cost by 45%.

3) For floatation tires (used in snow and poor road conditions), increase the cost by $4 500.

4) For desiel engines, increase the cab and chassis cost by 25%. The fuel consumption rate for desiel engine is 40% less than gasoline at 50 kmh, city driving test.

5) For stainless steel tank with indefinite life, multiply the steel tank cost by 3.0 (not usually used).

TABLE D-4. COST BREAKDOWN FOR 4500-LITRE TRUCK STEEL WATER TANK [6]

COMPONENT	COST*	PERCENTAGE
Tank shell	$ 2 000	13.8
Insulation and outer shell	2 500	17.2
Inside coating	700	4.8
Rear doghouse	1 200	8.3
P.T.O. pump & hydraulic piping	1 200	8.3
Hydraulic and controls	1 600	11.0
Painting	300	2.1
Mounting tank & truck frame	250	1.7
Reel and hose	1 000	6.9
Motor and pump	1 000	6.9
Piping and valves	1 000	6.9
Valve controls	500	3.4
Heating and piping	300	2.1
Wiring and electrical	300	2.1
Miscellaneous	650	4.5
	$14 500	100.0%
SUMMARY		
Non-insulated steel tank	$ 3 250	22.4
Insulation and outer shell	2 500	17.3
Appurtenances	8 750	60.3
	$14 500	100.0%

* F.O.B. Edmonton installed prices (1977) from Brian McKay of Edmonton Truck Body, Edmonton, Alberta.

D.3 Simplified Equations

A number of the parameters outlined in the detailed general equations are either not very significant, are common to most community conditions, or are a function of the equipment. If the typical values presented in Table D-1 are assumed, the truck equations become greatly simplified.

For water delivery:

$$THRS = POP\ (7.95 \times 10^{-2}\ VPCD + 1.02 \times 10^{-2}\ VPCD \times D + 1.37).$$

For sewage pump-out collection:

$$THRS = POP\ (5.57 \times 10^{-2}\ VPCD + 1.02 \times 10^{-2}\ VPCD \times D + 0.98).$$

where: THRS = total number of hours required to service the people or buildings within the defined group (hours),

POP = population, real or equivalent, within the defined group,

VPCD = volume of water consumed or waste generated (litres per person per day),

D = distance to the source or disposal point (kilometres).

These equations can also be used in terms of the number of buildings served (POP) and the total average daily demand per building (VPCD). The number of vehicles required to service the defined group is simply the next largest integer of the total hours from calculations for all buildings serviced, divided by the number of hours a vehicle is available per year, i.e., THRS ÷ 2145. These equations have been used to estimate the vehicle requirements as a function of population, distance and consumption in Figure D-2. Figure D-2(a) can be used to estimate the number of people that can be served by one vehicle or the number of vehicles required to service a given population. Figure D-2(b) indicates the average daily volume of fluid that can be handled by one vehicle.

From these simple equations the effects of changes in the most significant factors can be quickly assessed. Also, the labour costs and the vehicle requirements can be quickly calculated for preliminary estimates.

D.4 References

1. Government of the Northwest Territories, "General Terms of Reference for an Engineering Pre-design Report on Community Water and

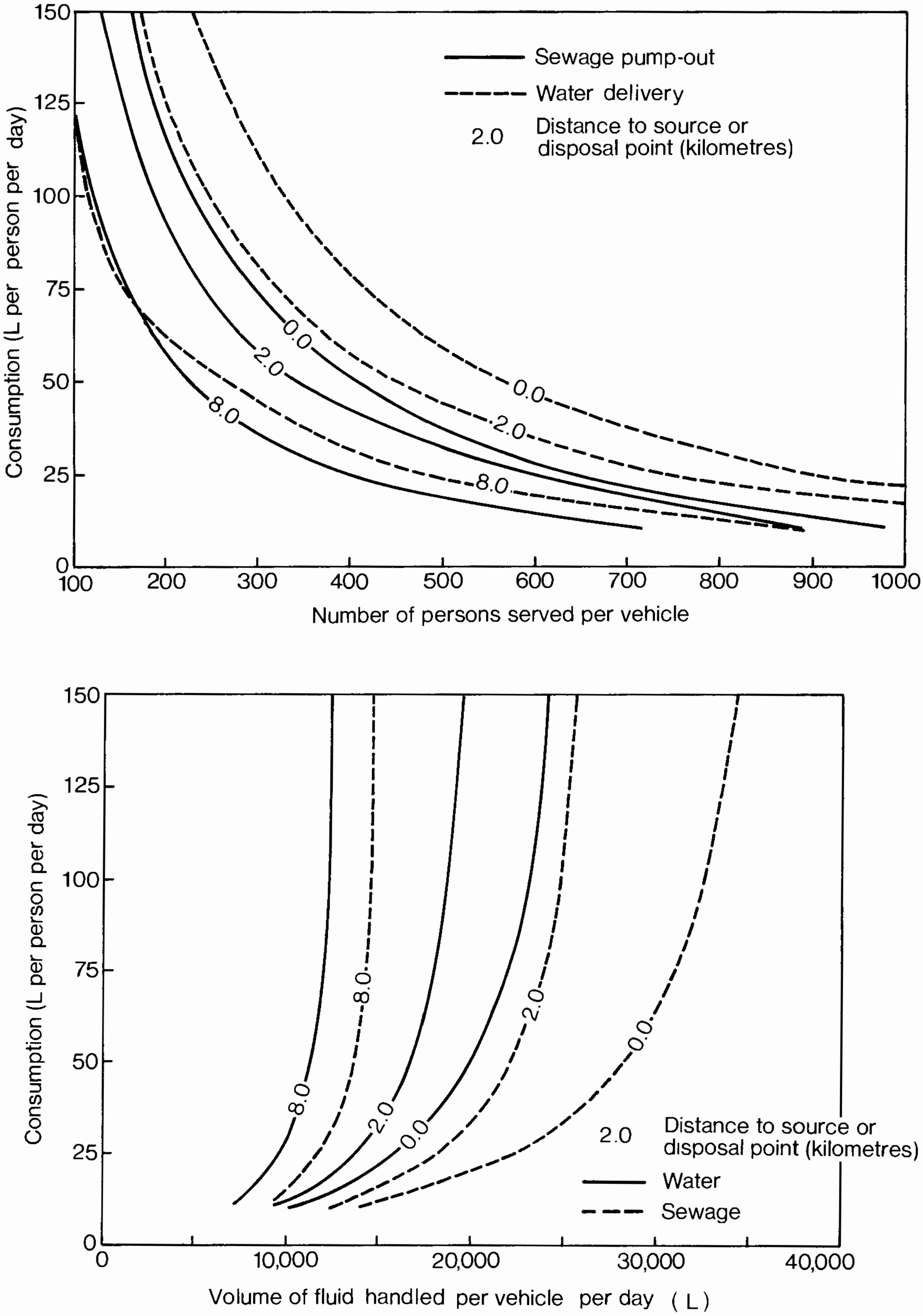


FIGURE D-2. VEHICLE REQUIREMENTS

Sanitation Systems", Department of Local Government, Government of the N.W.T., Yellowknife, N.W.T., 1978.

2. Gamble, D.J. and Janssen, C.T.L., "Evaluating Alternative Levels of Water and Sanitation Service for Communities in the Northwest Territories", Canadian Journal of Civil Engineering, 1(1):116-128, 1974.

3. Canadian Construction Association, "Rental Rates on Construction Equipment", Ottawa, Ontario, 1976.

4. Christensen, V. and Reid, J., "N.W.T. Water and Sanitation Policy and Program Review", Department of Local Government, Government of the Northwest Territories, Yellowknife, N.W.T., 1977.

5. Associated Engineering Services Ltd., "Demonstration of an Economic Analysis of Servicing Alternatives in Small Northern Communities", Prepared for: Dept. of Northern Saskatchewan, Dept. of Indian and Northern Affairs, Environment Canada, and Dept. of Regional Economic Expansion, Edmonton, Alberta, 1978.

6. Armstrong, B., Cameron, J. and Christensen, V., "Water and Sanitation Project Costs - A Consolidation of Historic Cost Information", Prepared for: Department of Local Government, Government of the Northwest Territories, Yellowknife, N.W.T., 1977.

APPENDIX E

VEHICLE SPECIFICATIONS

Index

E VEHICLE SPECIFICATIONS

E.1 Municipal Water Delivery Truck - Hydraulic Drive

These vehicle and tank specifications are abstracted from "Equipment Specification Number 601", prepared by the Department of Public Works, Government of the Northwest Territories, Yellowknife, N.W.T. The complete text should be consulted for detailed specifications.

Tank Body

A. Product: Potable Water

B. Capacity: 4500 L (1000 Imperial Gallons), nominal

C. Installation

1. Tank to be mounted on rubber bedding, attached to chassis with U-bolts. In addition to U-bolts, suitable steel lugs and pockets are to be installed to prevent lateral and longitudinal shifting of tank on chassis.
2. Tank body to be removable from chassis as a unit, lifting lugs provided and positioned so body is properly balanced for hoisting.
3. Installed to provide proper weight distribution between front and rear axles as recommended by chassis manufacturer.

D. Construction

1. Tank to be welded steel, minimum thickness 10 gauge (3.4 mm). Oval cross-section, overall width not to exceed width of cab. Interior of tank baffled to restrict surge action. Baffles designed to allow adequate circulation of water along bottom of tank to prevent freezing.
2. A compartment is to be included at the rear of the tank. This compartment, which is to be used for housing pump and hose reel, is to be constructed as an integral part of the tank, not as a separate attachment. The floor of the rear compartment is to be dropped such that the pump suction outlet will be level with the tank outlet.

3. Tank Outlets

   a) one 63.5 mm pipe thread outlet in rear head, at the bottom, for pump suction.

   b) one 50.8 mm pipe thread outlet in rear head, at the top, for filling tank and circulation return.

   c) One 50.8 mm pipe thread outlet in belly of tank, near the front, to be used as a cleanout. Outlet to be fitted with a square head pipe plug and sealed with teflon tape.

   d) All outlets will be extended 50 mm to clear the tank insulation and will be flanged for attaching the protective 18 gauge (1.2 mm) skin.

   e) Where the 63.5 mm suction outlet and the return outlet are installed in the tank, the tank will be reinforced with 10 gauge (3.4 mm) steel plate.

4. A combination top loading hatch, access manhole and vacuum/pressure breather is to be installed on top of tank.

5. An expanded metal walkway along top of tank, wide and extending the full length of the tank is to be installed.

6. A curbside access ladder will be installed adjacent to the top loading hatch.

7. Top loading hatch, walkway and ladder will be attached to the inner tank wall and not to the protective outer skin.

8. Insulation

   a) The complete tank and rear compartment, excluding compartment doors, but including both ends of the tank is to be insulated with 5 cm of sprayed-on urethane insulation.

   b) All insulation, including the insulation on the tank and compartment underside and compartment doors, is to be covered with a protective metal skin. This skin will be a minimum thickness of 18 gauge (1.2 mm).

9. Rear Compartment Access

   a) Two swing up compartment doors will be provided on the rear of the compartment. Both doors will be insulated with 4 cm of sprayed-on urethane insulation.

b) Hose rollers will be provided on both sides and bottom edge of hose hatch. The rollers will be positioned to allow dispensing hose at angles up to 45° without contacting edge of hatch.

10. Suction Hose Storage

    a) Two storage tubes to be provided for the 63.5 mm suction hose. Each tube long enough to contain a 2.4 m length of hose, with couplings and suction strainer.

11. A rear bumper will be installed to protect the rear of the tank body.

E. Water Pump

1. Pump installed is to be hydraulic motor driven Gorman Rupp Model 03H1-G centrifugal self priming PTO pump, mounted in rear compartment.

F. Water System - Piping and Valves

1. The system must be able to:

    a) Fill tank by drafting from a source.

    b) Discharge water from tank through hose.

    c) Discharge water from tank through fire outlet.

    d) Circulate water in tank.

    All piping to be galvanized steel schedule 40 with threaded/flanged/VICTAULIC joints. Sufficient unions to be installed to allow easy removal of pump and hose reel. All pipe threads to be sealed with teflon tape.

3. All valves to be 1/4 turn ball valves, lever operated.

4. VICTAULIC Couplings to be installed between the water tank and the pump suction valve and between the water tank and the circulate/return line.

G. Water System - Equipment

1. Delivery hose to be 30.5 m of 38.1 mm I.D. smooth bore, non-collapsing booster hose. Low-temperature type, flexible enough at -45°C to allow rewinding on reel. Dispensing end of hose fitted with a female quick coupling adaptor, EVER-TITE or compatible type coupling.

2. Two 2.4 m lengths of 63.5 mm I.D. rubber suction hose. Low temperature type, flexible to -45°C. One section equipped with a female quick coupling on one end, and a suction strainer on the other. Couplings to be EVER-TITE or compatible type.

3. Booster Reel

   a) Electric rewind.

   b) Auxilliary rewind crank supplied, to be mounted on brackets inside compartment.

   c) Reel push button mounted outside compartment.

   d) Roller hose guides to be provided.

H. Hydraulic Water Pump Drive System

1. Hydraulic System - General:
   The water delivery pump will be driven by a hydraulic motor and PTO mounted hydraulic pump. Hydraulic pump will be direct PTO mount type.

2. Reservoir:
   Mounted behind cab, alongside the truck frame, capacity to be 25 U.S. gallons.

3. Hydraulic Lines/Fittings:
   All hydaulic lines will be of a type approved for this service. Hose to be low-temperature type, rated for operation over the temperature range from -40°C to +80°C minimum.

I. Compartment Heater

1. A hot water heater is to be installed in the rear compartment.
2. Rated 12 000 W minimum, for 80°C supply water.

J. Controls - Hydraulic and Water Systems

Both the hydraulic system and water system will be provided with remote controls such that all functions can be achieved without opening the rear compartment doors.

K. Paint/Coatings

Interior of tank to be treated and coated with a non-toxic rust and corrosion preventive material approved for mobile potable water tanks.

L. Testing

Before acceptance the unit will be tested and the results of the tests recorded. The following tests must be satisfactorily completed:

a) Fill tank by suction from a source at least 2.4 m below the level of the pump centreline, with 4.9 m of suction hose connected.

b) Run a two hour pump test on a 50% duty cycle, pumping at full capacity for 15 minutes, resting for 15 minutes.

M. Operation and Maintenance (O&M) Manuals

1. Two complete copies are required for each vehicle.
2. Manuals must include:
   a) Parts catalogue for all installed equipment.
   b) Repair and service instructions.

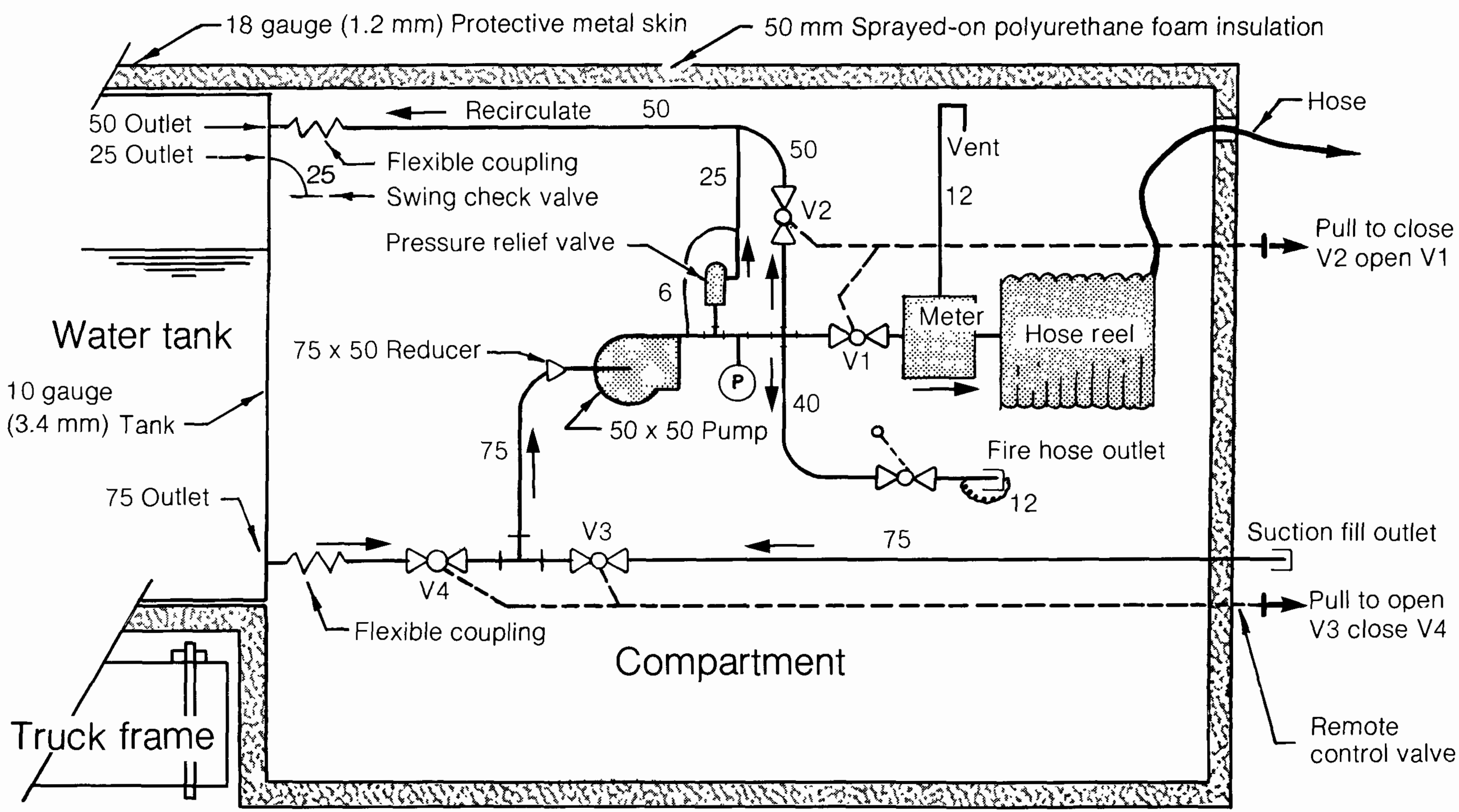


FIGURE E-1. WATER DELIVERY TRUCK TANK PIPING AND EQUIPMENT DIAGRAM

E.2 Municipal Vacuum Induction Sewage Truck - Power Take Off (PTO) Drive

These vehicle and tank specifications are abstracted from "Equipment Specification Number 607", prepared by the Department of Public Works, Government of the Northwest Territories, Yellowknife, N.W.T. The complete test should be consulted for detailed specifications.

