
Introduction to Wastewater Collection and Treatment in Cold Regions

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An Introduction to Wastewater Collection and Treatment in Cold Regions



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CONTENTS

1. GENERAL
2. DESIGN CONSIDERATIONS
3. APPURTENANCES
4. PUMP STATIONS
5. PRESSURE SEWERAGE
6. VACUUM SEWERAGE
7. WASTEWATER TREATMENT

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(The Figures, Tables and Formulas in this publication are at times a little difficult to read, but they are the best available. **DO NOT BUY THIS PUBLICATION IF THIS LIMITATION IS UNACCEPTABLE TO YOU.**)

1. GENERAL. The basic criteria for the design of sewage systems for facilities are available in the professional literature. The unique aspects of the design and construction of these systems in cold regions are covered in this publication. Further details on the use of these systems in cold regions are included herein. Moreover, some further details on the use of pressure and vacuum sewers, since the flat terrain and permafrost make it difficult to design a conventional gravity sewer system in the Arctic, are also included. Combined utility systems called utilidors are covered elsewhere. Table 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 in general, facilities are serviced by piped collection systems. Normally, a conventional gravity sewer system has the lowest life-cycle cost and must 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.

2. DESIGN CONSIDERATIONS. The location of the pipe, above or below ground, is critical to satisfactory performance. An above-ground 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 above-ground sewers. Above-ground sewers also hinder transportation, block surface drainage and snow removal, have high heat losses, and are more susceptible to vandalism. The operation and maintenance costs for above-ground systems are about three times higher than those for similar systems buried underground. Above-ground construction costs for a single pipe depend on the foundations required. If the pipe can be laid directly on the surface, construction costs will be 20 to 40 percent of that required for the same pipe installed on piling.

2.1 SEWAGE TEMPERATURES. Domestic wastewater from housing installations in the cold regions will range from 50 to 60 degrees F at the source. Wastewater from facilities not having hot water heaters can be as low as 35 degrees F.

| Type | Soil Condition | Desirable Topography | Economics | Other |
|----------|--|---|--|---|
| Gravity | Non-frost-susceptible or <i>Slightly</i> frost susceptible with gravel backfilling material. | Gently sloping to prevent deep cuts or lift stations. | Initial construction costs high but operational costs low unless must install above ground or use lift stations. | Low Maintenance. Must have adequate grade. Flushing of low use lines may be necessary. Large diameter pipes necessary. |
| Vacuum | Most useful for frost susceptible or bedrock conditions, but can be used with any soil conditions. | Level or gently sloping. | Initial construction cost moderately high. Operational costs moderate. | "Traps" every 300 ft. Low water use. Must have central holding tank for each 30 to 50 services with additional pumps to pump waste to treatment facilities. Can separate gray and black water. Uses small pipes. No exfiltration. |
| Pressure | Most useful for frost susceptible or bedrock conditions, but can be used with any soil conditions. | Level, gently sloping or hilly. | Initial construction costs moderate. Operational costs moderately high. | Low water use if water use fixtures are installed. Number of services not limited. No infiltration. Uses small diameter pipes. |

Table 1
Characteristics of wastewater collection systems

The temperature of wastewater in utilidors can be increased if steam or hot water lines are also included in the utility package. The thermal design of the sewer piping must include these wastewater temperatures for cost-effectiveness. Storm water will not be admitted to sewers in cold regions. It lowers the temperature of the wastewater and increases the cost of pumping, treatment, and disposal.

2.2 PIPE MATERIALS. The materials selected for sewerage systems will be in accordance with the professional standards.

3. APPURTENANCES. These include manholes, cleanouts, building or service connections, and flushing siphons.

3.1 MANHOLES. Figure 1 illustrates typical details for a buried sewer manhole structure in the cold regions. A plastic film wrapped around the outside of the manhole will be required to prevent bonding of the soil to the structure and thereby preventing damage from frost heaving. Typically, such manholes have been insulated with a minimum of 3 inches of polystyrene or urethane around the outside, with a plastic film or other external coating to prevent moisture damage to the insulation. An insulated cover will be provided over the wastewater chamber to further reduce heat loss. A firm foundation is essential, and may require either piling or excavation, and then sand and gravel backfill. If a poured-in-place concrete invert is used in the manhole as shown in Figure 1 and permafrost is at a relatively shallow depth, the concrete will be placed on insulation board to reduce the downward heat losses. Spacing of manholes will be in accordance with professional standards. Solid manhole covers will be required to prevent entry of surface water.

