Module 6
Water Supply and Waste Treatment in the Arctic

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Key Terms and Concepts

- drinking water
- lagoons
- sewage
- water-borne disease

Learning Objectives/Outcomes

Upon completion of this module, you should be able to

1. explain why a clean drinking water supply is essential to good human health.
2. explain why improper treatment of waste water can lead to disease epidemics, particularly in the Arctic.
3. describe how water is treated for communities in an attempt to promote good health.
4. describe how sewage, or waste water, is treated to prevent contamination of the environment and potential water supplies.
5. list several different types of water sources suitable for supplying drinking water.
6. list several different ways to treat drinking water for human consumption.

Reading Assignment

D. Smith (1996), *Cold Regions Utilities Monograph*, chapters 1 and 2 (Reston, VA: American Society of Civil Engineers).

Overview

The goal of this module is to discuss water and waste water management options for Arctic communities. The module begins with a discussion of the relationship between clean water and disease in Arctic communities. An overview of how water is collected and treated for human consumption in the Arctic is then presented. Finally, methods for waste water treatment and disposal are discussed.

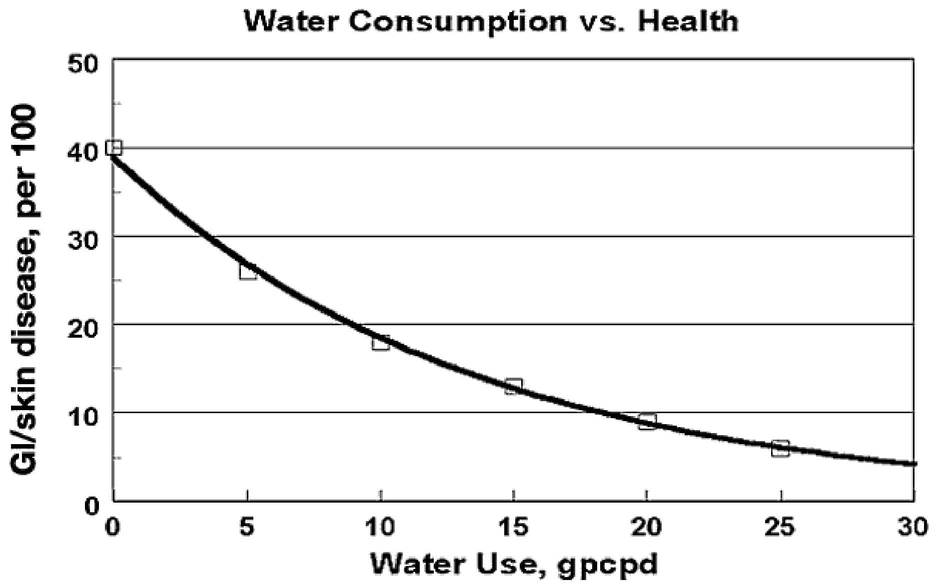
Lecture

The Role of Sanitation in Community Health

The Link between Disease and Water-borne Pathogens

Communities in northern Canada, Alaska, Scandinavia, and Russia have a long history of disease outbreaks. For example, high incidences of gastrointestinal illness as well outbreaks of more serious diseases, such as hepatits A, bronchitis, impetigo, and meningitis have been observed in Alaska's Aboriginal communities (Congress of the United States 1994). In many cases, these outbreaks have been attributed to inadequate sanitation facilities.

There are several reasons for the relatively large number of disease outbreaks observed in Arctic communities. Perhaps the most important is the lack of adequate amounts of running water to wash hands, flush toilets, and perform basic personal hygiene. Diseases linked to poor hygiene include gastroenteritis, diarrhea, skin and eye diseases, and other diseases transmitted through fecal-oral routes (Esrey 1996). As shown in figure 6.1, data from a study of communities in the Northwest Territories in Canada show that the incidence of gastrointestinal illness and skin disease are tied closely to the water use rate. Other factors apart from water and sanitation practice influence gastroenteritis and skin diseases; but, in general, the relationship between drinking water quantity and health has been well established (WHO 2003).