A. Product: Domestic sewage and wastewater.

B. Capacity: 1000 Imperial gallons (4500 L), nominal.

C. Installation

1. Tank mounted on rubber bedding, attached to chassis with U-bolts. In addition to U-bolts, suitable steel lugs and pockets are to be installed to prevent lateral and longitudinal shifting of tank on chassis.
2. Tank body removable from chassis as a unit, lifting lugs provided and positioned so body is properly balanced for hoisting.
3. Installed to provide proper weight distribution between front and rear axles as recommended by chassis manufacturer.

D. Construction

1. Tank to be all-welded steel pressure vessel. Round cross-section, overall diameter not to exceed width of cab.
2. Rear work step provided with open mesh, expanded metal surface. Step to be a minimum 300 mm deep, extending width of tank body.
3. Heavy gauge rear bumper installed, extending width of tank body and equipped with rubber dock bumpers. Bumper to extend beyond work step.
4. Hinged rear end bell or hinged manhole cover installed, minimum 810 mm diameter. Installed with re-usable gasket.
5. Float type water level gauge visible from operator's position while filling. Float designed so as not to rest on tank bottom when tank is empty (to prevent freezing).
6. Storage trays for suction hose on side of tank body.
7. Hooks installed on side of tank for temporary storage of fully assembled suction hose.

E. Vacuum/Pressure Pump

1. PTO/V-belt drive.
2. Vane type, rated 3.54 m^3/min free air, and up to 686 mm of mercury vacuum minimum.

F. Piping and Valves

1. Float type primary shutoff valve installed to prevent tank overflow into vacuum system.
2. Secondary water trap installed in vacuum line to prevent moisture being drawn into pump. Water trap equipped with sight glass.
3. Fill outlet:

   a) Positioned on rear end bell, or manhole cover is so equipped, at a maximum height of 1.37 m above ground level.

   b) 76.2 mm swing type check valve installed on the interior side of tank wall.

   c) Lever-operated, quick-opening gate valve, 76.2 mm pipe size.

   d) Quick-coupling, male hose adapter installed with female cap and keeper chain.
4. Discharge Outlet:

   a) Positioned adjacent to fill outlet on rear end bell, or manhole cover is so equipped.

   b) To be 152.4 mm pipe size.

   c) Lever-operated, quick-opening gate valve, 152.4 mm pipe size installed.

   d) Quick-coupling, male hose adapter installed with female cap and keeper chain.
5. All valves, adapters and piping of a type approved for water service.
6. Compound gauge installed visible from pump operator's position. Range: 762 mm of mercury vacuum to 345 kPa of pressure minimum.
7. Flexible rubber hose coupled to pump exhaust/intake discharging under tank body, away from operator. Hose end located as high above ground level as possible to prevent dust intake.

G. Equipment

1. Four, 2.4-m lengths of 76.2-mm suction hose equipped with quick couplers. Three lengths to have one female and one male quick coupler, one length to have female quick couplers both ends. Hose to remain flexible at -50°C.
2. All quick couplers supplied for hose, discharge valve and fill valve to be of the same make.

H. Controls

1. PTO lever or cable controlled from cab: "PTO ENGAGED" warning light in cab.
2. Valve controls to be easily accessible.
3. Pump operating instructions to be printed on side of tank near operator's position. Use permanent type decal or engraved plastic or metal plaque. (DYMO type embossed labels are not acceptable).

I. Paint

1. Interior of tank to be coated with a rust and corrosive preventative meterial.
2. All surfaces to be fully primed before painting.

J. Operations and Maintenance Manuals

Manuals must include:

a) Parts catalogue for all parts.
b) Repair and service instruction.
c) Operation manual.
d) Weight and balance sheet.
e) Equipment Data Sheet.

APPENDIX F

THAWING FROZEN PIPES

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F. THAWING FROZEN PIPELINES

F.1 Electrical Thawing

The thawing of relatively small-diameter metal pipes using electricity is fairly common [1]. Either portable gasoline or diesel driven generators or welders, or heavy service electrical transformers (110 or 220 volt) have been used (Figure F-1) [2]. AC or DC current at high amperage and very low voltage (seldom more than 15 volts) can be used.

The amount of heat generated when a current is passed through a pipe is:

$$W = I^2R$$

where: W = heat or power in Watts or J/s,
I = current in amps,
R = resistance in ohms,

The rate of thawing of a frozen pipe is directly proportional to the square of the current applied, the mass of the pipe (cross-sectional area times length), and the material's effective resistance to the passage of electricity. For example, doubling the current (I) will increase the heat generated by a factor of four, and higher currents and longer times are required to thaw larger diameter pipes. Generally, as much current (heat) as practical, with safety limits, should be provided so the thawing time is reduced.

The approximate times required to thaw different sizes of steel pipe using different currents are given in Figure F-2. These values are based on steel pipe. Copper has about one-ninth the resistance of steel and a smaller cross-secional area. Therefore, when thawing copper pipes, these current values should be increased by about 10% for 12-mm pipe, 25% for 20-mm pipe, and higher values for larger copper pipes. Also, when copper pipe with soldered joints is to be thawed, it should not be heated to the point where the solder melts. Silver solder can be used to alleviate this.

Steel lines with continuity joints can be expeditiously thawed with welders. Some typical examples from thawing companies in Anchorage, Alaska are as follows:

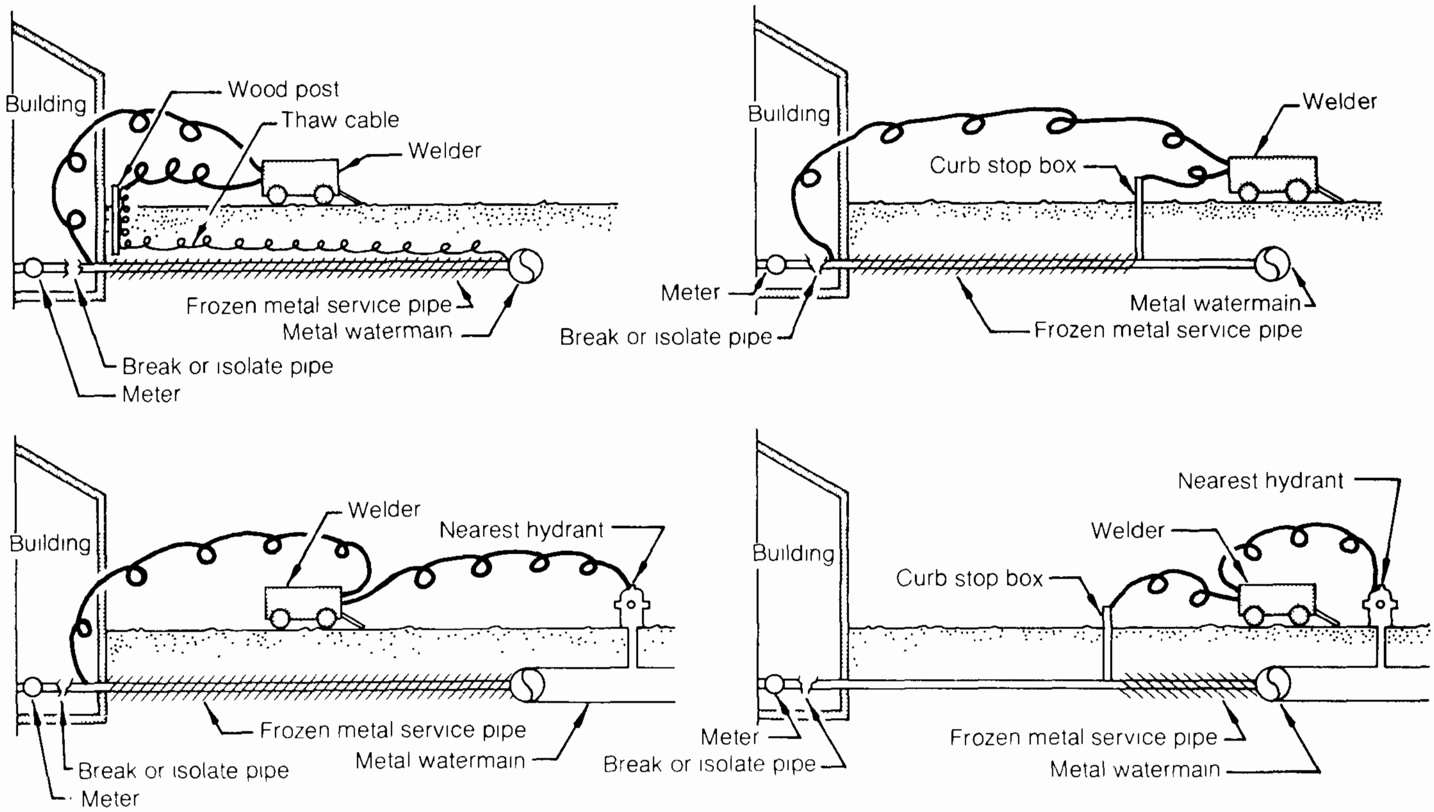

FIGURE F-1. ALTERNATIVES FOR THAWING SERVICE LINES

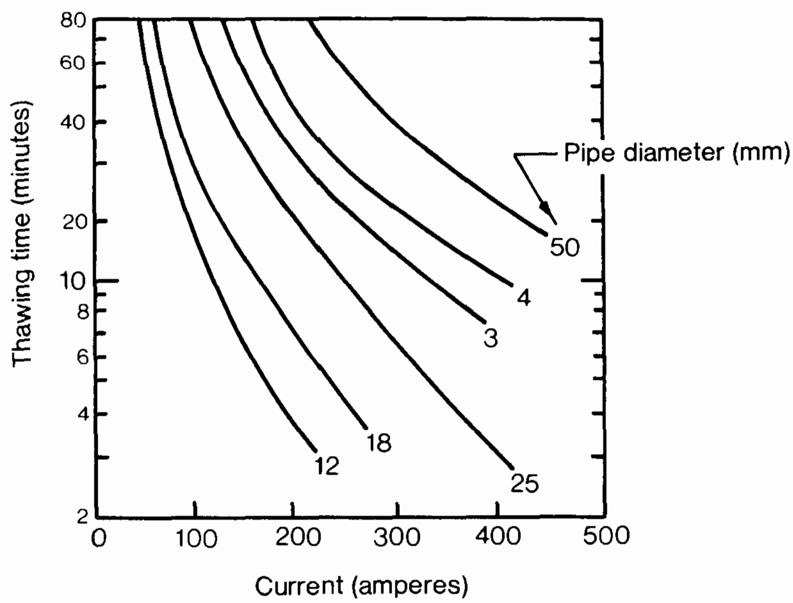

FIGURE F-2. APPROXIMATE TIME AND CURRENT FOR THAWING STEEL PIPES

	Number of Thawers
60 m of 100-mm pipe	3 machines (1 to 2 hours)
60 m of 100-mm pipe	4 machines (0.5 to 1.5 hours)
60 m of 150-mm pipe	4 machines (1 to 2 hours)
75 m of 40-mm pipe	2 machines (0.5 to 1 hour)
75 m of 40-mm pipe	1 machine (5 hours)

This information is based on using Miller Trailer Brazers 840 amp machines, which rent for $40/hour in Anchorage, Alaska. They will run continuously at 450 amps. They cost $3700 each (1975) plus $1000 for tanks and cables and average $5000 complete, F.O.B. Anchorage. They burn about 7.5 L of fuel per hour.

A 6.3 volt, 300 amp buzz box, which costs about $200 (1975), will produce the following heating when used to thaw a 19-mm copper service line ($R = 1.50 \times 10^{-4}$ Ω/m) [4].

Length of Copper Pipe (m)	Watts/meter
12	24
24	18
36	17
50	15
60	13

Using this method a 36-m length of service line was thawed in 10 minutes.

Another factor to be considered is the resistance and length of the cable used to connect the current-producing device to the pipe that is being thawed. Generally, the cable should be large enough that it does not get warm. Recommended cable sizes for various currents and lengths are given in Table F-1.

The following precautions should be taken when thawing pipes electrically:

1) Use on underground or protected pipe only (not indoor plumbing).
2) Don't use a high voltage. Twenty volts with 50 to 60 amps is sufficient. (Do not use constant voltage power source because there is usually no control for limiting the current.)

TABLE F-1. RECOMMENDED CABLE SIZES FOR ELECTRIC THAWING

	Distance (m) from welding machine or transformer to pipe connection											
Amperes	15	23	30	38	46	53	61	69	76	91	107	122
100	2	2	2	2	1	1/0	1/0	2/0	2/0	3/0	4/0	4/0
150	2	2	1	1/0	2/0	3/0	3/0	4/0	4/0	4/0	2.2/0	2.3/0
200	2	1	1/0	2/0	3/0	4/0	4/0	4/0	2.2/0	2.3/0	2.3/0	2.4/0
250	2	1/0	2/0	3/0	4/0	4/0	2.2/0	2.2/0	2.3/0	2.3/0		
300	1	2/0	3/0	4/0	4/0	2.2/0	2.3/0	2.3/0	2.4/0			
350	1/0	2/0	4/0	4/0	2.2/0	2.3/0	2.3/0					
400	1/0	3/0	4/0	2.2/0	2.3/0	2.3/0						

3) Make good, tight connections to the pipeline.
4) When conventional arc welders are used for thawing, do not operate them at their maximum rated amperage for more than five minutes. Only use about 75% of rated amperage if longer times are needed.
5) Disconnect electrical wires grounded to the water pipes in the buildings, or disconnect the service pipe from the house plumbing. Failure to do this could cause a fire.
6) Remove meters that may be in the service line.
7) A problem may be encountered with the thawing current jumping from the water service line into nearby gas or other lines. These should be separated by a 25-mm wood wedge.

Pipes equiped with electric heating cables may be thawed automatically, when power is restored, or by manually switching them on. They should be sized to thaw the pipe in a reasonable length of time. Figure F-3 illustrates the performance of various heating cables within a double service line utilidor.

F.2 Thaw Tubes

Small-diameter pipes, such as service lines, of any material may be quickly thawed by pushing a flexible 11-mm or smaller plastic tube into the frozen pipe while pumping warm water into the tube. Water

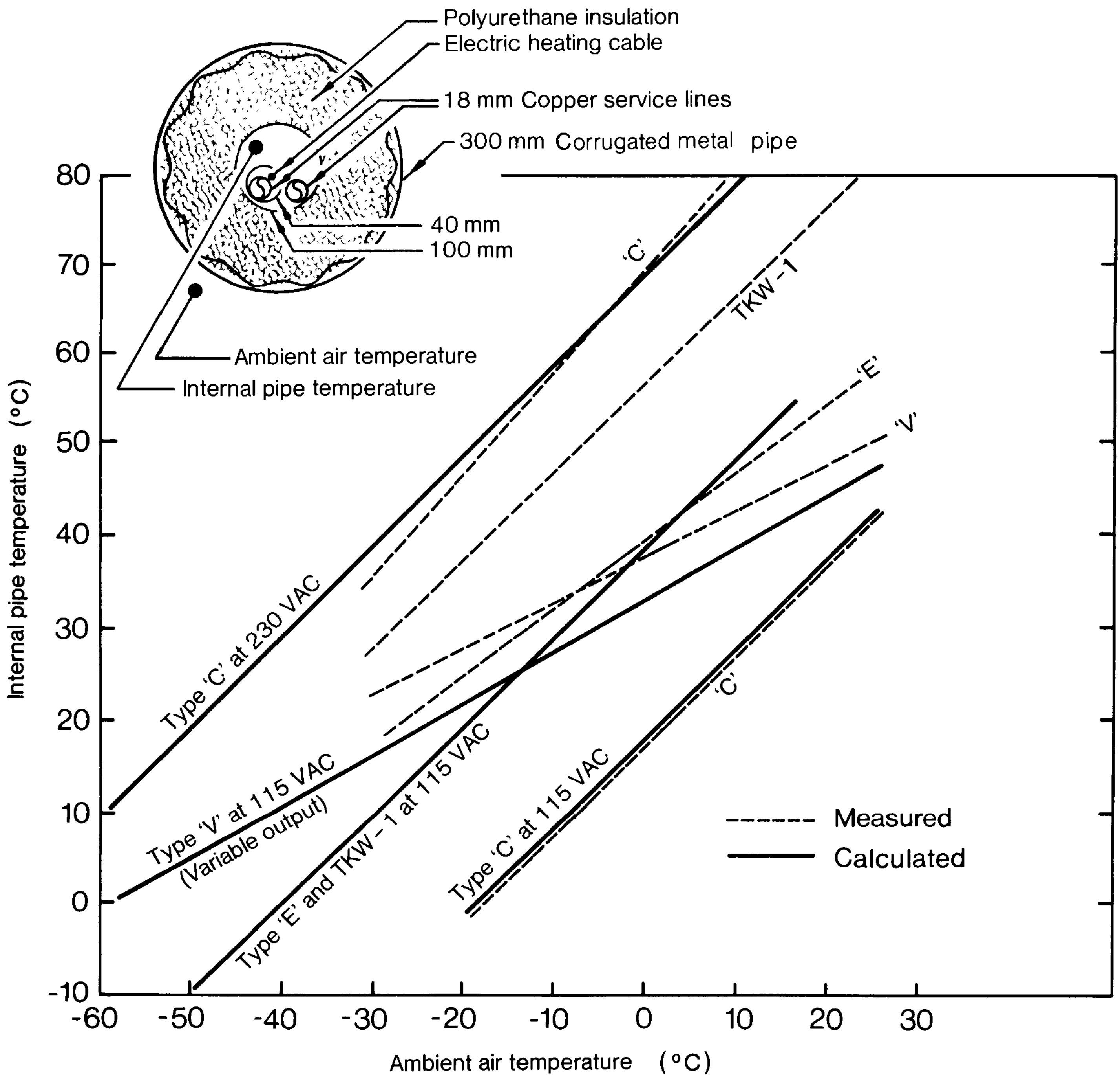

FIGURE F-3. ELECTRIC HEAT TAPE TESTS [5] pressure can be obtained from a nearby building, either directly or by connecting to the building plumbing. A conventional hand pump filled with warm water can also be used (Figure F-4). There is also commercial unit that produces a pulsating stream of water to pump warm water through the tube which is attached to the frozen pipe by a special fitting to ease the installation and reduce spillage [6].