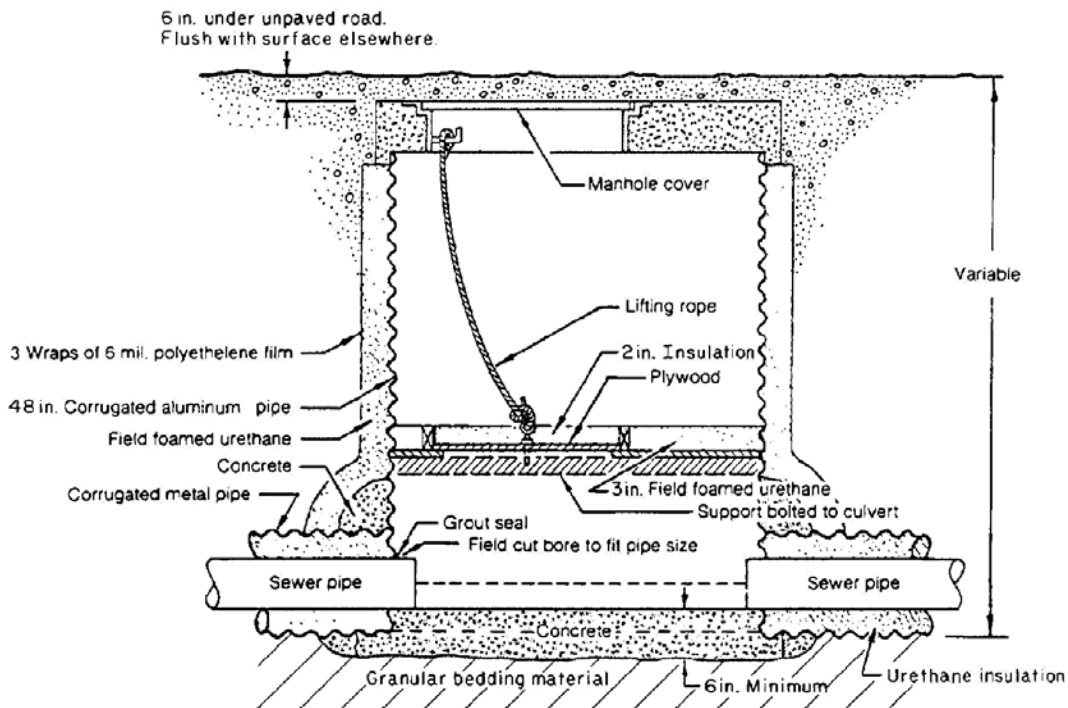


Figure 1

Typical sewer system manhole

3.2 CLEANOUTS. Cleanouts are typically used in building connections and in some cases are installed in place of manholes. They must be used with caution in cold regions since they are difficult to protect and are susceptible to frost heaving. Figure 2 illustrates details of a cleanout that has been successfully used in Canada.

3.3 SIPHONS. Sewers subject to low flows and velocities must be avoided 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 as shown in Figure 3, with proper precautions taken to prohibit cross connections.

3.4 BUILDING CONNECTIONS. Figures 4 and 5, for buildings on pile or post foundations, show typical connections for a gravity sewerage system in cold regions. The wall penetration shown in Figure 4 is more flexible than the floor penetration in Figure 5, and will permit more differential settlement without damage to the sewer line.

