UFC 3-130-05
16 January 2025

UNIFIED FACILITIES CRITERIA (UFC)

ARCTIC AND SUBARCTIC UTILITIES

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ARCTIC AND SUBARCTIC UTILITIES

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER CENTER

Record of Changes (changes are indicated by **1**\ ... /**1**/)

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This UFC supersedes UFC 3-130-05, dated 16 January 2004.

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FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States, its territories, and possessions is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA). Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Military Department's responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Systems Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Technical content of UFC is the responsibility of the cognizant DoD working group. Defense Agencies should contact the respective DoD Working Group for document interpretation and improvements. Recommended changes with supporting rationale may be sent to the respective DoD working group by submitting a Criteria Change Request (CCR) via the Internet site listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide website http://www.wbdg.org/dod.

Refer to UFC 1-200-01, *DoD Building Code*, for implementation of new issuances on projects.

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CHAPTER 1 INTRODUCTION

1-1 BACKGROUND.

The field of Arctic and Subarctic engineering, also known as cold regions engineering, covers a wide range of multidisciplinary topics and principles. Unique issues exist in the planning, design, construction, and operation of infrastructure and facilities in Arctic and Subarctic regions. Among them are permafrost, seasonal ground frost heave and thaw settlement, extreme low temperatures, high wind loads, heavy snow loads, and remote construction sites. Additionally, the implications of the rapidly changing climate in Arctic and Subarctic regions exacerbate these unique challenges.

The Unified Facilities Criteria (UFC) Arctic and Subarctic series includes five volumes that summarize relevant information and the most feasible approaches and solutions for planning, design, construction, and maintenance of infrastructure and facilities in the Arctic and Subarctic areas of the globe.

1-2 NEED FOR SPECIAL APPROACHES.

Unique problems exist in the planning, design, construction, and operation of water, wastewater, and energy utility systems in Arctic and Subarctic regions. Among them are permafrost, seasonal ground freezing and thawing with its associated frost heave and thaw settlement, extreme low temperatures, and often, remoteness of the construction site. The degree of influence of these factors varies significantly over these regions as they include vast geographical territory. Many components of conventional or temperate climate utilities can be used in cold regions. However, no conventional component should be used without careful analysis of the effects of cold stress on their operation and durability. Analysis should assume that the system will freeze. As a result, all systems should incorporate a plan for the recovery of a frozen component or system.

“Environmental Engineering Failures in Alaska,” by Schubert et al., provides case histories of utility failures in Alaska that illustrate the potentially catastrophic nature of utilities systems designed and operated without consideration of the extreme conditions in which they were installed. In some cases, failure resulted in abandonment of the structure or system; in other cases, repair or change in operation was able to correct the design shortcomings. In all cases, the cost of these failures was significant in social (interruption of service), environmental, and monetary terms.

1-3 REISSUES AND CANCELS.

This document supersedes and cancels inactivated UFC 3-130-05, dated 16 January 2004.

1-4 PURPOSE AND SCOPE.

The Arctic and Subarctic UFC series provides technical guidance and available technical requirements for planning, design, construction, and maintenance of DoD facilities worldwide for all Service elements in Arctic and Subarctic environments. These guidance and technical requirements are based on the International Building Code (IBC) and the requirements in UFC 1-200-01. The UFC 3-130 series covers many aspects of Arctic and Subarctic engineering with the specific exception of pavements, which is incorporated into the UFC 3-250 and 3-260 series as discussed in UFC 3-130-01, paragraph 1-6.3. In addition to this volume, there are four other series volumes:

- UFC 3-130-01, *Arctic and Subarctic Engineering*. UFC 3-130-01 serves as an introduction to the Arctic and Subarctic UFC series.
- UFC 3-130-02, *Arctic and Subarctic Site Assessment and Selection*. UFC 3-130-02 provides applicability and technical guidance for geotechnical site assessment for the Arctic and Subarctic environment conditions.
- UFC 3-130-03, *Arctic and Subarctic Foundations for Freezing and Thawing Conditions*. UFC 3-130-03 includes horizontal and vertical foundations, considerations affecting foundation design, and construction and monitoring of facilities in the Arctic and Subarctic areas.
- UFC 3-130-04, *Arctic and Subarctic Buildings*. UFC 3-130-04 includes building design in the Arctic and Subarctic areas.

This UFC provides criteria and guidance for the planning, design, and construction of utility systems for DoD facilities in Arctic and Subarctic regions. Only criteria and guidance unique to cold regions (the Arctic and Subarctic) are provided. Topics covered include water supply; wastewater collection, treatment, and disposal; fire protection; utility distribution systems; and the thermal calculation techniques needed for their cold regions design. These minimum technical requirements are determined by UFC 1-200-01. Where other statutory or regulatory requirements are referenced, the more stringent requirement must be met.

Specific discussion of centralized heating plants and their distribution systems, either steam or hot water, are beyond the scope of this UFC. The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) *District Heating Guide* and *Guide for Resilient Thermal Energy Systems Design in Cold and Arctic Climates* provide excellent references for this topic. Topics such as equipment redundancy and fault detection found in the *Resilient Thermal Energy Systems Design in Cold and Arctic Climates* are applicable to noncentralized systems also. Requirements for distribution pipelines carrying natural gas, manufactured gas, or Liquefied Petroleum Gas (LPG) in its vapor phase, that are installed on DoD owned property, from the point of delivery by the gas supplier to the points of connection to the buildings' fuel gas piping, are provided in UFC 3-430-05. As with water and wastewater piping, the thermal considerations for these pipelines are critical in cold regions. Chilled or warmed pipelines may affect frost heave and thaw settlement in such a way as to be catastrophic to the structural integrity of these systems. Further discussion can be found in resources listed in Appendix B.

1-5 APPLICABILITY.

This UFC follows the same applicability as UFC 1-200-01, paragraph 1-3, for those geographic locations in Arctic and Subarctic regions worldwide.

1-6 GENERAL BUILDING REQUIREMENTS.

This UFC is an integrated part of the Arctic and Subarctic UFC 3-130 series. Use the other documents of this series in conjunction with this UFC to address construction aspects unique to cold regions. See UFC 3-130-01, Chapter 2 for the definitions of Arctic and Subarctic.

Often, conventional construction practices are acceptable in Arctic and Subarctic regions with appropriate modification to account for extreme cold temperatures, frost heaving soils, and permafrost areas. This UFC modifies and supplements the criteria found in the core UFCs. Utility provider’s or Installation specific requirements must be considered.

1-7 CYBERSECURITY.

All facility-related control systems (including systems separate from a utility monitoring and control system) must be planned, designed, acquired, executed, and maintained in accordance with UFC 4-010-06, and as required by individual Service Implementation Policy.

1-8 COMMENTARY.

Because of the unique aspects of cold regions engineering, commentary has been added to the chapters. This commentary speaks to elements that are unique to cold regions applications. Section designations for such commentary are preceded by a “[C]” and the commentary narrative is highlighted with light gray.

1-9 BEST PRACTICES.

In cold regions engineering planning, design, and construction, much of the state of the practice is not codified. Lessons learned and the experiences of the Installation engineering staff are invaluable and may help avoid potentially costly and catastrophic infrastructure failures. Appendix A, Best Practices, provides guidance for accomplishing certain utilities design and engineering services in extreme Arctic and Subarctic environments. The Designer of Record (DoR) must review and interpret this guidance as it conforms to criteria and contract requirements and apply the information according to the needs of the project. If a Best Practices document guideline differs from any UFC, the UFC takes precedence. For Best Practices guidelines not discussed in a UFC, the DoR must submit a list of the guidelines or requirements being used for the project to the Government Project Manager with documentation sufficient for review and approval prior to completing the design.

1-10 GLOSSARY.

Appendix D contains acronyms and abbreviations. See UFC 3-130-01 for definitions of general cold regions engineering terms.

1-11 SUPPLEMENTAL RESOURCES.

Appendix B provides a list of reliable sources for information on subjects related to cold regions engineering, design, and construction. These resources are valuable tools to the civil engineer for additional information on topics pertinent to and affiliated with construction of utility systems in Arctic and Subarctic regions.

1-12 REFERENCES.

Appendix E contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies.

CHAPTER 2 PLANNING AND DESIGN

2-1 GENERAL.

Engineering decisions for the planning, design, construction, and maintenance of infrastructure in Arctic and Subarctic regions are based not only on applicable federal, state, and local codes, but also the expertise of engineers or practitioners with experience in dealing with the unique conditions provided by the extreme environment these regions experience. It is the intent of this UFC, and the Arctic and Subarctic UFC series, is to provide requirements and guidance to prevent significant missteps in the planning, design, and construction of cold regions infrastructure. Consultation with experienced engineers at the Command, District, and Installation level is required to ensure technologies and practices that are unsuitable for this environment, or a specific location, are not proposed. This UFC provides indicators of potential problem areas that may require unique engineering solutions outside the realm of those seen in temperate region or standard construction practices.

2-2 ENVIRONMENTAL CONDITIONS IN THE ARCTIC AND SUBARCTIC.

The planning, design, construction, and maintenance of utility systems are all affected by the special environmental conditions found in the Arctic and Subarctic. These conditions include adverse temperatures, extreme temperature variations, wind, humidity, and snow; high costs; remoteness of locations; limited availability of construction materials and labor; need for fuel additives, synthetic lubricants, oils, and greases for construction equipment; thermal stresses; and seasonal ground freezing, frost heaving, and permafrost.

2-2.1 Temperature.

[C] 2-2.1 The low temperatures prevailing in the cold regions are the most critical environmental factor. The intensity of the cold is important, but equally critical is the duration of the cold period. Mean annual air temperatures in the Northern Hemisphere are presented in UFC 3-130-01. Air temperatures in Arctic locations vary from highs of 80°F (27°C) in summer to lows of −75°F (−59°C) in winter. Interior locations away from the tempering effects of oceans or large water bodies tend to have the greatest extremes. Sub-zero temperatures can persist for months, and it is not uncommon for air temperatures to remain below −30°F (−34°C) for a week or more at many locations in Alaska.

2-2.2 Wind and Related Factors.

The combination of wind and low temperatures results in very large heat losses from exposed facilities and presents hazards for personnel. Blowing and drifting snow can create major construction and operational problems even when the total precipitation is low. The location and layout of utility systems and access points for operation and maintenance must be given careful consideration during planning and design to avoid problems with drifting snow.

[C] 2-2.2 Mean annual wind speeds for most Arctic and Subarctic locations are usually about 5 to 10 miles per hour (mph) (8 to 16 kilometers per hour [kph]) in the interior and 10 to 20 mph (16 to 32 kph) at coastal locations. During a 1972 extreme storm event, Thule, Greenland reported wind speeds in excess of 200 mph (322 kph).

2-2.3 Humidity.

Humidity is a critical factor in enclosed spaces, and both high and low extremes may be experienced in arctic situations. Since natural humidity is extremely low due to the low winter temperatures, humidifiers may be desirable in personnel spaces in order to maintain humidity at about 30 percent. Very high humidity is experienced in pump stations and enclosed treatment works, and thus, condensation may occur on cold surfaces causing damage and inconvenience. Corrosion under insulation is one example of the resulting damage, as are the potential negative effects of high humidity on wood (Type V) construction.

2-2.4 Permafrost.

The presence of frozen soil critically impacts the structural considerations for cold regions design and construction, potentially affecting the ability of the ground to support infrastructure loads. Therefore, the presence of permafrost, or perennially frozen ground, is typically a major design consideration. Figure 2-1 in UFC 3-130-01 illustrates the approximate distribution of permafrost in the Northern Hemisphere. In the zone of continuous permafrost, frozen ground is absent only at a few widely scattered locations such as at the bottoms of lakes and rivers. In the discontinuous zone, permafrost is found intermittently. Permafrost and seasonal frost are discussed in more detail in UFC 3-130-01.

2-3 PLANNING CONSIDERATIONS.

In the Arctic and Subarctic, utility systems are usually the costliest component in construction of military Installations. The layout of an Installation is often controlled by the type of distribution and collection systems selected for the utilities network. As a result, planning for a new Installation or the addition of new facilities on an existing Installation in the Arctic and Subarctic must include consideration of utilities at a very early stage to ensure overall cost effectiveness. Use UFC 3-201-01 for preliminary site analysis and evaluation of existing conditions such as geotechnical site investigation, environmental considerations, surveying, and topographic surveying. Use UFC 3-130-02 for site analysis topics specific to cold regions. Review the existing utility maps and Installation planning documents with Installation personnel to develop population estimates and plans for new service areas. Address Installation specific design preferences and standards with responsible engineering and operations personnel as part of the system design analysis.

DoD Installations in Arctic and Subarctic regions vary significantly by size, mission, and remoteness. Engineering design decisions for Installations manned by unaccompanied military, civilian, and contractor personnel may differ from those made for Installations where the tour of duty is accompanied, and family housing is provided on the Installation. In Figure 2-1 high voltage, insulated electrical lines on pipeline sleepers are placed directly on the ground at Thule Air Base, Greenland. Thule Air Base assignments are unaccompanied, limiting Installation access to DoD service members, civilians, and contractors. These ground surface electrical lines would likely be unacceptable for both safety and aesthetic reasons on less remote Installations where family members are present. The Installation, District, or Command engineering personnel must be involved in project planning and throughout the design process to ensure appropriate facilities to meet the locality mission are constructed.

Figure 2-1 Unprotected Insulated Power Lines at Thule Air Base, Greenland

2-3.2 Useful Life.

The harsh operating conditions for utility systems and equipment in cold regions reduces their useful life. Table 2-1 presents typical useful lives for some utilities components in the Arctic and Subarctic.

[C] 2-3.2 Equipment that must operate throughout the winter are particularly critical. Pumps and their controls, required to maintain pipe flow, are examples of critical equipment.

Table 2-1 Approximate Useful Life of Utility System Components in Cold Regions

Component	Useful Life (years)
Wells	30
Pumps and controls	5
Storage tanks	40
Water distribution lines	40
Meters	10
Valves	10
Sewage collection lines	30
Lift stations (not pumps)	30
Buildings	30
Paint (exterior)	10
Service connections	10–15
Trucks	4
Tracked vehicles	2–3
Backhoe (occasional use)	6–10
Compressors	5

2-3.3 Construction Methods.

The three basic construction techniques used are modular, stick built or in-place construction, and prefabricated. The method selected depends on site conditions and transportation facilities available. The normal construction season varies from two to three months along Alaska’s Arctic coast to six to eight months in southern areas of Alaska.

2-3.4 Installation Layout.

Consult UFC 2-100-01 for guidelines to Installation planning and infrastructure layout and UFC 3-130-04 for issues specific to cold regions. For existing Installations, consult the Installation Development Plan (IDP), or other Installation planning documents.

2-3.4.1 Utility Networks.

The critical planning decisions for utility networks are (1) whether the pipes should be above or below ground, and (2) whether the pipes should be installed as individual units or combined with other utility services in a utilidor. Heat loss is directly proportional to the difference between the inside and outside temperatures. An aboveground utilidor or pipeline is directly exposed to extreme weather conditions and therefore has a much higher maximum rate of heat loss (and therefore shorter time to freeze) compared to a similar pipeline buried just below the ground surface. In general, adopt belowground installation wherever possible. Pipes buried in permafrost or in the seasonal frost zone must not only be protected from freezing but must also resist the structural effects of heaving in the seasonal frost zone and potential thawing of the permafrost. Additionally, thermal considerations must be concerned with not only protecting the pipe from freezing, but also protecting the permafrost from thawing. The terrain is relatively flat in much of the Arctic, and maintenance of the necessary grades for gravity sewers in either the aboveground or buried mode is difficult. Use pump stations, or pressure or vacuum sewer systems, to overcome these constraints. The decision to combine multiple utility services in a utilidor is determined by a variety of factors. Benefits may be derived both during construction and maintenance, and the combined systems may be easier to protect from freezing. However, utilidors are generally larger structures and more expensive to build. The thermal contribution of multiple pipes in a single space, and their possible interaction, must be considered. Thermal considerations for above and belowground utility installation are covered in detail in Chapter 12 and utilidors are discussed further in Chapter 9.

[C] 2-3.4.1 Aboveground utility systems offer easier access for maintenance and repair and are cheaper to build where site conditions are poor. However, there are disadvantages. They are susceptible to vandalism and traffic damage, disrupt pedestrian and vehicle traffic patterns, and create snow removal problems. Belowground systems allow for more normal Installation layout, however pipe breaks and leaks in belowground pipes are harder to detect and locate, particularly in frozen ground.

2-3.4.2 Network Layout.

Utility network layout is dependent on the source and termination of each component of the system. Utilities may be provided from off Installation by local utility companies. Other Installations have centralized heating or power plants; water source, treatment, and storage facilities; and wastewater treatment facilities all on-site. Service lines from utility mains to individual buildings are the main source of freezing problems. Site buildings as close to the mains as possible with service lines 60 ft (18.3 m) or less in length. Do not design Installation layouts with dead-end streets unless a pipe connection can be made to an adjacent street for the circulating water system. Locate the largest consumers of water at the extremities of the distribution system if possible.

[C] 2-3.4.2 It is typical practice in temperate climates to bury most utility lines in the streets. However, there are thermal disadvantages to this practice in cold regions since clearing the roads of snow will allow greater frost penetration. Burying water and sewer mains in the front or back yards of dwellings, and in open areas where snow will not be removed, maintains warmer ground and pipe temperatures.

2-4 DESIGN.

Use UFC 3-201-01 for topics such as site development, grading, and storm drainage systems. Use UFC 1-200-02 for energy and sustainability.

2-4.1 Design Criteria.

Design utility systems to meet all applicable regulations and requirements of federal, state, and local governments, or overseas equivalent.

2-4.2 Approvals and Permits.

See UFC 3-130-01, paragraph 1-13, for the general approval and permit processes for Arctic and Subarctic construction. For new potable water supply systems, extensions to new areas, rehabilitation, or replacement of existing potable water supply systems, coordinate with the Safe Drinking Water Act primacy agency, as applicable, to determine primacy agency requirements. For new or rehabilitated sanitary sewer systems or facilities such as service extensions, domestic wastewater treatment, or industrial wastewater treatment, coordinate with the applicable primacy agency to determine permitting requirements.

2-5 EQUIPMENT.

For remote Arctic Installations, the initial cost of most utility equipment is not as important as its reliability. Redundant or split systems allow extended operation with a single unit failure for equipment such as boilers. Standby units for critical equipment are essential and are particularly important for emergency power and for heating systems. A large inventory of critical spare parts is recommended and standardization of equipment to reduce the parts inventory will prove economical.

2-6 ALARM SYSTEMS.

Provide alarms and safeguards, such as low water temperature alarms, low flow alarms, and low or high voltage alarms to warn operators of any pending problems. Incorporate instrumentation and monitoring into utility systems and facilities to allow for safe and efficient operation. All critical utility facilities must have instrumentation, monitoring, alarm, and notification systems to indicate critical conditions that would result in:

- cessation of essential service (for example, monitor flow, temperature, and pressure); or
- damage to facilities (for example, monitor for fire and low temperature).

Further discussion is given in paragraphs 3-6.4, 5-2.6, and 7-4.4. Paragraph 10-5 discusses integration of utility alarm instrumentation with the Installation central alarm system.

2-7 REVEGETATION.

Revegetate areas excavated and backfilled for utility systems to prevent erosion. Request planting criteria from the Installation, District, or Command environmental staff.

[C] 2-7 Locations may have significantly different grass, tree, and shrub species lists. The preferred or acceptable planting season may also vary by location.

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CHAPTER 3 WATER SOURCE DEVELOPMENT

3-1 GENERAL.

The water requirements and design capacity factors for domestic, fire, and other functional uses are specified in UFC 3-230 series. Per UFC 3-230-01, unless otherwise directed by the Government Project Manager, use nearby public potable water systems. However, if that is not practical, sources must be developed on the Installation. Both ground and surface waters are available in the Arctic and Subarctic, but the environmental conditions require special approaches for their development. In addition, ice and snow are sometimes used for water supply augmentation or as emergency or standby sources.

3-2 ENVIRONMENTAL CONSTRAINTS.

In most of the Arctic and Subarctic, precipitation is light, terrain is relatively flat, and runoff is concentrated in the short period during ice breakup. There are many small, shallow lakes, ponds, and numerous rivers and streams. Ice cover varies according to local conditions but generally lasts from 6 to 10 months and approaches 6 ft (1.8 m) in depth in small quiescent water bodies (see Appendix C, Example 1 for procedures to estimate thickness of ice formation). Hydrologic data for these regions are scarce, so it is difficult to predict reliable yields. Because permafrost is essentially impermeable, there is little direct recharge of most aquifers. Any penetration of the permafrost for exploration or for well development requires special engineering consideration and is costly.

3-3 SURFACE WATERS.

Many shallow lakes and small streams freeze completely in the winter, eliminating them temporarily as a water source. Some Installations pump water from such sources in the summer months to store for a winter supply. Larger streams and deep lakes can have liquid remaining beneath the ice, but the volume available is limited since there is no contribution from precipitation in the winter. The large quantity of ice and snow results in major annual flows occurring during the spring breakup. Hydrographs for Arctic rivers in the U.S. are available from the United States Geological Service (USGS) website https://waterdata.usgs.gov/nwis.

3-3.1 Rivers.

The volume of flow is low in the winter for Arctic and Subarctic rivers, but water quality is excellent since sediment transport from glacial sources is minimal and surface runoff recharges do not occur. Winter water temperatures are very low (33°F [0.6°C]), which creates difficulties for treatment, and intakes can clog due to formation of frazil ice. Floating ice during freeze-up and breakup periods can damage or destroy intake structures. Some facilities remove intake structures and rely on water from temporary storage locations during these periods. Development of intake galleries or wells in the stream bottom mitigates ice problems, but it is difficult to locate the permanent channel in alluvial and braided streams. The summer flows are higher in volume than winter flows, but they are poorer in quality, containing sediments which may be difficult to remove. These sediments are primarily glacial silts and are almost colloidal in size.

3-3.2 Lakes.