Source: Modified from Robinson and Heinke (1990)

Fig. 6.1 Link between disease rate and water use rate for three communities in the Northwest Territories

Contact with water-borne pathogens present in (or in some cases direct contact with) domestic waste water is a common mechanism by which diseases are transmitted in Arctic communities. In temperate climates, natural processes tend to reduce organic wastes and help to speed the inactivation of infectious materials. In the Arctic, however, permafrost and extended periods of cold tend to prolong the period during which waste and pathogens persist in the environment. The lack of waste water collection, treatment, and disposal systems increase the risk of disease, both by reducing a person's ability to maintain personal hygiene and by increasing the likelihood of disease transmission through contact with raw sewage. Liquid waste water disposal is particularly difficult to manage when there are no sewer collection systems. Improper handling and indiscriminate disposal of waste water in the living environment adds not only to environmental pollution, but also to degradation of public health.

Providing adequate sanitary infrastructure is a major challenge faced by most Arctic communities. Constructing safe water and waste water systems in cold regions is difficult, time consuming, and extremely expensive in comparison with more temperate locations. A greater emphasis on cold regions engineering—with concern over operating expense, heat loss, and redundant systems to ensure reliable operation—and high-quality materials are all factors that are required for system design and construction. Over the last 40 years, more than US$1 billion in capital construction funds have been used to provide water and sewer systems in Alaska.

Water Quality and Health

The United States and Canada regulate community water supplies at the national and state or provincial/territorial levels to ensure quality. All water suppliers must have a permit and periodically test the water to ensure that the water is safe. In the United States, federal legislation passed in 1972 established the Safe Drinking Water Act (SDWA). The purpose of the act was to protect the public from contaminated water supplies. The SDWA requires the federal Environmental Protection Agency (EPA) to identify contaminants in drinking water that may have an adverse effect on peoples' health and to establish maximum contaminant levels (MCLs). MCLs established include criteria for bacteria, inorganic and organic chemicals, physical parameters, and radionuclides.

Water Supplies in the Arctic

Groundwater

Availability

Groundwater in the Arctic is normally only available in thaw bulbs of deep lakes and rivers. In order for a stream to have a thaw bulb, it must flow year-round. If the stream freezes during winter, the permafrost will normally remain stable beneath the riverbed. Depending on the size of the river or lake, water in the thaw bulb may be sufficient to supply a community's needs.

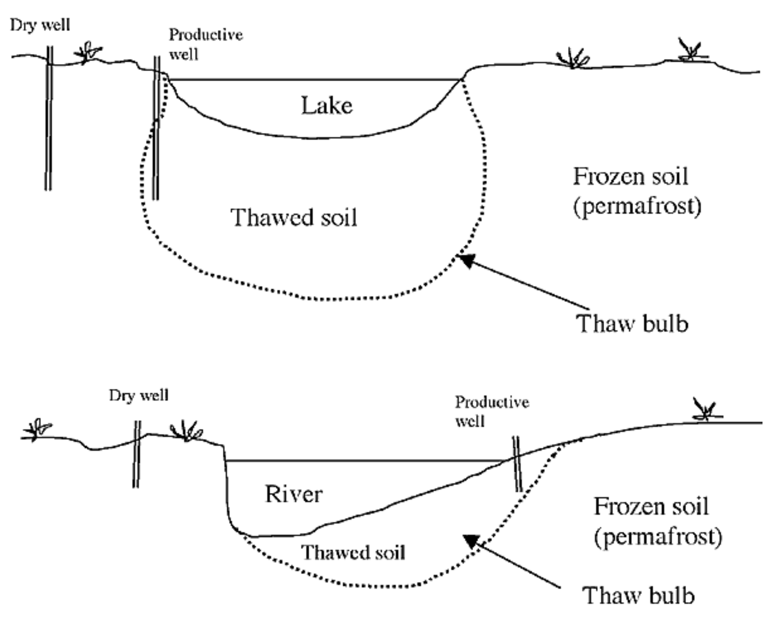


Fig. 6.2 Illustration of a thaw bulb beneath a lake and river. A thaw bulb such as these ones may be valuable sources of fresh, unfrozen water.

In some cases, groundwater may be available below the permafrost, but the water may be very deep and difficult to recover using conventional water well technology. The deeper the water, the older the water is—and the more likely it is to have unacceptable levels of dissolved minerals.