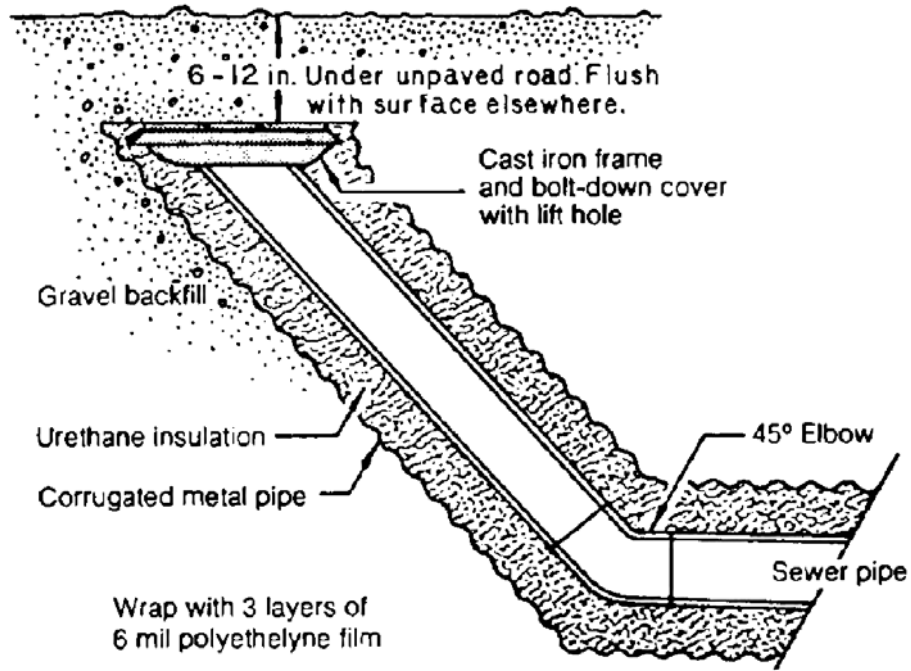


Figure 2
Typical cleanout

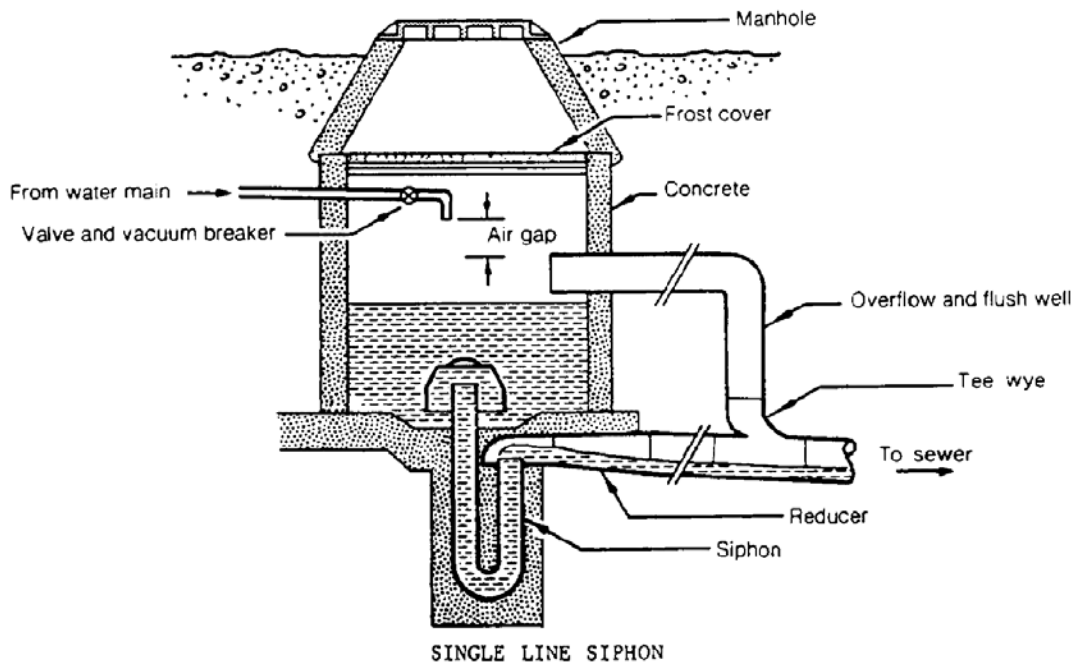


Figure 3
Typical Siphon

4. PUMP STATIONS. The basic hydraulic design of pumping stations will be in accordance with the professional literature. Special requirements and concerns for use in cold regions are discussed below.

4.1 INSULATION. The outside of the station structure will be insulated with at least 3 inches of urethane or polystyrene, with an outer covering to protect the insulation from moisture.

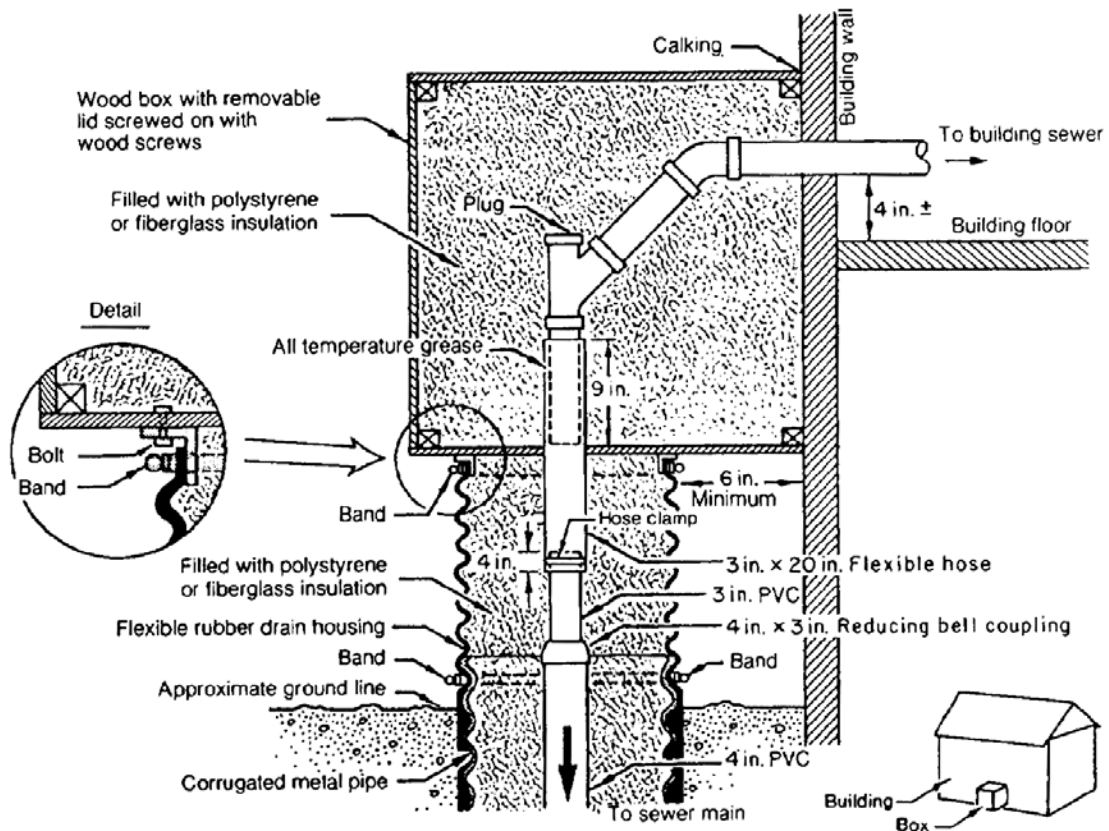


Figure 4
Typical service connection (wall)