Deep lakes are a reliable, continuous source of water. The quality of any liquid beneath the ice in a shallow lake or pond is typically poor. Impurities, such as most salts, are rejected from the freezing water, making the ice relatively pure but concentrating the impurities in the remaining liquid. A survey is required to identify lakes and ponds that may freeze deeply enough to create this condition. Chapter 12 discusses the thermal aspects of such an analysis.

3-3.3 Saline Waters.

Distillation or reverse osmosis is used to treat saline or brackish waters; these procedures are costly and energy intensive. Avoid such sources except as the last resort.

3-3.4 Augmentation.

In the Arctic, most of the annual precipitation is in the form of snow. Although total precipitation is low, advantage can be taken of windy conditions to induce snow drifting at selected locations. Collection of the melting snow augments the summer water supply. ASCE *Cold Regions Utilities Monograph,* Section 5.2.1, provides more information.

> [C] 3-3.4 Snow fences were used to induce drifting in the watershed of the Utqiagvik, Alaska water reservoir. It was shown that at least 800 gallons (3000 liters) of water were collected for every linear foot of 5-ft-high (1.5-m) snow fence that was installed, with the fences about 250 ft (76 m) apart.

3-4 GROUNDWATER.

Groundwater can be a more reliable water source than surface supplies. It is usually available on a year-round basis and is more consistent in its temperature and mineral quality than surface sources. Very shallow groundwaters are unsuited for potable water supplies without extensive treatment and the yield is limited. Subpermafrost groundwater or permafrost zones thawed by large rivers and lakes are the most reliable sources. Subpermafrost wells are technically feasible when the permafrost extends to a depth of a few hundred feet or less, and they have been successfully used in central Alaska. Costs for drilling and maintenance of such wells are high. The water must be protected from freezing, and the permafrost must be maintained in a frozen condition. This requires special well casings or grouting methods and unique operational methods. Subpermafrost water is generally deficient in dissolved oxygen and can also contain high concentrations of dissolved iron and manganese salts. Hardness is also common. Dissolved organics can create serious treatment problems because of interactions with the dissolved iron and the color imparted to the water. The most reliable and economical groundwater sources in the Arctic and Subarctic are in the thawed zones adjacent to large rivers and lakes. Most of the rivers are braided streams and have shifted their channels many times. The former stream channels may still be underlain by thawed material and represent a potential water source depending on the type of soils involved.

3-5 OTHER WATER SOURCES.

Consider snow, ice, and direct catchment of rainfall as potential water sources for augmentation or emergency supplies and for small facilities, temporary facilities, or facilities in support of military operations with a design life of five years or less. The natural quality of these sources is good, but a stockpile of snow or ice can be easily contaminated. Large volumes of snow are required to produce even small quantities of water and the costs for harvesting and melting are high. It is estimated that 4 to 5 ft^3 (0.11 to 0.14 m^3) of snow is required for every 5 gallons (19 liters) of water produced, and to melt this volume of snow would require about a pint of diesel fuel for the snow melting equipment. Brackish and saline ponds have been improved in quality by pumping out the concentrated brines that remain under the ice near the end of the winter and allowing fresh spring runoff to recharge the pond. If repeated several times the procedure allows the use of an initially unacceptable water source.

3-6 STRUCTURES.

Structures range from wells and their appurtenances, to simple temporary intakes placed on the river ice, to complex dam structures located on permafrost. The complete structural design of any of these is beyond the scope of this UFC (UFC 3-130-03 discusses embankment construction on permafrost). It is the intent of this section to point out those features that may require special attention in the cold regions. ASCE *Cold Regions Utilities Monograph,* Section 5.4, provides additional considerations in design of these structures.

3-6.1 River Intakes.

A permanent intake structure is usually employed for large-scale permanent military facilities in the Arctic. Structural damage from moving ice in the spring and in the fall is the major concern.

3-6.1.1 Temporary Intakes.

Temporary intakes are less expensive and are removed from the river during spring ice breakup; and storage is relied on as the water supply. This approach is suitable for small populations. A temporary intake consists of a pump and simple shelter.

3-6.1.2 Permanent Intakes.

Numerous arrangements and configurations for permanent intake structures have been designed. Special features of these designs include insulation, heat tracing in the wet well and in the intake line, and a recirculating line from the facilities served. Dual intakes are recommended to ensure reliability. Continuous water circulation is then used to prevent freezing. Frazil ice can be a serious problem for intakes during the freeze-up period. Frazil ice occurs as small crystals in flowing water slightly below 32°F (0°C) in temperature. It will adhere to and accumulate on any submerged object it contacts. Water intakes, trash racks and similar structures can become completely choked by frazil ice in a few hours. It can be avoided by locating the intake in a long, calm reach of the river where surface ice will occur before the water becomes supercooled. The surface ice cover then prevents rapid heat loss and precludes frazil ice formation. Heating the intake and bar screens to about 33°F (0.6°C) prevents formation of frazil ice. This can be done electrically or by back pumping hot water or steam.

3-6.2 Infiltration Galleries.

Infiltration galleries remove the structure from risk of ice damage and thereby offer advantages over direct intakes. The gallery is placed in thawed material in the stream bed or adjacent to it. The yield will depend on the type of soil present. Importation of coarse-textured material is necessary for gallery construction in fine-textured silty and clayey soils. Both electrical and steam lines have been used in galleries to prevent freezing. Steam lines are usually placed on the upper surface of the intake laterals and on a second level about 1.5 ft (0.5 m) above that. The heating elements or steam lines are not normally operated continuously but are used only in emergencies to restore a frozen or partially frozen system.

3-6.3 Wells.

See UFC 3-230-02, for basic procedures for water well design. The special concern for subpermafrost wells is not to allow thawing of the permafrost during drilling or operation of the well. The former may require either compressed air or nontoxic drilling muds or fluids with rotary drilling procedures. Avoidance of permafrost thawing during well operation may require multiple casings so that cold air can circulate in the annular spaces. Concurrent with protection of the permafrost is the necessity of maintaining the water in an unfrozen state, which requires heat addition for an intermittently used system. Artesian flow, from subpermafrost aquifers, may also cause issues for wells, especially on valley floors and at the bottom of hill slopes. In *Geologic Hazards of the Fairbanks Area: Alaska Division of Geological & Geophysical Surveys Special Report 15,* Péwé discusses this phenomenon and several cases of uncontrolled flow through and around the well casings in the Fairbanks area.

In nonpermafrost conditions, design wells for frost heave protection in the surface soils. Casings must be designed to prevent the bonding between the frozen soil and the pipe and thereby eliminate heave damage.

3-6.4 Pumping Stations.

Pumphouses provide shelter for pumping equipment controls, boilers, treatment equipment, and maintenance personnel who must operate and service the facility. The structural design depends on the requirements of each location and must be considered individually. The type of equipment housed within the shelter also depends on the individual system and may vary from a simple pump to a complex system with HVAC, standby power, and alarm systems to alert operators of malfunction. Any system must provide the degree of redundancy and other safeguards required by the nature of the operation and location. ASCE *Cold Regions Utilities Monograph,* Section 5.4.4, provides more information.

Alarms should include, but are not limited to, the following:

- no return flow
- low/no return pressure
- low/critical low return temperature
- high supply/fire flow
- high supply temperature
- pump trouble
- heating system or HVAC trouble
- Fire Flow Trouble

Consult Installation, District, or Command engineering and operations staff for specific requirements.

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CHAPTER 4 WATER TREATMENT

4-1 GENERAL.

See UFC 3-230-01, for the basic requirements, criteria, and procedures for water treatment systems for military facilities. This chapter discuss only those aspects unique to the Arctic and Subarctic. There are three major process concerns: the low temperature of the raw water, removal of glacial silt from surface sources and removal of dissolved minerals, and organics from surface or groundwater sources.

4-2 TEMPERATURE EFFECTS.

The temperature of surface water sources during winter will be at or very near 32°F (0°C), while groundwater sources in permafrost regions may be a few degrees warmer and maintain that level year-round. The water must be preheated to at least 40 to 50°F (4 to 10°C), or the unit processes must be designed for low temperature operation. The effect of low temperatures on equipment operations must also be evaluated during facility design. ASCE *Cold Regions Utilities Monograph,* Section 6, provides further guidance.

4-3 LOW TEMPERATURE TREATMENT.

Almost all physical, chemical, and biological processes used in water treatment are sensitive to temperature either through viscosity effects or as an influence on reaction rates. This must be considered for mixing, sedimentation, filtration, and disinfection. See the ASCE *Cold Regions Utilities Monograph,* Section 6.3, for further details.

As of 2015, there is no longer separate guidance for fluoridation in cold climates. See the UFC 3-230 series for specific requirements for military Installations.

4-4 REMOVAL OF MINERALS AND ORGANICS.

[C] 4-4 Ion exchange water softening is commonly used at smaller Installations with hard water. Lime-soda softening is frequently used when the water is both turbid and has a high hardness. Dissolved iron is common in cold regions groundwater. Aeration or chemical oxidation with chlorine have been successful for precipitation of elemental iron. Iron can foul zeolite and greensand ion exchange resin systems unless they are appropriately designed. If the groundwater has excessively high iron, precipitation is likely a better way to remove the iron, and then use greensand as a polishing measure for any remaining iron. However, iron/organic complexes are present in many cold regions groundwaters. Ozone has been shown to be effective in treating such water. Ozone and carbon adsorption are very effective for color and organics removal.

4-5 TREATMENT OF BRACKISH AND SALINE WATERS.

Distillation, reverse osmosis and freezing have all been used in cold regions to reduce saline concentrations to potable levels. See the ASCE *Cold Regions Utilities Monograph,* Section 6.3.11, for further details.

CHAPTER 5 WATER STORAGE

5-1 GENERAL.

Basic criteria for determination of capacity requirements, design, and construction of water storage facilities can be found in UFC 3-230-01. This chapter discusses only those aspects unique to the Arctic and Subarctic. Water is provided for domestic, industrial, and fire protection services. A design study to determine specific water needs must be undertaken for each new facility so that cost-effective designs for water supply, water storage, and wastewater systems can be ensured.

[C] 5-1 The requirements for water will typically be lower at remote facilities in the Arctic and Subarctic than at similar operations in the temperate zone due to conservation and lower external water needs. The water needs will vary with the type of facility, so general criteria are not possible.

5-2 WATER TANKS.

Structural design of water storage tanks generally follows temperate regions practice. Considerations specific to Arctic and Subarctic construction include insulation, thermal conditions, foundation design (see UFC 3-130-03), and the need to prevent ice damage. Ice buildup, either inside or on the exterior of the tank, due to leakage, may pose serious structural and safety risks. ASCE *Cold Regions Utilities Monograph,* Section 7.5, provides additional details on water tank design.

5-2.1 Tank Materials.

Construction materials for water tanks in cold regions include wood, steel, and concrete. In Alaska, welded steel tanks are the most commonly used. Tank insulation materials include polystyrene or polyurethane boards, or sprayed-on polyurethane. Concrete tanks have been used where aggregate is available and the foundation conditions permit slab construction. Insulate concrete tanks, or cover with earth, to reduce heat losses. Evaluate seismic conditions prior to selection of a rigid concrete tank. Welded steel tanks are more cost effective for high-risk seismic areas.

[C] 5-2.1 Wood stave tanks are constructed with prefabricated pieces that can be shipped relatively easily to any remote site. Leakage is a problem with intermittent or fill-and-draw operations since the joints can open slightly if the wood is allowed to dry.

5-2.2 Corrosion Protection.

Paint steel water tanks in accordance with applicable standards provided in UFC 3-230-01. When selecting paints, the in-service temperature range must include normal and possible extremes. Strictly follow manufacturers' recommendations regarding acceptable temperature limits for the application of these paints to avoid premature failure. Cathodic protection is also required.

[C] 5-2.2 The cost of sandblasting and liner replacement is very high in remote locations so the type of coating initially selected must be of high quality and properly applied.

5-2.3 Insulation.

Common tank insulation materials are earth cover (soil), polyurethane or polystyrene board, or sprayed on polyurethane materials. Selection is affected by factors including moisture exposure, attachment options, and cost, among other considerations. Moisture-resistant layers of insulation materials must be installed in contact with the tank at inaccessible locations since moisture from leaks, condensation, rain, or groundwater can drastically reduce the insulating effect. Insulation applied aboveground requires protection against accidental mechanical damage, vandalism, birds and animals, and weather. Aluminum or steel cladding provides a good barrier against weather and mechanical damage. Insulation materials are further discussed in paragraph 12-7.

[C] 5-2.3 Tanks may also be enclosed with a protective shell. Such an exterior shell is either constructed against the tank or a walkway provided between the tank and the exterior wall. The air gap and the wind protection will reduce heat losses, and this heat loss can be further reduced by installing insulation. Near-hydrophobic plastic foam insulations are readily available and commonly used. Polyurethane can be obtained as either prefabricated boards or foamed in place by spraying directly onto the tank. The latter has been the more common approach in Alaska.

5-2.4 Tank Design.

Design water storage tanks to prevent the formation of ice in the tank under all foreseeable circumstances, and tanks must be completely drainable. Surface icing can be avoided by maintaining the water temperature above 39°F (4°C) and ensuring continuous circulation. Double-wall, testable heat exchangers are recommended for sanitary purposes.

[C] 5-2.4 Floating ice in the tank can destroy interior appurtenances, and ice formed on the walls can collapse and cause structural failure or punctures in the tank bottom. In some cases, the return line of a circulating water distribution system is discharged to the storage tank to promote circulation and maintain temperatures. In other cases, a small amount of water is withdrawn, heated with a boiler or heat exchanger, and pumped back into the tank.

5-2.5 Appurtenances.

Locate breather vents on the inside of the tank and vent into an attached pump house or building rather than directly to the outside. Install overflow piping inside the tank or protect it with insulation and heat tracing if placed on the exterior.

[C] 5-2.5 Locating vents as discussed prevents ice from forming in an exposed vent due to condensation, which would cause a vacuum to form in the tank as water is withdrawn and, possibly, the tank to collapse.

5-2.6 Instrumentation.

Instrumentation includes water level indicators, with high- and low-level alarms, and thermal probes at various levels for control and alarm. Air temperature above the water surface is likely to be of interest. Since ice can damage float type water level indicators, a pressure type transducer is recommended. External lighting may improve security and an internal light may assist inspection. Thermal monitoring of permafrost foundation soils may be part of the overall project.

5-2.7 Thermal Considerations.

Whenever practical, tanks must be buried or covered with soil to reduce the effect of low air temperature. Avoid elevated tanks unless they are absolutely necessary for the water distribution system since they expose the greatest surface area to the worst climatic conditions. Insulate all exposed tank surfaces and pipe risers for elevated tanks. Thermal calculations are necessary to size heating systems when they are used to replace heat losses or to heat the water for distribution. The unit capacity of a heat exchanger or boiler must be equal to the maximum rate of heat loss. Water circulation within the tank or boiler heating are common for tanks with intermittent flow and refill.

5-2.8 Tank Foundations.

Foundation considerations for tanks are like those for other Arctic and Subarctic structures and are covered in UFC 3-130-03.

[C] 5-2.8 Foundation design for tanks is complicated by the very high loads imposed by the stored water and the need to keep the water in the unfrozen state. The unfrozen water is a heat source that can have an adverse effect on the underlying permafrost and must be considered during design for a tank on grade.

5-3 EARTH RESERVIORS.

Construct earth embankments for water reservoirs in accordance with UFC 3-130-03. A liner is necessary within the embankment, or to seal the entire reservoir, when permeable soils are present or used for construction. Ice formation, and its effect on the function of the reservoir, must be considered. ASCE *Cold Regions Utilities Monograph,* Section 7.3, provides more detail.

[C] 5-3 Water impoundments for domestic and industrial water supply and for hydropower have been successfully constructed in the Arctic and Subarctic. The most likely configuration for military facilities is an earthen embankment to either increase the storage capacity of an existing lake or stream or to impound water in a natural drainage swale.

CHAPTER 6 WATER DISTRIBUTION

6-1 GENERAL.

See UFC 3-230-01 for the basic criteria for design and construction of water distribution systems. This chapter presents information that is unique to the Arctic or Subarctic. Pressurized pipe distribution systems are used for exterior utilities and interior plumbing in most military facilities in the cold regions. An exception might be small, remote facilities separated from the main distribution network. If individual wells are not feasible, then vehicle delivery of water would be necessary. Truck delivery systems are common at remote civilian communities in Alaska, Canada, and Greenland. The location of pipe distribution systems and whether they should be buried, aboveground, or in a utilidor are discussed in Chapters 2, 8, and 9.

6-2 RECIRCULATION SYSTEMS.

6-2.1 Single Loop.

6-2.1.1 General.

Single pipe recirculation, or loop, systems are recommended for Arctic conditions. As shown in Figure 6-1, a single loop system consists of one uninterrupted loop originating at a recirculation facility and returning to that point without any branch loops. This layout eliminates dead-ends and related freezing problems and requires the minimum amount of piping as compared to other circulation methods. A simple, positive control of distribution is possible with flow and temperature indicators on the return lines at the recirculation facility. Typically, water pressure is regulated at the water recirculation facility. Manual and automatic control valves are frequently used, along with variable speed pumps to maintain pressure. Pipe network design uses the same procedures used for standard water systems. The return line does not have to be of the same size as the delivery pipe because of withdrawals in the network. If possible, locate mains at the rear of buildings or in areas not cleared of snow, rather than in the streets.

6-2.1.2 Water Temperatures.

Normally, water is pumped out at 39 to 45°F (4 to 7°C) and returns at 33 to 39°F (0.5 to 4°C). Where the mainline provides fire protection, NFPA 24 Chapter 7-5.2.2 requires water to be maintained above 40º F (4.4°C) for freeze protection, when exposed to freezing conditions. Otherwise, two scenarios exist:

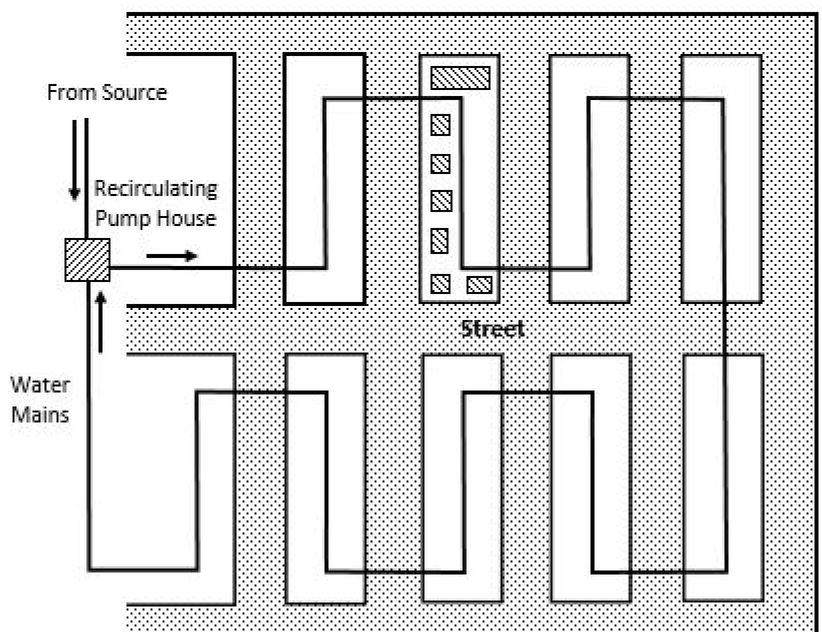
- Seasonally frozen ground with insulation/insulated pipe or pipes buried outside of the active layer—a minimum return temperature of 35°F (2°C) is suggested. Supply temperatures may vary by system parameters, but 5 to 10°F (9 to 18°C) above the minimum return temperate is common.
- Permafrost and above grade—suggest keeping the minimum return temperature at 40°F (4.5°C) if it is a circulating system. Return water may pick up heat on the way back to the recirculation building and can mask

lower temperatures realized in the field. Supply water temperature may be 5 to 15°F (9 to 29°C) above this setting to keep the return temperatures above the minimum.

Supply water temperature may be controlled by the source water (such as a tank or reservoir), which could cause higher temperatures than the recommended limits for part of the year. Water temperatures may need to be kept low to prevent thawing of permafrost soils in order to maintain stable foundation conditions. Return flow, temperature, and pressure monitoring are as essential as monitoring supply and heat addition.

[C] 6-2.1 Single loop mains also prevent water quality impairment because of low disinfectant residual and formation of disinfection byproducts which may occur in dead-ends. The use of circulating mains also allows for compliance sampling to occur at the point of return, generally in the water recirculation facilities, effectively centralizing operations, and daily compliance sampling. Fire water flow can be supplied through both the supply and return lines if required to meet hydrant or sprinkler flow requirements. In many cases, using both the supply and returns for fire flows can reduce the water main size as compared to using only the supply main.

Figure 6-1 Layout and Location of Mains for Single Pipe Recirculation



6-2.2 Branch Loops.

Branch loops use small bore piping take-offs with circulation pumps pumping around a full-bore check valve. This allows for flow monitoring and alarming but adds complexity and requires operational balancing. There are some requirements worth noting since the use of check valves affects fire flow. For example, circulated hangar loops should be pushed, not pulled. Branch loops also require more decentralized monitoring by operators. In Alaska, more complex distributions systems require more operator training/higher certifications to operate (State of Alaska 18 AAC 74.120).

6-3 ALTERNATIVE SYSTEMS.

Several types of alternate systems have been used historically. Three are discussed briefly here. ASCE *Cold Regions Utilities Monograph*, Section 8.6.3, provides more detail on these systems.

6-3.1 Conventional—No Recirculation Systems

For conventional water pipe mains with no recirculation high-volume consumers are placed at the ends of the main lines to ensure continuous flow. Return loops are therefore unnecessary. Sizing of the pipe network and other design details follow conventional practice. In Alaska, more complex distributions systems require more operator training/higher certifications to operate (State of Alaska 18 AAC 74.120).