Groundwater in the Arctic is also sometimes considered to be the water that accumulates in the thin layer of soil that thaws in the summer. Since the thaw layer normally reaches only 1 metre in thickness in the summer, the water is normally of very limited extent and difficult to collect. Water that collects in the seasonal thaw layer would normally not be sufficient in quantity to serve a community's needs. (See fig. 6.3.)

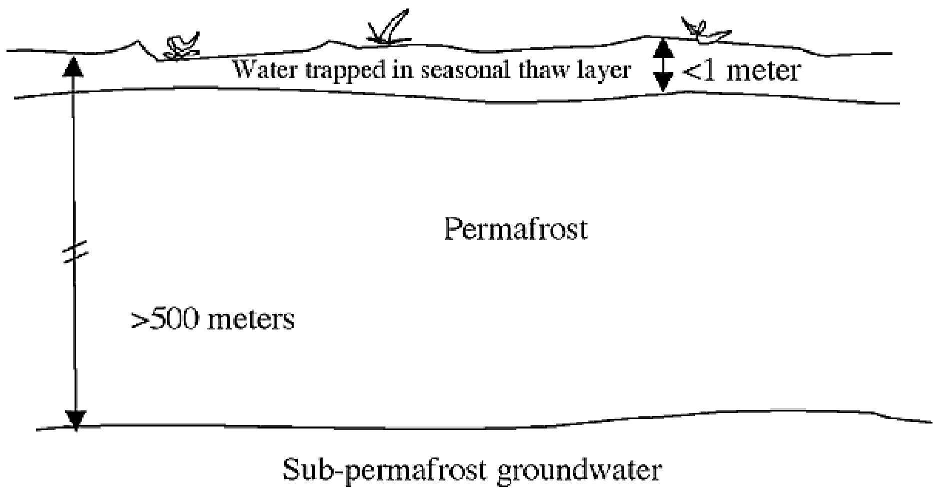


Fig. 6.3 Illustration of "groundwater" above and below permafrost

Quality

The primary health concern with groundwater is normally associated with elements or compounds that dissolve in water during its prolonged contact with minerals in the subsurface. These may include arsenic, copper, radon, iron, lead, and radionuclides. In cases where groundwater is under the direct influence of surface water (for example in the shallow thaw bulb of a river or lake), the presence of pathogens may also be of concern.

In general, the deeper the groundwater source, the less the water quality changes over the course of the seasons from year to year. The water from a deep groundwater source may be hundreds of years old and is very stable in quality. The water quality in a shallow thaw bulb, however, may change from year to year, depending on ice cover and seasonal precipitation.

Surface Water

Availability

In the Arctic, surface water sources for drinking water include lakes and rivers, but also small ponds, wetlands, surface infiltration galleries, and small impoundments. With some exceptions, most of the precipitation in the Arctic is trapped atop impermeable permafrost, creating numerous water bodies that are relatively shallow. Except for a few of the deeper rivers and lakes in the Arctic, most streams and lakes freeze to the bottom during the winter. These sources are only viable as a community water source if the supply can be collected during the warm months and stored during the winter to prevent freezing.

In some cases, surface water is collected in the form of snow or ice. Snow can be harvested for drinking water by trapping blowing snow behind tall fences. Ice, on the other hand, can be cut into blocks from frozen surface water bodies, such lakes or rivers. Snow and ice may be good supplemental sources of drinking water for individual residences, but they are difficult to use as a primary source of drinking water unless carefully designed facilities are in place. One Arctic community that uses a snow fence to collect drinking water in the form of snow is the village of Shishmaref, on the northern coast of the Seward Peninsula. When the snow collected melts in the spring, it supplies the community with a source of drinking water for the entire year.

Since water excludes impurities during the freezing process, snow and ice can be relatively free of contaminants. However, snow and ice cannot be used as a drinking water source unless it is properly disinfected because the harvesting process itself often leads to contamination of the water when the snow and ice melts.