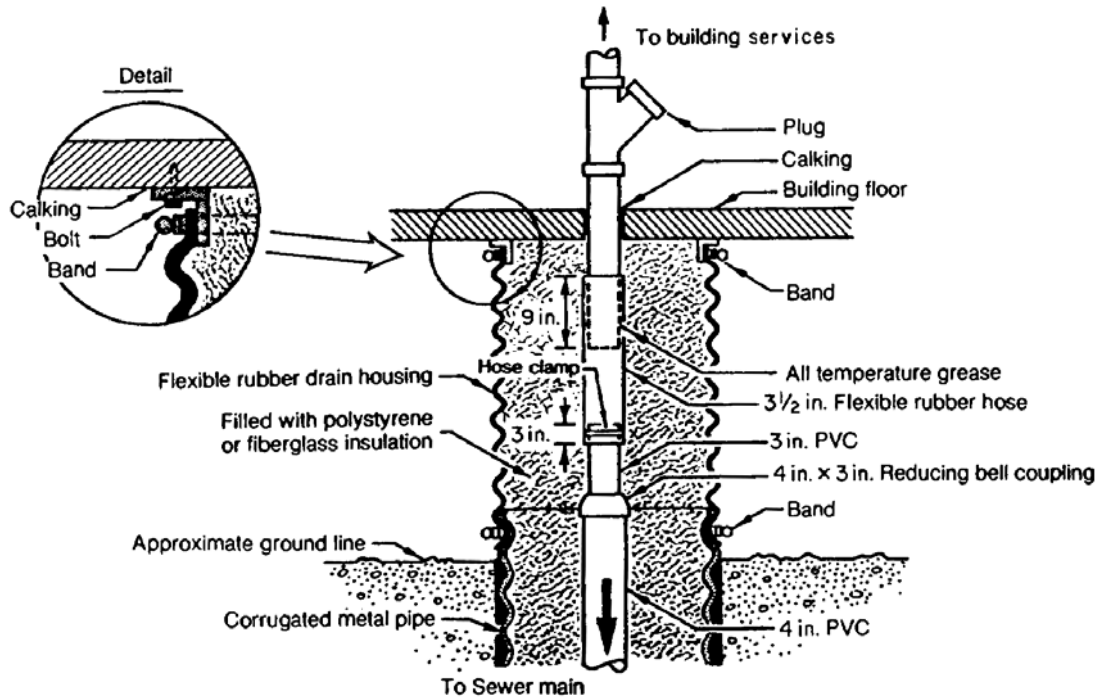


Figure 5

Typical service connection (floor)

Insulation will also be placed beneath the station when permafrost is present at a shallow depth to prevent settling due to ground thaw. A plastic film or some other bond breaker will be required to reduce frost jacking in the active layer. If thawing and settling under the station are anticipated, pile foundations extending well into the permafrost will 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.

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 actually put into service.

4.3 ALARMS. Alarms must be provided. All critical components, such as pumps and compressors, must be duplicated in each station. In addition, alarms must be set to warn of freezing temperatures in the station and to warn of sump pump malfunctions.

4.4 STANDBY POWER. Due to the dangers of freezing associated with extremely low temperatures, standby power facilities must be provided for each major pump station.

4.5 MAINTENANCE. During freezing conditions, each pump station must be checked daily by the operator. All entrance manholes must extend sufficiently above the ground surface to be above any flooding or snow drifts. All pump stations must be supplied with devices for measuring flow rates. Corrosion protection must be provided in accordance with professional standards. Sacrificial anode type systems do not work well when the ground surrounding the anode or pump station is frozen.

4.6 FORCE MAINS. Force mains must be designed to have scour velocities during pumping (2.5 to 3.5 feet 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.

5. PRESSURE SEWERAGE. 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. The hydraulic design of these pressure systems is not unique in cold regions and criteria is found in the professional literature. The pressure piping must be designed to drain by gravity to a low point or sump in case the system has to 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. Water conservation measures in each of the buildings served is required to reduce the costs of equipment and energy for pumping.

6. VACUUM SEWERAGE. Vacuum sewers do not depend on a specific grade for successful operation. They operate at a vacuum of 8-10 psi, and so are limited to an elevation difference of 15 to 20 feet within the system. The hydraulic design is not unique to 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 and/or heated for extreme low temperature conditions. The traps should also be drainable under emergency situations. A 50 house vacuum system in Noorvik, Alaska, was installed in 1977 and has operated successfully since that time.

7. WASTEWATER TREATMENT

7.1 GENERAL. Basic design criteria for domestic wastewater treatment systems can be found in the professional literature. This chapter provides information and guidance on those aspects unique to cold regions and presents general design criteria for those treatment systems most commonly used in the Arctic and Subarctic.

7.2 WASTEWATER CHARACTERISTICS. Wastewater characteristics in the cold regions will generally be different from those in temperate regions, with respect to quantity, quality, and temperature. The total quantity of wastewater discharged at 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.

7.2.1 QUANTITY. The determination of design flows should be based on a special analysis of the installation. The population equivalents and capacity factors presented in the professional literature will 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 will avoid the problem if the design cannot be based on actual flows.

7.2.2 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. For example, a biochemical oxygen demand (BOD) loading of 0.2 pound per capita per day might be assumed. At flow rates of 100 gallons per capita per day, this results in a BOD concentration of about 240 milligrams per liter (mg/L). At remote installations in cold regions, the BOD concentration will normally be over 300

mg/L for domestic wastewater, at the typical flow rates ranging from 60 to 80 gallons per capita per day.

7.2.3 TEMPERATURE. The wastewater temperature at many cold region facilities tends to be at least 50 degrees F due to transmission in insulated lines and sometimes heated lines. The heat available in this incoming wastewater should be considered during process design.

7.2.4 FLOW VARIATIONS. The diurnal flow pattern at installations tends to be the same regardless of climate and must be used to determine peak and minimum flow ratios for design purposes.