> [C] 6-3.1 Single pipe no recirculation systems, such as branch systems, are possible but require careful planning in the initial site layout for military Installations.

6-3.2 Dual-pipe Pressure Differential Systems

Dual-pipe systems are complex, and the control mechanisms tend to be elaborate as varying consumption in different locations can result in stationary water in certain areas at certain times. For these reasons, they are no longer commonly installed.

> [C] 6-3.2 Dual-pipe pressure differential systems rely on a large diameter supply line and a small diameter return line with a pressure differential between them. The return line is sized to maintain the desired flow in the system. For typical service connections from a dual system, the service lines tap from the main and return to the smaller diameter return line. The pressure differential between the delivery and the return line must be sufficient to induce circulation in the service loop.

6-3.3 Summer Line Systems

[C] 6-3.3 Some facilities have utilized seasonal transmission mains to convey the water from a summer source to storage tanks. Drain or blow out these lines each fall to reduce potential for freeze damage and properly disinfect them at the beginning of each use season.

6-4 SERVICE LINES.

The design of service lines must prevent freezing of the contained water but must also consider the effects of permafrost thawing, frost heaving and differential settlements between the pipes and the building. The minimum depth of burial, to be below the frost depth, varies depending on the specific location and its temperature conditions. Circulation in these service connections is the recommended method to prevent freezing. Insulation with heat tape is also commonly installed as a backup. The two most common methods for circulation are either a small pump inside the building or the use of pitorifices. Backup freeze protection is usually provided by a thermostatically controlled electrical heat tracer. If copper pipe is used for the service lines, an electrical connection between the two service pipes at the main allows electrical resistance thawing from within the building as a second backup system. See Appendix A, paragraph A-7.1, for references that provide example schematics of service lines and minimum depth of burial for various locations.

6-5 MATERIALS.

Select pipe materials in conformance with UFC 3-230-01; the UFGS, such as UFGS 33 11 00; and the standards listed therein. Standards listed in the UFC and UFGS may provide specific cold weather requirements (for example, ASTM F2620).

Materials must be selected to meet specific site conditions and soil characteristics. Consider freeze tolerance and thermal expansion of pipe material according to pipe location and flow temperatures. The discussion that follows is intended to give some indication of the performance of these materials in the Arctic and Subarctic. Note that though no longer approved for installation, asbestos cement pipes may be encountered in existing systems. ASCE *Cold Regions Utilities Monograph*, Appendix A, provides more information and discussion on piping material options.

6-5.1 Copper.

Copper pipe selected must be rated for utility service, typically Type K. Copper should have only conditional use, consult Installation, District or Command engineering and operations staff. Install copper pipe in continuous runs where joints are minimized or eliminated, unless installed in a controlled space such as utilidor box with access points at each joint or in seasonally frozen ground. Isolation for corrosion potential may be required. Copper may be coated to meet this need.

[C] 6-5.1 Copper pipe is commonly used for service lines because it can be thawed by using electrical resistance, while plastic pipes cannot be thawed in this manner.

6-5.2 Ductile Iron.

Ductile iron pipe can take some shock loadings and is slightly flexible. It is a heavy, durable pipe often used in rocky areas or where adequate pipe bedding materials are not available. Ductile iron pipe is generally available in 18–20 ft (5.5–6.1 m) lengths, which may offer easier shipping and construction logistics than longer steel pipe. It can be thawed with electrical resistance.

Ductile iron has poor corrosion resistance, and lining is necessary. Corrosion protection is required in corrosive soils such as magnesium anodes and pipe bonds. Consider isolation if used above grade. Some ductile iron pipe installations may warrant specialty coatings for corrosion protection.

6-5.3 Steel Pipe.

Steel pipe is less commonly used in Alaska. Expansion and contraction, including necessary thrust anchors, as well as the differential expansion and contraction between a steel pipe and rigid heat tracing components or insulation attached to the pipe, must be considered. Corrosion protection is required in corrosive soils such as magnesium anodes and pipe bonds. Consider isolation if used above grade. Some steel pipe installations may warrant specialty coatings for corrosion protection.

[C] 6-5.3 Steel pipe is lighter, more flexible, and more corrosion resistant than ductile iron. Continuously welded steel pipe has been used to obtain maximum span between piles. It can also be thawed using electrical resistance.

6-5.4 High Density Polyethylene (HDPE).

High Density Polyethylene (HDPE) is recommended for Arctic Installations. Typically, HDPE water pipe is pre-insulated and then covered with a polyethylene, aluminum or steel jacket as discussed in paragraph 6-5.7. Joints must be leak-free and have the same or higher strength than the pipe, and either butt-fusion or electrofusion joints should be considered. Insulate field joints and cover with heat shrink couplings. Consider thermal expansion and contraction when using HDPE pipe owing to its high coefficient of expansion. Heat trace systems are recommended when freeze protection is warranted, see paragraph 6-7.1.

[C] 6-5.4 HDPE pipe is very flexible and impact resistant, with a high coefficient of expansion and contraction, high corrosion resistance, and a smooth interior, but it cannot be threaded. Butt-fused polyethylene pipe has been used extensively in Canada for water and sewer mains. The most common use has been in buried systems, and experience has shown that the pipe and contained water can freeze solid without breaking the line.

6-5.5 Polyvinyl Chloride (PVC).

PVC is not recommended for use where there is a chance of the pipe being exposed to freezing conditions. Heat trace systems are recommended when freeze protection is warranted, see paragraph 6-7.1. Conditional use of PVC pipe for certain applications may be considered such as:

- Burial—seasonal frozen soils only, and pipe must be located below maximum season frost in snow cleared soil plus factor of safety or protected by designed insulation (insulation canopy or factory installed pre-insulated and jacketed pipe).
- Above grade—insulated and heat traced locations only.

Joint types should be solvent weld or bell and spigot. PVC pipe is at higher risk for shipment damage or loss.

[C] 6-5.5 PVC can be threaded, is corrosion resistant and has a smooth interior but is not as flexible as polyethylene. It may become brittle and rupture if pipe and contents freeze.

6-5.6 Concrete.

Concrete pipes may be considered. Reinforced concrete is usually used for large transmission lines. Concrete pipe is at higher risk for shipment damage or loss.

6-5.7 Pre-Insulated Pipe.

Pre-insulated pipe units are composed of an inner-core pipe, insulation, and outer jacket, heat tracing may be provided for freeze protection. The pipe materials described above, with the exception of concrete, are typically insulated with high density urethane foam at the factory and covered with either a steel, HDPE, or aluminum jacket, depending on the final conditions of exposure in the field. The jacketing protects the insulation from moisture and mechanical damage. Prefabricated pipe units are shipped to the job site with preformed half shells of urethane insulation for the joints. Heat shrink sleeves or special tape is used to complete the field joint when HDPE is used as the outer jacket. Pipe insulation, such as spray foam, maybe done on-site, but cost and quality control must be considered. Factory prefabrication usually ensures better quality insulation. Exceptions are appurtenances, such as hydrants, where foamed-in-place urethanes are commonly employed. Design calculations to determine insulation thickness and insulation materials are described in Chapter 12. ASCE *Cold Regions Utilities Monograph*, Section A.6, provides more information and an expanded discussion on pre-insulated pipes.

6-6 APPURTENANCES.

On a typical water distribution system, these include hydrants and valves. ASCE *Cold Regions Utilities Monograph,* Section 8.8, provides additional considerations for design of these structures.

6-6.1 Hydrants.

Hydrants must be dry-barrel type conforming to AWWA C502. Hydrants installed on an aboveground water main must have an insulated hydrant box specially designed and fabricated to fit the equipment to be used at the specific location. Insulate the hydrant barrel and wrap the hydrants in polyethylene sheeting prior to backfill to prevent frost heave damage; hydrants that are insulated and jacketed with a polyurea coating do not need polyethylene sheeting wrap for frost jacking. After use, during the winter months or when ambient air temperatures at the hydrant location drop below freezing at any point during the day, the hydrant must be pumped out since frozen ground conditions may prevent self-draining. Alternate freeze protections such as secondary heat tracing or food grade propylene glycol protection are options if hydrants cannot be reliably drained or pumped out. In-ground or buried hydrants on airfields require special consideration to prevent freezing and maintain service. Consult Installation, District or Command engineering and operations staff. See Appendix A, paragraph A-7.4, for references that provide example schematics of hydrants.

For a buried water main, install hydrants directly on the main to minimize the possibility of freezing, with a frost-isolating gasket between the hydrant barrel and the tee into the main. Isolating valves are typically put in the main or both sides of the tee to allow for hydrant repair or replacement. The vertical riser from the main to the hydrant base should be as short as possible, limited to the tee's branch length plus the height of a flange connected to it, and freeze protected so that heat conducted from the water flowing in the main can keep the hydrant from freezing. If laterals are used, their length must be minimized. Dead-end segments at hydrants run the risk of water quality issues without regular operator flushing programs. Typically, the maximum dead-end leg length is 10 ft (3 m) to prevent freezing for systems that rely on depth of bury rather than a recirculation system. Consider installing heat trace if secondary freeze protection is required. ASCE *Cold Regions Utilities Monograph,* Section 8.8.1, provides additional considerations for design of these structures.

[C] 6-6.1 Water main alignment can be selected to minimize or eliminate dead-end legs to hydrants, by placing the hydrant tee in the flow path of the main, with the hydrant directly above the tee. This will eliminate any horizontal piping but may require additional mainline fittings to accomplish.

6-6.2 Valves.

The riser stem for buried valves is insulated in a manner similar to that described above for hydrants. Nonrising stem-gate valves are most practical for buried or completely insulated locations.

6-7 BACKUP FREEZE PROTECTION AND THAWING.

Backup freeze protection is provided by reserve systems to either prevent freezing if circulation stops in the lines or to thaw the system if freezing occurs. The procedures apply to both main lines and service piping, and wastewater systems. They include heat tracing to prevent freezing, and various methods to thaw systems. ASCE *Cold Regions Utilities Monograph,* Section 8.9 and Appendix D, provide additional information for heat tracing and thawing of frozen systems.

6-7.1 Heat Trace Systems.

A heat trace system is the standard backup used in most piped water distribution systems. Constant monitoring is required on such electrical systems if they are to perform as intended. Easy replacement of heat trace lines should be a standard feature of any system. For under insulation heat trace systems self-regulating heat trace designs are the preferred solution. With these systems, end of line illuminated terminations provides easy verification that the system is functioning and are preferred where a simple monitoring method is required. Some heat trace can generate higher temperatures than HDPE and PVC can withstand; however, pre-insulated HDPE piping is available with the appropriate heat trace pre-installed in channels under the insulation.

[C] 6-7.1 If the controlling thermostats are not working properly or the sensors are in the wrong location, either too much electric energy will be expended at great cost, or the heat trace will fail to do its job when required. If the heat trace is in a channel or tube, it is typically easy to replace by exposing both ends. When it is placed under the insulation and applied directly to the pipe, replacement is very difficult.

6-7.2 Steam or Hot Water Thawing.

Steam or hot water thawing systems can be used with most types of pipe materials but are not recommended for plastic pipes which could melt or be damaged.

[C] 6-7.2 These systems use a source of steam or hot water introduced under pressure into the frozen pipe via a suitable hose or tube to thaw out the pipe. Units specifically designed for this purpose are available commercially.

6-7.3 Service Line Thawing.

[C] 6-7.3 Small-diameter service lines of any material may be thawed by pushing a flexible 0.5 inch (1.27 cm) or smaller plastic tube into the frozen pipe while pumping warm water into the tube. Water 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. Commercial units produce a pulsating stream of water to pump warm water through a tube attached to the frozen pipe by a special fitting to ease installation and reduce spillage.

6-7.4 Electrical Resistance Thawing.

ASCE *Cold Regions Utilities Monograph,* Section D.3 provides additional discussion.

[C] 6-7.4 Historically, the thawing of metal pipes using electricity was fairly common, and equipment specifically designed for this purpose is available commercially. This method is still in use in some rural areas, but not typically on larger military Installations. Caution must be exercised to prevent electrical or fire mishaps.

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CHAPTER 7 WASTEWATER COLLECTION

7-1 GENERAL.

See UFC 3-240-01 for the basic criteria for design of wastewater collection or sanitary sewer systems for military facilities. The unique aspects of design and construction of these systems in cold regions are discussed in this section. In addition, some further detail is included on the use of pressure and vacuum sewers since the flat terrain and permafrost may make it difficult to design a conventional gravity sewer system in the Arctic. Combined utility systems, or utilidors, are covered in Chapter 8. Table 7-1 compares the characteristics of gravity, vacuum, and pressure systems for use in cold regions. Vehicle hauling of water and wastewater is still used at some remote sites, but generally, military facilities are serviced by piped collection systems. Normally, a conventional gravity sewer system has the lowest life cycle cost and should be used whenever practicable. Gravity systems have an additional advantage over pressure systems in that they seldom flow full. As a result, gravity pipes are less likely to break if freezing occurs.

Table 7-1 Characteristics of Wastewater Collection Systems

Type	Soil Conditions	Desirable Topography	Economics	Other
Gravity	Nonfrost-susceptible or slightly frost-susceptible with gravel backfill	Gently sloping to prevent deep cuts or lift stations	Initial construction costs high, but operational costs low unless aboveground or lift stations used	Low maintenance; must have adequate grade; larger diameter pipes required; flushing of low-use lines may be required
Vacuum	Most useful for poor soils or bedrock conditions; can be used with any soil type	Level or gently sloping	Initial construction costs moderately high; operational costs moderately high	Low water use requirement; traps every 300 ft; 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 soils; can be used with any soil type	Level to hilly topography	Initial construction costs moderate; operational costs moderately high	Low water use, if low water use fixtures are installed; number of services not limited; no infiltration; uses small pipes

7-2 DESIGN CONSIDERATIONS.

As described in Chapter 2, the location of the pipe, above or below ground, is critical to satisfactory performance. An aboveground location with the piping installed on piles may be necessary because of soil conditions. However, the grades necessary for gravity flow are difficult to maintain with aboveground sewers. Aboveground sewers also hinder transportation, block surface drainage and snow removal, have high heat losses, and are more susceptible to vandalism.

[C] 7-2 The operation and maintenance costs for aboveground systems are about three times higher than those for similar systems buried underground. Aboveground construction costs for a single pipe depend on the foundations required. If the pipe can be laid directly on the surface, construction costs may be 20 to 40 percent of that required for the same pipe installed on piling.

7-2.1 Sewage Temperatures.

Domestic wastewater from dormitories, dining halls, and family housing on military installations in the cold regions will range from 50 to 60°F (10 to 16°C) at the source. Wastewater from facilities not having hot water heaters can be as low as 35°F (2°C). The temperature of wastewater in utilidors (Chapter 8) can be increased if steam or hot water lines are also included in the utility package. However, if temperatures are too high, hydrogen sulfide may form, requiring hydrogen peroxide injection. The thermal design of the sewer piping (Chapter 12) must include these wastewater temperatures for cost-effectiveness. Do not admit storm water to sewers in cold regions.

[C] 7-2.1 Storm water lowers the temperature of the wastewater and increases the cost of pumping, treatment, and disposal.

7-2.2 Pipe Materials.

Select materials sewer systems in accordance with the criteria given in UFC 3-240-01 and UFGS 33 30 00. Chapter 6, paragraph 6-5 discusses the cold climate aspects of these materials.

7-3 APPURTENANCES.

Appurtenances include manholes, cleanouts, building or service connections, and flushing siphons.

7-3.1 Manholes.

Manholes or access holes require protection from frost heaving because of uplift forces on the sides or under the structures. Polyethylene sheeting around the outside of the manhole can prevent bonding of the soil to the structure and thereby reduce damage from frost heaving. Insulate manholes around the outside, and appropriately treat the insulation to prevent moisture damage. Provide an insulated cover over the wastewater chamber to further reduce heat loss. A firm foundation is essential to prevent settlement and may require either installation of pilings under the manhole or over excavation and backfill with nonfrost susceptible soil (sand and gravel). If a poured-in-place concrete invert is used in the manhole and permafrost is at a relatively shallow depth, place the concrete on insulation board to reduce the downward heat losses. Space of manholes in accordance with UFC 3-240-01. Solid manhole covers are required to prevent entry of surface water. Any electrical device in a manhole must be electrically rated as well as be sealed should a manhole be flooded—this may include thermostatic controls or heat tracing.

[C] 7-3.1 Manholes provide multidirectional access for sewer maintenance, but confined space is required for access. Manhole flow channels may either be traditional open channels or closed piped through the manhole.

7-3.2 Cleanouts.

Cleanouts are typically used in building connections and, in some cases, are installed in place of manholes as described in UFC 3-240-01. Like manholes, they require protection from frost heave uplift forces. Wrapping polyethylene sheeting around the outside of the cleanout riser and the use of non-frost susceptible backfill soils can prevent bonding of the soil to the riser and thereby reduce damage from frost heaving.

[C] 7-3.2 Cleanouts provide above grade access to sewer mains for inspection and obstruction clearing without the need for confined space access and significantly less capital cost to install. Cleanouts are directional for access, one direction, unless a bidirectional cleanout is installed. They are typically provided at large changes in sewer direction and at intervals along a main or service. The same thermal design considerations are needed to prevent transmitting cold into the sewer main, but supplemental heating may not be needed for all installations.

7-3.3 Siphons.

Avoid sewers subject to low flows and velocities, if possible, in the system design since a trickle flow may result in gradual freezing and ice build-up in the pipe. If such sewers are necessary, then a pump station or a flushing siphon must be included. These must be designed to discharge a slug of relatively warm water into the system. If there is insufficient wastewater available to operate the siphon frequently enough to avoid freezing, it may be necessary to add water, with proper precautions taken to prohibit cross connections.

7-3.4 Building Connections.

Building connections for gravity sewer systems in cold regions may be through either the wall or floor of the building. Special attention to prevent freezing of water and wastewater connections and separation or damage because of differential settlement is required, especially for buildings with ventilated spaces beneath the structure. For floor penetrations, avoid bringing the riser up into the building less than 5 ft (1.5 m) from any exterior wall to prevent freezing.

[C] 7-3.4 Wall penetrations are more flexible than the floor penetrations and will permit more differential settlement without damage to the sewer line.

7-4 PUMP STATIONS.

The basic hydraulic design of pumping stations must be in accordance with UFC 3-240-01. Special requirements and concerns for use in cold regions are discussed below. See ASCE *Cold Regions Utilities Monograph,* Section 9.7, for further discussion.

7-4.1 Insulation.

Insulate the outside of the station structure with at least 3 inches (7.6 cm) of urethane or polystyrene, with an outer covering to protect the insulation from moisture. Place insulation beneath the station when permafrost is present at a shallow depth to prevent settling because of ground thaw. Polyethylene sheeting or other bond breakers are required to reduce frost jacking in the active layer. If thawing and settling under the station are anticipated, pile foundations extending well into permafrost may be required. All stations must be attached to concrete base slabs to provide sufficient weight to overcome the buoyancy of the station. Pressure couplings or flexible connections are required for the inlet and outlet pipes to prevent station differential movement from breaking the lines.

7-4.2 Condensation.

A prefabricated, below-grade pumping station must not be installed without immediately placing the heater and dehumidifier into operation. Condensation caused by the surrounding cold earth could corrode the controls and electrical equipment before the system is put into service.

7-4.3 Multiple Units.

Duplicate all critical components, such as pumps and compressors, in pump stations serving base infrastructure where service disruption is unacceptable. Stations must have at least two pumps for redundancy with each pump capable of providing at least 2/3 of required capacity of the pump, lift station, or systems it serves. A single pump may be used for a wastewater pumping station serving extremely low flows, such as a remote gate house, when justification is provided to and approved by the Installation engineering staff.

Where possible, maintain replacement equipment on the shelf for backup. If not possible, service kits need to be stored on-site to repair equipment. Electrical components such as motor starters are often overlooked and should be included in backups.

7-4.4 Alarms.

Provide alarms in accordance with the requirements of UFC 3-240-01. In addition, set alarms to warn of freezing temperatures in the station and to warn of sump pump malfunctions. Alarms must be annunciated as required in UFC 3-240-01. Consult Installation, District or Command engineering and operations staff for specific requirements.

Alarms should include, but are not limited to, the following:

- high or critical high level
- low or critical low level
- low wastewater temperature
- pump trouble
- water in motor (if pump is equipped with sensor)
- heating system or HVAC trouble
- atmosphere detection or gas detector alarm

7-4.5 Standby Power.

Because of the dangers of freezing associated with extremely low temperatures, provide standby power facilities for each major pump station. Where multiple pump installations are required, as discussed in paragraph 7-4.3, it is implicit that the site is more critical in nature and requires backup power or contingency for portable backup power connection. Otherwise, consult the Installation engineering staff to evaluate the need for standby power for smaller pump stations depending on the nature of the collection area.

7-4.6 Maintenance.

Extend all entrance manholes sufficiently above the ground surface to be above any flooding or snow drifts. Supply all pump stations with devices for measuring flow rates. Corrosion protection must be provided in accordance with UFC 3-240-01. Sacrificial anode type systems do not work well when the ground surrounding the anode or pump station is frozen.

7-4.7 Force Mains.

Force mains are pressure lines into which the sewage pumps discharge. They must comply with all temperate region standards required in UFC 3-240-01. Design force mains to have scour velocities during pumping (2.5 to 3.5 ft per second [0.76 to 1.1 m per second]) and to drain between pumping cycles. This can be accomplished by an electrically operated ball valve in the line to allow drainage back into the wet well between pump cycles. If this is not possible, the line must be placed in a heated utilidor, or heat traced. Another option would be to time the pumping cycle so that wastes stay in the line for a calculated period, and to size the wet well at the pump station to hold at least the volume of the force main.

[C] 7-4.7 Consideration may be given to increasing the flowrate or reducing pipe size. Doubling velocity through the pipe approximates the same flowrate through the pipe with a single pipe diameter reduction. This would not change the heat flux to the pipe appreciably, but it halves the contact time a slug of wastewater is in contact with the pipeline for the perceived purpose of freeze protection. The designer needs to determine which is more important: transferring heat to the force main pipe system to maintain a thawed condition or minimizing the resident time of wastewater in the main.