Quality

Surface water in the Arctic generally contains dissolved and suspended inorganic and organic compounds. One of the most problematic contaminants is the natural organic material (NOM) that leaches from the vast Arctic peat deposits. If the organic matter is not removed from the water prior to chlorine disinfection, compounds harmful to human health may be formed. In addition, surface waters in the Arctic carry biological contaminants, including *Giardia lamblia* and *Cryptosporidium parvum*, which are known human pathogens. Since many birds breed in the Arctic, the shallow ponds and wetlands can be frequented by many different avian species over the course of the short summer season. Birds are well-known carriers of human pathogens. (Esrey 1996)

Water Treatment Options for Arctic Communities

The type of water treatment process that should be used in an Arctic community depends on the quality of the available source water and the treatment objectives. In addition to the objective of reaching a desired quality of water, surface water sources and groundwater sources under the direct influence of surface water must be treated to comply with multiple water treatment regulations. Several other factors related to water quantity, including operating costs, system reliability, and goals and objectives of the community and users enter into selection of a water treatment process. Surface water treatment requirements include filtration and disinfection, as well as other parameter-specific water treatment processes to address removal of contaminants whose concentrations exceed drinking water standards.

Water treatment can be simplified into a number of unit processes, each intended to remove one or more contaminants, or groups of contaminants, from the water. For example, water softening is intended to remove calcium (Ca^{2+}) and magnesium (Mg^{2+}) from water. The Ca^{2+} and Mg^{2+} are called "hardness," and excessive quantities of these compounds can cause accumulations of white precipitates to form on fixtures and in boilers. While water softening makes water more aesthetically pleasing, the most important water treatment processes are those that protect human health. Filtration and disinfection are two processes designed to remove human pathogens from water.

Filtration

Drinking water filtration in the Arctic is often accomplished by using cartridge or bag, granular media, or membrane filtration. In most cases, filtration is used to remove particulates and pathogens from surface waters before disinfection. However, some groundwaters that contain high concentrations of iron and manganese can also be treated using filtration technologies.

Cartridge or Bag Filtration

Cartridge or bag filters are typically constructed of natural or synthetic polymer materials, with nominal filter pore size ratings ranging between 1 and 200 micrometers (microns). These filters are effective at removing colloidal-sized materials and are often used on small systems where the source water has consistently low turbidity. Once the cartridge or bag filter becomes loaded with debris captured in the filter medium, the filter must be discarded and replaced. Cartridge or bag filters will pass dissolved water contaminants. Some cartridge or bag filters can have small-enough pore sizes to trap harmful protozoans, such as *Giardia* and *Cryptosporidium*. Cartridge and bag filters are not, however, designed to remove bacteria and viruses that can cause human diseases.

Granular Media Filtration

In granular media filtration, particulates are removed from water when it is passed through a bed of granular media. Clean, high-quality sands and gravel (and occasionally antracite coal) that have specific grain sizes are commonly used in granular media filters. In some cases, a medium called "green sand" is used. Green sand filters contain a medium that acts as a filter and as an oxidizer, aiding in the removal of dissolved iron and manganese.

Granular media filters can operate in what is called gravity mode. In these systems, the water pressure needed to force water through the filter is supplied by gravity. Filters are open to the atmosphere and two to three feet (about a metre) of water is maintained above the filter. Granular media "pressure filters," on the other hand, are closed to the atmosphere and can maintain a source water's pressure at the inlet to the treatment plant. For example, if the water source is a high mountain lake, water piped down the mountain to the community will be under high pressure. This pressure can be adequate to force water through a granular medium. If this head is sufficient, use of pressure filter vessels can also eliminate the need to use service pumps downstream of the treatment plant to pressurize the distribution system with potable water.

A combination of mechanisms allows both gravity and pressure filters to effectively remove particles. While some physical straining of the particles occurs in granular media filters, effective removal of the micron-sized colloids, such as bacteria, typically requires that a chemical coagulant be added to the water to make the particles stick to the filter medium. In order to ensure extended operations of the filter medium and reliable effluent water quality, effective backwashing of the granular filter medium is critical. Backwashing is the process in which the water flow is reversed. This reversal dislodges the particles removed by the filter. The backwash water is collected and treated as waste water. A pressure filter is shown in figure 6.4.

Fig. 6.4 In this figure, the green and blue steel tank in the background is a granular media pressure filter. The filter stands approximately 6 feet (2 metres) tall and is approximately 3 feet (1 metre) in diameter. In the foreground is a bag filter. Inside the stainless steel canister is a bag, much like the bag in a vacuum cleaner. The system shown is in the Arctic community of Nuiqsut in Alaska.