7.3 UNIT OPERATIONS. Practically all of the basic unit operations used in waste water 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 degrees F are expected and the entire system is to be housed in a heated building, then conventional practice will be used. If temperatures below 50 degrees F are expected, or significant temperature changes are allowed to occur within the system, then adjustments will be necessary in the design of the unit operations. Figure 6 will be used to make the necessary adjustments in design to compensate for viscosity effects. The power requirements for mixing, the detention time or size of grit chambers and primary clarifiers, and the efficiency of gravity filters will all be adjusted using Figure 6 where low temperature liquid is expected. For example, a detention time of 2 hours is typically specified for primary clarifiers. If wastewater at 35 degrees F is expected, then the detention time will be increased as follows:

$$\text{Multiplier} = (3.07) e^{-0.0165T} \text{ (from Figure 6)}$$

$$\text{At 35 deg F} = (3.07) e^{-0.0165(35)}$$

$$\text{Adjusted time} = (2 \text{ hr})(1.723)$$

$$= 3.45 \text{ hr.}$$

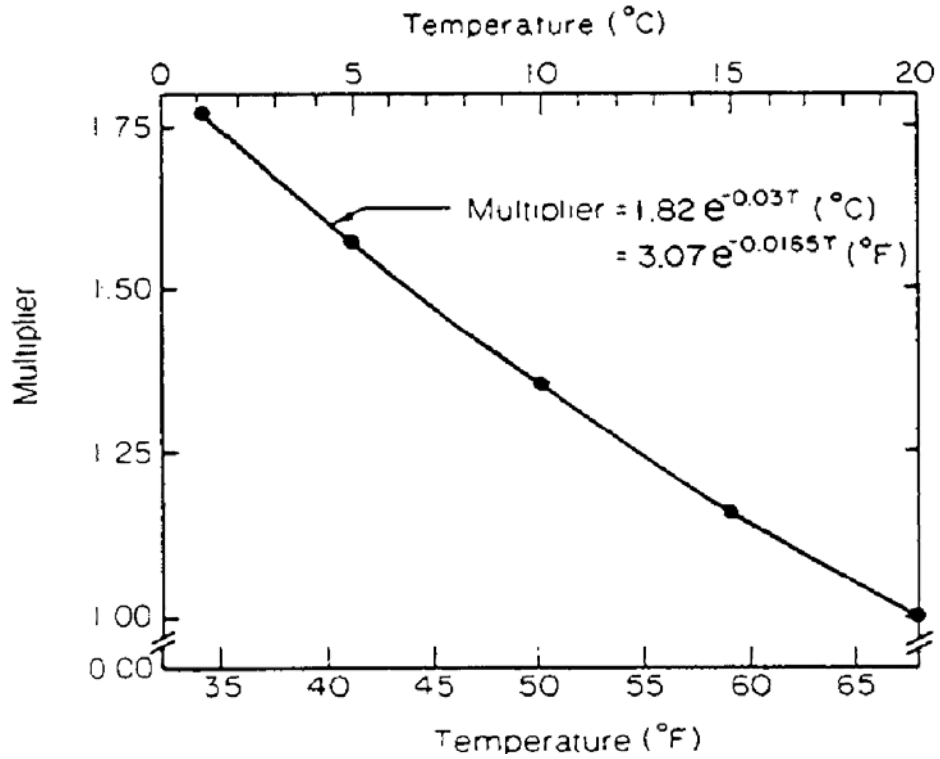


Figure 6

Viscosity effects vs. temperature

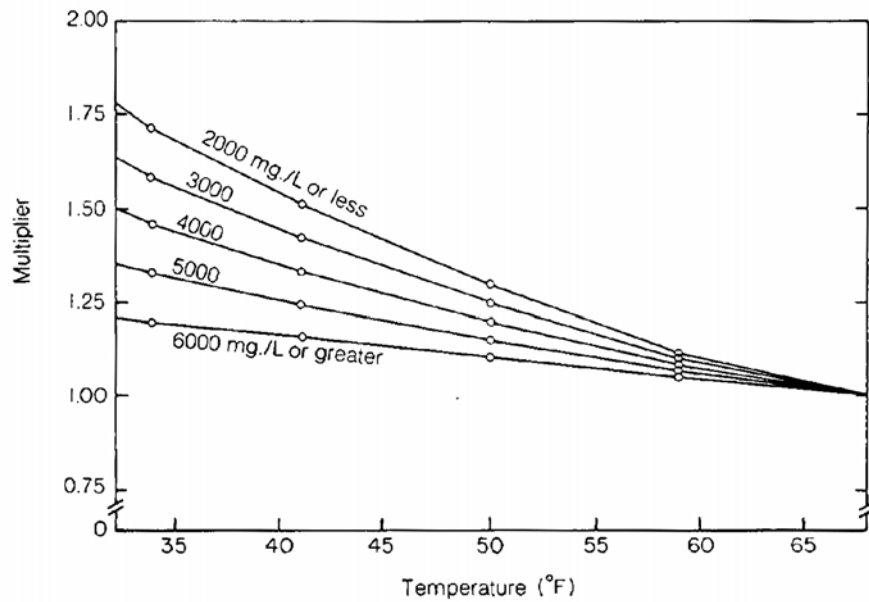


Figure 7

Settling detention time vs. temperature

7.3.1 GAS TRANSFER. The solubility of oxygen and other gases in water increases as the liquid temperature decreases. However, the viscosity of the liquid also increases so that the opportunity for contact between gas bubbles and liquid molecules is decreased. The net practical effect is little improvement in overall gas transfer in cold wastewater without additional mixing.

7.3.2 ADSORPTION AND CHEMICAL REACTIONS. Adsorption is not affected by low temperatures with the range of values experienced in wastewater treatment. Most chemical reaction rates are slower at low temperatures. This can affect treatment and must be considered in preparing chemical solutions for use in wastewater treatment. The solubility of some common treatment chemicals is given in Table 2 below.

| | <i>Pounds per gallon at</i> | |
|-----------------------------|-----------------------------|-------------|
| | 32°F | 60°F |
| Alum | 6.0 | 7.3 |
| Ferrous sulfate | 0.5 | 2.0 |
| Sodium hydroxide | 2.4 | 4.4 |
| Calcium hypochlorite | 1.8 | 1.9 |

Table 2
Solubility of common treatment chemicals

7.3.3 FLOCCULENT SEDIMENTATION. Secondary clarifiers and sludge thickeners generally receive relatively high concentrations of solids and are not dependent on temperature as predicted by Stoke's law. The multipliers shown in Figure 7 will be used to adjust the size or detention time of these units, depending on the design solids concentration. At solids concentrations of 2000 mg/L or less, and for primary clarification, temperature effects are close to that predicted by Figure 6, but as the solids concentration increases, the influence of temperature decreases and Figure 7 will be used. Density currents can completely disrupt the operation of settling tanks and

thickeners, so protective elements will be required in cold regions to maintain the temperature of tank contents as close as possible to that of the incoming liquid.