7-5 PRESSURE SEWERS.

The hydraulic design of pressure sewer systems is not unique to the cold regions, use criteria found in UFC 3-240-01. Design the pressure piping to drain by gravity to a low point or sump in case the system must be shut down in the winter. The grinder pump units, holding tanks, and septic tanks must have a firm foundation and must be protected from frost heaving as discussed previously for manholes (paragraph 7-3.1). Water conservation measures in each of the buildings served are required to reduce the costs of equipment and energy for pumping.

[C] 7-5 The main advantage of pressure sewers is that specific grades need not be maintained throughout the system. Typically, grinder pump units are used so that smaller diameter pipes can be installed without the risk of clogging. Grinder pumps may be installed in each building or in a holding tank serving several buildings. An alternative to grinder pumps is to install a two-compartment septic tank with a conventional submersible pump in the second compartment.

7-6 VACUUM SEWERS.

Vacuum sewers do not depend on a specific grade for successful operation. They operate at a vacuum of 8–10 psi (55–69 kPa), and so are limited to an elevation difference of 15 to 20 ft (4.6 to 6.1 m) within the system. The hydraulic design is not unique to the cold regions. The concept depends on providing traps in the system to maintain a vacuum. Since these traps are full of water for extended periods, they must be insulated, heated, or both, for extreme low temperature conditions. The traps should also be drainable under emergency situations.

CHAPTER 8 WASTEWATER TREATMENT

8-1 GENERAL.

See UFC 3-240-01 for basic design criteria for domestic wastewater treatment systems. UFC 3-240-01, paragraph A-6.6, also includes special considerations for cold and Arctic locations outside the U.S. This chapter provides additional information and requirements on those aspects unique to cold regions and presents general design criteria for treatment systems most commonly used in the Arctic and Subarctic. More detailed information is provided by ASCE *Cold Regions Utilities Monograph*, Section 10. *Prevention of Freezing and Other Cold Weather Problems at Wastewater Treatment Faculties* provides design information and case studies on the prevention of freezing and other issues for cold regions wastewater treatment facilities.

8-2 WASTEWATER CHARACTERISTICS.

Wastewater characteristics in the cold regions are generally different from those in temperate regions with respect to quantity, quality, and temperature. The total quantity of wastewater discharged at military Installations in cold regions tends to be very close to the quantity supplied for potable water use since there is little external or industrial use, storm water is usually excluded, and groundwater infiltration is not a factor in the newer insulated and tightly sealed pipe systems. As a result, wastewater in the Arctic and Subarctic tends to be more domestic in nature and higher in strength than at comparable facilities elsewhere.

8-2.1 Quantity.

Determine design flows by a specific analysis of the Installation. The population equivalents and capacity factors presented in UFC 3-240-01 tend to overestimate the volume of flow to be expected at remote Installations in the Arctic and Subarctic with small populations. This may result in operational problems with some biological treatment units. Selection of less sensitive processes or use of two smaller units in parallel avoids the problem if the design cannot be determined by actual flows.

8-2.2 Quality.

The mass of pollutants in cold region wastewaters is comparable to that in other locations, but the concentration will generally be higher because of lower water usage rates.

8-2.3 Temperature.

The wastewater temperature at many cold region facilities tends to be at least 50°F (10°C) owing to transmission in insulated and sometimes heated lines. Consider the heat available in this incoming wastewater during process design.

8-2.4 Flow Variations.

The diurnal flow pattern at military Installations tends to be the same regardless of climate.

8-3 UNIT OPERATIONS.

Practically all the basic unit operations used in wastewater treatment are affected by temperature through liquid viscosity changes or changes in chemical reaction rates. An analysis during the early stages of design is required to predict the thermal status of major components in the treatment system. If wastewater temperatures above 50°F (10°C) are expected and the entire system is to be housed in a heated building, then conventional practice as defined in the UFC 3-240-1 must be used. If temperatures below 50°F (10°C) are expected or significant temperature changes are allowed to occur within the system, then adjustments are necessary for the design of the unit operations. ASCE *Cold Regions Utilities Monograph,* Section 10.4.2, provides additional information on design adjustments required for mixing, sedimentation, filtration, gas transfer, and adsorption and chemical reaction operations for wastewater treatment facilities in the Arctic and Subarctic.

8-4 UNIT PROCESSES.

Unit processes include preliminary treatment, primary treatment, and a variety of biological or chemical processes for secondary treatment. All are subject to temperature influences on their performance. ASCE *Cold Regions Utilities Monograph,* Section 10.4.3, provides additional information.

8-4.1 Preliminary Treatment.

Preliminary treatment commonly includes screening, grit and scum removal and grinding, or comminution. Conventional equipment can be used, and basic design criteria must be in accordance with UFC 3-240-1 with appropriate adjustments in grit chamber detention time for the projected operating temperatures. Construct protective, insulated shelters over trash racks, bar screens, and grit chambers to avoid icing problems in the winter. Where structures are unheated, condensation and icing may occur on the inner surfaces of exterior walls. In these instances, select materials and coatings accordingly, and locate controls on dry interior walls or in another remote location.

8-4.2 Primary Treatment.

Adjust the design detention time of primary clarifiers for the projected operating temperatures. In general, design tanks in the conventional manner as buried or partially buried structures. However, the presence of shallow permafrost, particularly ice-rich, fine textured soils, requires aboveground tanks or special foundations (see UFC 3-130-03). Temporary covers for heat retention purposes are recommended for winter operation of buried or exposed tanks in the Arctic and Subarctic. Tanks above grade also require sidewall insulation or enclosure in a protective structure.

Mechanical measures for primary treatment are also commercially available, such as microscreens and rotating belt filters. These technologies have been used in indoor wastewater treatment applications for years and can achieve primary treatment in about 1/10th the footprint of a conventional gravity settling basin. These systems require a heated, insulated building.

8-4.3 Secondary Treatment

In cold regions where mechanical treatment is used, the biological treatment systems deployed are often similar to warm weather processes, with additional insulation or housed entirely inside of a heated building. Packaged treatment systems are commercially available and must be housed in appropriately insulated and climate-controlled buildings. Certification may be required for the operators of these systems.

Biological systems for secondary treatment that have been successfully used in cold climates include lagoons or ponds, both facultative and aerated, several activated sludge variations and attached growth systems. Each has special requirements for successful cold regions performance.

> [C] 8-4.3 In general, biological alternatives using outdoor lagoons require a large footprint, but will have minimal operations and maintenance needs and offer moderately good effluent quality. Biological treatment using indoor systems require a much smaller footprint; will have higher operations, maintenance, and electrical power needs, with the associated costs; and provide superior effluent quality.

8-4.3.1 Lagoons.

8-4.3.1.1 Facultative.

The treatment performance of facultative lagoons during winter is greatly reduced by low temperatures and by ice and snow cover, with removal rates roughly comparable to those of primary treatment alone. Total retention of wastewater during winter months may be required with controlled discharge commencing in late spring and in early fall. Standard construction techniques can be used except where permafrost is present. Fine textured, ice-rich permafrost must be avoided if possible since thawing can result in failure or at least require frequent repair of dikes and berms. Lagoons may be installed in permafrost that is physically stable after thawing. Additional design and construction information is provided in ASCE *Cold Regions Utilities Monograph*, Section 10.4.3.

> [C] 8-4.3.1.1 Where sufficient land area and suitable soil conditions exist, facultative lagoons are the most economical alternative in the cold regions because of their low construction cost and simplicity of operation.

8-4.3.1.2 Aerated.

Partially mixed aerated lagoons, also called facultative-aerated ponds, have been used successfully in cold regions. Basic process design criteria are similar to those of temperate regions. Additional design and construction information is provided in ASCE *Cold Regions Utilities Monograph*, Section 10.4.3.

> [C] 8-4.3.1.2 Aerated lagoons require less land area but more energy and more operational attention than facultative lagoons.

8-4.3.2 Treatment Plants.

8-4.3.2.1 Activated Sludge Systems.

Activated sludge systems that have been successfully used in cold regions include conventional and pure-oxygen activated sludge, contact stabilization, and extended aeration concepts in both package plants and oxidation ditches. Basic design criteria for these processes must be in accordance with UFC 3-240-1. When the system is enclosed and incoming wastewater temperatures exceed 50°F (10°C), basic design criteria apply. Special measures are necessary only when incoming wastewaters are below 50°F (10°C) or if a significant temperature drop is expected within the system. All the biological reaction rates involved are temperature sensitive and must be adjusted using Equation 8-1.

Equation 8-1. Biological Reaction Rate Coefficient

$$\boldsymbol{k_T = k_{20}\theta^{(T-20)}}$$

Where:
k_T = reaction rate coefficient at the temperature T
k_{20} = reaction rate at 20°C (68°F)
θ = temperature coefficient
T = temperature in °C

Use the θ values given in Table 8-1 in Equation 8-1 to adjust the reaction rate for the design wastewater temperature. Additional design and construction information is provided in ASCE *Cold Regions Utilities Monograph,* Section 10.4.3.

8-4.3.2.2 Attached Growth Systems.

These include trickling filters, rotating biological discs, and other devices with plastic, rock, or wooden media. Effective treatment depends on maintaining a thin film of liquid over the media. These units are susceptible to freezing and must therefore be enclosed in a protective structure. Use criteria from UFC 3-240-01 for design, along with the temperature coefficients given in Table 8-1. The need for additional heat in the protective structure depends on the temperature of incoming wastewater and on the degree of treatment required. Additional design and construction information is provided in ASCE *Cold Regions Utilities Monograph,* Section 10.4.3.

Table 8-1 Temperature Coefficients for Biological Treatment

Process	θ	Temperature Range (°F)
Oxidation pond	1.072–1.085	37–95
Facultative lagoon	1.06–1.18	39–86
Anaerobic lagoon	1.08–1.10	41–86
Aerated lagoon	1.026–1.058	36–86
Activated sludge	1.00–1.041	39–113
Extended aeration	1.037	50–86
Trickling filter (conventional)	1.035	50–95
Biofilter (plastic media)	1.018	–
Rotating disc		
Direct filter recirculation	1.009	50–86
Final effluent recirculation	1.009	55+
Final effluent recirculation	1.032	40–55

8-5 SLUDGE MANAGEMENT.

Large-scale, conventional treatment facilities and those operating in a heated environment can be expected to produce sludge at rates similar to those of conventional temperate zone practice. Thickening, digestion, and dewatering of sludge all follow temperate zone practice in accordance with UFC 3-240-01.

8-5.1 Freeze-thaw Dewatering.

Sludge from water or wastewater treatment operations can be flooded onto conventional open sand drying beds in layers and allowed to freeze. It is important to avoid rewetting the sludge once it has been freeze-thawed by providing a roof overhead or physically moving the solids around after they have been frozen.

8-5.1.1 Depth of Sludge.

Calculate the depth of sludge that can be frozen (or thawed) with Equation 8-2.

Equation 8-2. Application Depth of Frozen Sludge

$$X = m_s(I_A)^{1/2}$$

Where:
X = depth of sludge that can be frozen (inches)
m_s = proportionality coefficient for sludge, use 0.6 for sludge concentrations in range of 0–7% solids (higher concentrations are difficult to spread on bed) (°F-days)$^{-1/2}$
I_A = Air freezing (or thawing) index (°F-days)—use warmest winter of record for freezing calculations

Sludge with an undrainable jelly-like consistency will dewater immediately upon thawing and then have a granular consistency. Solids concentrations of 20–25 percent immediately after thawing are typical and after a few more weeks of drying will approach 50 percent.

8-5.1.2 Repeated Applications.

The total depth of sludge that can be frozen is also related to the depth of frost penetration that will occur in a particular location. Repeated applications in thin layers are recommended to ensure that each layer freezes completely. Use Equation 8-3 to estimate the potential total depth of sludge that could be frozen (applied in 3-inch [7.6-cm] layers) if the maximum depth of frost penetration for a site is known.

Equation 8-3. Potential Total Depth of Frozen Sludge

$$\Sigma X = 1.76(f_p) - 40$$

Where:
ΣX = total depth of sludge that could be frozen in 3-inch (7.6-cm) layers (inches)
f_P = maximum depth of frost penetration for area (inches)

> [C] 8-5.1 At most facilities it is not be cost effective to depend entirely on freezing since this would require sludge storage during the warmer months. The optimum design to avoid storage determines the amount of material that can be frozen and then thawed by early summer so that the beds can be used in the conventional drying mode for the balance of the warm season.

8-5.2 Sludge Disposal.

Landfills or land application of sludge are the most appropriate techniques for disposal in cold regions. Temporary sludge storage will be necessary where winter conditions or frozen ground prevents surface application or landfill operations. Disposal must be in accordance with local environmental regulations.

8-6 OUTFALLS.

Outfall structures require special consideration to prevent freezing of the effluent and to prevent structural damage from ice in the receiving waters. In some cases, these problems can be avoided by designing for seasonal discharge. However, an unused outfall is still exposed to damage by ice in the winter and during spring thaw. Insulate and heat-trace exposed outfall piping. The thermal design must be in accordance with Chapter 12. A submerged outfall is recommended wherever possible. However, in shallow streams the pipe must be protected from ice scour that can occur during spring break-up. If possible, install the pipe underground with the outlet completely submerged in water and below the maximum penetration depth of winter ice. If these conditions cannot be satisfied an elevated outfall is required. Design the support piling in accordance with UFC 3-130-03 to resist the uplift forces generated by a floating ice sheet. This is particularly critical at coastal locations with significant tidal action. It is usually not practical to design simple pile supports to resist the lateral forces from ice movements during spring break up. Use break-away couplings to prevent complete destruction of the outfall structure. Design elevated outfalls, in general, to discharge on top of the ice since an open water surface cannot always be maintained. Most of the effluent will then freeze and form a large mound of ice as the winter progresses.

8-7 ALTERNATIVES TO TREATMENT AND DISPOSAL.

At many remote Installations that have small populations or with intermittent usage, it may not be cost effective or technically feasible to construct one of the treatment or disposal options discussed above. Consider small-scale on-site systems that may be feasible for these situations. Conventional septic tanks and soil absorption systems have been used throughout Alaska with mixed results. Sludge accumulates at high rates in septic tanks in low temperature soils. Annual sludge removal is required to avoid clogging problems in the adsorption field. Design procedures are similar to conventional practice for these systems. Insulation of the septic tank is desirable and recommended for intermittently operated systems. Where feasible, deep seepage pits are preferred over conventional absorption fields because of their greater thermal efficiency. In locations where in-ground disposal is not practical or feasible, vault storage and truck haul may be required.

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CHAPTER 9 UTILIDORS

9-1 GENERAL

A utilidor is a structure that contains multiple utility systems such as water, sanitary sewer, fuel oil, gas, electrical power, communications, and central heating in various combinations or, in some cases, all together. The term is often applied to aboveground insulated water and wastewater piping as well. They are commonly used at military Installations and civilian communities in the North American Arctic. Utilidors may be constructed above- or belowground, or at ground level, and range in size from a simple insulated conduit to a walk-through passageway. Their size and shape are determined by considering the number and sizes of the pipes they will contain, their location relative to the ground surface, and the ease of access desired for maintenance or repairs. A 1981 survey of Fort Wainwright, Alaska reported approximately 200 configurations of utilidors with sizes ranging from 1 ft by 1 ft to 7 ft by 9 ft (30 cm by 30 cm to 2 m by 3 m), and pipe sizes varying from 1 inch to 24 inch (2.54 cm to 61 cm) in diameter.[1] The ASCE *Cold Regions Utilities Monograph,* Section 11, provides additional discussion of utilidors and their design considerations.

9-2 DESIGN CONSIDERATIONS.

Use Chapter 12 procedures for the thermal design of utilidors. Design foundations in accordance with UFC 3-130-3. Both designs should consider the types of utilities to be included. The inclusion of power, telephone, and gas lines, along with water and sewer pipes in a utilidor is common, but the overall utilidor design must account for the interactions between these components. Locate the heat sources for freeze protection near the bottom of large utilidors, if possible, to ensure distribution of heat.

The installation of pipe identification markers or stenciling is recommended within manholes. Flanged elbows or pipes must be large enough to insert cleaning or thawing equipment. Standard fittings or smaller pipes do not provide adequate access in both directions. Figure 9-1 illustrates cross sections of two typical utilidors. Utilidors may be prefabricated. When transport methods permit, prefabrication of the major utilidor components is recommended to reduce construction costs in the field.

> [C] 9.2 The inclusion of central heating lines in utilidors is often beneficial. Their heat losses are usually great enough to protect the water and sewage pipes from freezing, but the utilidor is most often larger to provide continuous easy access to steam and condensate lines, and therefore, construction costs will increase. Problems also occur because this heat source operates all or most of the year. In the summer, undesirably high domestic water supply temperatures may result because of exposure to the excess heat (>80°F [>27°C]). Thermal stratification can cause freezing of the lower pipes in large utilidors even when the average air temperature is above freezing.

[1] *Losses from the Fort Wainwright Heat Distribution System*, Phetteplace et al.

9-2.1 Materials.

It is critically important to calculate thermal expansion and contraction of the various types of piping material within the utilidor. Unlike buried pipes, pipes located in a utilidor can experience a large temperature range throughout the year, especially if steam or condensate piping are not operational year-round. Expansion joints or flexible couplings may be required to prevent a rupture, major leak, or pipe anchor failure.

9-2.2 Insulation.

Separate insulation of domestic water lines is recommended to maintain acceptable cold-water temperatures for domestic use, and to prevent condensation and pipe corrosion. Do not install insulation on the hydrant lateral piping between the water main connection and the riser penetration through the utilidor roof.

9-2.3 Water and Sewer Line Proximity.

For Installations in the state of Alaska, placement of water and sewer lines (including sump drain lines) within a single utilidor requires a waiver from the State of Alaska, Department of Environmental Conservation (ADEC) under *Standard 18 AAC 80, Drinking Water.* This is a part of the standard permitting process in the state of Alaska (Section 2-3.2). When both water and sewage lines are exposed in the same utilidor, the sewer access cleanouts must be sealed to prevent cross contamination.

9-3 MOLD.

Utilidors are kept warm for water and sewer utility piping. They are normally dry unless a leak or infiltration has occurred. Consider low point drains or positive ventilation in walk-through passages. For box or pipe utilidors use closed cell insulation with a moisture barrier to keep moisture out of the foam. Polyureas or plastic resist mold formation if they are clean and free of dirt or other materials.

> [C] 9.3 Mold growth is inhibited by keeping utilidors clean and disinfected.

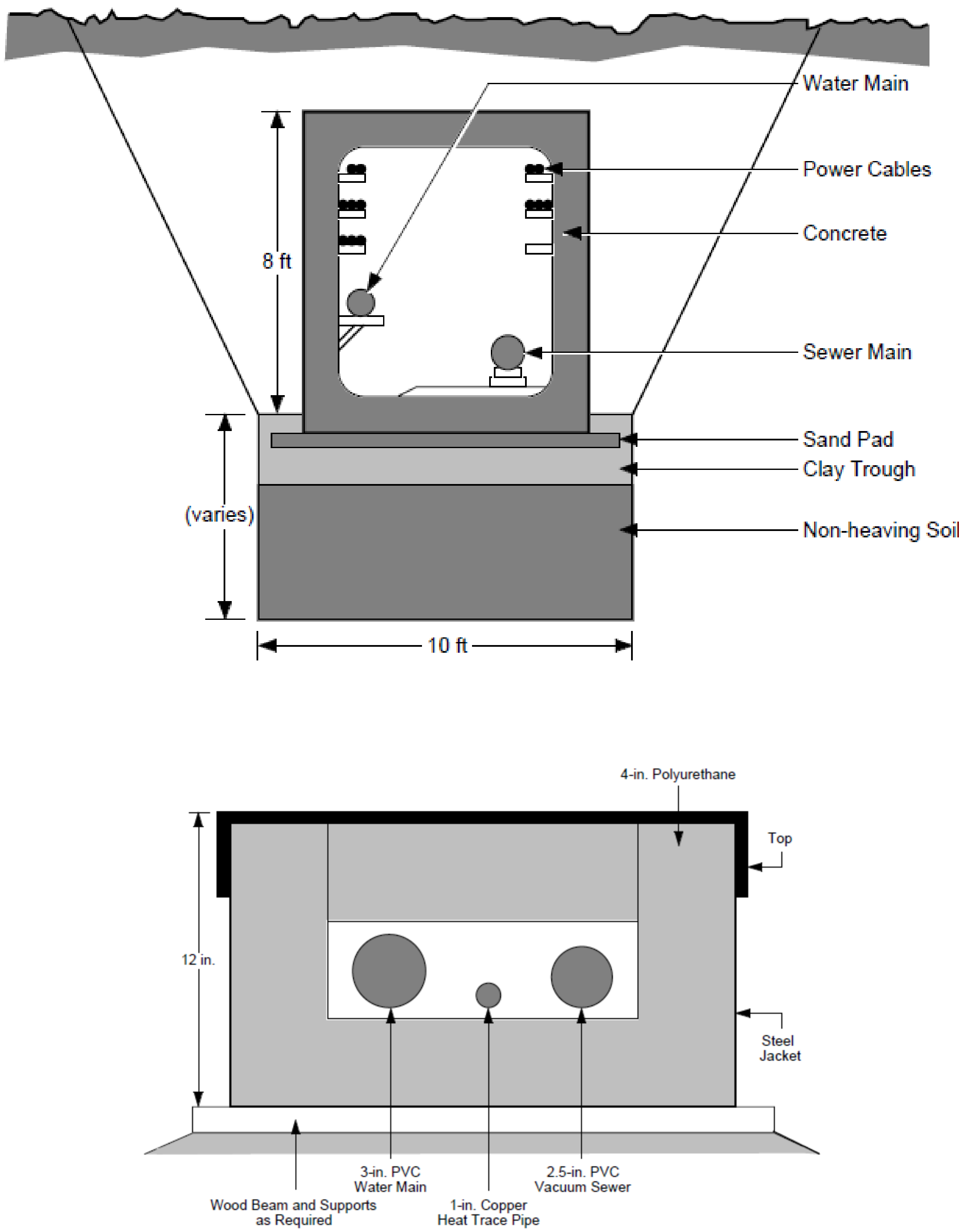
9-4 MAINTENANCE CONSIDERATIONS.