This method is reported to be about 50% successfull [7]. Most of the failures have occurred because the thaw tube could not be inserted due to mineral build-ups, sharp bends, and kinks in the service pipe. The success rate would be much higher if the pipes were installed with this thawing technique in mind.

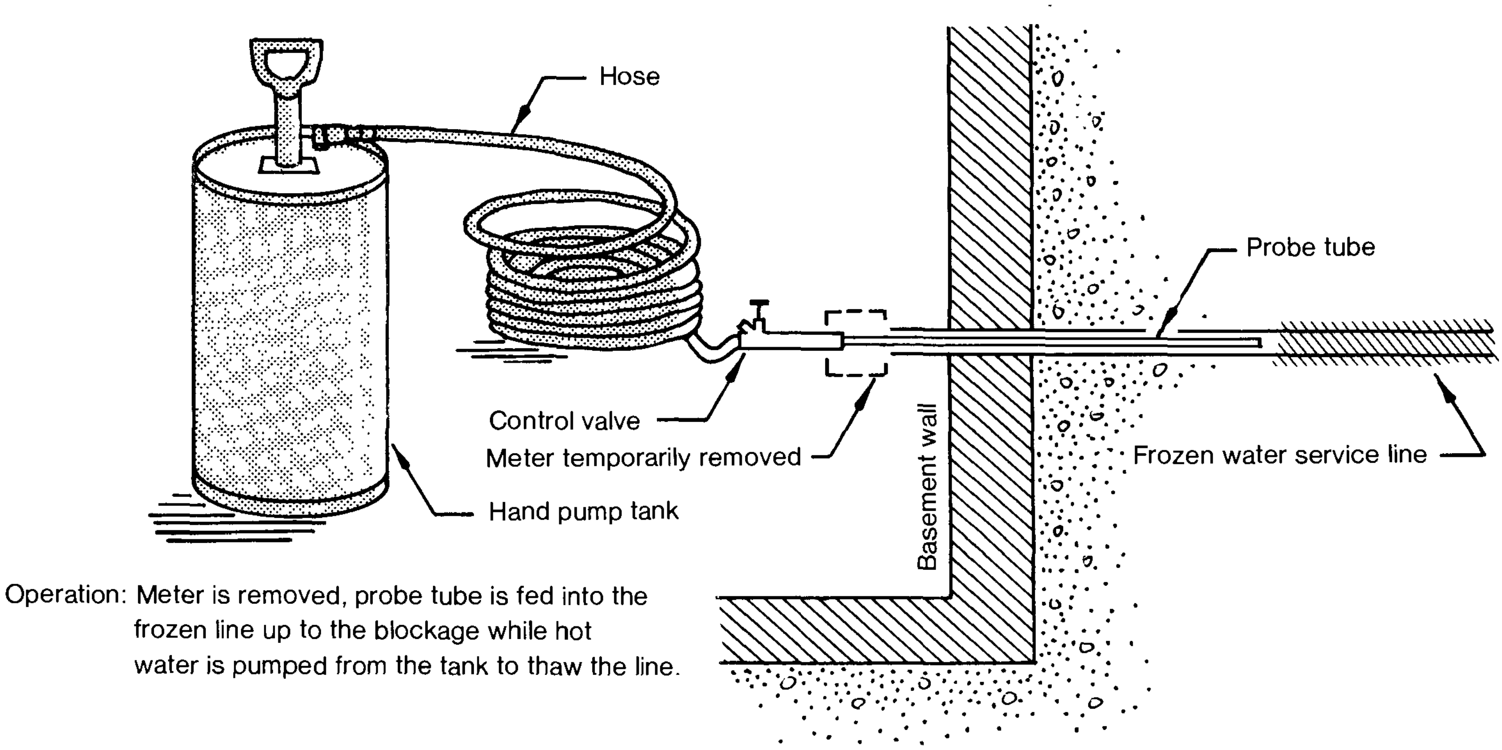

FIGURE F-4. THAW TUBE THAWING METHOD

F.3 References

1. Bohlander, T.W., "Electrical Methods for Thawing Frozen Pipes", Journal of American Water Works Association, 55(5):602-608, 1963.

2. Eaton, E.R., "Thawing of Wells in Frozen Ground by Electrical Means", Water and Sewage Works, 3(8):350-353, 1964.

3. Alter, A.J. "Water Supply in Cold Regions", U.S. Army Cold Regions Research and Engineering laboratory, Hanover, New Hampshire, Monograph 111-5a, 1969.

4. Longstaff, T., Personal communications, Alaska Area Native Health Service, Department of Health, Education, and Welfare, Anchorage, Alaska.

5. Ryan, W. "Design Guidelines for Piping Systems", Utilities Delivery in Arctic Regions, Environmental Protection Service, Environment Canada, Ottawa, Ontario, Report No. EPS 3-WP-77-1, pp. 243-255, 1977.

6. Curry, J.R. "Thawing of Frozen Service Lines" Presented at: Utilities Delivery in Northern Regions, 19-21 March, 1979, Edmonton, Alberta, Environmental Protection Service, Environment Canada, Ottawa, Ontario (In preparation).

7. Nelson L.M., "Frozen Water Services", Journal of American Water Works Association, 68(1):12-14, 1976.

APPENDIX G

FIRE PROTECTION STANDARDS

Index

DFC NO. 405

DRAFT NO. 3

STANDARD FOR

WATER SUPPLIES

OCTOBER

1978

DOMINION FIRE COMMISSIONER

CONTENTS

STANDARD FOR
WATER SUPPLIES

405.1 GENERAL

405.1.1 Scope

(a) This Standard describes the requirements for water supplies for the protection of Government of Canada properties from fire.

(b) In the case of buildings in Northern or remote areas, where the requirements of this Standard cannot be met in their entirety, they should be applied to the maximum extent possible as required by the DFC or his authorized representative.

405.1.2 Application

(a) The requirements of this Standard shall be applicable to all property whose importance or value as determined by the Administrative Official is such as to require protection from loss by fire, except as required in (b).

(b) In the case of properties, where in the opinion of the DFC or his authorized representative there is a potential life hazard, the requirements of this Standard shall be applicable in all cases.

405.1.3 Administration

(a) This Dominion Fire Commissioner or his authorized representative is responsible for the administration and enforcement of the requirements of this Standard.

(b) In any case where deviation from these requirements may be necessary, specific approval in writing shall be obtained from the Dominion Fire Commissioner and this specific approval shall apply only to the particular case for which it is given.

405.1.4 Standards

Where reference is made to other standards, unless otherwise stipulated, the reference shall be to the latest edition.

405.1.5 Definitions

Exposure Fire Flow means the water flow additional to the fire flow required to protect an exposed building from ignition due to fire in an exposing building.

Fire Flow means the water flow required to control, extinguish and overhaul a fire.

Floor area means the space on any storey of a building between exterior walls and required fire walls, including the space occupied by interior walls and partitions.

Unprotected Opening (as applying to exposing building face) means a doorway, window or opening other than one equipped with a closure having the required fire-protection rating.

405.2 FIRE FLOW

405.2.1 Basic Fire Flow

(a) Except for one and two storey dwellings of floor areas up to 200 m^2 (2,000 $ft.^2$) the basic fire flow shall be determined by the following formula:

$$F = K\sqrt{A}$$

where F = basic fire flow

A = building floor area

K = 10 when A in $ft.^2$ and F = g.p.m. (Can)

= 2.5 when A in m^2 and F = L/s

405.2.2 Area

(a) Except as provided in (b) the total Fire Flow and quantity of water provided shall be determined on the basis of the estimated largest fire, as determined by the DFC or his authorized representative.

(b) In the case of large or high risk properties as determined by the DFC or his authorized representative, the total Fire Flow and quantity of water provided shall be determined on the basis of the probability of the two estimated largest fires occurring at the same time.

(c) The area used for calculating the fire flow shall be equal to the total area of all floors of a building except as permitted by (d) and (e).

(d) Where fire walls of at least 2 hour fire resistance rating compart buildings into fire areas the fire flow shall be calculated on the basis of the maximum floor area.

(e) In cases where buildings have automatic sprinklers in accordance to Section 405.6, the area used for calculating the fire flow shall be 2.0 x design area of the sprinkler system for unprotected combustible construction and 1.5 x design area of the sprinkler system for all other types of construction.

405.2.3 Required Fire Flow

(a) The required fire flow (F) is dependent upon: the type of construction, nature of occupancy, fire fighting facilities available, and location of building with respect to the fire fighting facilities available . Except for 1 and 2 storey dwellings, these factors shall be applied to modify the basic fire flow quantified in subsection 405.2.1 using the modified formula:

$$F = KC_F\, C_c\, C_o \sqrt{A}$$

where C_c = Construction Coefficient (See Subsection 405.2.4)

C_o = Occupancy Coefficient (See Subsection 405.2.5)

C_F = Firefighting facilities coefficient (See Subsection 405.2.6)

$K = 10$ when $A = ft^2$ and F = g.p.m. (Can)

$= 2.5$ when $A = m^2$ and F = L/s.

(b) Additional exposure fire flow (F_E) may be required for exposure protection in accordance to Section 405.3.

(c) The minimum fire flow shall not be less than C_F x 15 L/s or C_F x 200 g.p.m. (Can)

(d) For property consisting entirely of 1 and 2 storey dwellings of floor areas up to 200 m^2 (2,000 $ft.^2$) and detached at least 15 m (50 ft.) from each other, the minimum fire flow stipulated in (c) shall be considered adequate.

(e) The maximum required fire flow including exposure fire flow for any building shall be 640 L/s (500 g.p.m. (Can)).

405.2.4 Construction Coefficient

(a) The construction coefficient used for the determination of the fire flow in accordance with Clause 405.2.3(a) shall be as shown in TABLE 405.2.4A.

TABLE 405.2.4A
Forming Part of Clause 405.2.4(a)

Type of Construction	Fire Resistance Rating	Construction Coefficient, C_C
Unprotected Combustible	(<3/4 HR)	1.0
Protected Combustible	(≥3/4 HR)	0.8
Unprotected Noncombustible	(<2 HR)	0.6
Protected Noncombustible	(≥2 HR)	0.4

(b) For buildings consisting of more than one type of construction, the construction coefficient for the determination of the water flow, in accordance with Clause 405.2.3(a) shall be equal to the average of the different construction coefficients.

405.2.5 Occupancy Coefficient

(a) The Occupancy Coefficient used for the determination of the fire flow in accordance with Clause 405.2.3 (a) shall be as shown in Table 405.2.5 A.

TABLE 405.2.5 A
(Forming part of Clause 405.2.5(a))

OCCUPANCY GROUP DIVISION	COEFFICIENT
C D F_3	1.0
A (1-4) B (1-2) E F_2	1.5
F_1	2.0

4.5.2.6 Fire Fighting Facilities Coefficient

(a) The fire fighting facilities coefficient used for the determination of the fire flow in accordance with Clause 405.2.3 (a) shall be as shown in Table 405.2.6A

(b) The estimated time it takes for fire fighting facilities to start applying the fire flow on the fire from start of fire shall be determined. If the time is undeterminable, maximum time shall be used.

TABLE 405.2.6A
(Forming part of clause 405.2.6 (a))
Coefficient C_F

	CAPABILITY OF FIRE DEPARTMENT	TIME (MINUTES) FOR APPLYING WATER ON A FIRE			
		0-5	> 5-10	> 10-20	> 20
(1)	Trained, fire fighting experience, capable fire fighting team. Turn out certain, sufficient equipment, adequate dispatching and communication system. Regular building inspections and other related fire work.	1.0	1.0	1.1	1.2
(2)	Similar to (1) except no regular building inspections and other related fire prevention work.	1.0	1.1	1.2	1.3
(3)	Trained fire fighting team not fitting all the requirements of (1) or (2).	1.1	1.2	1.3	1.4
(4)	Very little training, or none at all and/or little experience at fire fighting.	1.2	1.3	1.4	1.5

405.3 EXPOSURES

405.3.1 Dwellings

(a) For property consisting entirely of 1 or 2 storey dwellings of floor area up to $200m^2$ ($2000\ ft^2$) detached less than 15m (50 ft) from each other, the minimum water flow as stipulated in clause 405.2.3 (d) shall be adjusted by the appropriate factors for the exposures given in Table 405.3.1A

TABLE 405.3.1A
(Forming part of Clause405.3.1 (a))

Distance of exposing dewlling		Factor C_E
> 15m	(> 50 ft)	0
> 12-15m	(> 40-50 ft)	0.1
> 9-12m	(> 30-40 ft)	0.2
> 6-9m	(> 20-30 ft)	0.3
0-6	(0-20 ft)	0.4

(b) The factors stipulated in (a) shall apply to not more than three exposures of which not more than 2 exposures should be considered if over 9 m (30 ft).

(c) Where the exposing face of the dwelling has a fire-resistance rating of at least 3/4 hr., with no windows and is clad with non-combustible material the exposure factors may be reduced by 50% except as indicated in clause (d).

(d) Where the exposure distance is less than 2,5 m (8ft) there shall be no reduction in the exposure factor.

405.3.2 Buildings other than dwellings

(a) For buildings other than 1 & 2 storey dwellings up to 200m^2 (2000 sq.ft.) in floor area, the exposing building face area, the area of the unprotected openings in the exposing building face area expressed as a percentage of the exposing face area and the occupancy shall be determined.

If the exposure distance is less than the values given in Table 403.3.2A, exposure fire flow shall be required in additionto the required fire flow.

TABLE 405.3.2A
Forming Part of Clause 405.3.2 (a)

OCCUPANCY	EXPOSURE DISTANCE (m)				
OPENINGS	AREA OF EXPOSING BUILDING FACE (m^2)				
> 50 %		140m^2 < 1500ft^2	140m^2-460m^2 1500-5000ft^2	460m^2-1850m^2 5000-20,000ft^2	>1850m^2 >20,000ft^2
≤50%	140m^2 < 1500ft^2	140m^2-460m^2 1500-5000ft^2	460m^2-1850m^2 5000-20,000ft^2	> 1850m^2 >20,000ft^2	
A, B, C, D, F_3	15m(50ft)	30m(100ft)	45m(150ft)	60m(200ft)	90m(300ft)
E, F_1, F_2	30m(100ft)	45m(150ft)	60m(200ft)	90m(300ft)	120m(400ft)

(b) The exposure fire flow shall be determined from the required fire flow for the exposing building adjusted using the appropriate factors given in Tables 403.2B and 403.2C below, but not exceeding the limits stipulated in this subsection.

TABLE 405.3.2B

(Forming part of clause 405.3.2 (b))

OCCUPANCY GROUPS: A, B, C, D, F_3

EXPOSURE FACTOR		EXPOSURE DISTANCE m (ft)				
OPENINGS		EXPOSING BUILDING FACE (ft^2)				
	> 50		$140m^2$ ≤ 1500	$140m^2$-$460m^2$ 1500-5000	460-$1850m^2$ 5000-10,000	> $1850m^2$ 20,000
≤ 50		$140m^2$ ≤ 1500	$140m^2$-$460m^2$ 1500-5000	460-$1850m^2$ 5000-20,000	> $1850m^2$ > 20,000	
.2	.4	0-8m (0-25)	0-14m (0-45)	0-20m (0-65)	0-27m (0-90)	0-40m (0-130)
.15	.3	8-12m (25-40)	14-20m (45-65)	20-30m (65-100)	27-40m (90-130)	40-60m (130-195)
.10	.2	12-15m (40-50)	20-24m (65-80)	30-37m (100-120)	40-49m (130-160)	60-74m (195-240)
.05	.1	15-18m (50-60)	24-30m (80-100)	37-46m (120-150)	49-60m (160-200)	74-90m (240-300)
0	0	> 18m (> 60)	> 30m (> 100)	> 46m (> 150)	> 60m (> 200)	> 90m (> 300)

TABLE 405.3.2C

(Forming part of clause 405.3.2 (c))

OCCUPANCY GROUPS: E, F_1, F_2

EXPOSURE FACTOR		EXPOSURE DISTANCE (ft)				
OPENINGS		EXPOSING BUILDING FACE (ft^2)				
	>50		$140m^2$ ≤1500	$140\text{-}460m^2$ 1500-5000	$460\text{-}1850m^2$ 5000-20,000	$>1850m^2$ >20,000
≤50		$140m^2$ ≤1500	$140\text{-}460m^2$ 1500-5000	$460\text{-}1850m^2$ 5000-20,000	$>1850m^2$ >20,000	
.4	.8	0-15m (0-50)	0-23m (0-75)	0-30m (0-100)	0-46m (0-150)	0-60m (0-200)
.3	.6	15-23m (50-75)	23-34m (75-110)	30-46m (100-150)	46-69m (150-225)	60-90m (200-300)
.2	.4	23-27m (75-90)	34-40m (110-130)	46-53m (150-175)	69-76m (225-260)	90-105m (300-350)
.1	.2	27-30m (90-100)	40-46m (130-150)	53-60m (175-200)	76-90m (260-300)	105-120m (350-400)
0	0	>30m (>100)	>46m (>150)	>60m (>200)	>90m (>300)	>120m (>400)

(c) The maximum exposure fire flow shall not exceed 1/2 the required fire flow as determined in Clause 405.2.3 (a) except:

i) where the exposing building is a Group F_1 occupancy;

ii) in areas of high wind velocity as determined by the DFC or his authorized representative; or

iii) where the start of fire fighting operations would be greater than 10 minutes after receipt of an alarm.