Membrane Filtration

Membrane water treatment systems are filtration processes that separate colloidal and/or dissolved contaminants from the source water by means of passing the water through membrane filters (see fig. 6.5.). There are four groups of membrane processes. These are microfiltration (MF), ultrafiltration (UF), nanofiltation (NF), and reverse osmosis (RO). All four types of filters are constructed of cast polymer materials. MF and UF processes are used to remove colloidal contaminants including microbial pathogens such as *Giardia lamblia* and *Cryptosporidium parvum* from source waters. Separation of colloidal materials from the feed water is achieved primarily on the basis of size exclusion or straining. MF membranes have a range of pore sizes from 0.1 to 0.4 microns, and UF membranes have pore sizes that range from 0.01 to 0.2 microns. Both types of membranes are typically offered in a configuration where they are periodically backwashed to remove captured particulate material. If the objective of water treatment includes removal of dissolved contaminants such as NOM, which imparts a yellow-brown colour to water, then NF membranes can be used. If the objective of treatment is to remove dissolved salts, such as Ca^{2+} and Mg^{2+}, then RO membranes are used. NF and RO membranes reject dissolved contaminants on the basis of both physical size exclusion and differences in molecular charge and diffusivity. Pore sizes for NF and RO membranes are usually expressed in terms of molecular weight, or daltons, and range between 100 and 400 daltons for NF and 20 to 100 daltons for RO. Membrane filtration systems can assume a number of configurations. MF and UF membranes are often configured as hollow fibre membranes, while NF and RO membranes are configured as sheets of membranes wound around a perforated core tube.

Fig. 6.5 The white tubes shown on the left are nanofilter pressure vessels. Inside the 20 plus–foot long vessels are membranes that separate dissolved contaminants from water. The tan-coloured columns on the right are pressure vessels containing microfilter membranes. These membranes remove colloidal matter from the water. Untreated water first passes through the microfilter and then through the nanofitler for complete treatment. The system shown is in the Arctic community of Nuiqsut, Alaska.

Disinfection

Disinfection is the inactivation or destruction of disease-causing micro-organisms. A variety of agents can be used, but disinfection is most commonly accomplished by use of chemicals, such as chlorine in the gaseous or liquid form (calcium or sodium hypochlorite), or chlorine in combination with ammonia (chloramination). Other oxidants such as ozone and chlorine dioxide are used, as well as physical agents such as heat (boiling) and light (ultraviolet radiation). Practical considerations for small systems in the Arctic limit the options to chemical disinfection with chlorine, ozone, and UV radiation.

Chlorine disinfection has been used for more than 100 years and is the most widely used water treatment method in the United States. It reduces the viability of micro-organisms by oxidizing the cellular material. Chlorine can be supplied in several forms, including gas, liquid hypochlorite solutions (sodium hypochlorite), and solid calcium hypochlorite. It can also be electrically generated on-site, using a salt (NaCl) brine solution. Small-system installations in the Arctic typically consist of a chemical vat and a small positive displacement diaphragm pump, or direct injection from a hypochlorite generator. The use of chlorine gas is no longer recommended for most Arctic communities.

Ozone is a gas consisting of three oxygen atoms. It is formed by electrical discharge into an air or oxygen stream. It is widely used in European countries, and has only recently been available for small systems in the United States. Ozone is a very strong oxidant and operates by oxidizing cell material in the micro-organism. Ozone decomposes rapidly in water. Ozone is generated by electrical discharge between flat plates or other electrode configurations as air moves across. High-energy, high-intensity light tubes, termed photochemical generators, can also generate ozone. If air is used, a maximum of up to 2% by weight of ozone can be generated. A fan is required to move the air and cool the equipment. After it is generated, the ozone is piped into the water stream for mixing. Because of its toxicity, a system to collect ozone off-gas must be included. Ozone requires large amounts of electricity, so it is expensive to generate and rarely used in the Arctic.

Ultraviolet (UV) radiation causes damage to micro-organism genetic material (DNA or RNA), thus destroying the disease-causing micro-organisms' ability to reproduce. Mercury vapour lights, with many different configurations, produce UV energy. The lamps are normally covered with a quartz glass sheath and immersed into the flowing water, either parallel or perpendicular to the flow direction. Recent research by manufacturers and others that supports the effectiveness of UV radiation for *Giardia* inactivation has allowed greater regulatory acceptance of the technology and the establishment of minimum operating criteria.