7.4 UNIT PROCESSES. These 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.

7.4.1 PRELIMINARY TREATMENT. This commonly includes screening, grit and scum removal and grinding or comminution. Conventional equipment can be used and basic design criteria applied; adjustment in grit chamber detention time will be as described above. Protective, insulated shelters will be constructed 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, materials and coatings will be selected accordingly and controls will be located on dry interior walls or in another remote location.

7.4.2 PRIMARY TREATMENT. The design detention time of primary clarifiers will be adjusted as described above. In general the tanks will be designed in the conventional manner as buried or partially buried structures. However, the presence of shallow permafrost, particularly ice-rich, fine textured soils, will require above ground tanks or special foundations. Temporary covers for heat retention purposes are recommended for winter operation of buried and exposed tanks in the Arctic and Subarctic. Tanks above grade will also require sidewall insulation or enclosure in a protective structure.

7.4.3 BIOLOGICAL PROCESSES. 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.

7.4.3.1 FACULTATIVE LAGOONS. 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. Treatment performance 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 will be required with controlled discharge commencing in late spring and in early fall. This is a common practice in Canada and the north-central United States. Three or more cells will be used to avoid short circuiting. Each cell will be isolated briefly and then discharged in turn during the specified period. Rectangular cells with a minimum 3:1 length to width ratio are recommended to further reduce short circuiting. For a three-cell system, approximately one half of the total volume needed will be provided in the primary cell, with the remainder equally divided among the other cells (a four-cell system will have two-fifths the volume in the first cell). The design BOD₅ loading over on the total area will be 20 pounds per acre per day maximum. The design volume for controlled discharge ponds will be fixed by the time interval between discharges, and not by the minimum detention for BOD₅ reduction. The BOD₅ loading on the first cell in controlled discharge systems will not exceed 50 pounds/acre/day to avoid odor problems.

7.4.3.1.1 DESIGN DEPTH. The design depth will be based on winter conditions and will allow a freeboard of 1 foot plus the ice thickness, plus 5 feet from the underside of the ice to the lagoon bottom. Adjustable weirs will be provided at the outlet so that the water level can be raised to provide the necessary depth at the start of winter, and then lowered to the normal operating depth in the summer. Ice thickness will be best determined from actual records or from observations made at small ponds or lakes in the area. An approximation of the maximum ice cover that can occur will be calculated with the following equation, applicable only to unaerated ponds:

$$d = m(l_A)^{1/2}$$

where,

d = maximum ice depth, inches

m = coefficient depending on site conditions

= 0.8 for windy site, no snow cover on ice

= 0.68 for moderate snow cover

(See the professional literature for other conditions.)

I_A = the annual air freezing index, in degree days, $(\text{deg F}\cdot\text{d})^{-1/2}$.

(See the professional literature for procedures to determine the air freezing index and for typical values.)

For example, if Fairbanks, Alaska, has a mean air freezing index of $5500^\circ\text{F}\cdot\text{d}$, and a moderate snow cover on the lagoon is assumed, then the maximum depth of ice is:

$$d = 0.68 (5500)^{-1/2} = 50.4 \text{ inches}$$

7.4.3.1.2 SPECIAL CONSTRUCTION FEATURES. Standard construction techniques can be used except where permafrost is present. Fine textured, ice-rich permafrost must be avoided if possible since thawing will 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. Construction techniques for dikes and berms, and the use of lining materials are essentially the same as those described in the professional literature. Synthetic rubber has been most commonly used for lagoon liners at installations in Alaska (see EPA report MCD 54 for additional information). Details of inter-basin transfer structures and outlet works are shown in Figure 8. The use of the stop-log manhole concept as shown in this figure will permit easy control of depth in the lagoon cells and is an alternative to adjustable weirs.

7.4.3.2 AERATED LAGOONS. Partially mixed aerated lagoons, also called facultative-aerated ponds, have been used successfully in cold regions. They require less land area, but more energy and more operational attention than facultative lagoons. A basic process design criterion is based on:

$$S_e/S_o = 1/(1 + kt)$$

where,

S_e = effluent BOD₅, mg/L

S_o = influent BOD₅, mg/L

t = total detention time, days = V/Q

V = Total volume of lagoon, millions of gallons (mg) or ft³

Q = average daily flow, millions of gallons per day (mgd)

k = overall reaction coefficient (base e), days⁻¹ as used in Alaska and northwest Canada: typical winter value = 0.14 (= 33 deg F); typical summer value = 0.28 (60deg F – 70 deg F); one can also use $k_T = (k_{20})(\theta)(T-20)$ with $k_{20} = 0.28$, $\theta = 1.036$

For several cells in series, the equation becomes:

$$S_e/S_o = 1/[1 + (kt/N)]^N$$

where N = number of cells (other terms are defined above). This equation can be solved to determine the optimum number of cells in the system. In general, winter conditions will determine the number and size of cells and summer conditions will control the design of the aeration equipment. Detention time and number of cells may be calculated as follows:

| Number of cells (N) | Total detention time, t (days) |
|---------------------|--------------------------------|
| 1 | 50 |
| 2 | 26 |
| 3 | 21 |
| 4 | 19 |
| 5 | 18 |

There is no further significant decrease in total detention time after three cells, so the design should be based on three. The first cell in a three-cell unit should contain about half of the design volume.