In such cases the maximum exposure fire flow shall not exceed the fire flow.

(d) The factors stipulated in (b) shall apply to not more than 3 exposures.

(e) Where buildings are sprinklered and/or where approved automatic fire suppression systems have been installed to protect exterior walls the exposure factor may be reduced by 50%.

(f) Where exposed exterior wall is a blank masony wall with a fire protection rating of not less than 3 hours, the exposure factor may be reduced to zero.

(g) Where there is an absence of combustible material on an exposed wall the exposure factor may be reduced 25%.

(h) Where the exposed exterior wall consists of wooden shingles and/or wooden window frames the exposure factor shall be increased by 25%.

405.4 WATER SUPPLIES

405.4.1 Quantity

(a) The minimum quantity of water available for fire protection shall be 8000 L (1700 gal. (Can)).

(b) The total quantity of water available for fire protection shall be determined from the maximum required fire flow (F_{MAX}) according to the formula:

$$Q = 57.6\, F_{MAX}^2 - 1800\, F_{MAX} \quad \text{in litres}$$

$$= 0.072\, F_{MAX}^2 - 30\, F_{MAX} \quad \text{in Canadian gallons.}$$

& $F_{MAX} = F + F_E$ determined as described in Sections 405.2 and 405.3.

405. 5 WATER SUPPLY FACILITIES

405.5.1 Adequacy & Reliability

a) The water supply for fire protection as required by this Standard shall be available at all times and under all conditions and for the required duration.

405.5.2 Natural Sources

a) When natural sources of water supply as described in b) are not sufficient to supply the required fire flow for the entire duration or where buildings cannot be reached with 80m (250 ft) of 45mm (1 1/2 in) hose, 150m (500 ft) of 70mm (2 1/2 in) hose, 300m (1,000 ft) of 75mm (3 in) hose or 780m (2,500 ft) of 90mm (3 1/2 in) hose or larger, an approved system of underground mains and hydrants shall be installed.

b) Natural sources of water may include rivers, streams, reservoirs, canals, lakes, ponds, wells and cisterns that are easily accessible to fire fighting equipment and personnel.

c) The water supply from any natural source shall be acceptable to the DFC or his authorized representative based upon its adequacy and reliability.

d) The maximum depth of any well shall be 60m (200 ft).

405.5.3 Distribution System

a) The water supply for fire protection may be in common to the water supply for domestic or other needs, but the system shall be so designed that the water supply required for fire protection is always available and based upon the maximum daily rate for domestic and industrial use.

b) Hydrants shall be so distributed and located that every part of the interior of the building not covered by a standpipe can be reached by two hose streams.

c) When hose lines are intended to be used directly from hydrants, the hydrants shall be located so that not more than 75m (250 ft) of hose line is used except as in (i) & (ii) below:

(i) when the required fire flow is greater than 450 L/sec (6,000 gpm (Can)) the maximum length of hose shall not exceed 60m (200 ft) except that:

(ii) all parts of a lumberyard shall be reached by using not more than 60m (200 ft) of hose for all flows.

d) Pressure shall be sufficient in the water system so that the required fire flow can be supplied with fire department pumpers in addition to the water supply required for sprinklers and standpipes.

e) The minimum pressure at the hydrants with the required fire flow shall be 140 kPa (20 psig) unless otherwise approved.

405.5.4 Pumps

a) Pumps shall be ULC certified or as otherwise designated by the DFC or his authorized representative.

b) Where the required flow is greater than 75% of the capacity of fire department pumper(s), approved vehicle mounted pump or portable pump in combination, permanently installed pumps, elevated storage tanks, reservoirs or a combination thereof shall be provided to meet the required flow.

c) The system shall be designed to deliver the required fire flow with the largest pump out of service.

d) Power for pumps shall be selected on the basis of reliability of power supply in accordance to (f).

e) Where pumps are used in natural sources of water, intakes should be screened to prevent debris from entering the pump.

f) In large water plants where two or more pumps are required, pumps shall be electrically driven and supplied from an emergency power source of sufficient capacity to operated the largest fire pump for the required period of operation, except as permitted in (g).

g) A propane or diesel engine driven pump of equivalent capacity to the largest electrically driven pump may be installed in lieu of providing emergency power.

405.6 Automatic Sprinkler Systems

a) Only in cases where an approved sprinkler system conforming to DFC No. 403 "Standard for Sprinkler Systems" shall the design area of the sprinkler system be in accordance with clause 405.2.2(e).

b) In cases where the sprinkler system has not been installed in accordance to DFC No. 403, or where manual inspections are not possible, or no automatic means of supervising sprinkler systems, the area used for calculating <u>fire flow</u> shall be determined as though no sprinkler system existed unless otherwise specified by the DFC or his authorized representative.

c) Partially sprinklered buildings in which certain hazardous areas are sprinklered shall be treated as unsprinklered buildings with some credit determined by the DFC or his Regional Representative for the hazard reduction of the occupancy.

APPENDIX - EXAMPLE CALCULATION

The undernoted example illustrates how the water supply for the fire protection of an Indian Reserve may be calculated.

A. DATA . The buildings on the reserve are assumed to be: Several 1 & 2 Family Dwellings: 1 & 2 storey; area < 2000 ft^2; minimum distance apart - 30 ft. with no dwelling exposed by more than 3 others.

Band Hall: 1 storey; area - 4000 ft^2; 3/4h combustible construction, no exposures.

Offices: 2 storeys; area - 3000 ft^2; /floor; unprotected noncombustible construction, exposure - Warehouse No. 1 - 70 ft; building face area - 1100 ft^2; unprotected openings $>$ 50%.

Warehouse No. 1: 1 storey; area - 5000 ft^2; protected noncombustible construction; exposures - offices - 70 ft, warehouse No. 2 - 100 ft; Bldg. Group F_3; building face area - 1400 ft^2; unprotected openings $<$ 50%.

Warehouse No. 2: 1 storey; area 10,000 ft^2; protected noncombustible construction; fully sprinklered - design area - 3000 ft^2; exposure - Warehouse No. 1 - 100 ft; Bldg. Group F_1; building face area 2000 ft^2; unprotected openings $<$ 50%.

. The estimated time of response for a well trained municipal fire department not making regular inspections is $>$ 5-10 minutes.

B. CALCULATIONS

. REQUIRED FIRE FLOW - FORMULA

From clause 405.2.3 (a), the required fire flow

$$F = K\, C_F\, C_c\, C_o \sqrt{A}$$

where C_F = 1.1 from the data & Table 405.2.6A.

. Fire flow for dwelling protection

From clause 405.2.3 (d), required Fire Flow $F = C_F \times 200$ gpm

$= 1.1 \times 200$ gpm

$= 220$ gpm (Can)

From clause 405.3.1(a) Exposure Fire Flow $F_E = 3 \times 0.3 \times 220$ gpm

$\simeq 200$ gpm (Can)

$\therefore$ Total Fire Flow = $F + F_E$ = 420 gpm (Can)

. FIRE FLOW FOR BAND HALL

$K = 10; C_F = 1.1; C_o = 1.5$ (GROUP A): $C_c = 0.8; A=4000$

$\therefore$ Required Fire Flow = $10 (1.1) (0.8) (1.5)\sqrt{4000}$
= 835 gpm (Can)

No exposures, $\therefore F_E = 0$ and Total Flow = 835 gpm (Can)

. FIRE FLOW FOR OFFICES

$K = 10; C_F = 1.1; C_o = 1.0$ (GROUP D); $C_c = 0.6; A = 6000$

$\therefore$ REQUIRED FIRE FLOW = $10 (1.1) 0.6) (1.0)\sqrt{6000}$
= 510 gpm (Can)

TOTAL FIRE FLOW = REQUIRED FIRE FLOW + EXPOSURE FIRE FLOW.

EXPOSURE FIRE FLOW will be dependent upon required fire flow for exposing building - Warehouse No. 1.

FIRE FLOW FOR WAREHOUSE NO. 1

$K = 10; C_F = 1.1; C_o = 1.0$ (GROUP F3); $C_c = 0.4; A = 5000$

$\therefore$ REQUIRED FIRE FLOW = $10 (1.1) 0.4) (1.0)\sqrt{5000}$ gpm.
= 310 gpm (Can)

TOTAL FIRE FLOW = REQUIRED FIRE FLOW + EXPOSURE FIRE FLOW

$$F_T = F + F_E$$

BUT From table 405.3.2A, $F_E = 0$

$\therefore$ Total Fire Flow = 310 gpm (Can)

. FIRE FLOW FOR OFFICES (cont.)

From Table 405.3.2B, exposure factor = 0.2

$\therefore$ Exposure Fire Flow = 0.2 x Required Fire Flow for Warehouse No. 1
= 0.2 x 310 gpm
= 62 gpm (Can)

$\therefore$ Total Fire Flow = 510 + 62 gpm
= 572 gpm (Can)

. FIRE FLOW FOR WAREHOUSE No. 2

$K = 10$; $C_c = 1.1$; $C_o = 2.0$ (GROUP F_1); $C_c = 0.4$; $A = 1.5 \times 3000$;

Design area for sprinkler system = 3000 ft^2

$\therefore$ Required Fire Flow = $10\ (1.1)\ (0.4)\ (2.0)\sqrt{4500}$

= 590 gpm (Can)

Total Fire Flow = Required Fire Flow + Exposure Fire Flow

$$F_T = F + F_E$$

Exposure is from Warehouse No. 1 at 100 ft.

From Table 405.3.2(c), exposure factor = $0.3 \div 2$.

$\therefore$ $F_T = 590 + 0.15\ (310)$

= 640 gpm (Can)

. TOTAL FIRE FLOW & QUANTITY OF WATER PROVIDED

Clause 405.22 (a) pertains and so the "largest estimated fire" could involve the Band Hall & a total fire flow of 835 or say 850 gpm (Can) would be required.

From clause 405.4.1(b), Quantity of water = $0.072\ (850)^2 - 30\ (850)$

= 26,520 gal (Can)

G-21

FINAL DRAFT GUIDELINES

Ministry of the Environment

Ontario

The Honourable
George R. McCague
Minister

K.H. Sharpe
Deputy Minister

G-23

GUIDELINES FOR THE DESIGN

OF

WATER STORAGE FACILITIES

June 1978

MUNICIPAL AND PRIVATE APPROVALS SECTION

ENVIRONMENTAL APPROVALS BRANCH

MINISTRY
OF THE
ENVIRONMENT

APPENDIX B

DESIGN CRITERIA
FOR
SIZING WATER STORAGE FACILITIES

TOTAL STORAGE REQUIREMENT = A + B + C

Where A = Fire Storage
B = Equalization Storage (25 percent of Projected Maximum Day Demand)
C = Emergency Storage (25 percent of "A" + "B")

Par 1 The maximum day demand referred to in the foregoing equation should be calculated using the factors in the following Table I, unless there is existing flow data available to support a different factor. Where existing data is available, the required storage should be calculated on the basis of a careful evaluation of the flow characteristics within the system.

TABLE I

POPULATION RANGE	MAXIMUM DAY FACTOR	PEAK RATE FACTOR (PEAK HOUR)
0 - 500	3.00	4.50
501 - 1,000	2.75	4.13
1,001 - 2,000	2.50	3.75
2,001 - 3,000	2.25	3.38
3,001 - 10,000	2.00	3.00
10,001 - 25,000	1.90	2.85
25,001 - 50,000	1.80	2.70
50,001 - 75,000	1.75	2.62
75,001 - 150,000	1.65	2.48
greater than 150,000	1.50	2.25

MAXIMUM DAY DEMAND = Average Day Demand x Maximum Day Factor

TABLE II

FIRE FLOW REQUIREMENTS

POPULATION	SUGGESTED FIRE FLOW		DURATION (hours)
	L/s	gpm	
under 1,000	38	500	2
1,000	64	840	2
1,500	79	1,050	2
2,000	95	1,250	2
3,000	110	1,450	2
4,000	125	1,650	2
5,000	144	1,900	2
6,000	159	2,100	3
10,000	189	2,500	3
13,000	220	2,900	3
17,000	250	3,300	4
27,000	318	4,200	5
33,000	348	4,600	5
40,000	378	5,000	6

Par 2 When determining the fire flow allowance for commercial or industrial areas, it is recommended that the area occupied by the commercial/industrial complex be considered at an equivalent population density to the surrounding residential lands.

Par 3 NOTE: When an entirely new water supply and distribution system is being designed this guide should be used in conjunction with Guidelines for the Design of Water Distribution Systems.

APPENDIX H

ENERGY MANAGEMENT DATA

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List of Figures

List of Tables

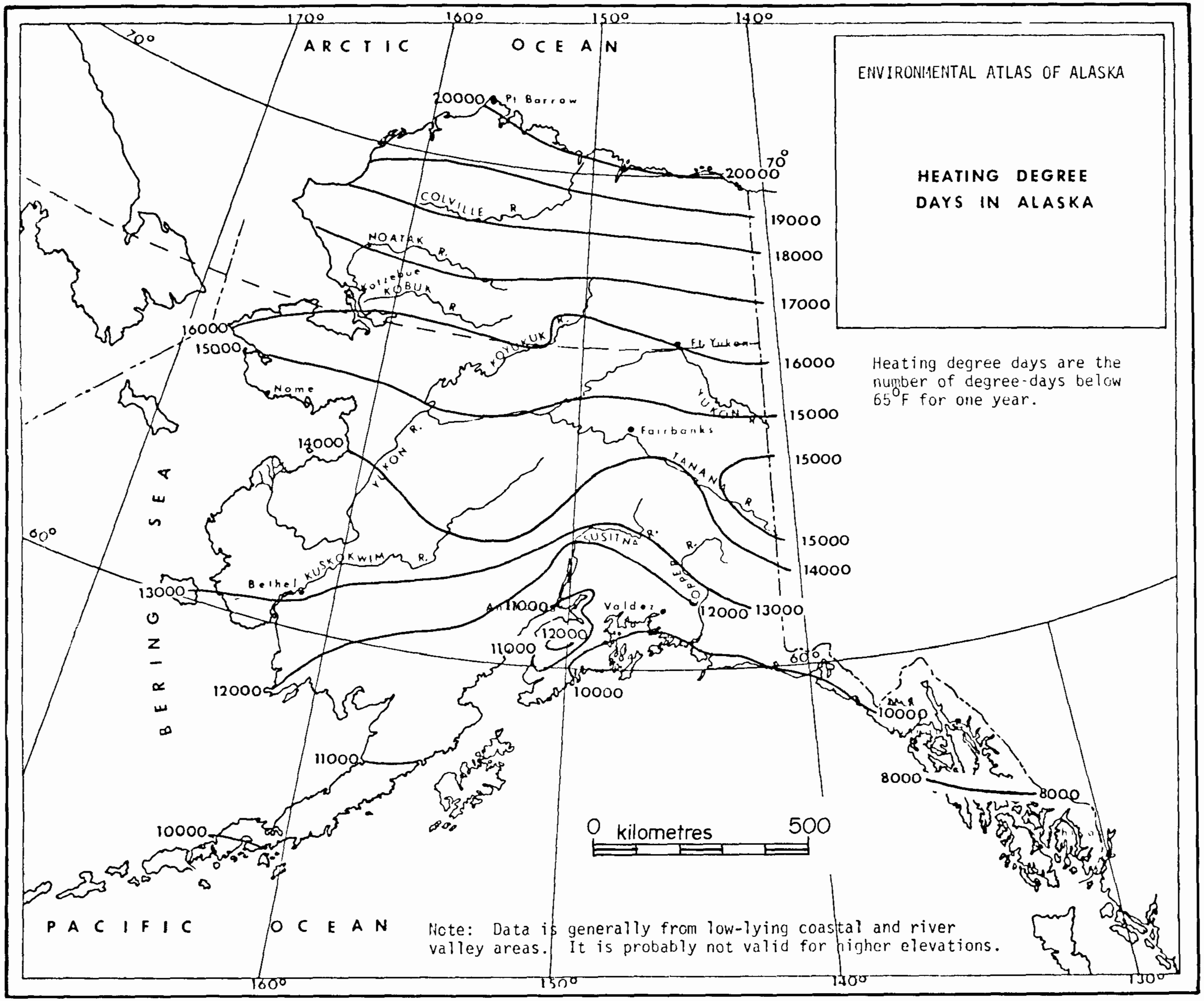

FIGURE H-1. HEATING INDEX DISTRIBUTION ACROSS ALASKA. BASE 65°F = 18.33°C.
Source: Environmental Atlas of Alaska, Johnson and Hartman; University of Alaska.