Maintenance and inspection should be determined by construction materials and the following:

- Above grade or at grade—If operators perform daily service rounds, the system should be observed during those activities. General conditions should be inspected and documented monthly. Program maintenance based on surface finish conditions and corrosion observations. Base mechanical equipment maintenance on manufacturer’s recommendations.
- Buried—If the utilidor is a walk-through passage, operators should review conditions during daily rounds and perform monthly inspections. Pipe or

box systems are difficult to access. Buried utilities should be inspected and cleaned during any maintenance activity.

Figure 9-1 Example Cross Sections of Utilidors Constructed in the Arctic[2]



[2] *Two-Dimensional Analysis of Natural Convection and Radiation in Utilidors,* Richmond.

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CHAPTER 10 FIRE PROTECTION

10-1 GENERAL.

Use UFC 3-600-01 for fire protection requirements. The ASCE *Cold Regions Utilities Monograph*, Section 15, provides additional information.

10-2 HYDRANTS.

Cold regions hydrant features were discussed in paragraph 6-6.1. Hydrants must be accessible and operable at all times regardless of frost depth, snow cover, and temperature.

10-3 TRUCK SYSTEMS.

Where winter operation in the Arctic requires tank trucks on standby, provide heated garages and a freeze-protected water point with a pumping capability of at least 350 to 500 gallons per minute (1,325 to 1,900 liters per minute) for refilling the tank trucks if hydrants are not available.

[C] 10-3 Historically, motorized fire pumping apparatus with booster tanks and hoses provided protection for remote buildings not serviced by the water distribution system or sprinklers within the facility.

10-4 FIRE PROTECTION SYSTEMS.

Fire protection systems are covered in Chapter 9 of UFC 3-600-01. The use of post-indicating valves on the main lines coming into buildings is not recommended as they act as a thermal bridge to the water lines. Street valves are permitted. Locate the primary shutoff valve inside the building in a room accessible from the exterior per National Fire Protection Association (NFPA) 24. A minimum 1-hour fire rating is required unless otherwise approved by the Installation, District or Command engineering and operations staff.

[C] 10-4 If recirculation and heating systems are used, this may not be an issue.

Foaming equipment will not function at optimum levels in air temperatures below –15°F (–26°C) since aspiration of the foam is not complete. Standard carbon dioxide fire extinguishers will also not function properly at below-freezing temperatures. Dry chemical extinguishers have been used successfully and range in size from hand-held units to large dolly-mounted units containing about 350 pounds (160 kilograms) of chemical. Per paragraph 9-16 of UFC 3-600-01, installation of a new Halon 1301 systems is prohibited except by special approval of Service Signature Authority.

10-5 ALARM SYSTEMS.

Design central alarm systems in accordance with UFC 3-600-01. For Installations with direct digital control (DDC), see UFC 3-410-02. Monitoring and alarm systems must be compatible with the Installation reporting system. Transmit all signals to the fire department and other central alarm centers where appropriate action can be initiated.

[C] 10-5 In many cases, it is advantageous to integrate the systems with other utility system sensors for protection of the water distribution network and sewage transmission lines (see Chapter 6 and Chapter 7).

CHAPTER 11 POWER DISTRIBUTION AND COMMUNICATION SYSTEMS

11-1 GENERAL CONSIDERATIONS.

With a few exceptions, the basic design requirements for wire and cable networks for power transmission and communication systems are not unique to the cold regions. Use UFC 3-501-01, UFC 3-550-01, and the regulatory and industry standards adopted therein, for design of these systems. Power distribution and communication systems must also comply with any specific requirements of the Installation or, for privatized systems, the utility contractor. Special attention is needed to ensure proper grounding in permafrost areas, to maintain stability of towers, poles, guy wires and anchors, and for direct burial of cables.

11-2 GROUNDING.

Soils in both seasonal frost and permafrost areas may not provide acceptable grounding conditions owing to the high electrical resistivity of frozen ground—up to several orders of magnitude higher than that of unfrozen soil. This may require finding areas where soils are less likely to freeze or where the seasonal frost zone or permafrost layer is thinnest and installing ground rods or piles in the warmer soils. *Electrical Grounding in Cold Regions*, by Henry, discusses this further. In some permafrost locations all the facilities are tied together, including electrical wiring; petroleum, oil, and lubricant (POL) piping metal building; POL storage tanks; water and sewer lines; and so on, to form one large grid network. This network is then connected to a water well casing that penetrates the permafrost layer and results in an acceptable ground. If no well casing exists, the grid system is connected to a ground rod that does not penetrate the permafrost. This provides a common floating ground with everything at the same electrical potential. This is an acceptable approach as long as everything is bonded to that common ground. Another possibility is to place a grounding cable grid into a nearby lake or other body of water that does not freeze. The ASCE *Cold Regions Utilities Monograph*, Section 17.5.3, provides additional information on the grounding. All grounding measures must comply with UFC 3-550-01.

11-3 UNDERGROUND SYSTEMS.

Power and communication networks have been successfully installed in the utilidor systems described in Chapter 8. However, some Installations do not install electrical distribution systems within utilidors. Directly burying cables in frost-susceptible soils within the active layer must be carefully considered. Place buried conduits or ducts in nonfrost susceptible backfill materials. Otherwise, place a gravel or other nonfrost-susceptible material pad on the existing ground surface and bury the cables in this new pad if a buried system is required. The gravel pad may also serve as a road or walkway.

Buried cables, or conduit, connected to a wall mounted cabinet may rip the cabinet off the wall because of conduit jacking. Similarly, direct buried cables terminating in a post mounted termination cabinet can be pulled out of their terminations as a result of the post and cabinet being subjected to long term jacking. If jacking conditions are present, provide sufficient cable or flexible conduit slack to permit cable movement and prevent cabinet damage.

[C] 11-3 The freezing and expansion of soils in the active layer may result in structural failure of cables or severe mechanical damage. Oil industry facilities near the Arctic Ocean use direct burial single phase armored cables instead of conductors in conduit for below grade construction.

11-4 AERIAL SYSTEMS.

Ice buildup is a problem for aerial cables, particularly in coastal locations. Preventative measures have included the use of a steel conductor to increase tensile strength and to allow resistance thawing. The major engineering problem with aerial systems in the cold regions is the stability of the supporting towers or poles. The practical effect of frost heave on towers and poles is an upward force to the unit that may result in overstress and mechanical failure or in differential vertical movement between components. It is necessary to design towers and poles to resist these upward forces, or to allow the units to float up and down with the expansion and contraction caused by heaving of the active layer, or to replace the frost-susceptible soils with clean gravel. In many cases, the utility pole will move up due to the heaving forces but cannot return to its original position because of the flow of soil into the void. The net effect is an annual increment of upward movement that will eventually jack the pole out of the ground.

[C] 11-4 The upper soil layer, known as the active zone, goes through a freezing and thawing cycle on an annual basis. In the spring, this zone may go through several freezing cycles because of warm days and cold nights. This freezing causes significant soil expansion, or frost heave, depending on the soil type and moisture content. The expansion is very significant with fine-textured silty soils when a source of unfrozen water is available. Further details on frost heave can be found in UFC 3-130-3.

11-4.1 Poles.

As mentioned in paragraph 11-4, a very strong bond can develop between the frozen soil and the surface of an imbedded power pole. This bond, if developed in the active layer with frost-susceptible soils, will lift the pole out of the ground. This phenomenon is called frost jacking. Wooden poles are commonly used for both power and communications systems. Two measures are commonly taken for permanent construction where permafrost is relatively close (3–5 ft [0.9–1.5 m]) to the surface;

- The pole is sufficiently embedded in permafrost so that the bond developed in that zone can resist the uplift forces due to heaving in the active layer.

- The active zone portion of the hole is backfilled with nonfrost-susceptible materials, or this portion of the pole is wrapped with a 10-mil polyethylene sleeve to prevent development of a bond.

Set poles to a minimum depth of 10 percent of the aboveground height plus another 4 ft (1.2 m) into the permafrost (ASCE *Cold Regions Utilities Monograph,* Section 17.5.3). For example, a 50 ft (15 m) aboveground height would require 9 ft (2.7 m) of embedment. However, this depth may need to be increased to fully prevent frost jacking. Holes for these poles or support piles are made with a drill or soil auger and are made slightly larger (3–4 inch [8–10 cm]) than the diameter of the pole. A slurry of native soil or sand with water is then placed around the pole to the top of the permafrost. This construction is often done in the winter when the active layer is also frozen to allow easier access with minimal environmental disturbance. Rock-filled cribs are used where permafrost is very deep, the rock is very shallow, or for temporary facilities or facilities in support of military operations with a design life of five years or less.

11-4.2 Towers.

Typical designs for tower foundations are gravel pads with footings constructed on frost-susceptible soils or gravel backfill with footings in frost-susceptible soil. Foundations are discussed in UFC 3-130-3.

[C] 11-4.2 Above-surface gravel pads provide some surcharge for resistance to heaving forces, but some vertical movement is likely. At the end of the thaw period, the pad will settle to its original position. The anchors for guyed towers provide the major resistance to uplift and provide lateral stability. If the footings for towers are placed in the frost-susceptible material, they will be moved upward during the heaving phase, but as described in paragraph 11-4.1, the footing will not then settle back to its original position when seasonal thawing is complete. A progressive failure will result because the footing will be moved upward another increment each year until the resistance to overturning is insufficient.

11-4.3 Anchors.

Design anchors for tower guy wires in accordance with UFC 3-130-3. Both grouted and ungrouted anchor types used in temperate climates may also work in areas of seasonal frost or permafrost. However, the embedment depth must be such that the anchor can withstand frost jacking forces within the active layer as well as the design guy line loading. Manufacturers' ratings for design capacities of commercially available earth anchors may be reduced by 75% if placed in thawed soil above the permafrost layer.[1] Install anchors into the permafrost when it exists and is shallow. The active layer

[1] *Design and Construction of Foundations in Areas of Deep Seasonal Frost and Permafrost*, Linell and Lobacz.

dynamics will cause loose guy lines unless anchors are firmly installed into the permafrost and below long-term warming thaw depth.

An additional major concern is progressive movement, or creep, of anchors embedded in ice-rich permafrost with temperatures just below the freezing point. Make provisions for adjusting the tension of guy lines in both summer and winter, since the pole, tower, or structure being guyed and anchored may experience heave or settlement quite different from that of the anchors.[2]

11-5 SPECIAL CONSIDERATIONS.

The following other special considerations relate to construction of electrical distribution systems in the cold regions because of responses to low temperatures or other environmental factors:

- Nylon-jacketed conductors (type THWN), when used at low ambient temperatures, tend to experience separation of the insulation from the jacket.
- Molded case circuit breakers and stored potential switches are not always dependable at extremely low temperatures. Consider the alternative use of fuses, if approved by Installation engineering personnel, or supplemental heat provided to raise the ambient temperature of the equipment enclosure.
- Low temperature, special alloy steel is frequently used for transformers, circuit breakers and other exterior electrical distribution apparatus.
- At some Installations, such as Thule Air Force Base (AFB), electric and communication conductors are installed on the ground surface supported by sleepers, as shown in Figure 2-1. Timber sleepers are typically 4 inch by 4 inch by 24 inch (10 cm by 10 cm by 61 cm), and generally spaced 10 to 15 ft (3 to 4.6 m) apart. Conductors are clamped to the sleepers. All the conductors are insulated and armored to protect personnel. This method avoids issues with icing and wind damage and keeps costs low. This type of installation is not recommended on facilities with accompanied personnel, because of potential hazard to children.

[2] Ibid.

CHAPTER 12 THERMAL CONSIDERATIONS

12-1 GENERAL CONSIDERATIONS.

The thermal aspects of utility system designs are among the most critical elements for cold regions systems. The potential problems are failure of pipes due to freezing of water, thaw settlement or heaving of foundation soils, thermal strains and the associated stresses, the cost-effective selection of materials and insulation thicknesses, and economical operation of the system. This chapter presents criteria for the most critical thermal calculations that might be required for design of pipes, utility structures, and appurtenances. Example problems of the use of the thermal consideration equations are given in Appendix C.

EPA-600/8-79-027, Section 15.10; ASCE *Cold Regions Utilities Monograph*, Section 4.7; and Chapter 6, "Heat Transfer Calculations for Piping Systems," of the ASHRAE *District Heating Guide* provide additional discussion and example problems.

12-2 FREEZING OF PIPES AND TANKS.

Damage or failure occurs due to the expansion of water changing to ice. The hydrostatic pressure on the still-unfrozen liquid can reach several hundred atmospheres, and it is this pressure, not the contact of the ice, which typically causes pipe failure. Prevention of freezing is accomplished via the most cost-effective combination of insulation, heat trace, circulation, and other measures. Insulation alone does not necessarily prevent freezing; it reduces the rate of heat loss and extends the freeze-up time. Small diameter service connections may have a freeze-up time measured in minutes or a few hours. These are the most vulnerable portions of the system and will usually freeze first. Thawing capability is mandatory for these small diameter pipes.

> [C] 12-2 There are some methods of insulating (such as foam board) that allow capture of ground heat, such as those employed at Joint Base Elmendorf-Richardson. These systems are sufficient on their own to prevent freezing. References listed in paragraph A-8 discuss these methods.

12-3 THAWING OF FROZEN PIPES.

Remote electrical thawing methods that can be incorporated in the original design include skin effect, impedance, 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 riser. Once a small annulus is melted, the flow can be restarted, and it will thaw the remaining ice. Chapter 6 discusses thawing of frozen pipes.

12-4 HEAT LOSS FROM PIPES.

The total heat loss and the freeze-up time are dependent on the ambient and internal temperatures in the pipe system. Aboveground piping systems must be designed for the lowest expected air temperatures, which range from –40 to –75°F (–40 to –59°C). These extreme surface temperatures are attenuated by burial, depending on the thermal properties of the soil. Frost penetration is greatest in rock or bare, dry soils. A snow cover typically reduces the depth of frost penetration by an amount equal to the snow depth. Locating utility lines away from snowplowed surfaces takes advantage of this potential.

[C] 12-4 For example, the air temperature at the surface might have an annual variation of 150°F (66°C). At a depth of 6 ft (2 m), the temperature may vary slightly with the season, and at 30 ft (9 m), seasonal temperature fluctuations are negligible. There is also a time lag involved with frost penetration so that maximum depth of frost penetration will occur long after the extreme winter temperatures. At a depth of 6 ft (2 m) the lag time may be one to five months after the onset of freezing conditions at the surface. The specific time depends on soil properties and moisture conditions.

12-4.1 Direct Burial.

Water and sewer mains are typically buried below the maximum depth of seasonal frost. In cold regions, the frost penetration is often greater than the common pipe burial depths of 6 to 10 ft (1.8 to 3 m) and may be 20 ft (6 m) or more in exposed dry soil or rock. Deep frost penetration, high groundwater, hilly terrain, rock, or other factors make it more practical and economical to install all or portions of the utility system within the frost zone. In these cases, the degree of freeze protection necessary depends on the ground temperatures at the pipe depth. Where pipes are only intermittently or periodically within frost, such as during a particularly cold winter or at a more temperate location, conventional bare pipes may be adequate, provided a minimum flow can be maintained by circulation, bleeding, or consumption. Frost-proof appurtenances, appropriate monitoring and alarms, stable backfill, and some heating may also be necessary. Provide continuous monitoring of any system buried above the seasonal frost depth to alert for malfunction. Heat loss and freeze danger are significantly reduced by insulating the pipes. Insulated pipes may be installed in shallower trenches or within berms at ground surface. In these cases, the minimum depth of cover would be 1.5 to 3 ft (0.5 to 1 m) for exposed ground surfaces. Greater depths are necessary if heavy surface traffic is expected. For long pipelines which are trenched, installed in frozen soils, and which rely on the soil bond to overcome expansion forces, initial warm up of the pipes after construction may result in upheaval buckling of pipeline if backfill material is not allowed sufficient time to consolidate and secure the pipe in the trench.

12-4.2 Insulation Barrier for Buried Pipes.

Buried pipes within seasonal frost can also be protected by placing a layer of insulation board, usually polystyrene, above the pipe. This method, using bare pipes and fittings and board insulation, is often less expensive (for materials) than use of prefabricated insulated pipe; however, the construction cost will be higher, and the effectiveness of the insulation is lower than direct insulation on the 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 the insulation board. The necessary thickness and width of the board increases for shallower pipes and deeper frost penetration. The relative economics, compared to that for insulated pipes, is improved when pipes are placed in a common trench under insulation board and when warm sewer or central heating lines are included. Generally, the insulation should be a minimum of 4 ft (1.2 m) wide for a single pipe, and the thickness is determined by the proposed depth of burial and the expected or calculated frost penetration. The heat loss and trench width may be reduced by placing the insulation in an inverted U on both the top and sides of the pipe. Example 3 in Appendix C illustrates frost penetration calculations beneath an insulation board.

[C] 12-4.2 In terms of reducing frost penetration, 2 inches (5 cm) of polystyrene foam insulation (k = 0.02 Btu/hr·ft·°F [0.035 W/m °C]) is roughly equivalent to 4 ft (1.2 m) of sand or silt or 3 ft (0.9 m) of clay cover over the pipe.

12-4.3 Deep Burial.

Deeper pipes will experience less extreme ambient temperatures, lower maximum rates of heat loss, and a longer safety factor time against freezing. However, pipes installed in permafrost require freeze-protection all year.

12-5 PHYSICAL METHODS FOR 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, use only near-hydrophobic insulations. Even these insulations usually require some physical and moisture protection. Consideration corrosion resistant external coatings of pipe segments or factory applied insulation which is bonded to the pipe surface and forms a water impervious barrier. Assure pipes are protected from moisture entry at joints, connections, and other features where moisture may come in contact with pipe materials.

12-5.1 Amount of Insulation.

Perform an economic analysis to balance heating and insulation costs to determine the minimum amount of insulation that is required. Include factors such as the freeze-up time, the maximum rate of heat loss, and practical dimensional considerations. Heat loss estimates for pipe systems must consider exposed sections of pipes, joints and appurtenances, and thermal breaks such as at pipe anchors. To ensure safe design, the thermal resistance around appurtenances must be 1.5 times that required around adjacent pipe sections. Where insulation is applied to relatively complex equipment features that require frequent maintenance or access, a removable insulated blanket may prove cost effective.

[C] 12-5.1 For example, a 5-inch (13-cm) gate valve has a surface area equivalent to 3 ft (1 m) of bare pipe. If this valve were left exposed, it would lose as much heat as about 200 ft (61 m) of 5-inch (13-cm) pipe insulated with 2 inches (5 cm) of polyurethane insulation, and freezing would occur at the valve first.

12-5.2 Location of Insulation.

The amount of heat loss from a single pipe or multiple pipe system is reduced by minimizing exposed surface area. Minimizing the surface area also requires less insulation. This is especially important for aboveground pipes, facilities, and appurtenances where insulation is most effective when it is placed directly around the source of heat. For a single pipe, insulation is best applied in an annulus directly around the pipe. Where there is an air space, for example between an insulated pipe and a jacket or casing, the thermal resistance of the air space may be quite significant and must be considered. For the same total volume of insulation, it is more effective to group several pipes in a single insulated conduit or small utilidor than to separately insulate each pipe. The ASCE *Cold Regions Utilities Monograph*, Section 4.5, and Chapter 6, “Heat Transfer Calculations for Piping Systems,” of the ASHRAE *District Heating Guide* provide additional discussion and example problems.

12-6 HEAT LOSS REPLACEMENT.

If ambient temperatures are below 32°F (0°C), freezing will eventually occur in the pipe unless the cold fluid is replaced by warmer fluid, or heat is added to the fluid. Heat can be added either at point sources, such as pump stations, or continuously along the length of the pipe with heat tracing. Friction generated by the fluid moving through the pipe may also generate heat, but it is negligible at typical flow velocities.

12-6.1 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 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 or where the flow rate is reliable and high, such as in some water supply pipelines or mains. 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 still decline unless warmer water is added, or the recirculating water is heated.

[C] 12-6.1 Bleeding of water has been used historically to maintain or enhance the flow in service lines, dead-ends, and intermittent flowing pipelines, but the wasting of large quantities of water is inefficient, costly, and results in water supply and wastewater treatment problems.

12-6.2 Point Sources of Heat.

Water may be heated at the source, treatment plant, pumping stations, along the pipeline, or within distribution systems as required. There must also be sufficient flow within the piping system to distribute the heat. If the normal water demand is too low or is intermittent, then bleeding or recirculation is necessary. Maintain a minimum water temperature 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. Higher velocities must be balanced with the electrical energy requirements for pumping and are not usually practical for large diameter mains. The ASCE *Cold Regions Utilities Monograph*, Section 4.4.2, provides additional information.

12-6.3 Heat Tracing.

Replacement of heat losses and maintenance of minimum temperature can also be accomplished with pipe heat tracing systems. Circulation of warm air has been used in large, open utilidors, but the most common heat tracing systems use either separate fluid or electrical lines as the heat source.

12-6.3.1 Fluid Heat Tracing.

For pipe heat tracing, fluids generally between 175°F and 200°F (79°C and 93°C) are much simpler to use than either steam or higher temperature water. The ASCE *Cold Regions Utilities Monograph*, Section 4.4.3, provides additional information.

12-6.3.2 Electric Heat Tracing.