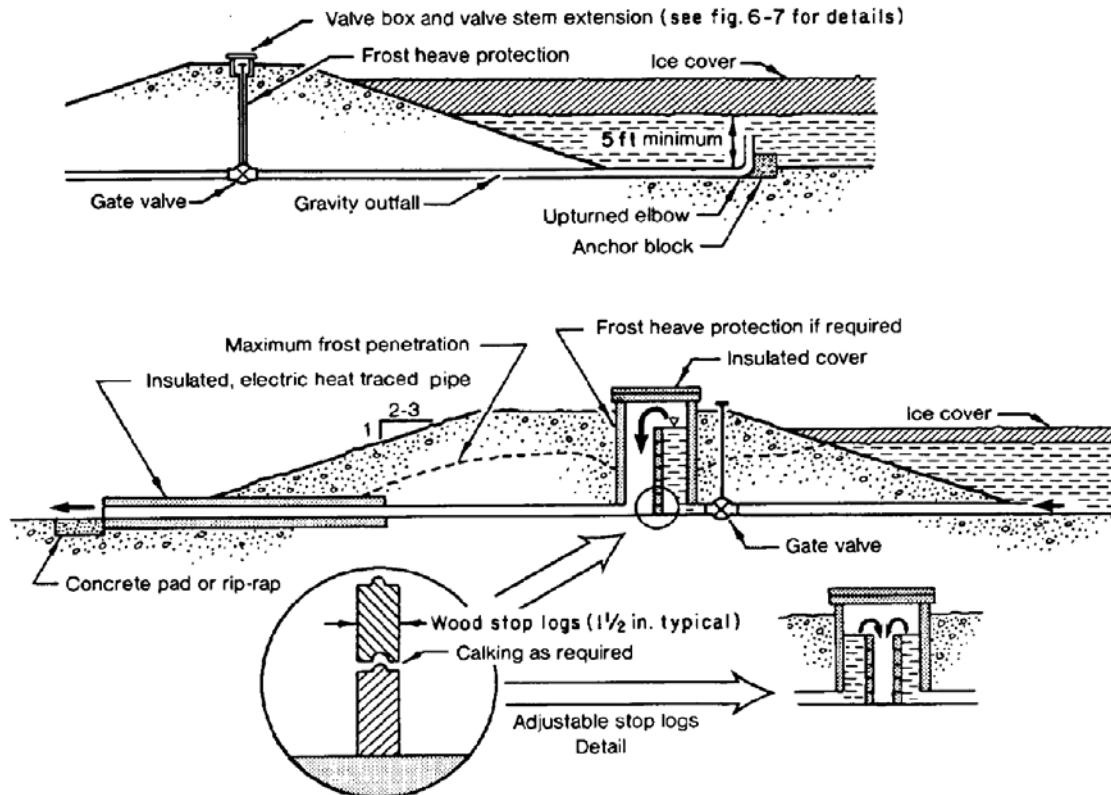


Figure 8

Lagoon construction details

7.4.3.2.1 DESIGN DEPTH. The effective lagoon depth must allow for ice cover in the winter and sludge accumulation on a year-round basis. Ice will not form continuously over the surface of aerated lagoons. Even under extreme winter conditions (-50 deg F), there will be small areas of open water where air will bubble to the surface from a submerged aeration system. Aerated lagoons in central Alaska and northwest Alaska (freezing index >5000 deg F days) have been successfully designed assuming a 12-inch ice cover. A single-cell lagoon near Anchorage, Alaska (freezing index 2500 deg F days), and receiving warm sewage, has an ice cover of less than 3 inches in the winter. If specific values are not available from similar lagoons in a similar climate, an assumed value of 15 percent of the total for design depth is recommended for ice cover

allowance in the arctic and subarctic regions. About 5 percent will be allowed for sludge accumulation on the bottom. The depth required for treatment in the winter is in addition to both of these factors.

7.4.3.2.2 AERATION DESIGN. A submerged aeration system is required for year-round operation in the arctic and subarctic regions since icing problems can interfere with the performance of surface aerators. The aeration design for these partial mix lagoons is based on supplying the required oxygen, not on keeping all of the solids in suspension. As a result there will be settlement of sludge on the bottom of the lagoon, and some algae growth in the liquid portion. Summer conditions control aeration design since biological reaction rates are the highest and the amounts of oxygen that can be dissolved are the lowest. The oxygen required for partial-mix lagoons will be set at double the organic loading as follows:

$$O_2 = 2 (BOD)(Q)(8.34)$$

where,

O_2 = oxygen required, lb/day

BOD = influent BOD₅, mg/L

Q = design flow, MGD

Under standard conditions, air contains about 0.0175 pounds per cubic foot (pcf) oxygen (specific weight of air at standard temperature and pressure is 0.0750 pcf, with 23.2 % oxygen), so the air required in cubic feet per minute (CFM) is:

$$\begin{aligned} \text{CFM} &= [(2)(BOD)(Q)(8.34)(60)]/[(E)(0.0175)(86,400 \text{ sec/day})] \\ &= [(0.662)(BOD)(Q)]/E \end{aligned}$$

where E = efficiency.