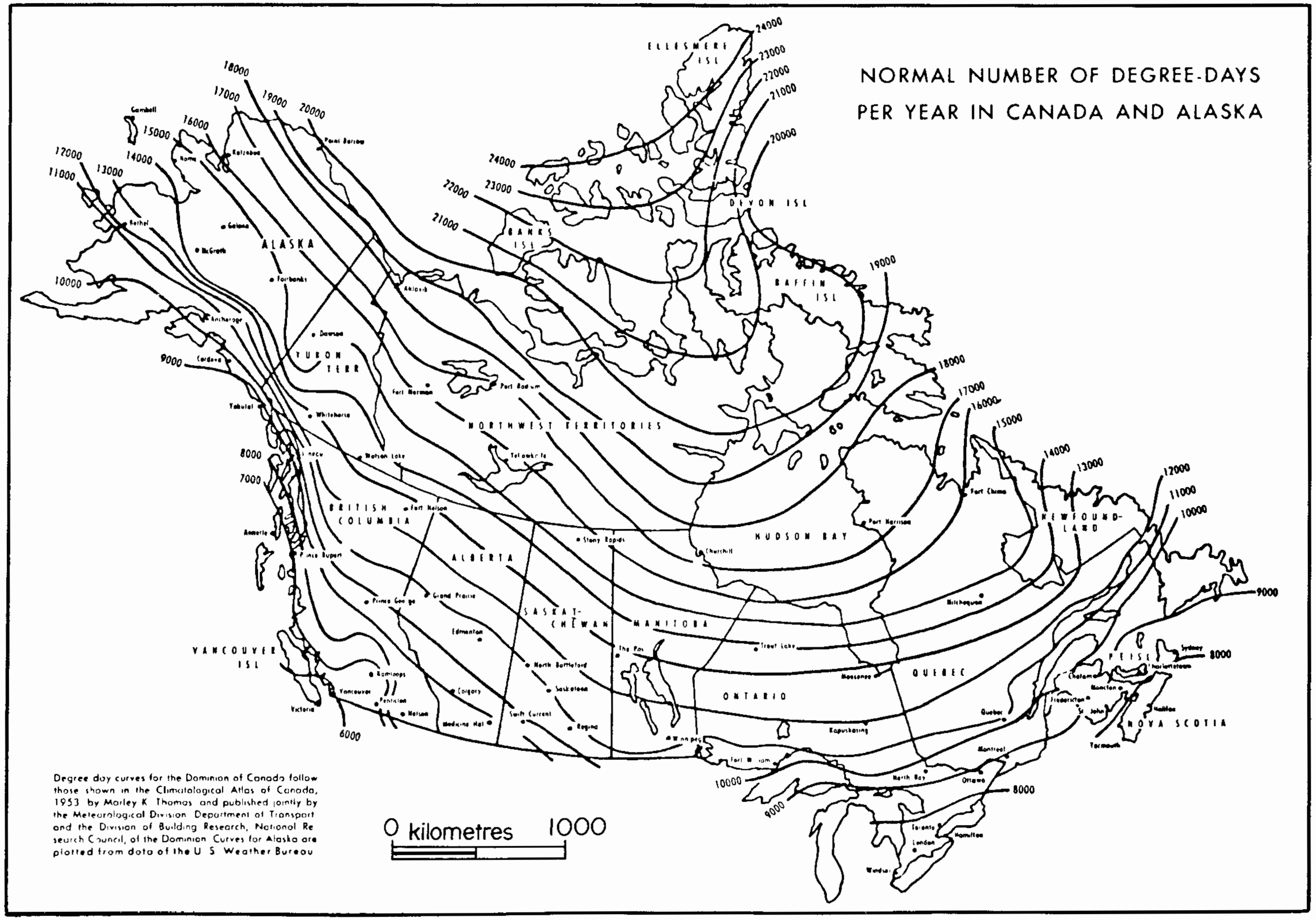

FIGURE H-2. HEATING INDEX DISTRIBUTION ACROSS CANADA. BASE 65°F = 18.33°C. Source: Environmental Atlas of Alaska; Johnson and Hartman, University of Alaska.

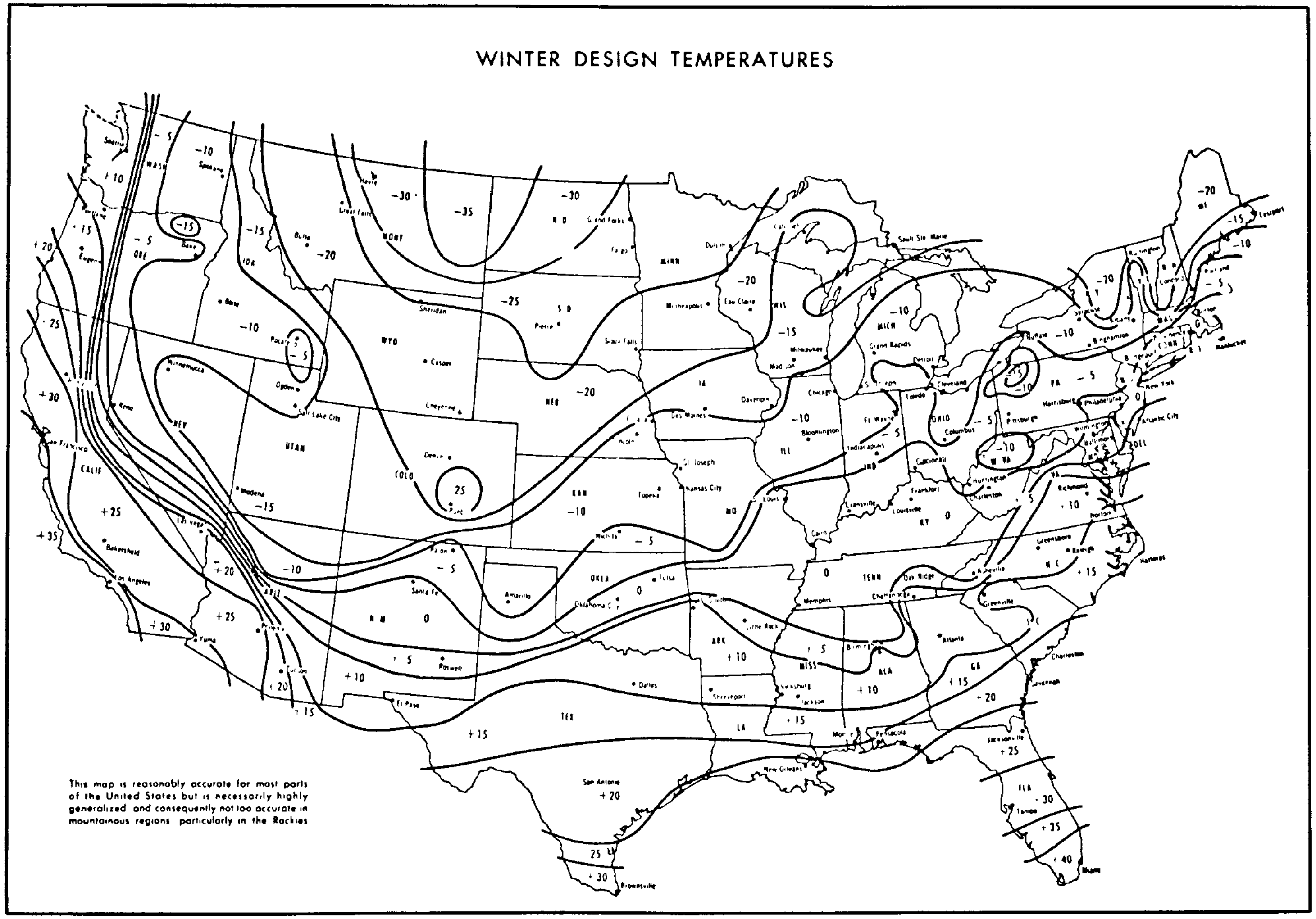

FIGURE H-3. WINTER DESIGN TEMPERATURE DISTRIBUTION ACROSS THE CONTIGUOUS UNITED STATES. Source: Handbook of Air Conditioning Heating and Ventilating; Strock and Koral; Industrial Press.

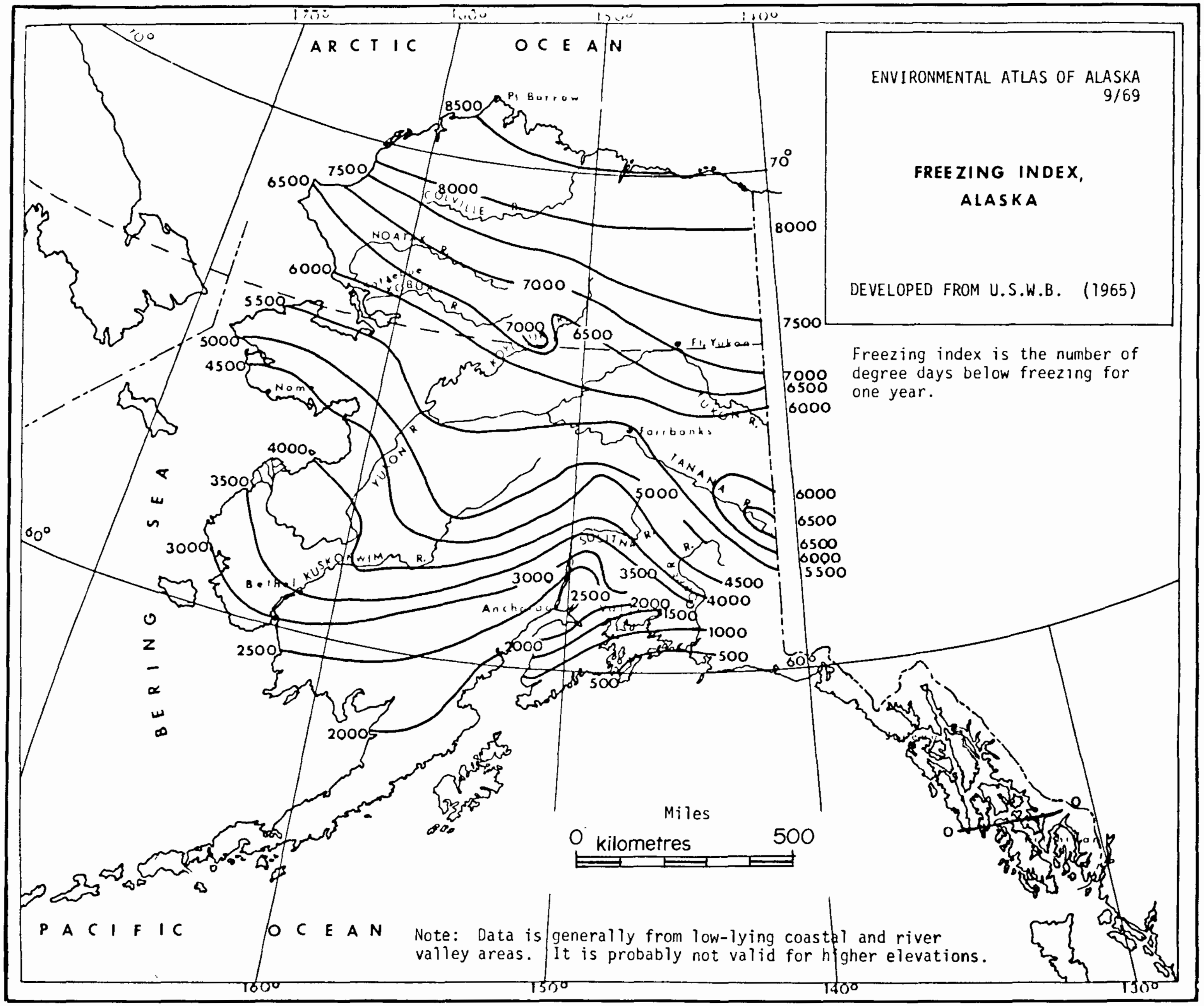

FIGURE H-4. FREEZING INDEX DISTRIBUTION ACROSS ALASKA (°F). Source: Environmental Atlas of Alaska; Johnson and Hartman; University of Alaska.

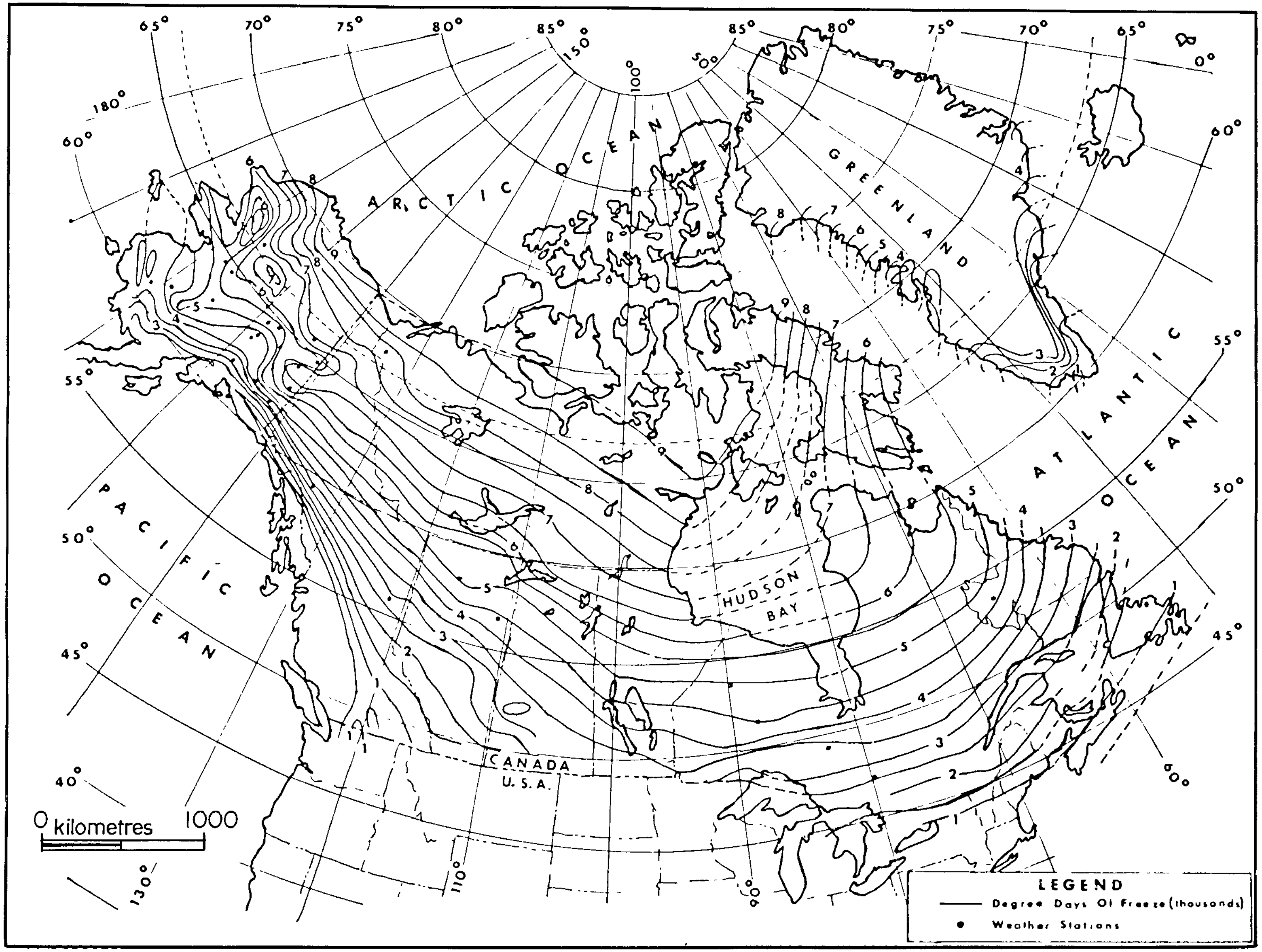

FIGURE H-5. FREEZING INDEX DISTRIBUTION ACROSS CANADA (°F). Source: Environmental Atlas of Alaska; Johnson and Hartman; University of Alaska.