Electric heat tracing systems are relatively easily installed and controlled. They can be installed continuously on water and sewer pipelines or only at freeze-susceptible locations, such as road crossings, service connections, or at appurtenances such as fire hydrants. A variety of electric heat tracing systems and products are available from a number of manufacturers. Exterior heat tracing on pre-insulated pipe is commonly installed within a raceway channel or conduit attached to the pipe surface, which facilitates fabrication, installation, removal, and replacement. Plastic pipes, insulation, and the electric heat tracing system itself must be protected from overheating unless the self-limiting heating cable is used. To provide freeze protection, automatic control systems must activate the electric heat tracing system at a set point above 32°F (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. The sensors must be located with care to provide proper control, freeze-protection, and prevent the waste of energy. They should be located where the lowest pipe temperatures within the section being controlled are expected, such as at exposed windswept areas or shallow buried sections. The ASCE *Cold Regions Utilities Monograph*, Section 4.4.4, provides additional information.

12-6.4 Pipe Friction.

Friction heating is negligible for smooth pipes with fluid velocities less than 6 ft per second (1.8 m per second), which is about the desirable upper limit for flow in pipes. At high velocities, frictional heat is significant, but deliberately increasing velocity for this purpose is an inefficient method of heating since the energy is supplied by pumping. The equations for frictional heat input are presented in Figure 12-1.

12-7 INSULATION MATERIALS.

Insulation materials include, but are not limited to, polyurethane foam, extruded polystyrene board, fiberglass, molded calcium silicate, and molded polyisocyanurate. Insulation can be installed in the form of boards or may be factory applied on the pipe with appropriate jacketing. Factory insulated pipe may also include heat tracing or channels for heat tracing installation. The insulation materials selected must be in accordance with the criteria given in applicable UFGS, such as UFGS 23 07 00. The ASHRAE *District Heating Guide* provides additional information on insulation types and thermal properties, including obsolete insulation materials that may be found on renovation projects.

For design purposes, the structural and thermal properties for the worst conditions must be used. These conditions occur after aging, compaction, saturation, and freeze-thaw cycles. Other selection considerations are ease of installation, vapor 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. In the past, the lack of a near-hydrophobic insulation made the design of piping in moist environments very difficult and is a major reason for the development of aboveground utilidors.

12-8 THERMAL CALCULATIONS.

The analytical thermal equations presented in this section use a number of simplifying approximations. The user must determine their applicability to specific problems and consider the various models and a range of values for physical and temperature conditions. This chapter's equations include time-independent steady-state heat flow procedures as well as calculations to determine ground temperature and the depth of freezing and thawing. The symbols used for this chapter's figures are defined in Table 12-1. The thermal conductivity values of common materials are given in Table 12-2. Solutions to utility system example problems are given in Appendix C to illustrate the methods involved.

12-8.1 Steady-State Pipeline Heat Loss.

Steady-state calculations include typical cases for bare and insulated pipes, and single and multiple pipes in above- and belowground configurations. These methods are presented in Figure 12-1, 12-2, 12-3 and 12-4.

- Figure 12-1 presents equations for estimating the temperature drop (or gain) along a pipeline system. In addition, simple procedures to determine freeze-up times under no-flow conditions are included.
- Figure 12-2 presents equations for estimating heat flow from above-surface pipes. The pipe configurations include 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 equations are also included. Where applicable, procedures are given for relevant thermal resistance, rates of heat flow and insulation thicknesses.
- Figure 12-3 presents equations for estimating heat flow from buried pipes. The pipe configurations include a bare pipe with no thaw, a bare pipe with a thaw zone, an insulated pipe with no thaw, and an insulated pipe with a thaw zone. In addition, equations are included to estimate the dimension of the thaw zone.
- Figure 12-4 presents equations for estimating the thermal resistance of typical applications of pipe insulation and utilidor insulation.
- Steady-state thermal influences in isotropic, homogenous soils can be summed, and geometric modifications and approximations can be made to the basic steady-state 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 area influenced by short-term air temperature fluctuations, the ground temperatures around the pipeline resemble a slowly changing series of steady-state conditions.[1] 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. Heat loss from deep pipes can also be estimated by replacing the ground surface temperature in the steady-state equations with the undisturbed ground temperature at the pipe depth.[2] Calculate heat loss from a buried pipe over a time period from the heating index during that period. ASCE *Cold Regions Utilities Monograph*, Section 4.6, provides additional discussion.

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[1] *Underground Utility Lines*, Prokhaer.
[2] “Water Supply Systems for Frozen Ground,” Janson.

Table 12-1 List of Symbols used in Thermal Calculations shown in Figures 12-1 through 12-4

Variable		Subscript	
A	thaw factor [Figure 12-3]	A	air [Figures 12-1 and 12-2]
a	height of insulation (ft) [Figure 12-4]	C	conduit [Figure 12-2]
b	width of insulation (ft) [Figure 12-4]	D	design [Figure 12-1]
c	equation variable (ft) [Figure 12-3]	E	exterior casing (of utilidor) [Figure 12-2]
C	volumetric heat capacity (Btu/ft3 °F) [Figure 12-1]	f	friction [Figure 12-1]
d	insulation thickness (ft) [Figures 12-2 and 12-4]	f	freezing or frozen [Figure 12-3]
δ	effective thickness of fictitious soil layer (ft) [Figure 12-4]	F	freeze [Figure 12-1]
D	scaling parameter (ft) [Figure 12-1]	G	ground (surface) [Figure 12-3]
f	friction head loss (ft/ft) [Figure 12-1]	I	Insulation [Figures 12-2–12-4]
F	friction heat constant, 0.2515 Btu/ft4 [Figure 12-1]	j	denotes pipe number [Figure 12-2]
h	thermal film or convective heat coefficient [Figures 12-2 and 12-4]	L	refers to thermal lining (of utilidor) [Figure 12-2]
k	thermal conductivity (Btu/h ft °F) [Figures 12-1–12-4]	P	pipe [Figures 12-2–12-4]
l	length (ft) [Figure 12-1]	S	soil [Figures 12-3 and 12-4]
L	volumetric latent heat (Btu/ft3) [Figure 12-1]	SF	safety factor [Figure 12-1]
N	equation variable [Figure 12-2]	t	thawed, thawing [Figure 12-3]
p	separation between pipes (ft) [Figure 12-4]	U	utilidor [Figure 12-2]
P	perimeter (mean) (ft) [Figure 12-2]	W	water (fluid) within a pipe [Figures 12-1 and 12-2]
q	fluid flow rate (ft3/s) [Figure 12-1]	Z	refers to zone of thaw [Figure 12-3]
Q	rate of heat loss per unit longitudinal length (Btu/ft h) [Figures 12-1 and 12-2]	0	(zero) refers to freezing point of water [Figures 12-1–12-4]
r	radius (ft) [Figures 12-1–12-4]	1, 2	input fluid, output fluid [Figure 12-1]; layers [Figure 12-4]; Pipes [Figure 12-4]
R	thermal resistance of unit longitudinal length (h ft °F/Btu) [Figures 12-1–12-4]		
s	offset of cylindrical insulation (ft) [Figure 12-4]		
S	equation variable [Figure 12-4]		
t	time (unit varies) [Figure 12-1]		
T	temperature (°F) [Figures 12-1–12-3]		
W	wind function [Figure 12-2]		
v	fluid mean velocity (ft/h) [Figure 12-1]		
V	wind velocity (mph) [Figure 12-2]		
x	depth [Figure 12-3]		

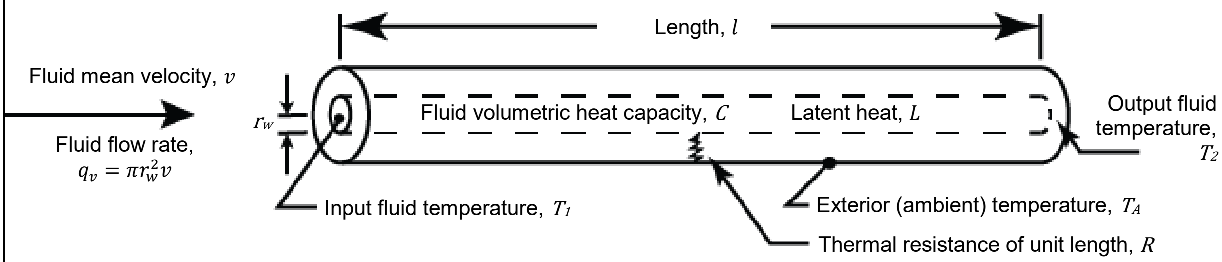
Table 12-2 Thermal Conductivities of Common Materials[1]

Material	Unit Weight (dry) lb/ft^3	Specific Heat Capacity Btu/lb-°F	Thermal Conductivity Btu/ft·h·°F
Air, no convection (32°F)		0.24	0.014
Air film, outside, 15 mph wind (per air film)			0.50
Air film, outside (per air film)			0.14
Polyurethane foam	2	0.4	0.014
Polystyrene foam	0.19	0.3	0.020
Rock wool, glass wool	3.4	0.2	0.023
Snow, new, loose	5.3	0.5	0.05
Snow, on ground	19	0.5	0.13
Snow, drifted and compacted	31	0.5	0.4
Ice at –40°F	56	0.5	1.54
Ice at 32°F	56	0.5	1.28
Water at 32°F	62.4	1.0	0.34
Peat, dry	16	0.5	0.04
Peat, thawed, 80% moisture	16	0.32	0.08
Peat, frozen, 80% ice	16	0.22	1.0
Peat, pressed, moist	71	0.4	0.40
Clay, dry	106	0.22	0.5
Clay, thawed, saturated (20%)	106	0.42	1.0
Clay, frozen, saturated (20%)	106	0.32	1.2
Sand, dry	125	0.19	0.06
Sand, thawed, saturated (10%)	125	0.29	1.9
Sand, frozen, saturated (10%)	125	0.24	2.4
Rock, typical	156	0.20	1.3
Wood, plywood, dry	37	0.65	0.10
Wood, fir, or pine, dry	31	0.6	0.07
Wood, maple, or oak, dry	44	0.5	0.10
Insulating concrete (varies)	12 to 94		0.04 to 0.35
Concrete	156	0.16	1.0
Asphalt	156		0.42
Polyethylene, high density	59	0.54	0.21
PVC	87	0.25	0.11
Wood stave (varies)	–		0.15
Steel	486	0.12	25
Ductile iron	468		30
Aluminum	169	0.21	115
Copper	550	0.1	220

[1] Values are representative of materials, but most materials have variable properties.

Figure 12-1 Temperature Drop and Freeze-Up Time in Pipes (After “Calculation of Heat Loss in Pipes,” by Thornton)

Heat Loss and Temperature Drop in a Fluid Flowing through a Pipe	Freeze-Up Time for a Full Pipe Under No-Flow Conditions (v = 0)



Comments: The above is a 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 = scaling parameter $= \pi r_W^2 vCR$

Calculate T_1 or T_2, given R, T_1 or T_2, T_A

$$T_1 = T_A + (T_2 - T_A)/\exp(-l/D)$$

$$\cong T_A + (T_2 - T_A)/(1 + l/D), \text{ if } \frac{l}{D} \leq 0.1$$

$$T_2 = T_A + (T_1 - T_A)\exp(-l/D)$$

Calculate R, given T_1, T_2, T_A

$$R = l/\pi r_W^2 vC \ln[T_2 - T_A/T_1 - T_A]$$

Calculate v, given T_1, T_2, T_A, R

$$v = l/\pi r_W^2 RC \ln[T_2 - T_1/T_1 - T_A]$$

Calculate heat loss (Q), given T_1 or T_2, T_A, v, R

$$Q = D/R\,(T_1 - T_A)[1 - \exp(-l/D)]$$

$$\cong (\tfrac{l}{R})(T_1 - T_A) \text{ for } l/D \leq 0.1$$

$$= D/R(T_2 - T_A)[\exp(l/D) - 1]$$

Calculate Friction Heating (Q_f), given v, f

$$Q_f = F r_W^2 v f$$

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.

$$t_D = \pi r_W^2 RC \ln\left[\frac{T_1 - T_A}{T_O - T_A}\right]$$

Safety Factor Time

t_{SF}= Time for the fluid to drop to the nucleation temperature. Same as t_D but with T_0 replaced by 27°F

Complete Freezing Time

t_F= Time for the fluid at freezing point, 32°F, to completely freeze solid.

$$t_F = \pi r_W^2 RL/(T_O - T_A)$$

Figure 12-2 Steady-State Thermal Equations for Above-Surface Pipes (After "Calculation of Heat Loss in Pipes")

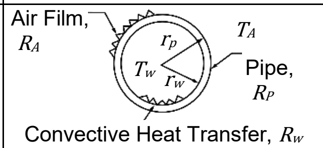
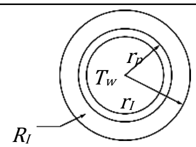
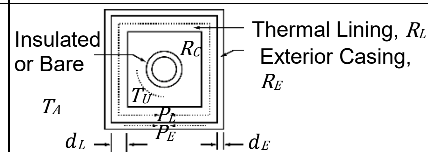
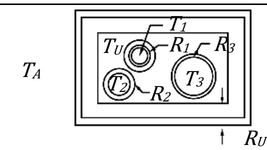
	(a) Bare Pipe	(b) Insulated Pipe	(c) Single Pipe in Utilidor	(d) Multiple Pipes in Utilidor
Sketch				
Assumptions	Thin-walled pipe ($r_p \leq 2r_W$). R_W is negligible, $R_P \leq R_A$.	All thermal resistances but that of the insulation are neglected.	Convection ensures the temperature inside the utilidor, T_U is uniform. Utilidor air spaces are neglected.	Same as (c).
Thermal Resistance	$R_P = \frac{\ln(r_P/r_W)}{2\pi k_P}$ $R_A = 1/2\pi r_P h_A$ $h_A = N\left(\frac{T_W - T_A}{r_P}\right)^{0.25} W(V)$ $N = 0.23\ Btu/h\,ft\,°F$ $W(V) = \sqrt{12.5V + 1}$ for V in mph $R_C = R_P + R_A$	$R_C = R_I = \frac{\ln(r_I/r_P)}{2\pi k_I}$	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 $T_U (\leq T_W)$. $R_L = d_L/P_L k_L$ $R_E = d_E/P_E k_E$ $R_U = R_L + R_E$ $R = R_C + R_U$ $T_U = \frac{(T_W/R_C) + (T_A/R_U)}{(1/R_C) + (1/R_U)}$ If bare pipe, solution is found by iteration of T_U.	Calculate R for each pipe as in (c) to get R_j Where: 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, solution is found by iteration of 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	$r_I - r_P$ $= r_P \left\{exp\left[\frac{2\pi k_1 (T_W - T_A)}{Q}\right] - 1\right\}$ $= \pi k_I (T_W - T_A) Q$ if $r_I \leq 2r_p$	Obtain R_E and R_C as above $d_L = R_L k_L [\frac{(T_W - T_A)}{Q} - R_E - R_C]$ If bare interior pipe, iterate T_U, R_C and hence d_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 $d_L = P_L k_L [\frac{T_U - T_A}{\sum Q_J} - R_E]$ If bare pipes, iterate T_U, R_J and hence d_L.
Comments	Often, for metal pipes, R_P may be neglected. If R_P is significant, the expression above 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, iterate.	The value of h_A, and hence R_A, is insensitive to the choice of T_U, and so one iteration of T_U is usually sufficient. Often R_E may be neglected. A similar calculation may be performed for pipes and utilidors of different cross section.	Same as (c). If 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 12-3 Steady-State Thermal Equations for Below-Surface Pipes (After "Calculation of Heat Loss in Pipes")

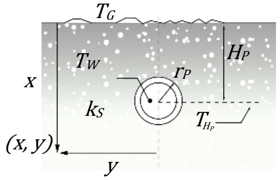
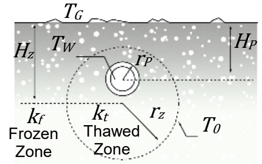
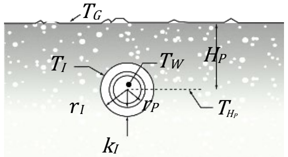
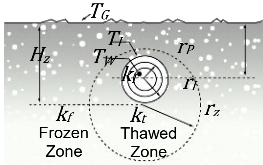
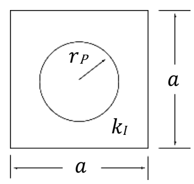
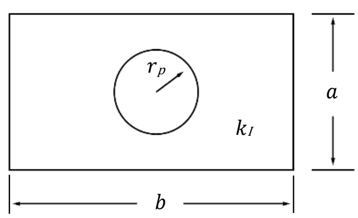
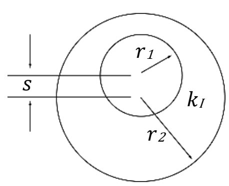
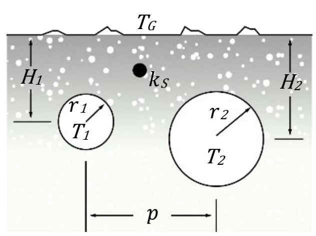
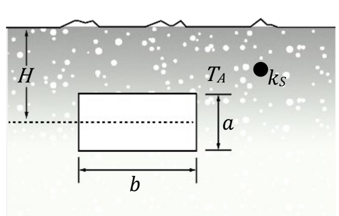
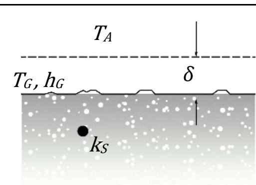
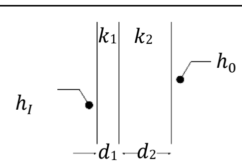
	(a) Bare, No Thaw	(b) Bare, with Thaw Zone	(c) Insulated, No Thaw	(d) Insulated, with Thaw Zone
Sketch				
Assumptions	Neglect all thermal resistances except that of the soil.	Same as (a), but accounting for the different conductivities of thawed and frozen soil.	Neglecting all thermal resistances except 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	$R_S = \frac{\text{arccosh}(\frac{H_P}{r_P})}{2\pi k_S}$ $= \frac{ln\left\{\left(\frac{H_P}{r_P}\right) + \left[\left(\frac{H_P}{r_P}\right)^2 - 1\right]^{1/2}\right\}}{2\pi k_S}$ $\cong \frac{\ln(2H_P/r_P)}{2\pi k_S}$ if $H_P \geq 2r_P$	$T'_W = \frac{k_t}{k_f}(T_W - T_O) + T_0$ $T' = \frac{(T_O - T_G)}{(T'_W - T_G)}$ $c = \sqrt{H_P^2 - r_P^2}$ $A = T' \text{ arccosh}(\frac{H_P}{r_P})$ $H_Z = c \coth A \quad r_Z = c \text{ csch } A$ R_t, R_f, and R_S ($= R_t + R_f$) as given in (d), but with r_t replaced by r_P	R_1 as given in Figure 12-2 (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 thermal resistance to prevent thaw, R'_1, (such as $T_I = T_O$) is given by: $R'_1 = \frac{T_W - T_O}{T_O - T_G} R_S$	R_I as given in Figure 12-2 (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: $A = T'[\text{arcosh}(H_P/r_P) + 2\pi k_t R_I]$ $T_I = T_W - \frac{R_I(T'_W - T_G)}{R'_S + (k_t/k_f)R_I}$ Also, $R_t = \frac{[\text{arcosh}(H_P/r_I) - \text{arcosh}(H_Z/r_Z)]}{2\pi k_t}$ $R_f = \text{arcosh}(H_Z/r_Z)/2\pi k_t$ $R_S = R_f + R_t$
Rate of Heat Loss	$Q = \frac{T_W - T_G}{R_S}$	$Q = \frac{T'_W - T_G}{R'_S}$ Where: $R'_S = \frac{\text{arcosh}(H_P/r_P)}{2\pi k_f}$	$Q = \frac{T_W - T_G}{R_I + R_S}$	$Q = \frac{T'_W - T_G}{R'_S + (k_t/k_f)R_I}$
Insulation Thickness	N/A	N/A	For no thawing outside the insulation the minimum insulation thickness is given by: $r_I - r_P = r_P[\exp(2\pi k_I R'_I) - 1]$	$R_I = [(A/T') + \text{arcosh}(H_P/r_I)]/2\pi k_t$ $r_I - r_P$ 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 $k_t \cong k_f$ and/or $r_Z \cong r_I$, 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 12-4 Steady-State Thermal Resistance of Various Shapes and Bodies (After *Fundamentals in Heat Transfer* and EPA-600/8-79-027)

Condition	Sketch	Thermal resistance
Square insulation		$R = \frac{1}{2\pi k_I}\ln 1.08\frac{a}{2r_P}$
Rectangular insulation		$R = \frac{1}{2\pi k_I}\ln(\frac{4a}{\pi r_P} - 2S)$ b/a / S: 1.00 0.08290; 1.25 0.03963; 1.50 0.01781; 1.75 0.00816 b/a / S: 2.00 0.00373; 2.25 0.00170; 2.50 0.00078; 3.00 0.00016 b/a / S: 4.00 6.97×10^{-6}; 5.00 3.01×10^{-7}; ⋮ ⋮; ∞ 0
Eccentric cylindrical insulation		$R = \frac{1}{2\pi k_I}\ln\frac{\sqrt{(r_2+r_1)^2 - s^2} + \sqrt{(r_2-r_1)^2 - s^2}}{\sqrt{(r_2+r_1)^2 - s^2} - \sqrt{(r_2-r_1)^2 - s^2}}$ $= \frac{1}{2\pi k_I} arccosh\frac{r_1^2 + r_2^2 - s^2}{2r_1 r_2}$
Two buried pipes		Where: $H_1 \geq 3r_1$, $H_2 \geq 3r_2$ and $p \geq 3(r_1 + r_2)$ $R_{1-2} = \frac{1}{2\pi k_S}\cdot\frac{\ln\frac{2H_1}{r_1}\cdot\ln\frac{2H_2}{r_2} - \left[\ln\sqrt{\frac{(h_1+h_2)^2+p^2}{(h_1-h_2)^2+p^2}}\right]^2}{\ln\frac{2H_2}{r_2} - \left[\left(\frac{T_2 - T_G}{T_1 - T_G}\right)\ln\sqrt{\frac{(h_1+h_2)^2+p^2}{(h_1-h_2)^2+p^2}}\right]}$
Buried rectangular duct		$R = \frac{1}{k_S(5.7 + \frac{b}{2a})}\ln\frac{3.5H}{b^{0.25}\ a^{0.75}}$
Surface thermal resistance		Surface thermal resistance between the ground surface and air can be approximated by adding a fictitious soil layer with an effective thickness equal to: $\delta = \frac{k_S}{h_G}$ For further soil thermal resistance calculations this thickness is simply added to the actual burial depth of the pipe.
Composite wall		$R = \frac{1}{h_I} + \frac{1}{h_O} + \frac{d_1}{k_1} + \frac{d_2}{k_2}$

12-8.2 Depth of Freezing and Thawing

Obtain the depth of freezing or thawing of soil, and the ice thickness on water bodies, by field measurements when possible. If required, they can be estimated using one of the many analytical solutions available. Because of the assumptions necessary in these analytical solutions, such as assuming a step change in surface temperature or neglecting the soil temperature changes, they generally overestimate the maximum freezing isotherm depths for the given conditions and are, therefore, conservative for engineering applications.