Conventional Filtration Package Plants

A conventional filtration “package water” treatment plant is a commercially available, pre-assembled, skid-mounted, modular treatment system designed to be shipped to the project site, connected to water and power, and placed into service. Owing to the fact that these systems are completely integrated, they are popular in the Arctic. Package plants are typically fabricated of steel, although one manufacturer uses an aluminum alloy. Package plants are supplied with integral pumps, chemical feeders, electrical controls, and wiring. They are physically compact and are able to address a variety of source water quality conditions. The major unit processes incorporated into the system are coagulation, flocculation, sedimentation, and filtration. Different coagulants can be used along with polymer flocculent aids to improve end water quality.

Student Activity

1. Where does your water come from?

2. Who is responsible for treating your water?

3. What method is used for treating your water? Why is that method used?

Waste Water Treatment and Disposal in the Arctic

Proper waste water treatment and disposal is critical to good sanitation in the Arctic. Waste water typically has a high concentration of human pathogens, and if it is not treated, the pathogens will remain in the environment and eventually cause disease.

Waste Water Treatment

Decentralized On-site Systems

The homes of individuals or small communities can treat and dispose of waste water in a conventional septic tank/leach field arrangement. Septic tanks are designed to remove solids from waste water. Waste water free of solids can then flow out of the septic tank and into a leach field. The leach field is a bed of gravel and rock in which micro-organisms break down organic components of the waste water as it seeps into the ground. Septic tank/leach field arrangements are uncommon in the Arctic because settled waste water will not percolate into frozen soil. In some areas where thaw bulbs are left in permafrost from rivers or lakes, septic systems can be used. For a leach field, all waste water must be discharged underground.

Individual fixed activated sludge processes are another type of waste treatment that can be used in the Arctic. In a fixed activated sludge process, bacteria are grown on a plastic media. As the waste water passes over the plastic medium, the micro-organisms degrade organic components of the waste water. When the organic matter is decomposed, the waste water can be disinfected using ultraviolet light and in some cases discharged on the ground surface.

Decentralized, on-site systems can be successful waste water treatments in the Arctic, where soils are sufficiently thawed (septic tank/leach field) or where power is available to operate a fixed activated sludge systems. All on-site systems periodically require pumping of solids that accumulate. Unless these solids are disposed of according to federal regulations, they can be a significant source of human pathogens.

Centralized Mechanical Treatment Plants

Mechanical treatment plants use a combination of biological and physical processes to treat waste water. Tanks, pumps, blowers, controls, and other mechanical components are used. For small waste water flows, "package" plants are typically used. In mechanical treatment plants, the waste water is aerated in the presence of bacteria. The bacteria break down the organic matter in the waste water. A method of separating the solids from the liquid is required, along with methods of treating and/or disposing of the solids. Advantages of mechanical package plants include the very small land area required, in comparison with the lagoons (discussed below); the potential for a very high waste water quality effluent that can be discharged to surface water bodies or drainage courses; and the relatively low capital construction costs.

Disadvantages to mechanical treatment plants include the need for a skilled and dedicated operations staff, a building structure to house the process, high energy requirements, and the need to consistently operate and maintain the facilities.

Lagoons

Lagoons are typically large earthen basins intended to allow micro-organisms to break down waste water constituents over a long period of time. Lagoons are often considered "natural" treatment processes. Most lagoons are designed to allow micro-organisms that use oxygen to break down the waste.

Facultative lagoons are the most common method of waste water treatment in the Arctic (see fig. 6.6). In a facultative lagoon, aeration is provided by wind action and algae. Several different operating modes have been used, such as continuous discharge and seasonal discharge. Because waste water flows continuously, the most attractive lagoon design also discharges continuously. In the Arctic, however, the river or lake the lagoon discharges to may be frozen much of the year. Because lagoon effluent may not be discharged to a frozen water body, the lagoon must be large enough to collect and hold all the waste water while the receiving lake or river is frozen. This is called a seasonal discharge lagoon.