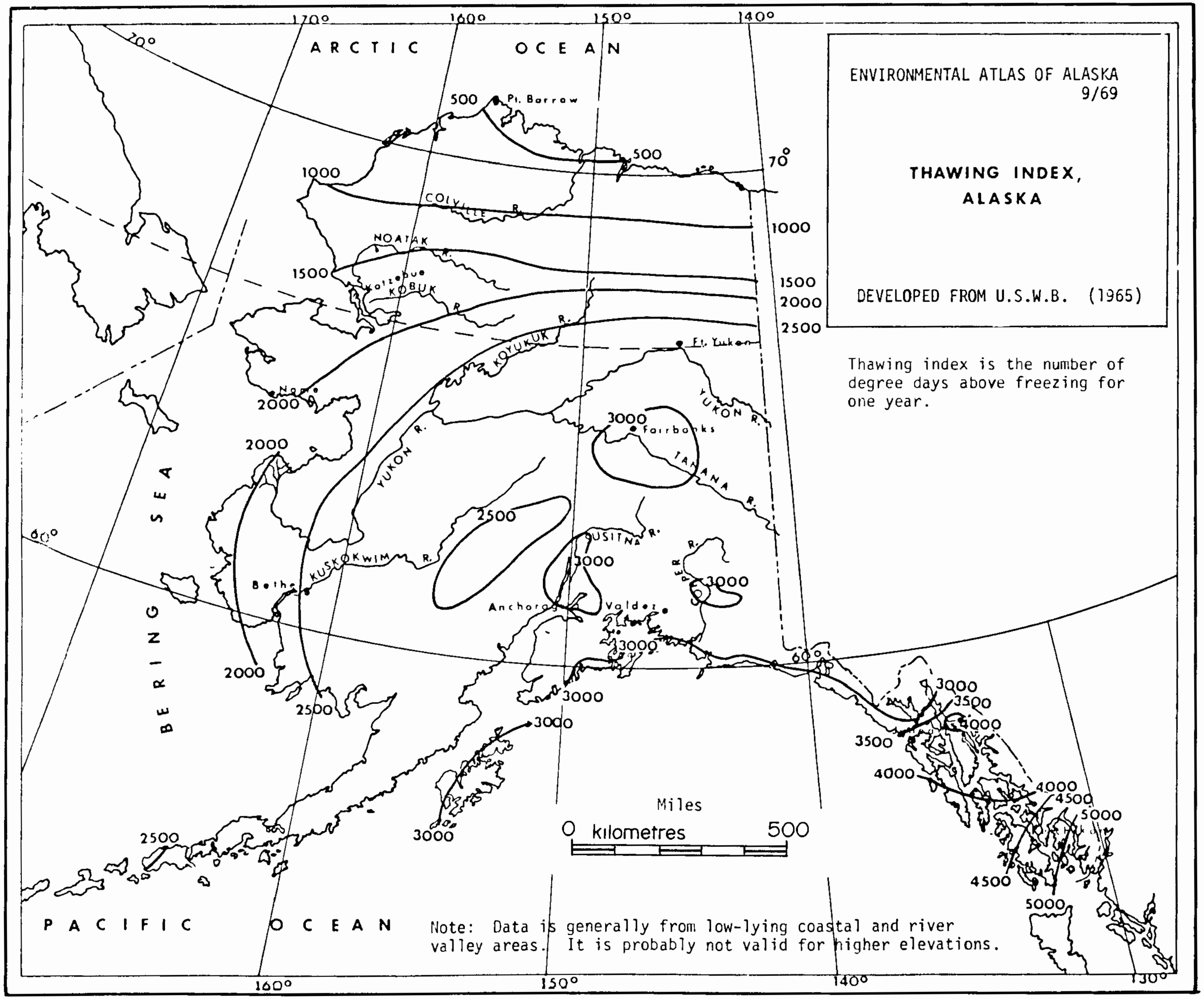

FIGURE H-6. THAWING INDEX DISTRIBUTION ACROSS ALASKA (°F). Source: Environmental Atlas of Alaska; Johnson and Hartman; Unviersity of Alaska.

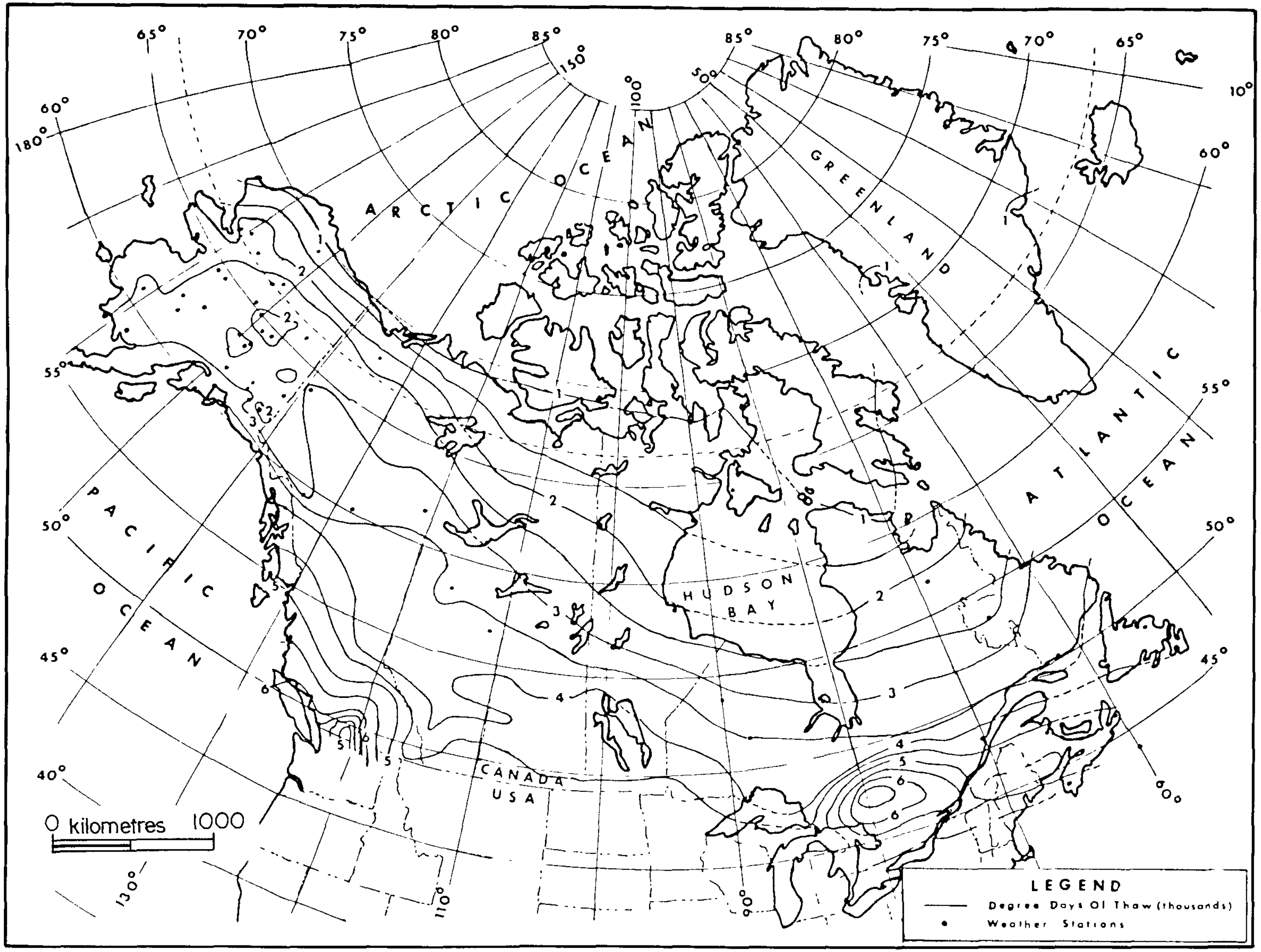

FIGURE H-7. THAWING INDEX DISTRIBUTION ACROSS CANADA (°F). Source: Environmental Atlas of Alaska; Johnson and Hartman; University of Alaska.

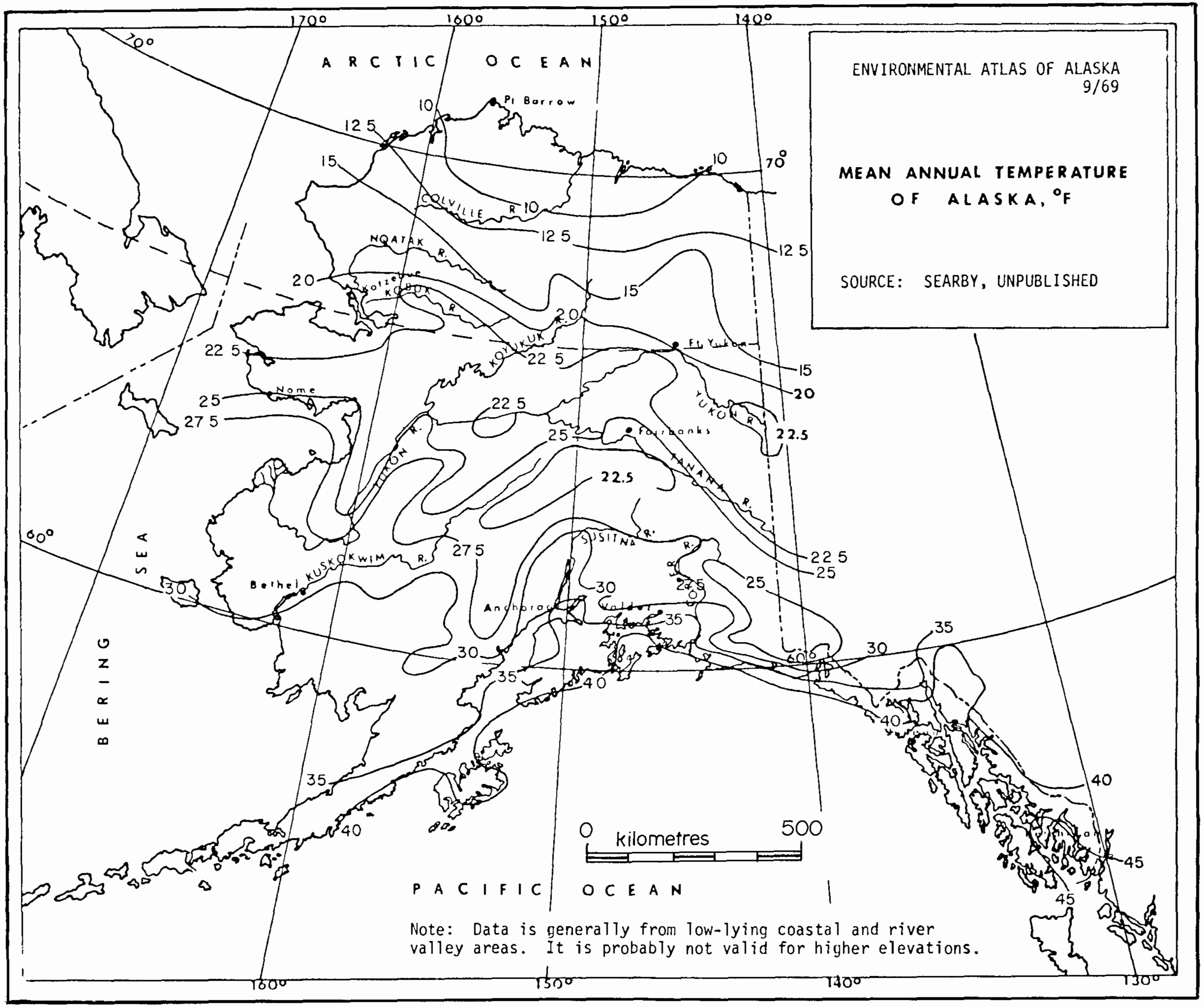

FIGURE H-8. MEAN ANNUAL AIR TEMPERATURE DISTRIBUTION ACROSS ALASKA (°F).
Source: Environmental Atlas of Alaska; Johnson and Hartman; University of Alaska.

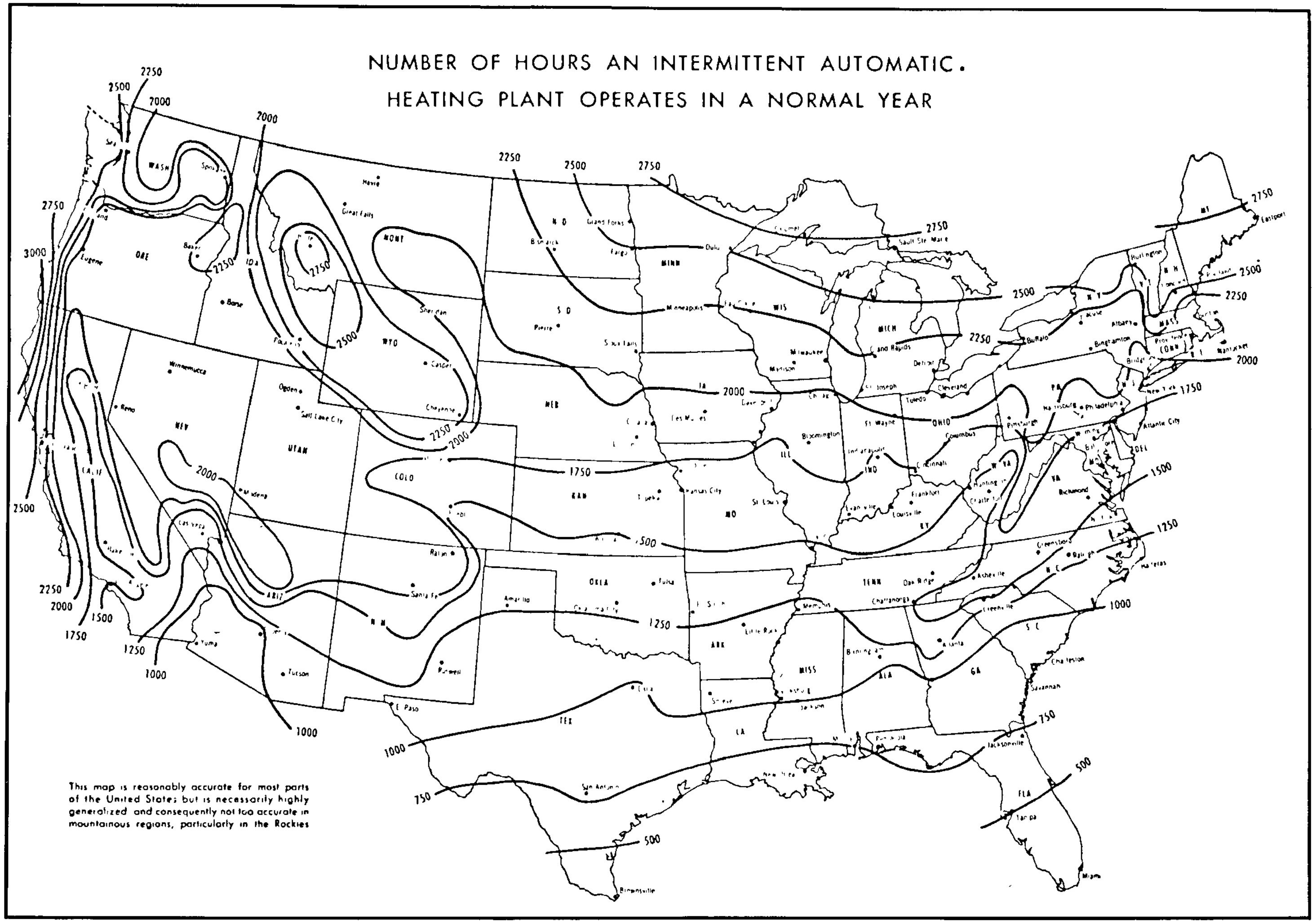

FIGURE H-9. HEATING PLANT UTILIZATION ACROSS THE CONTIGUOUS UNITED STATES. Source: Handbook of Air Conditioning Heating and Ventilating; Strock and Koral; Industrial Press.

TABLE H-1. HEATING INDEX VALUES FOR VARIOUS ALASKAN COMMUNITIES. BASE 65°F = 18.33°C. Source: a) Handbook of Air Conditioning Heating and Ventilating; Strock and Koral; Industrial Press. b) Alaska Regional Profiles; Selkregg; University of Alaska (data compiled by Environmental Data Service and AEIDC Staff).

a)

City	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Total
Anchorage	239	291	510	899	1281	1587	1612	1299	1246	888	598	339	10789
Annette	262	217	357	561	729	896	942	809	384	672	496	321	7096
Barrow	784	825	1032	1485	1929	2237	2483	2321	2477	1956	1432	933	19994
Bethel	326	381	591	1029	1440	1792	1804	1565	1659	1146	775	372	12880
Cordova	363	360	510	750	1017	1190	1240	1089	1082	858	685	471	9615
Fairbanks	149	296	612	1163	1857	2297	2319	1907	1736	1083	546	193	14158
Galena	171	311	624	1175	1818	2235	2303	1887	1894	1224	670	226	14538
Gambell	642	598	747	1042	1254	1655	1854	1767	1845	1425	1135	810	14474
Juneau (A)	319	335	480	716	957	1159	1203	1056	998	765	558	342	8888
Juneau (C)	279	282	426	651	864	1066	1101	983	949	738	533	315	8187
Kotzebue	384	443	723	1225	1725	2130	2220	1952	2065	1536	1097	651	16151
McGrath	206	357	630	1159	1785	2241	2285	1809	1789	1170	676	283	14390
Nome	477	493	690	1085	1446	1776	1841	1660	1752	1320	970	576	14086
Northway	186	350	675	1262	2016	2474	2545	2083	1801	1176	626	312	15506
St. Paul Island (A)	592	527	591	803	936	1107	1197	1154	1256	1047	924	705	10839
Yakutat	381	378	498	722	939	1153	1194	1036	1060	855	673	465	9354

b)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Chignik	1147	1109	1203	996	639	396	443	409	528	787	912	1082	9651
Kodiak	1073	941	1020	843	676	459	338	313	450	753	906	1088	8860
Homer	1352	1123	1159	900	704	489	394	391	540	856	1104	1352	10364
Sterling	1817	1431	1426	960	670	402	322	353	594	1014	1335	1742	12066
Anchorage	1649	1322	1280	891	583	312	220	282	507	936	1317	1612	10911
Talkeetna	1724	1392	1395	972	629	306	220	322	567	1020	1425	1736	11708
Summit	1965	1635	1668	1245	856	480	403	508	753	1271	1659	1925	14368
Sheep Mt.	1838	1562	1528	1119	722	426	375	453	699	1181	1545	1817	13265
Gulkana	2241	1711	1566	1044	657	333	254	366	642	1184	1767	2173	13938
Chitina	2192	1524	1491	933	592	297	236	332	579	1073	1626	2105	13080
McCarthy	2533	1613	1426	987	648	357	276	397	624	1119	1707	2161	13848
Valdez	1463	1193	1184	882	657	414	363	403	555	853	1167	1411	10545
Cordova	1302	1072	1110	870	660	438	360	372	510	787	1032	1252	9765
Yakataga	1159	983	1032	849	682	477	375	381	492	738	924	1094	9186

$$°F.days \times \frac{5}{9} = °C.days$$

$$°F.days \times 13.33 = °C.h$$

TABLE H-2. HEATING INDEX VALUES FOR VARIOUS CANADIAN COMMUNITIES. BASE 65°F = 18.33°C. Source: Handbook of Air Conditioning Heating and Ventilating; Strock and Koral; Industrial Press.