12-8.2.1 Basic Analytical Solution Form.

Analytical solutions are generally Neumann- or Stefan-based equations which have the basic form:

Equation 12-1. Depth of Freezing or Thawing (Stefan Solution, Empirical Coefficients)

$$X = m\left(I_g\right)^{1/2}$$

Where:
X = depth of freezing or thawing (ft)
m = coefficient of proportionality (ice thickness $\boldsymbol{m}$-factor)
I_g = ground surface freezing (I_f) or thawing (I_t) index (°F-days)

12-8.2.2 Specific Solutions.

Equations 12-2 through 12-5 incorporate various assumptions that are useful for specific conditions:

- Equation 12-2 is the Stefan solution for a homogeneous material with a step change in surface temperature (see Appendix C, Example 1). Equation 12-2 is identical to Equation 12-1 except 12-1 uses empirical coefficients and 12-2 uses the values of the physical properties. Equation 12-2 overestimates the depth of freezing as a result.
- Equation 12-3 is a two-layer modification of the Stefan equation and is useful for calculations involving snow cover, a gravel pad, or a board of thermal insulation, in which the surface layer has no latent heat (see Appendix C, Example 2 and Example 3.
- Equation 12-4 is a close approximation of the Neumann solution when the ground temperatures are near freezing.
- Equation 12-5, the modified Berggren equation, is perhaps the most commonly used approach for determining thermal responses of soils. When the soil has a high moisture content the correction coefficient λ

approaches unity and the equation is identical to the Stefan approach (Equation 12-2).

- In 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.

Equation 12-2. Depth of Freezing or Thawing (Stefan Solution)

$$X = \left(\frac{2kI_g}{L}\right)^{1/2}$$

Equation 12-3. Depth of Freezing or Thawing (Stefan Solution, Two-Layer)

$$X = \left(\left(\frac{k_2}{k_1}d_1\right)^2 + \frac{2k_2I_g - \frac{d_1^2L_1}{2k_1}}{L_2}\right)^{1/2} - \left(\frac{k_2}{k_1} - 1\right)d_1$$

Equation 12-4. Depth of Freezing or Thawing (Neumann Solution Approximation)

$$X = \left(\frac{2kI_g}{L}\right)^{1/2}\left(1 - \frac{CI_g}{8Lt}\right)$$

Equation 12-5. Depth of Freezing or Thawing (Modified Berggren Solution)

$$X = \lambda\left(\frac{2kI_g}{L}\right)^{1/2}$$

Where:

k = *thermal conductivity of the material above the freezing isotherm (Btu/hr·ft·°F). Subscripts f and t refer to freezing and thawing, and subscripts 1 and 2 refer to the surface layer and the underlying material (all symbols are also defined in Table 12-1).*

L = *volumetric latent heat of the material undergoing phase change (Btu/ft^3). For water L = (144 Btu/lb)(62.4 pcf) = 8986 Btu/f^3*

C = *volumetric heat capacity of the material above the freezing isotherm.*
For thawed soil: $C_t = \gamma\,[C_{mS} + C_{mW}(w/100)]$
For frozen soil: $C_f = \gamma\,[C_{mS} + C_{mi}\,(w/100)]$

γ = *dry unit weight of soil (pcf)*

C_{mS} = *mass heat capacity of mineral matter in soil; assume a value of 0.2 Btu/lb*

C_{mW} = *mass heat capacity of water = 1.0 Btu/lb*

C_{mi} = *mass heat capacity of ice, assumed value of 0.5 Btu/lb*

w = *moisture content of soil (%)*
T_m = *mean annual site temperature (°F)*
t = *freezing or thawing period, consistent units*
T_0 = *freezing point, 32°F for water*
d = *thickness of layer of material (ft)*
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) that are calculated using Equation 12-6 and Equation 12-7. λ is determined from Figure 12-5.*

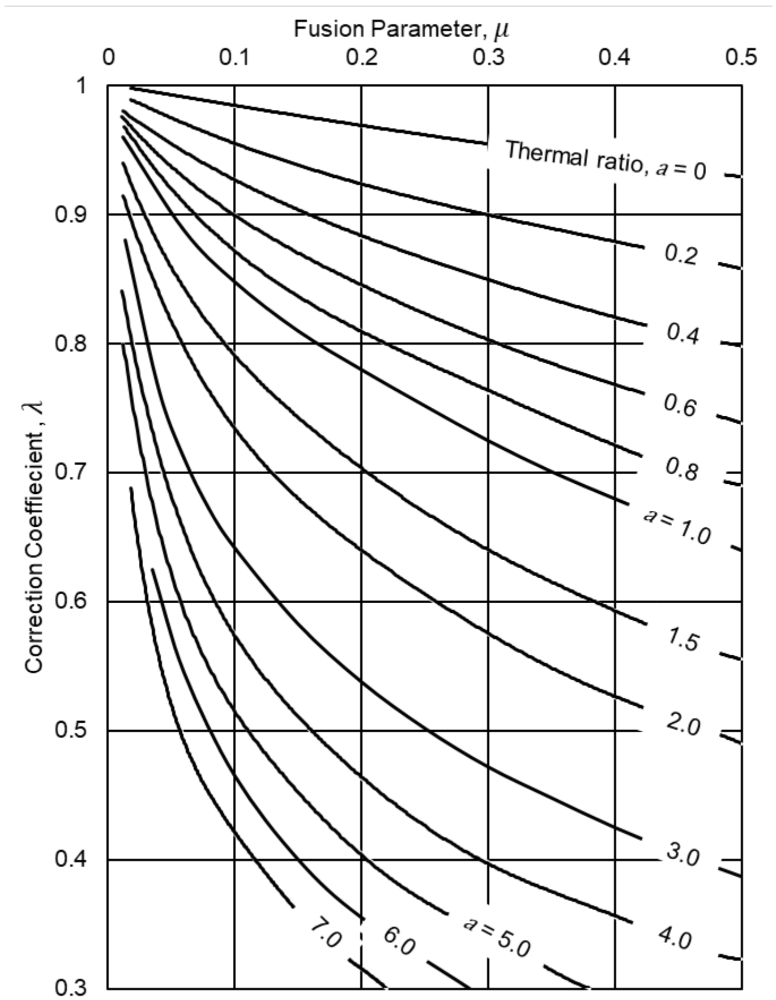
Equation 12-6. Thermal Ratio (*a*)

$$\mathrm{a} = \frac{(T_m - T_0)}{T_m} = \frac{(T_m - T_0)t}{I_g}$$

Equation 12-7. Fusion Parameter (*μ*)

$$\mu = \frac{CI_g}{Lt}$$

Figure 12-5 Correction Coefficient λ for use in Berggren Equation



12-8.2.3 Multi-layered Soil Systems.

Solve multilayered soil systems 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} layer is calculated by Equation 12-8.

Equation 12-8. Partial Freezing or Thawing Index

$$I_n = \frac{L_n d_n}{\lambda^2} \sum_{1}^{n-1} \left(R + \frac{R_n}{2} \right)$$

Where:

I_n = *the partial freezing or thawing index required to penetrate the n^{th} layer (°F·hr)*
L_n = *volumetric latent heat in the n^{th} layer (Btu/ft^3)*
d_n = *thickness of the n^{th} layer (ft)*
λ = *the coefficient based on the weighted average values for μ down to and including the n^{th} layer*
$\sum_1^{n-1}\left(R + \frac{R_n}{2}\right)$ = *the sum of the thermal resistances of the layers above the n^{th} layer*
R_n = d_n/k_n, *the thermal resistance to the n^{th} layer (h ft °F/Btu)*

The solution for multilayered 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. 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 with convective and conductive heat exchange at the air-ground surface is used:

Equation 12-9. Ground Surface Freezing or Thawing Index

$$I_g = nI_A$$

Where:

I_A = *air freezing or thawing index*
n = *n-factor, ratio of the surface and air temperature indices*

The n-factor is very significant in analytical ground thermal considerations. It is surface and site specific, highly variable, and usually estimated from published observations such as the values listed in Table 12-3.

12-8.2.4 Ice Thickness.

Estimate ice thickness on water bodies from the previous depth of freezing equations or from Equation 12-1 with the m values in Table 12-4 (see Appendix C, Example 1). Snow cover has a significant insulating effect and can significantly reduce the maximum ice thickness (see Appendix C, Example 2). The ice formation can be greater than 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 the original ice.

Table 12-3 Typical Values of the n-factor of Air Temperature with Surface Temperature of Various Materials

Surface	n-factors		
	Thawing	Freezing	
Snow	—	1.0	General application
Pavement free of snow and 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	—	Inuvik, Northwest Territories (NWT)
Willows	0.82	—	Inuvik, NWT
Weeds	0.86	—	Inuvik, NWT
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 to 2.70	—	Fairbanks, Alaska
White painted surface	0.76 to 1.25	—	Fairbanks, Alaska
Peat bales on road	1.44 to 2.28	—	Fairbanks, Alaska
Dark gravel	1.15 to 1.73	—	Fairbanks, Alaska

Table 12-4 Example m-factors for Ice Thickness

m-factor inch /(°F-days)$^{1/2}$	Conditions
0.90–0.95	Practical maximum for ice not covered with snow
0.8	Windy lakes with no snow
0.7–0.8	Medium-sized lakes with moderate snow cover
0.6–0.65	Rivers with moderate flow
0.4–0.5	River with snow
0.2–0.4	Small river with rapid flow

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APPENDIX A BEST PRACTICES

A-1 INTRODUCTION.

The Best Practices Appendix is considered to be guidance and not requirements. Its main purpose is to communicate proven facility solutions, systems, and lessons learned, but may not be the only solution to meet the requirement. It identifies additional background information and practices for accomplishing utilities design and construction in the Arctic and Subarctic. The DoR must review and interpret this guidance as it conforms to criteria and contract requirements and apply the information according to the needs of the project. If a Best Practices document guideline differs from any UFC, the UFC takes precedence. For Best Practices guidelines not discussed in a UFC, the DoR must submit a list of the guidelines or requirements being used for the project to the Government Project Manager with documentation sufficient for review and approval prior to completing the design.

A-2 WHOLE BUILDING DESIGN GUIDE.

The Whole Building Design Guide (WBDG) provides additional information and discussion on practice and facility design, including a holistic approach to integrated design of facilities. The WBDG provides access to all Construction Criteria Base criteria, standards and codes for the DoD Military Departments, and other agencies. These standards include UFC, UFGS, Performance Technical Specifications, design manuals, and specifications. For approved government employees, it also provides access to nongovernment standards.

A-3 CANADIAN EXPERIENCE.

The Government of the Northwest Territories (GNWT) *Good Engineering Practice for Northern Water and Sewer Systems* contains performance guidelines, preferred materials and methods, and logistical considerations developed from decades of Canadian experience with the design and construction of water and sewer systems in the far north. Over time, certain products and approaches to constructing water and sewer systems have proven successful and have been adopted by design consultants and builders working in the Northwest Territories. These guidelines should be reviewed as they document both failures and successes in cold regions utilities construction and durability.

A-4 PLANNING AND DESIGN CONSIDERATIONS.

Military Installations in cold regions may have their own heating or power plants, water source and treatment facilities, and wastewater treatment facilities. Alternatively, Installations may be connected to local utility providers. Virtually all Installations have existing overhead and underground distribution systems that have been in service for many years. Utility systems at some Installations are provided by public utility companies or have been privatized. Work for these systems must follow the standards of the utility owner or current utility contractor. Other Installations still own, operate, and maintain their utility systems. For those Installations, direction from the Installation staff, often in the form of Installation Facilities Standards (IFS), should be solicited and followed. IFS are available on the WBDG website at https://wbdg.org/airforce/ifs. New Installations may benefit from the guidance used at existing military Installations or local municipalities if differing design conditions are considered, especially climatic conditions. Revegetation after construction should follow IFS guidance and local requirements, such as Eielson AFB *Design Guidelines 04—Establishing Vegetation.*

Modular construction, where the entire facility or a major component is preassembled and shipped via barge to the point of use, has been used at oil field developments on the northern coast of Alaska. It is advantageous in these locations since large barges can be used, the construction season is short, and labor is very expensive. Barges can usually begin to arrive in Utiqiagvik (formerly Barrow), Alaska and the Eastern Arctic around the first of September. This means the nonmodular construction materials must be shipped a year in advance and stockpiled for the next construction season. The stick-built approach, where all fabrication is done on-site, and the prefabrication approach, where some components are preassembled at the point of manufacture, are more common at interior locations where transport is limited to air or small rivers. Prefabrication of insulating piping units has been shown to be cost effective for remote locations.

A-5 WATER SOURCE DEVELOPMENT.

The ADEC Standard 18 AAC 80 *Drinking Water* provides additional guidance for water wells. ADEC is the utilities permitting authority for the State of Alaska and all military Installations therein.

A-6 WATER TREATMENT.

See ADEC 18 AAC 80 *Drinking Water* standard.

UFC 3-230 series provides additional water treatment Best Practices. ADEC 18 AAC 80 *Drinking Water* is the regulatory standard document for water systems in Alaska.

A-7 WATER STORAGE AND DISTRIBUTION.

A-7.1 GENERAL.

UFC 3-230-01 provides general Best Practices for water storage and distribution. ADEC 18 AAC 80 *Drinking Water* is the regulatory standard for water systems in Alaska. Local municipalities and utility companies also publish standards that include minimum burial depth at specific locations, lists of materials that have performed well in their jurisdiction, and example detail drawings of pipes and appurtenances. Examples of such documentation are as follows:

- Anchorage Water and Wastewater Utility, *Design and Construction Practices Manual*

- Utility Services of Alaska, *Standards of Design and Construction* (Fairbanks, AK)
- City of North Pole, *Utility Standards of Construction*
- City of North Pole, *Service Line Requirements for Water and Wastewater—Commercial and Residential Structures*
- Doyon Utilities, *Water, Wastewater, Steam, & Utilidor Systems* (Fort Wainwright and Fort Greely)
- Doyon Utilities, *Division 60 Water Distribution Systems* (Joint Base Elmendorf-Richardson)

A-7.2 MATERIALS.

Unless otherwise approved by the Installation, Command, or District engineering staff, direct bury waterlines should be HDPE as this material can typically survive freeze expansion without rupturing.

A-7.3 MAINS.

Locating mains in the rear of buildings or in areas that retain their snow cover provides greater thermal protection, results in less risk of damage to manholes and other appurtenances, and allows shorter, less costly service connections to the buildings. There are special advantages to this approach for barracks and family housing areas where large numbers of similar structures tend to be laid out in a regular pattern.

A-7.4 HYDRANTS.

Comply with any specific requirements of the Installation, or for privatized systems, the utility contractor. It is best to avoid any kind of nonemergency operation of hydrants during the winter months.

A-8 WASTEWATER COLLECTION AND TREATMENT.

UFC 3-240-01 provides Best Practices for wastewater collection and treatment; paragraph A-6.6 provides guidance specific to cold regions. ADEC 18 AAC 72 *Wastewater Disposal* is the regulatory standards document for wastewater systems in Alaska, including required minimum separation distances between water and sewer mains (including manholes) and the criteria for obtaining a waiver if the required separation distances cannot be achieved. Local municipalities and utility companies also publish standards that include lists of material that have performed well in their jurisdiction, and example detail drawings of pipes and appurtenances. Contractors for Installations with privatized utilities system, or the Installation itself, may have specific design standards that must also be considered. Examples of such documentation are as follows:

- Anchorage Water and Wastewater Utility, *Design and Construction Practices Manual*
- Utility Services of Alaska, *Standards of Design and Construction* (Fairbanks, AK)
- City of North Pole, *Utility Standards of Construction*
- City of North Pole, *Service Line Requirements for Water and Wastewater—Commercial and Residential Structures*
- Doyon Utilities, *Water, Wastewater, Steam, & Utilidor Systems* (Fort Wainwright and Fort Greely)
- Doyon Utilities, *Division 50 Wastewater Collection Systems* (Joint Base Elmendorf-Richardson)

"Chatfield Wastewater Treatment Facility Improvements: A Design and Operational Review, Focused on Cold Weather Issues," by Wedin, provides a discussion of wastewater treatment facilities issues specific to cold regions operations.

A-9 UTILIDORS.

ADEC is the permitting authority for utilidors in the State of Alaska, and all utilidor designs must comply with ADEC standards or have an appropriate waiver. Follow the Eielson AFB *Design Guidelines 10—Utilidors*, generated by the 354th Civil Engineer Squadron, Operations Engineering Flight (354 CES/CEO), where applicable. Privatized utilities systems may have specific design standards that must be considered. An example of this would be Doyon Utilities, *Water, Wastewater, Steam, & Utilidor Systems.*

A-10 FIRE PROTECTION.

Follow Installation guidance such as the Eielson AFB *Design Guidelines 17—Fire Alarm Systems Standards* and Eielson AFB *Design Guidelines 71—Fire Protection* where applicable.

A-11 POWER DISTRIBUTION AND COMMUNICATIONS SYSTEMS.

A-11.1 GENERAL

Follow UFC 3-530-01 for exterior lighting, such as street and parking lot lighting.

Follow the Eielson AFB *Design Guidelines 14—Electrical Standards*, where applicable. Privatized utilities systems may have specific design standards that must be considered. An example of this would be Doyon Utilities, *Electrical System.*

A-11.2 GROUNDING

The GNWT *Good Building Practice for Northern Facilities* provides the following recommendations, in their order of preference, for obtaining the best possible electrical grounding in cold regions:

1. Exothermic (cad) weld to a minimum of four steel pipe piles
2. Minimum 9.5 mm (3/8 inch) bolts (copper, bronze, or brass) tapped and threaded to a minimum of four steel pipe piles

   Rationale: The large surface area of a steel pile or foundation system that is in contact with the ground can provide the best ground possible in northern areas. Cad welding provides a permanent connection.

3. A minimum of three steel rod electrodes
4. Ufer ground (concrete incased electrode)
5. Plate electrodes
6. Municipal piped water system

GNWT suggests the use of additives where obtaining low ground resistance is critical and standard methods are insufficient. GNWT notes: “Additives will degrade over time, reducing the effectiveness of the grounding system, however they may be warranted in some situations.” Additionally, they recommend designers avoid using dissimilar metals to protect from galvanic action, which may occur under certain soil conditions. All grounding measures must comply with UFC 3-550-01.

A-12 UTILITIES ENGINEERING RELATED GUIDANCE.

The following documents provide guidance on the specific topics indicated.

INSTALLATION GUIDELINES

Eielson Air Force Base (AFB) *Design Guidelines 04—Establishing Vegetation*, 354 CES/CEO

Eielson AFB *Design Guidelines 10—Utilidors*, 354 CES/CEO

Eielson AFB *Design Guidelines 14—Electrical Standards*, 354 CES/CEO

Eielson AFB *Design Guidelines 17—Fire Alarm Systems*, 354 CES/CEO

Eielson AFB *Design Guidelines 18—Utility Metering Requirements*, 354 CES/CEO

Eielson AFB *Design Guidelines 71—Fire Protection*, 354 CES/CEO

INSTALLATION FACILITIES STANDARDS (IFS), https://wbdg.org/airforce/ifs

MUNICIPAL

Anchorage Water and Wastewater Utility, Design and Construction Practices Manual, https://www.awwu.biz/about-us/reliable-infrastructure/design-and-construction-practices-manual

City of North Pole, *Service Line Standards for Water and Wastewater—Commercial and Residential Structures,* Stantec Consulting Services, Inc., https://www.northpolealaska.com/utilities/page/utility-construction-standards

City of North Pole, *Utility Standard of Construction for Extensions to the North Pole Utility*, PDC Inc. Engineers, https://www.northpolealaska.com/utilities/page/utility-construction-standards

Utility Services of Alaska, *Standards of Design and Construction,* http://www.akwater.com/construction_standards.shtml

NATIONAL FIRE PROTECTION ASSOCIATION

https://www.nfpa.org

NFPA 24, *Standard for the Installation of Private Fire Service Mains and their Appurtenances*

STATE OF ALASKA

https://dec.alaska.gov/commish/regulations/

State of Alaska, ADEC, Standard 18 AAC 80, *Drinking Water*

State of Alaska, ADEC, Standard 18 AAC 72, *Wastewater Disposal*

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/dod/ufc

UFC 3-530-01, *Interior and Exterior Lighting Systems and Controls*

UFC 3-550-01, *Exterior Electrical Power Distribution*

UTILITY COMPANIES

To request copies of the following documents, go to: https://www.doyonutilities.com/dustandards

Doyon Utilities LLC, *Division 50 Wastewater Collection Systems, Joint Base Elmendorf-Richardson Stand Construction Specification and Details*

Doyon Utilities LLC, *Division 60 Water Distribution Systems, Joint Base Elmendorf-Richardson Stand Construction Specification and Details*

Doyon Utilities LLC, *Electrical System, Design and Construction Standards, Fort Wainwright, Fort Greely & Joint Base Elmendorf-Richardson*

Doyon Utilities LLC, *Water, Wastewater, Steam, & Utilidor Systems, 2021 Design and Construction Standards, Fort Wainwright, and Fort Greely*

OTHER

"Chatfield Wastewater Treatment Facility Improvements: A Design and Operational Review, Focused on Cold Weather Issues," *ASCE Cold Regions Engineering 2009: Cold Regions Impacts on Research, Design and Construction*, T.M. Wedin, ASCE, 2012, https://doi.org/10.1061/41072(359)57

Good Building Practice for Northern Facilities, Government of the Northwest Territories (GNWT), Yellowknife, NT, Canada

Good Engineering Practice for Northern Water and Sewer Systems, GNWT, Yellowknife, NT, Canada

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APPENDIX B SUPPLEMENTAL RESOURCES

The following references are reliable sources for information related to utilities planning, design, and construction in the Arctic and Subarctic. These sources provide direction for specific applications not addressed in this UFC or provide additional information to guide or aid the designer in the various phases of the design. This list is provided for the convenience of the designer and may not include references for all specific applications relevant to all projects. The designer is responsible for ensuring the design conforms to all criteria relevant to the project.