Advantages of facultative lagoons include the ability to meet waste water quality criteria on a consistent basis; the ease of operation; and the low maintenance requirements. The disadvantages of facultative lagoons include the need for a relatively large land area, high capital costs, periodic odours after periods of ice cover, and aesthetic concerns related to location.

Fig. 6.6 Example of a facultative lagoon for waste water treatment near Denali National Park and Preserve. Note the ice cover and spring thaw.

Aerated lagoons are modifications of the facultative lagoon process in which oxygen is supplied to micro-organisms by mechanical means. Aerated lagoons are typically deeper, and because oxygen addition is supplied mechanically, the surface areas are much smaller than those required for facultative lagoons. Several different methods of mechanical aeration have been used, including fixed-bottom coarse diffusers, surface aerators, and fine-pore diffusers.

Advantages of aerated lagoons include smaller land area compared to facultative lagoons, with resulting lower-capital construction cost, the ability to control the quality of the waste water discharged through the aeration process, and high-quality effluent under proper operating conditions. Disadvantages include higher operation expenses associated with air blower operation and the need for periodic maintenance and repair to the aeration system components. Failure to properly operate and maintain the system would result in anaerobic conditions, with resulting poor effluent quality, odours and public complaints.

Waste Water Disposal

After treatment, disposal of waste water to a surface water body can be permitted by state and federal regulatory agencies. Waste water treatment objectives typically focus on the reduction of organic material as measured by biological oxygen demand (BOD) and suspended solids. Owing to cold temperatures, very little reduction in pathogenic micro-organisms occurs during the natural process as occurs in waste water lagoons. In the past, treated waste water was disinfected with chlorine. Because of the toxic effect of chlorine on fish, this practice was discontinued, or the waste water is dechlorinated prior to discharge. Several other means of disinfection, such as ultraviolet light and ozone, are also used to disinfect waste water.

Options for land disposal of waste water include discharge to natural or constructed wetlands. The soil conditions and vegetative cover provide a combination of additional treatment and disposal of the waste water effluent. Regulators have showed renewed interest in land applications, and permitting is now more acceptable.

Percolation cells are large, fenced areas in which treated waste water is allowed to percolate into the soil. Percolation cells rely on the liquid movement through the pores and voids in the subsurface soil for disposal. Site-specific conditions determine whether this method of disposal is a viable option. Percolation cells have been used in frozen soil conditions, in which the percolation occurs horizontally through the active layer. In some cases, the organic soil covering has been removed, the ground permitted to thaw, and rock fill placed into a berm for use for percolation.

Summary

Good sanitation is critical for human health. Nowhere is this more important than in the Arctic. Good sanitation means both clean water and proper waste water disposal. Since pathogens are long-lived in the Arctic environment, it is critical that water be well treated before use. It is also critical that sufficient water be used for drinking, cooking, and cleaning to keep pathogenic micro-organisms out of the food chain.

The options for water collection and treatment are limited in the Arctic. While groundwater may be a good source of thawed water in some areas, groundwater is largely unavailable in the Arctic, where the ground is permanently frozen (i.e., permafrost). Surface lakes and rivers can also be a viable source of fresh water in the Arctic but may be frozen solid for 6–9 months of the year.

Water treatment in the Arctic must be compact and able to operate in a harsh climate. Filtration technologies are the most common method by which water is treated in the Arctic. These technologies range from bag filters to reverse osmosis membranes. Even when the best filters are used, water must be disinfected to protect humans from pathogens.

In order to protect the environment and human health, waste water must be treated to reduce the viability of pathogens and reduce the concentration of organic matter. Whereas many rural regions of the world use conventional septic tanks/leach fields to treat waste water, these systems fail in frozen ground. In the Arctic, waste water lagoons are the most common method of waste water treatment.

Supplementary Reading

On the topic of small and decentralized waste water treatment systems, see Mackenzie L. Davis and David A. Cornwell (1998), *Introduction to Environmental Engineering* (third edition, New York: McGraw-Hill Book Co.

Study Questions

1. Explain why clean drinking water is essential to good human health.
2. Explain why improper treatment of waste water can lead to disease epidemics, particularly in the Arctic?
3. Explain two water treatment technologies that would lend themselves to Arctic applications.
4. What is the most common waste water treatment technology in the Arctic? Why?
5. In an Arctic tundra region, what are the available sources of fresh water? What is their seasonal availability?

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