(Data by M.K. Thomas and D W. Boyd; reproduced by permission of Meteorological Branch, Department of Transport, Canada)

City	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total
ALBERTA													
Calgary	410	710	1110	1430	1530	1350	1200	770	460	270	110	170	9520
Edmonton	440	750	1220	1660	1780	1520	1290	760	410	220	90	180	10320
Grande Prairie	450	800	1300	1750	1820	1600	1380	830	460	250	150	220	11010
Lethbridge	350	620	1030	1330	1450	1290	1120	690	400	210	60	100	8650
McMurray	520	880	1500	2070	2210	1820	1540	920	500	270	120	220	12570
Medicine Hat	300	600	1070	1440	1590	1380	1130	620	320	130	20	50	8650
BRITISH COLUMBIA													
Atlin	560	870	1240	1590	1790	1540	1370	960	670	410	350	360	11710
Crescent Valley	330	680	990	1220	1360	1080	940	610	400	220	90	120	8040
Bull Harbour	340	490	630	770	820	710	690	580	470	340	270	260	6370
Estevan Point	310	460	580	710	760	670	700	580	470	340	270	240	6090
Fort Nelson	460	920	1680	2190	2200	1870	1460	890	460	220	120	220	12690
Kamloops	200	540	890	1170	1320	1050	780	450	210	80	10	30	6730
Penticton	200	520	820	1050	1190	960	780	490	260	100	20	20	6410
Prince George	460	750	1110	1440	1570	1320	1110	740	480	280	200	260	9720
Prince George City	430	740	1100	1450	1540	1290	1070	730	470	250	170	220	9460
Prince Rupert	340	510	680	860	910	810	790	650	500	350	270	240	6910
Vancouver	220	440	650	810	890	740	680	480	320	150	70	70	5520
Vancouver City	200	430	650	810	880	720	650	470	300	140	70	70	5390
Victoria (Pat Bay)	260	470	660	790	870	720	690	520	370	220	130	130	5830
Victoria City	250	410	600	730	800	660	620	470	350	230	160	150	5410
MANITOBA													
Brandon	350	730	1290	1810	2010	1730	1440	820	420	170	60	100	10930
Churchill	710	1110	1660	2240	2590	2320	2150	1580	1130	670	360	390	16910
Dauphin	320	670	1250	1740	1940	1670	1430	830	420	150	50	90	10560
The Pas	440	840	1480	1980	2200	1850	1620	1010	550	250	80	160	12460
Winnipeg	311	686	1255	1778	1993	1714	1441	810	411	147	37	75	10658
NEW BRUNSWICK													
Bathurst	310	650	1010	1480	1690	1520	1300	880	520	180	40	90	9670
Chatham	270	640	970	1450	1620	1450	1250	850	490	180	40	80	9290
Fredericton	250	600	940	1410	1570	1410	1180	780	420	150	50	70	8830
Grand Falls	330	660	1000	1540	1750	1570	1340	870	480	190	100	120	9950
Moncton	260	590	910	1340	1520	1380	1190	830	480	200	50	80	8830
Saint John	280	590	880	1300	1440	1310	1160	830	510	260	80	100	8740
Saint John City	250	530	830	1250	1400	1270	1100	780	500	250	110	110	8380
NEWFOUNDLAND													
Cape Race	350	600	800	1080	1240	1170	1150	950	780	560	350	260	9290
Corner Brook	320	640	890	1200	1410	1360	1240	900	640	350	90	140	9180
Gander	320	660	920	1230	1430	1320	1270	970	650	380	130	160	9440
Goose Bay	440	840	1220	1740	2020	1710	1530	1101	770	410	130	220	12140
St. John's (Torbay)	320	610	820	1130	1270	1180	1170	920	700	460	190	170	8940
NORTHWEST TERRITORIES													
Aklavik	800	1400	2040	2530	2580	2310	2290	1690	1050	480	280	460	17910
Fort Norman	700	1220	1940	2460	2550	2190	2040	1390	730	280	170	350	16020
Frobisher	880	1280	1580	2120	2560	2280	2230	1690	1250	800	600	650	17920
Resolute	1240	1810	2220	2660	2890	2730	2720	2170	1550	970	780	860	22600
Yellowknife	580	1060	1740	2420	2570	2270	2020	1410	790	370	160	250	15640

TABLE H-2. (CONT'D).

City	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total
NOVA SCOTIA													
Halifax (Dartmouth)	230	510	790	1160	1280	1220	1090	800	530	250	80	90	8030
Halifax City	190	469	745	1109	1262	1180	1042	765	484	226	55	58	7585
Sydney	220	510	780	1130	1310	1280	1160	850	570	270	60	80	8220
Yarmouth	230	480	720	1040	1180	1100	1010	750	510	270	110	120	7520
ONTARIO													
Fort William	370	740	1170	1680	1830	1580	1380	890	540	230	90	140	10640
Hamilton	140	470	800	1150	1260	1190	1020	670	330	70	20	30	7150
Kapuskasing	420	790	1280	1770	2030	1750	1550	1030	600	240	110	180	11750
Kenora	320	710	1270	1800	1980	1670	1420	860	430	160	40	80	10740
Kingston City	160	500	820	1250	1420	1290	1110	710	380	100	30	40	7810
Kitchener City	170	520	860	1240	1350	1240	1080	680	330	80	30	40	7620
London	150	490	840	1200	1320	1210	1040	650	330	90	20	40	7380
North Bay	320	670	1080	1550	1710	1530	1350	840	470	170	70	120	9880
North Bay City	270	620	1000	1510	1690	1490	1280	810	420	120	40	90	9340
Ottawa (Uplands)	200	580	970	1460	1640	1450	1220	730	330	70	30	60	8740
Peterborough City	180	540	890	1320	1470	1330	1130	690	330	90	30	40	8040
Sault Ste. Marie	340	650	1010	1410	1590	1500	1310	820	470	210	120	160	9590
Sioux Lookout	390	780	1310	1850	2060	1750	1510	950	520	220	70	120	11530
Southampton	190	500	830	1200	1350	1270	1140	760	450	170	70	90	8020
Sudbury	310	680	1100	1500	1720	1450	1340	870	510	190	60	140	9870
Timmins	410	780	1270	1740	1990	1680	1530	1010	550	240	110	170	11480
Toronto (Malton)	180	540	840	1220	1360	1260	1090	700	370	100	30	40	7730
Toronto City	154	465	777	1126	1249	1147	1018	646	316	73	8	29	7008
Trenton	160	470	840	1280	1400	1280	1080	670	330	70	20	30	7630
White River	440	820	1270	1770	1990	1740	1550	1010	590	280	160	230	11850
Windsor	120	410	780	1130	1220	1100	950	580	270	70	10	10	6650
PRINCE EDWARD ISLAND													
Charlottetown	240	550	850	1210	1460	1370	1220	870	560	250	60	70	8710
QUEBEC													
Bagotville	370	740	1160	1730	1950	1710	1450	940	570	220	80	120	11040
Fort Chimo	700	1040	1440	2010	2410	2170	1920	1460	1010	610	380	450	15600
Fort George	550	890	1270	1880	2340	2090	1950	1330	920	530	350	380	14480
Knob Lake	670	1080	1500	2010	2410	2040	1810	1300	910	450	300	410	14890
Megantic	330	660	1000	1480	1640	1490	1290	870	500	190	80	140	9670
Mont Joli	310	660	1030	1440	1650	1470	1310	910	550	230	70	120	9750
Montreal (Dorval)	190	550	910	1390	1590	1430	1180	730	270	60	10	40	8350
Montreal City	180	530	890	1370	1540	1370	1150	700	300	50	10	40	8130
Nitchequon	590	970	1430	2050	2340	2010	1820	1310	910	490	270	320	14510
Port Harrison	730	1050	1430	2050	2470	2290	2190	1610	1140	790	560	570	16880
Quebec (An Lorette)	290	650	1030	1530	1690	1510	1300	850	430	130	40	90	9540
Quebec City	250	610	990	1470	1640	1460	1250	810	400	100	20	70	9070
Sherbrooke City	240	590	920	1400	1560	1410	1190	750	370	90	20	70	8610
Three Rivers City	250	610	980	1490	1690	1490	1250	770	370	80	20	60	9060
SASKATCHEWAN													
North Battleford	380	750	1350	1820	1990	1710	1440	800	400	190	60	110	11000
Prince Albert	410	780	1350	1870	2060	1750	1500	850	440	210	70	140	11430
Regina	370	750	1290	1740	1940	1680	1420	790	420	190	70	110	10770
Saskatoon	380	760	1320	1790	1790	1710	1440	800	420	180	60	110	10960
YUKON TERRITORY													
Dawson	660	1170	1890	2410	2510	2160	1830	1100	570	250	170	320	15040
Whitehorse	570	940	1510	1900	1850	1640	1350	1000	600	310	280	350	12300

$$°F.days \times \frac{5}{9} = °C.days$$

$$°F.days \times 13.33 = °C.h$$

TABLE H-3. DESIGN TEMPERATURES FOR VARIOUS ALASKAN COMMUNITIES. [Handbook of Air Conditioning Heating and Ventilating; Strock and Koral; Industrial Press].

State and Station	Location			Winter		Summer Design Data											
	N Lat	W Long	Elev., Ft	Design Basis, Percent										Dry Bulb, F		Wet Bulb, F	
				99	97½	1	2½	5	10	1	2½	5	10	93	80	73	67
	Deg. Min			Design Dry Bulb, F						Wet Bulb, F				Hours Exceeded			
ALASKA:																	
Adak (Joint Unit)	—	—	—	20	23	60	58	56	54	58	56	54	52	0	0	0	1
Anchorage	61 10	149 59	105	—25	—20	74	71	68	64	63	61	59	57	0	6	1	6
Aniak	61 40	159 42	81	—52	—45	75	71	67	63	65	63	61	57	0	8	0	15
Annette	55 02	131 34	113	10	13	73	69	66	62	64	62	61	57	0	4	0	3
Anvile Mountain AFS	—	—	—	—33	—29	63	59	56	53	56	54	52	50	0	0	0	0
Attu	52 48	173 10E	92	20	23	54	53	52	50	52	51	50	49	0	0	0	0
Barrow	71 18	156 47	31	—45	—42	58	54	50	46	54	51	48	44	0	0	0	0
Barter Island	70 08	143 38	50	—47	—43	56	52	49	46	51	48	46	43	0	0	0	0
Bear Creek AFS	—	—	—	—44	—36	76	72	69	64	63	61	59	57	0	3	0	0
Bethel	60 47	161 48	131	—32	—28	74	69	66	62	65	63	61	58	0	4	0	9
Bettles	66 54	151 31	666	—50	—43	78	75	72	68	65	63	61	59	0	16	0	15
Big Delta	64 00	145 44	1268	—45	—41	80	76	73	69	62	60	59	57	0	37	0	1
Big Mountain AFS	—	—	—	—33	—28	69	64	61	57	58	56	54	52	0	0	0	0
Boswell Bay AFS	—	—	—	—14	—9	67	63	60	57	61	59	57	55	0	0	0	0
Cape Lisbourne AFS	—	—	—	—36	—32	59	56	54	51	54	52	50	48	0	0	0	0
Cape Newenham AFS	—	—	—	—15	—12	61	58	56	53	56	54	53	51	0	0	0	0
Cape Romanzof AFS	—	—	—	—17	—15	63	60	57	54	57	55	53	51	0	0	0	0
Cape Sarichef AFS	—	—	—	10	13	64	61	58	55	62	59	56	53	0	0	0	0
Cold Bay	55 12	162 43	96	3	9	60	58	56	54	58	56	54	52	0	0	0	0
Cordova	60 30	145 30	44	—13	—8	70	66	63	60	62	60	58	56	0	1	0	2
Diamond Ridge AFS	—	—	—	—10	—4	67	64	62	59	61	59	57	55	0	0	0	0
Driftwood Bay	53 58	166 53	1277	13	16	68	65	60	54	63	61	57	52	0	0	0	2
Dutch Harbor	53 53	166 32	13	15	18	67	63	60	56	65	61	58	54	0	0	0	20
Eielson AFB	—	—	—	—51	—47	82	78	75	71	65	63	61	59	0	56	0	11
Fairbanks	64 49	147 52	440	—53	—50	82	78	75	71	64	63	61	59	1	53	1	9
Fairbanks AFS	—	—	—	—48	—44	79	75	72	68	63	61	59	57	0	25	0	0
Fort Yukon	66 35	145 18	419	—63	—54	81	78	75	71	65	63	61	59	0	35	1	13
Galena	64 43	156 54	123	—49	—46	79	75	72	67	65	62	60	58	0	27	0	15
Granite Mountain AFS	—	—	—	—43	—40	76	72	69	64	62	59	57	55	0	0	0	0
Gulkana	62 09	145 27	1572	—48	—41	79	76	72	68	62	60	59	57	0	15	0	1
Homer	59 38	151 30	67	—7	—1	70	67	65	62	63	61	59	57	0	0	0	5
Indian Mountain AFS	—	—	—	—29	—27	69	65	61	57	57	54	52	50	0	0	0	0
Juneau	58 22	134 35	20	—7	—4	75	71	68	63	66	64	62	58	0	6	0	12
Kalakaket Creek AFS	—	—	—	—49	—46	79	75	72	67	65	62	60	58	0	27	0	15
Kenai	60 34	151 19	85	—25	—18	70	67	65	62	63	61	59	57	0	0	1	6
Kodiak FLEWEACEN	—	—	—	8	12	71	66	63	60	62	60	58	56	0	3	0	3
Kogru River AFS	—	—	—	—47	—43	57	53	50	46	53	50	47	44	0	0	0	0
Kotzebue	66 52	162 38	16	—39	—30	68	64	61	58	60	58	56	54	0	0	0	0
McGrath	62 58	155 37	341	—47	—44	80	76	71	67	67	64	62	59	0	30	0	35
Middleton Island AFS	—	—	—	18	21	61	60	59	57	58	57	56	55	0	0	0	0
Murphy Dome AFS	—	—	—	—34	—30	76	72	69	65	60	58	56	54	0	0	0	0
Naknek	58 41	156 39	49	—28	—23	74	69	66	62	62	60	58	56	0	8	1	5
Naptowne AFS	—	—	—	—26	—19	69	66	64	61	63	61	59	57	0	0	1	6
Neklason Lake AFS	—	—	—	—24	—19	73	70	67	64	63	61	59	57	0	3	1	6
Nikolski	52 55	168 47	705	19	21	57	55	53	51	56	54	52	50	0	0	0	0
Nome	64 30	165 26	18	—32	—28	66	62	59	56	58	56	54	52	0	0	0	0
Northeast Cape AFS	—	—	—	—24	—21	59	56	53	51	54	52	51	49	0	0	0	0
North River AFS	—	—	—	—38	—30	68	65	62	59	61	59	57	54	0	0	0	0
Northway	62 58	141 58	1718	—56	—50	79	76	73	69	64	62	60	58	0	18	0	0
Ohlson Mountain AFS	—	—	—	—11	—5	66	63	61	58	60	58	56	54	0	0	0	0
Pedro Dome AFS	—	—	—	—39	—35	78	74	71	67	62	60	58	56	0	0	0	0
Petersburg	56 49	132 57	100	—2	1	70	67	64	61	60	59	58	56	0	3	0	0
Pillar Mountain AFS	—	—	—	6	10	68	63	60	57	60	58	56	54	0	0	0	0
Port Heiden AFS	—	—	—	—2	2	66	63	61	58	60	58	56	54	0	1	0	0
Port Moller	56 00	160 31	1038	6	8	63	59	56	53	60	57	54	51	0	0	0	0
Rabbit Creek AFS	—	—	—	—30	—25	65	62	59	56	57	55	53	51	0	0	0	0
Richardson, Fort, Elmendorf AFB		—	—	—23	—18	73	70	67	64	63	61	59	57	0	3	1	6
St Paul Island	57 09	170 13	22	—2	2	54	52	51	50	52	51	50	49	0	0	0	0
Shemya Island	52 43	174 06E	125	20	23	54	53	52	50	52	51	50	49	0	0	0	0
Sitkinak AFS	—	—	—	6	10	69	64	61	58	60	58	56	54	0	0	0	0
Soldotna AFS	—	—	—	—26	—19	70	67	65	62	63	61	59	57	0	0	1	6
Sparrevohn AFS	—	—	—	—31	—27	73	69	65	60	61	59	56	54	0	3	1	5
Tanana	65 10	152 06	232	—51	—43	82	78	75	70	65	63	61	59	0	47	1	10
Tatalina AFB	—	—	—	—33	—29	77	73	69	65	61	59	57	55	0	19	0	2
Tin City AFS	—	—	—	—33	—29	58	55	52	49	54	52	50	48	0	0	0	0
Umiat	69 22	152 08	385	—56	—54	73	70	66	61	68	64	61	56	0	4	6	41
Unalakleet	63 54	160 47	14	—37	—29	69	66	63	60	62	60	58	55	0	0	0	0
Unalakleet AFS	—	—	—	—38	—30	67	64	61	58	60	58	56	53	0	0	0	0
Utopia Creek AFS	—	—	—	—44	—40	77	73	69	65	62	60	58	56	0	12	0	5
Wainwright, Fort Jonathan M		—	—	—49	—46	82	79	76	72	64	63	61	59	1	64	1	9
Wildwood Station	—	—	—	—26	—19	70	67	65	62	63	61	59	57	0	0	1	6
Yakutak	59 31	139 40	31	—5	—1	68	63	61	58	61	58	56	54	0	1	0	6

$$(°F - 32) \times \frac{5}{9} = °C$$

TABLE H-4. WINTER DESIGN TEMPERATURES FOR VARIOUS CANADIAN COMMUNITIES. Source: Handbook of Air Conditioning Heating and Ventilating: Strock and Koral; Industrial Press.