AMERICAN SOCIETY OF CIVIL ENGINEERS

"Analytical Methods for Ground Thermal Regime Calculations," *Thermal Design Considerations in Frozen Ground Engineering,* T.G. Krzewinski (Ed.), ASCE, New York, NY, 1985

COLD REGIONS ENGINEERING (ASCE Cold Regions Engineering Division), https://www.asce.org/communities/institutes-and-technical-groups/cold-regions-engineering/

Journal of Cold Regions Engineering, https://ascelibrary.org/journal/jcrgei

"Section Three - Geotechnical Thermal Analysis," *Embankment Design and Construction in Cold Regions.* E.G. Johnson (ed.), ASCE, New York, NY, 1988

AMERICAN SOCEITY OF MECHANICAL ENGINEERS

https://www.asme.org/

"Geotechnical Aspects of Northern Pipeline Design and Construction," In *Proceedings of the 2002 4th International Pipeline Conference,* J.M. Oswell, ASME, Calgary, Alberta, Canada, 29 September–3 October 2002

Pipeline Geohazards: Planning, Design, Construction and Operations, M. Rizkalla and R. Read (eds.), ASME Press, New York, NY, 2019

ENVIRONMENTAL PROTECTION AGENCY

EPA-600/8-79-027, Cold Climate Utilities Delivery Design Manual

OTHER

CSA Z662:19, *Oil and Gas Pipeline Systems*, Canadian Standards Association

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APPENDIX C EXAMPLE PROBLEMS

Appendix C gives example problems. EPA-600/8-79-027, Section 15.10 and the ASCE *Cold Regions Utilities Monograph*, Section 4.7 provide additional example problems.

C-1 EXAMPLE 1

Estimate the ice thickness on a water reservoir with no snow cover when the annual air freezing index (I_g) is 3000°F-days.

Use Equation 12-1:

$$X = m\left(I_g\right)^{1/2}$$

From Table 12-4: m = 0.80 inch/(°F-days)$^{1/2}$

X = 0.80(3000)$^{1/2}$ = 43.82 inches = 3.65 ft

The Equation 12-2 can also be used. However, Equation 12-1 uses empirical values from observations, and Equation 12-2 uses only the values of the physical properties of water. It is expected that Equation 12-2 overestimates the ice thickness compared to Equation 12-1.

$$X = \left(\frac{2kI_g}{L}\right)^{1/2}$$

Where:

k = thermal conductivity of material above the freezing isotherm, ice in this case, so from Table 12-2:

k_{ice} = 1.28 Btu/ft hr °F

L = volumetric latent heat of material undergoing phase change, in this case water, so:

Latent heat of water at 32°F = 144 Btu/lb

Density of water at 32°F = 62.4 lb/ft^3

L = (144 Btu/lb)(62.4 lb/ft^3) = 8985.6 Btu/ft^3

I_g = (3000°F-days)(24 hr/day) = 72,000°F hr

Solving for the practical maximum ice thickness:

$$X = \left(\frac{2(1.28 Btu/ft\ hr\ °F)(72{,}000\ °F\ hr)}{8986\ Btu/ft^3}\right)^{1/2} = 4.5 \text{ ft}$$

C-2 EXAMPLE 2

Estimate the ice thickness on the reservoir in Example 1 when there is an 8-inch snow cover on top of the ice and I_g is 3000°F-days.

From Equation 12-1, and Table 12-4:

$$X = m\left(I_g\right)^{1/2}$$

$$X = 0.7(3000)^{1/2} = 38 \text{ inch} = 3.2 \text{ ft}$$

Or use the Stefan equation (Equation 12-2) for a two-layer soil system:

$$X = \left(\left(\frac{k_2}{k_1}d_1\right)^2 + \frac{2k_2 I_g - \frac{d_1^2 L_1}{2k_1}}{L_2}\right)^{1/2} - (\frac{k_2}{k_1} - 1)d_1$$

The first layer is snow, d_1 = 8 inch = 0.667 ft, assumed to be drifted and compact. From Table 12-2, k_1 = 0.4 Btu/ft hr °F. Since no phase change occurs in the snow, L_1 = 0.

For Ice: k_2 = 1.28 Btu/ft hr °F

L_2 = (144)(62.4) = 8986 Btu/ft^3

$$X = \left(\left(\left(\frac{1.28}{0.4}\right)(0.667)\right)^2 + \frac{2(1.28)(3000)(24)}{8986}\right)^{1/2} - (\frac{1.28}{0.4} - 1)(0.667)$$

= $(4.55 + 20.5)^{1/2} - 1.47$ = 3.5 ft (includes the 8 inch snow)

C-3 EXAMPLE 3

The Equation 12-3 can be used to estimate the depth of frost penetration beneath a gravel pad or an insulation board. The L_1 in either case would be zero. The L_2 in this example would be the latent heat of fusion for the soil and would be dependent on the moisture content in the soil.

Assume: sandy soil, dry density 125 pcf, moisture content 6%, and a freezing index (I_g) of 3000°F-days.

Find depth of frost penetration under 3-inch thick polystyrene board. From Table 12-2:

k_1 = 0.020 Btu/ft °F hr (for polystyrene)

k_2 = 1.0 Btu/ft °F hr (for sand), and thus
d_1 = 3/12 = 0.25 ft

The moisture content in the soil = (0.06)(125 pcf) = 7.5 lb water/ft^3 soil.

Latent heat of water = 144 Btu/lb

L_2 = (144 Btu/lb)(7.5 lb/ft^3) = 1080 Btu/ft^3 of soil

L_1 = 0

$$X = \left(\left(\frac{k_2}{k_1}d_1\right)^2 + \frac{2k_2 I_g}{L_2}\right)^{1/2} - \left(\frac{k_2}{k_1} - 1\right)d_1$$

$$X = \left(\left(\frac{1.00}{0.02}(0.25)\right)^2 + \frac{2(1.00)(3000)(24)}{1080}\right)^{1/2} - \left(\frac{1.00}{0.020} - 1\right)(0.25)$$

$$X = (156 + 133)^{1/2} = 4.75 \text{ ft}$$

The depth of frost penetration would be 11.5 ft in the same soil, under the same conditions, if the insulation board were not in place.

C-4 EXAMPLE 4

Determine the rate of heat loss per linear foot of aboveground pipe from a 5-inch interior diameter (wall thickness ½ inch) plastic pipe encased in 2-inch thick polyurethane insulation. Water inside the pipe is maintained at 40°F, ambient air temperature is −40°F, and wind speed is 15 mph. Thermal conductivity of pipe material (k_P) is 0.208 Btu/°F ft hr and thermal conductivity of the insulation material (k_I) is 0.0133 Btu/°F ft hr.

Use equations from columns (a) and (b) of Figure 12-2:

Thermal resistance of pipe $R_P = \frac{ln(r_P/r_W)}{2\pi k_P}$

Inside pipe radius = r_W = 2.5 inch

Outside pipe radius = r_P = 2.5 + 0.5 = 3.0 inch

$$R_P = \frac{ln(3.0 - 2.5)}{2(3.14)0.208} = \frac{0.182}{1.307}$$

$$R_P = 0.139 \text{ hr ft °F/Btu}$$

Thermal resistance of insulation: $R_I = \frac{ln(r_I/r_P)}{2\pi k_I}$

Outside pipe radius, r_P = 3 inch

Insulation radius, r_I = 5 inch

$$R_I = \frac{ln(5/3)}{2(3.14)0.0133}$$

= 6.115 hr ft °F/Btu

The total resistance of the pipe, R_C, is found as

$R_C = R_I + R_p$ = (6.115 + 0.139) = 6.254 hr ft °F/Btu

To determine the thermal resistance of the air film (R_A) it is necessary to estimate the surface heat transfer coefficient (h_a). From Figure 12-2 column (a):

$$h_A = N\left(\frac{T_S - T_A}{r_S}\right)^{0.25} W(V)$$

Where T_s is the outer surface temperature of the insulated pipe. (Note that in Figure 12-2 column (a) it was assumed that the thermal resistance of the pipe wall was negligible so that $T_s = T_w$. In the present case the pipe is insulated, and that assumption cannot hold.) From Figure 12-2 column (a), N = 0.23 and $W(V) = (12.5V + 1)^{1/2}$ where V is the wind speed (mph):

$W(V) = ((12.5)(15)+1)^{1/2} = 13.73$

In this case, R_P is to the outer surface of the insulation, 5 inches or 0.417 ft. For the first iteration one must assume a surface temperature (Ts). This is close to air temperature. Assuming Ts is −39°F, then:

$$h_a = 0.23\left(\frac{-39-(-40)}{0.417}\right)^{0.25}(13.73)$$

= 3.930 Btu/hr °F ft

Then, to calculate thermal resistance of air film:

$$R_A = \frac{1}{2(\pi)r_p h_a}$$

$$\mathrm{R_A} = \frac{1}{2(3.14)(0.417)(3.930)} = 0.0971\ \mathrm{hr\ ft\ °F/Btu}$$

Then, check the assumed air film temperature:

$$T_S = T_A + (T_W - T_A)(\frac{R_A}{R_A + R_I + R_P})$$

$$T_S = -40 + (40 - (-40))(\frac{0.0971}{0.0971 + 6.116 + 0.1396})$$

= -40 + (80)(0.0153)

= −38.78°F (versus assumed −39.0°F, which is close enough).

If the values did not check, it would be necessary to repeat the calculation with another assumed T_S until a reasonable check is attained. The combined thermal resistance (R_C) is:

$R_C = R_A + R_I + R_P$

= 0.0971 + 6.116 + 0.139 = 6.352 hr ft °F/Btu

The rate of heat loss (Q) is:

$$Q = \frac{(T_W + T_A)}{R_C}$$

$$Q = \frac{(40 + (-40))}{6.352}$$

= 12.59 Btu/hr linear ft of pipe.

C-5 EXAMPLE 5

Compare the heat losses for the water pipe in Example 4 if installed at Utqiagvik, Alaska, aboveground or at a depth of 4 ft. Assume the minimum air temperature is −58°F, and the minimum mean daily soil temperature at a depth of 4 ft is 1.4°F. The thermal conductivity of the soil is 1.2 Btu/ft hr °F.

(1) Aboveground installation. Assume a 5-inch interior diameter plastic pipe with 2 inches of polyurethane insulation:

R_C = 6.254 hr ft °F/Btu (from Example 4).

The water inside the pipe will be maintained at 40°F so that the maximum rate of heat loss:

$$Q = \frac{(T_W - T_A)}{R_C}$$

$$Q = \frac{(40 - (-58))}{6.254}$$

= 15.5 Btu/hr linear ft of pipe.

(2) *Buried installation*. Assume that the top of the pipe is 4 ft below the surface, and the radius to the outer surface is 5 inches (0.416 ft). The depth to center of the pipe H_P is 4.416 ft, and the radius of pipe r_P is 0.416 ft, therefore the condition H_p is greater than $2r_p$ is true. So, from Figure 12-3 column (a), the thermal resistance of the soil (R_S) is:

$$R_S = \frac{ln(2\,H_P/r_P)}{2\pi k_S}$$

$$R_S = \frac{ln[2(4.416/0.416)]}{2(3.14)(1.2)}$$

= 0.405 hr ft °F/Btu

The air film is not a factor for a buried pipe of this type, so the combined resistance R_C equals:

$R_c = R_P + R_I + R_S$

= 0.1396 + 6.116 + 0.405
(R_P and R_I from the previous example)

= 6.661 hr ft °F/Btu

So, the heat loss Q equals: $Q = \frac{(T_W - T_G)}{R_C}$

T_G in this case is soil temperature 1.4°F

$$Q = \frac{(40 - 1.4)}{6.661}$$

= 5.79 Btu/hr linear ft of pipe.

This is about one-third the heat loss rate calculated for an above

ground installation in the same location. The responsible factor is the attenuation of the extreme surface temperature at the 4-ft depth.

C-6 EXAMPLE 6

Determine the mean size of the thaw zone and the average rate of heat loss from a 6-inch steel pipe buried 4 ft below the surface in a clay soil, where the soil thermal conductivities are as follows: k_t (thawed) = 0.60 Btu/hr ft °F, and k_f (frozen) = 1.0 Btu/hr ft °F. Mean soil temperature at the ground surface is 27.5°F, and the water in the pipe is maintained at 45 °F. (See Figure 12-3 column (b) for schematic, symbols, and equations). A bare steel pipe has negligible thermal resistance, so:

R_P = 0

Outer pipe radius r_P = 6 inch/(2)(12) = 0.25 ft

Depth to center of pipe H_P = 4.0 ft

$$T'_W = \frac{k_t}{k_f}(T_W - T_0) + T_0$$

Where:

T_W = water temperature inside pipe

T_0 = soil temperature at interface of the thawed zone

= 32°F

$$T'_W = \frac{0.6}{1.0}(45 - 32) + 32 = 39.8\ °\text{F}$$

$$T' = \frac{T_0 - T_G}{T'_W - T_G}$$

T_G = temperature at ground surface

$$T' = \frac{32 - 27.5}{39.8 - 27.5} = \frac{4.5}{12.3} = 0.366\ °\text{F}$$

Depth to center of thawed zone, H_Z = *(c)(coth A)*

Radius of thawed zone, r_Z = *(c)(csch A)*

$$c = (H_P^2 - r_P^2)^{1/2} = (4^2 - 0.25^2)^{1/2} = 3.99\ \text{ft}$$

$$A = T' \operatorname{arcosh}(H_P / r_P)$$

If $H_P \geq 2r_P$

$$A \cong T' \ln(2H_P / r_P) = (0.366)(3.466) = 1.268$$

$$H_Z = (3.99)(\coth 1.268) = (3.99)(1.172) = 4.68 \text{ ft}$$

$$r_Z = (3.99)(\operatorname{csch} 1.268) = (3.99)(0.5215) = 2.08 \text{ ft}$$

The thaw zone, under steady state conditions, will be a cylinder of soil enclosing and parallel to the pipe. The radius of this zone will be 2.08 ft, and the axis will be about 5.2 inches below the bottom of the pipe:

The axis = $H_Z - (H_P + r_P) = 4.68 - 4.25 = 0.43$ ft = 5.2 inches below pipe

The heat loss (Q) from this pipe would be:

$$Q = \frac{T'_W - T_G}{R'_S}$$

$$R'_S = \frac{\operatorname{arcosh}(H_P/r_P)}{2\pi k_f}$$

If $H_P \geq 2r_P$:

$$R'_S = \frac{\ln(2\,H_P/r_P)}{2\pi k_f}$$

$$R'_S = \frac{\ln[2(4.0/0.25)]}{2(3.14)(1.0)} = 0.552 \text{ hr ft °F/Btu}$$

$$Q = \frac{(39.8 - 27.5)}{0.552} = 22.3\ \frac{\text{Btu}}{\text{hr}} \text{LF of pipe}$$

C-7 EXAMPLE 7

Determine the design time, the safety factor time and the complete freezing time for the pipe designed in Example 4 if the water stopped flowing. From Example 4, assume a 5-inch interior diameter plastic pipe with 2-inches of polyurethane insulation, constructed aboveground. The temperature of the water flowing into the pipe (T_1) is 40°F, the ambient air temperature (T_A) is −40°F, and the wind speed is15 mph. Use equations from Figure 12-1.

Design time equals the time for water in pipe to drop to freezing temperature (32°F); see Figure 12-2 for definition of terms.

$$t_D = \pi r_W^2 RC\, ln\left[\frac{T_1 - T_A}{T_0 - T_A}\right]$$

$$t_D = (3.14)(0.2080)^2(6.306)(62.4)\, ln\left[\frac{40-(-40)}{32-(-40)}\right] = 5.6 \text{ hr}$$

Safety factor time equals the time for water in the pipe to reach nucleation temperature for ice formation. Assume 27°F.

Substitute 27°F for T_2 in previous equation:

$$T_{SF} = (3.14)(0.208)^2(6.306)(62.4)\, ln\left[\frac{40-(-40)}{27-(-40)}\right] = 9.5 \text{ hr}$$

Complete freezing time equals the time for water at 32°F in pipe to freeze completely solid.

$$T_F = \frac{\pi r_W^2 RL}{T_0 - T_A}$$

Where:

L = volumetric latent heat of water

= (144 Btu/lb)(62.4 lb/ft^3)

= 8986 Btu/ft^3

Other factors are as defined above.

Therefore:

$$T_F = \frac{(3.14)\pi(0.208)^2(6.306)(8986)}{32-(-40)} = 107 \text{ hrs}$$

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APPENDIX D GLOSSARY

D-1 ACRONYMS

ADEC	Alaska Department of Environmental Conservation
AFB	Air Force Base
AFCEC	Air Force Civil Engineer Center
ASCE	American Society of Civil Engineers
BIA	Bilateral Infrastructure Agreements
Btu	British thermal unit
C	Celsius
cm	Centimeter
CCR	Criteria Change Request
DoR	Designer of Record
DDC	Direct Digital Control
F	Fahrenheit
ft	Feet
FGS	Final Governing Standards
GNWT	Government of the Northwest Territories
HQUSACE	Headquarters, US Army Corps of Engineers
HDPE	High Density Polyethylene
HNFA	Host Nation Funded Construction Agreements
hr	Hour
IFS	Installation Facility Standard
kPa	Kilopascal
m	Meter
mph	Miles per hour

NAVFAC	Naval Facilities Engineering Systems Command
OEBGD	Overseas Environmental Baseline Guidance Document
POL	Petroleum, oil, and lubricant
PVC	Polyvinyl Chloride
pcf	Pounds per cubic ft
psi	Pound per square inch
s	Seconds
SOFA	Status of Forces Agreements
UFC	Unified Facilities Criteria
W	Watt
WBDG	Whole Building Design Guide

APPENDIX E REFERENCES

AMERICAN SOCIETY OF CIVIL ENGINEERS

https://ascelibrary.org

Cold Regions Utilities Monograph, https://doi.org/10.1061/9780784401927

AMERICAN SOCIETY OF HEATING, REFRIGERATION AND AIR-CONDITIONING ENGINEERS

https://www.ashrae.org/

District Heating Guide

Guide for Resilient Thermal Energy Systems Design in Cold and Arctic Climates, A. Zhivov (ed.)

AMERICAN SOCIETY FOR TESTING AND MATERIALS

https://www.astm.org

ASTM F2620, *Standard Practice for Heat Fusion Joining of Polyethylene Pipe and Fittings*

AMERICAN WATER WORKS ASSOCIATION

https://www.awwa.org/

AWWA C502, Dry-Barrel Fire Hydrants

INTERNATIONAL CODE COUNCIL

http://www.iccsafe.org/

International Building Code

STATE OF ALASKA

https://dec.alaska.gov/commish/regulations/

Standard 18 AAC 72, *Wastewater Treatment and Disposal, ADEC*

Standard 18 AAC 74, *Water and Wastewater Operator Certification and Training, ADEC*

Standard 18 AAC 80, *Drinking Water*, ADEC

UNIFIED FACILITIES CRITERIA

https://www.wbdg.org/dod/ufc

Consult active UFCs for all aspects of design, including but not limited to:

UFC 1-200-01, *DoD Building Code*

UFC 1-200-02, *High Performance and Sustainable Building Requirements*

UFC 2-100-01, *Installation Master Planning*

UFC 3-130-01, *Arctic and Subarctic Engineering*

UFC 3-130-02, *Arctic and Subarctic Site Assessment and Selection*

UFC 3-130-03, *Arctic and Subarctic Foundations for Freezing and Thawing Conditions*

UFC 3-130-04, *Arctic and Subarctic Buildings*

UFC 3-201-01, *Civil Engineering*

UFC 3-230-01, *Water Storage, Distribution, and Treatment*

UFC 3-230-02, *Operation and Maintenance: Water Supply Systems*

UFC 3-240-01, *Wastewater Collection and Treatment*

UFC 3-410-02, *Direct Digital Control for HVAC and Other Building Control Systems*

UFC 3-430-05, *Natural Gas and Liquified Petroleum Gas (LPG) Distribution Pipelines*

UFC 3-501-01, *Electrical Engineering*

UFC 3-550-01, *Exterior Electrical Power Distribution*

UFC 3-600-01, *Fire Protection Engineering for Facilities*

UFC 3-410-01, *Heating, Ventilating, and Air Conditioning Systems*

UFC 4-010-06, *Cybersecurity of Facility-Related Control Systems*

UNIFIED FACILITIES GUIDE SPECIFICATIONS

https://www.wbdg.org/dod/ufgs

UFGS 23 07 00, *Thermal Insulation for Mechanical Systems*

UFGS 33 11 00, *Water Utility Distribution Piping*

UFGS 33 30 00, *Sanitary Sewerage*

UNITED STATES GEOLOGICAL SERVICE

https://waterdata.usgs.gov/nwis

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OTHER

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Underground Utility Lines, Technical Translation TT-1221, G.V. Prokhaer, National Research Council, Ottawa, Ontario, 1959

Water Supply Systems in Frozen Ground, L.R. Janson, in *Proceedings International Permafrost Conference,* 403–433, National Academy of Science, Washington, D.C., 1966