The accompanying winter design temperatures for heating are those values in degrees F at or below which 1%, 2½%, 5% or 10% of the January hourly outside temperatures occur. Letters *A* or *C* following the city name indicate an airport or city weather station, respectively.

These data are by Morley K. Thomas, Deputy Chief, Climatological Service, Meteorological Service of Canada, and Donald W. Boyd, Climatologist, Division of Building Research, National Research Council of Canada, and are reprinted here by permission.

City	Winter Design Temp., Deg. F.			
	1%	2½%	5%	10%
ALBERTA				
Banff	—	−29	—	—
Colgary-A	−35	−29	−25	−16
Camrose	—	−33	—	—
Cardson	—	−30	—	—
Edmonton-A	−39	−33	−29	−21
Grande-Prairie-A	−43	−39	−34	−27
Hanna	—	−34	—	—
Jasper	—	−31	—	—
Lethbridge-A	−38	−32	−28	−19
Lloydminster	—	−37	—	—
McMurray-A	−48	−42	−37	−30
Medicine Hat-A	−41	−35	−31	−22
Red Deer	—	−33	—	—
Taber	—	−33	—	—
Wetaskiwin	—	−33	—	—
BRITISH COLUMBIA				
Chilliwack	—	8	—	—
Courtenay	—	10	—	—
Dawson Creek	—	−38	—	—
Estevan Point-C	14	17	21	27
Fort Nelson-A	−42	−38	−33	−28
Hope	—	2	—	—
Kamloops	—	−21	—	—
Kimberley	—	−25	—	—
Lytton	—	−6	—	—
Nanaimo	—	13	—	—
Nelson	—	−8	—	—
Penticton-A	−14	−6	−1	4
Port Alberni	—	12	—	—
Prince George-A	−43	−32	−25	−16
Prince Rupert-C	5	8	12	18
Princeton	—	−14	—	—
Revelstoke	—	−22	—	—
Trail	—	−8	—	—
Vancouver-A	8	11	15	21
Vernon	—	−13	—	—
Victoria-C	12	15	19	25
Westview	—	10	—	—
MANITOBA				
Brandon-C	−36	−32	−28	−24
Churchill-A	−43	−42	−40	−37
Dauphin	—	−32	—	—
MANITOBA (Ctd.)				
Flin Flon	—	−42	—	—
Neepawa	—	−32	—	—
The Pas-A	−43	−39	−30	−26
Portage la Prairie	—	−30	—	—
Swan River	—	−36	—	—
Winnipeg-A	−33	−29	−25	−21
NEW BRUNSWICK				
Bathhurst	—	−9	—	—
Campbellton-C	−14	−11	−8	−3
Chatham	—	−9	—	—
Edmunston	—	−14	—	—
Fredericton-C	−9	−6	−3	2
Moncton-A	—	−8	—	—
Saint John-C	—	−3	—	—
Woodstock	—	−12	—	—
NEWFOUNDLAND				
Corner Brook-C	−4	−1	2	6
Gander-A	−6	−3	0	4
Goose Bay-A	−29	−26	−24	−20
Grand Falls	—	−4	—	—
St. John's-A	−1	1	4	7
NORTHWEST TERRITORIES				
Aklavik-C	−50	−46	−43	−39
Fort Norman-C	−46	−42	−39	−35
Frobisher-A	−51	−47	−43	−39
Resolute-C	−45	−42	−40	−36
Yellowknife-A	−49	−47	−45	−41
NOVA SCOTIA				
Bridgewater	—	2	—	—
Dartmouth	—	2	—	—
Halifax-C	0	4	7	11
Halifax-A	−3	2	5	9
Kentville	—	0	—	—
New Glasgow	—	−1	—	—
Springhill	—	−3	—	—
Sydney-A	−7	1	4	8
Truro	—	−1	—	—
Yarmouth-A	4	7	10	13

$$(°F - 32) \times \frac{5}{9} = °C$$

TABLE H-5. DESIGN TEMPERATURES FOR VARIOUS CANADIAN AND GREENLAND COMMUNITIES. Source: Handbook of Air Conditioning Heating and Ventilating; Strock and Koral; Industrial Press

Continent, Country and Station	Elev, Ft	Winter		Summer Design Data													
		Design Basis, Percent												Dry Bulb, F		Wet Bulb, F	
		99	97½	1	2½	5	10	1	2½	5	10	93	80	73	67
		Design Dry Bulb, F						Wet Bulb, F				Hours Exceeded			
NORTH AMERICA:															
Canada: Argentia, Nfld.	55	6	10	69	67	65	63	66	64	63	61	0	0	0	30
Armstrong, Ont.	1065	−34	−28	84	80	77	73	71	68	66	64	1	82	9	117
Baffin Island AS	—	−40	−38	62	58	55	51	56	53	50	47	0	0	0	0
Baldy Hughes AS, B.C.	—	−41	−30	81	77	73	69	65	63	61	59	0	50	0	20
Cape Harrison, Lab.	33	−20	−18	78	74	70	65	64	62	60	57	0	22	0	8
Cartwright AS, Lab	—	−24	−21	78	74	70	66	68	65	63	60	0	18	4	49
Churchill, Man.	115	−41	−39	78	73	69	63	67	64	61	57	0	2	0	3
Cut Throat Island, Lab	30	−20	−18	78	74	70	65	64	62	60	57	0	22	0	8
Elliston Ridge, Nfld	50	−1	2	78	75	72	69	69	67	65	62	0	25	2	100
Fort Nelson	1230	−41	−36	84	81	78	74	68	66	65	62	0	100	0	53
Fort William, Ont.	644	−26	−21	83	80	77	72	71	68	66	64	1	92	12	156
Fox Harbor, Lab.	10	−18	−15	71	69	66	64	60	59	58	56	0	0	0	0
Frobisher Bay	68	−40	−38	62	58	55	51	56	53	50	47	0	0	0	0
Gander, Nfld.	482	−4	0	80	77	74	70	68	66	65	62	1	36	2	85
Goose Bay, Nfld.	144	−26	−23	83	77	73	69	67	64	62	60	2	51	2	30
Grande Prairie, Alb	2190	−40	−35	81	78	74	70	64	62	61	58	0	59	0	7
Halifax, N S	136	2	8	78	75	73	70	69	68	66	64	0	21	0	157
Harmon AFB, Ernest, Nfld	—	−3	2	75	72	69	67	67	65	64	62	0	6	2	38
Hopedale, Lab.	35	−28	−25	69	65	62	59	60	58	56	54	0	0	0	0
Kamloops, B C.	1262	−20	−10	92	88	85	81	68	67	66	64	22	381	0	59
Kamloops AS, B.C	—	−18	−8	77	73	70	66	59	58	57	55	0	0	0	0
Kapuskasing, Ont	752	−31	−27	84	81	77	73	71	69	67	64	3	110	15	190
La Scie, Nfld	50	−10	−7	74	72	69	67	63	62	61	59	0	0	0	0
Makkovik, Lab.	10	−24	−22	74	70	66	62	62	60	58	56	0	10	0	5
Melville AS, Lab	—	−26	−23	83	77	73	69	67	64	62	60	2	51	2	30
North Bay, Ont.	1210	−18	−14	82	79	76	73	70	69	67	65	0	69	1	228
Ottowa, Ont	339	−18	−11	89	85	82	79	75	73	71	69	9	292	108	636
Padloping Island, N.W.T.	130	−39	−36	56	53	51	47	46	44	42	39	0	0	0	0
Pepperrell AFB, Nfld.	—	3	8	78	75	72	68	70	68	66	63	0	22	5	117
Porquis Junction, Ont.	1009	−30	−26	85	81	78	74	71	69	68	65	1	101	6	176
Prince George, B C.	2218	−41	−30	81	77	73	69	65	63	61	59	0	52	0	19
Puntzi Mountain AS, B C.	—	−25	−16	77	73	69	65	61	59	57	55	0	1	0	0
Resolution Island, N W T.	127	−28	−26	51	48	45	42	47	44	43	40	0	0	0	0
Saglek Bay, Nfld.	70	−23	−21	69	64	59	55	59	55	52	49	0	3	0	3
Saskatoon, Sask.	1645	−33	−29	87	83	80	75	68	66	64	62	3	148	3	59
Saskatoon Mountain AS	—	−40	−35	78	75	71	67	62	60	59	56	0	15	0	5
Seven Islands, Que.	190	−19	−16	74	71	69	65	65	63	61	59	0	3	0	13
Sioux Lookout, Ont.	1227	−38	−33	84	80	77	74	70	68	66	64	1	70	6	103
Spotted Isle, Lab	10	−23	−20	78	74	70	66	65	63	61	58	0	20	0	30
St Anthony, Nfld.	45	−17	−14	71	69	66	64	60	59	58	56	0	0	0	0
St. Anthony AS, Nfld.	—	−20	−17	68	66	63	61	58	57	56	54	0	0	0	0
Stephenville AS, Nfld	—	−6	−1	71	68	65	63	65	63	62	60	0	0	0	10
Torbay, Nfld.	463	1	4	76	73	70	67	69	67	65	62	0	4	3	100
Vancouver, B C.	16	7	13	76	74	72	69	67	65	64	62	0	9	0	35
Whitehorse, Y T.	2289	−47	−38	79	75	72	67	61	59	57	55	0	21	0	0
Winnepeg, Man	786	−34	−27	88	85	81	77	74	72	69	67	7	223	48	327
Yarmouth, N S	136	2	9	76	73	71	68	68	67	65	63	0	10	0	75
Yellowknife, N W.T.	682	−46	−44	77	74	71	68	64	62	61	59	0	8	0	4
Greenland: Narsarssuak AB	—	−12	−2	66	63	61	59	56	54	52	50	0	0	0	0
Simiutak AB	—	2	5	58	55	52	49	52	49	48	46	0	0	0	0
Sondrestrom AB	—	−40	−36	67	65	62	59	57	55	53	51	0	0	0	0
Thule AB	—	−34	−33	55	52	50	47	47	45	44	42	0	0	0	0
Mexico Mexico City	7575	32	35	83	81	79	76	61	60	59	58	0	171	0	0

$$(°F - 32) \times \frac{5}{9} = °C$$

TABLE H-6. AIR AND GROUND TEMPERATURES AND DEPTH OF PERMAFROST IN CANADA. SOURCE: Map 1246A, Permafrost in Canada, Geological Survey of Canada; Department of Energy, Mines and Resources.

Location	Mean Annual Air Temperature (°F)	Ground Temperature (°F) At Depth (Number In Brackets - Feet)	Thickness Of Permafrost (Feet)
1. Aishihik, Y.T.	24.5	28.3 (20)	50-100
2. Asbestos Hill, P.Q.	17	19-20 (50-200)	> 900
3 Churchill, Man.	19	27.5-28.9 (25-54)	100-200
4. Dawson, Y T.	23.6	—	200
5. Fort Simpson, N.W.T.	25 0	35.4-33.2 (0-5)	40
6. Fort Smith, N.W.T.	26 2	About 32 (15)	?
7 Fort Vermilion, Alta.	28.2	39.8-38.9 (0-5)	Nil
8 Inuvik, N W.T.	15 6 (Aklavik)	26 (25-100)	> 300
9 Keg River, Alta.	31	31-32 (5)	5
10. Kelsey, Man.	25.5	30.5-31 5 (30)	50
11 Mackenzie Delta, N.W T.	15 6 (Aklavik)	23.8 26.5 (0-100)	300
12. Mary River, N W.T.	6.3 (Pond Inlet)	10 (30)	?
13. Milne Inlet, N.W.T.	6.3 (Pond Inlet)	10 (50)	?
14. Norman Wells, N.W.T.	20.8	26-28.5 (50-100)	150-200
15 Port Radium, N.W.T.	19.2	—	350
16 Rankin Inlet, N.W T.	11.2 (Chesterfield In.)	15-17 (100)	1000
17. Resolute, N.W.T.	2.8	10-8 5 (50-100)	1300
18. Schefferville, P.Q.	23.9	30-31.5 (25-190)	> 250
19. Thompson, Man.	24 9	31-32 (25)	50
20. Tundra Mines Ltd., N.W.T.	17	29 (325)	900
21. Uranium City, Sask.	24	31-32 (30)	30
22 United Keno Hill Mines Ltd., Y.T.	24.2 (Elsa)	—	450
23. Winter Harbour, N.W.T.	—	—	1500
24 Yellowknife, N.W.T.	22.2	33.0-31.4 (2.3-8.3)	200-300

$$(°F - 32) \times \frac{5}{9} = °C$$

$$ft \times 0.3048 = m$$

TABLE H-7. AVERAGE GROUND TEMPERATURES FOR VARIOUS ALASKAN COMMUNITIES. FOR DEPTHS OF 0 TO 3 m BELOW THE SURFACE COMPUTED ON THE BASIS OF THE METHOD USING MONTHLY AVERAGE AIR TEMPERATURES, Described by T. Kusuda and P.R. Archenback in "Earth Temperature and Thermal Diffusivity at Selected Stations in the United States"; ASHRAE Transactions, Vol. I, Part 1, p. 61, 1965.

Alaska	Spring	Summer	Fall	Winter	Avg.
Anchorage AP	25	29	46	42	35
Annette AP	40	42	51	49	46
Barrow AP	4	7	16	14	10
Bethel AP	18	23	41	37	30
Cold Bay AP	33	35	43	41	38
Cordova AP	32	35	45	43	39
Fairbanks AP	14	19	38	34	26
Galena AP	13	18	37	33	25
Gambell AP	15	19	34	30	24
Juneau AP	34	36	47	45	41
Juneau CO	36	39	49	46	42
King Salmon AP	25	28	44	40	34
Kotzebue AP	10	14	31	27	21
McGrath AP	14	18	37	33	25
Nome AP	16	20	37	33	26
Northway AP	12	16	32	29	22
Saint Paul Island AP	31	32	40	38	35
Yakutat AP	33	36	45	43	39

$$(°F - 32)\,\frac{5}{9} = °C$$

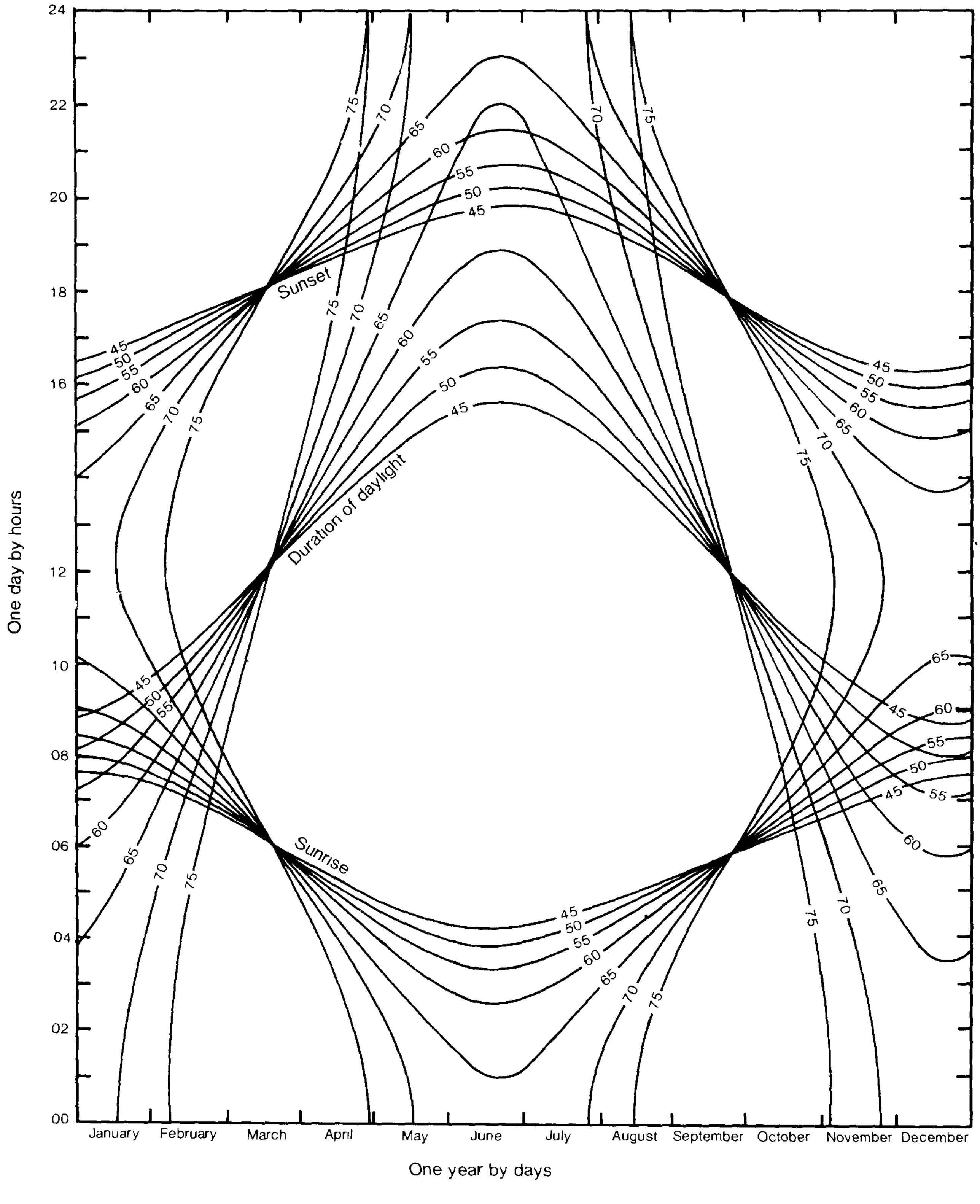

FIGURE H-10. HOURS OF DAYLIGHT AT VARIOUS LATITUDES

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