The aeration efficiency depends on the depth of water, type of diffuser, mixing turbulence and basin configuration. For example, a typical efficiency (E) of submerged tubing is 16 percent. Therefore, for a design flow of 1 MGD and a BOD of 240 mg/L, the air requirements would be:

$$\text{Air required} = (0.662)(240)(1)/(0.16) = 993 \text{ cfm}$$

7.4.3.2.3 AERATION SYSTEM OPERATION. Aeration systems that have been successfully used in cold region lagoons include perforated tubing, tubing with diffuser inserts, air guns, and helical diffusers, all available from a number of commercial sources. Table 3 summarizes the characteristics of these devices. The values in the table will be used for a preliminary estimate of the number of devices required for a particular system. Manufacturers' literature is then consulted for the final design of a specific system. About 65 percent of the aeration capacity will be located in the first cell of the lagoon system. Submerged tubing and, to a lesser degree, air gun systems are susceptible to clogging due to precipitation of carbonate and bicarbonate salts around the air outlets. The potential severity of the problem increases with the hardness of the sewage. A number of tubing systems in Alaska have been replaced because of this problem. The problem can be overcome by including a gas cleaning system using anhydrous hydrogen chloride gas. The acid produced at the air outlets dissolves the incrustations.

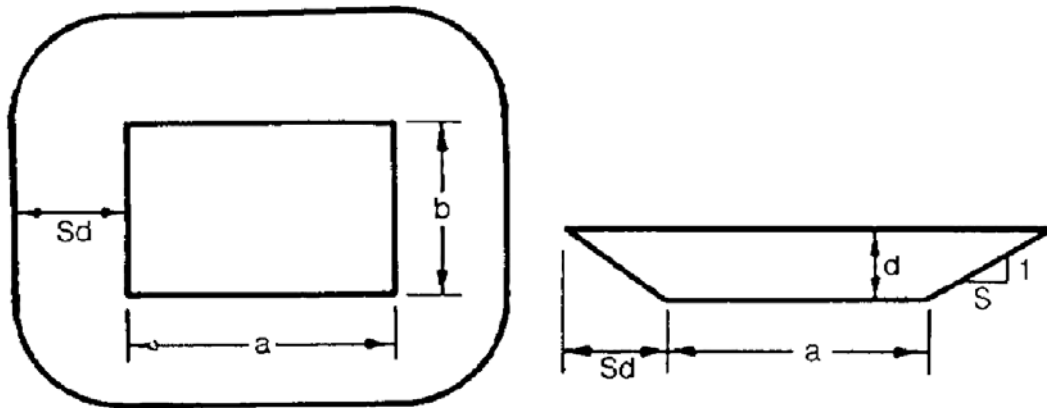
7.4.3.2.4 CONFIGURATION AND CONSTRUCTION. The prevention of short circuiting and minimization of heat losses must both be considered in the design. The optimum configuration for minimal heat loss would be a circular basin with vertical side walls, but construction costs would be prohibitive. A square basin with sloping sidewalls would be slightly more efficient thermally than a regular basin of the same volume, but would be prone to greater short circuiting. In general, hydraulics will control design and long rectangular cells (length to width ratio greater than 3:1) will be used to reduce short circuiting. A maximum slope of 1:3 is required for interior sidewalls. Figure 9 will be used to calculate the dimensions of the cells. Inlet and outlet structures, and other

construction details, are the same as those for facultative lagoons. The general provisions for construction of dikes and lagoon structures will be as described in the professional literature.

| Equipment | Oxygen Provided* (lb/day) | Common Depth (ft) |
|------------------|---------------------------|-------------------|
| Submerged tubing | 3-10/100 LF | 8-15 |
| Air gun | 80-150/unit | 12-20 |
| Helical diffuser | 100-400/unit | 10-20 |

* These values can be used to estimate the number of units or linear feet (LF) of tubing required to satisfy the oxygen requirements. Manufacturers' literature should be consulted for absolute aeration efficiency ratings.

Table 3
Typical aeration equipment



$$\text{Volume} = V = d [(a + Sd) (b + Sd) + .333 S^2 d^2]$$

Note: The last term (.0472 S² d²) can be dropped for preliminary estimates

Figure 9
Dimensions of lagoons

7.4.3.3 ACTIVATED SLUDGE SYSTEMS. Systems that have been successfully used in cold regions include conventional and pure-oxygen activated sludge, contact

stabilization, and extended aeration concepts, both in package plants and in oxidation ditches. Basic design criteria for these processes can be found in the professional literature. When the system is enclosed and incoming waste-water temperatures exceed 50 degrees F, basic design criteria will apply. Special measures are necessary only when incoming wastewaters are below 50 degrees F or if a significant temperature drop is expected within the system. All of the biological reaction rates involved are temperature sensitive and must be adjusted using:

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

where,

k_T = reaction rate coefficient at temperature T

k_{20} = reaction rate at 20 degrees C

T = design wastewater temperature, degrees C

θ = temperature coefficient

The θ values given in Table 4 will be used in the equation above to adjust the reaction rate for the design wastewater temperature. The basic reaction rate coefficients are found in the professional literature.

| 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 |

Table 4

Temperature coefficients for biological treatment

7.4.3.3.1 SPECIAL REQUIREMENT. A permanent ice cover must be avoided in the aeration compartments of activated sludge systems. An ice cover will inhibit atmospheric aeration and will entrap solids, both of which reduce treatment efficiency. The design must provide for a minimum of exposed liquid surface area to reduce heat losses. An unheated shelter, a temporary tank cover or a wind break is required during the winter. Clarifiers associated with these systems will require similar protection to avoid freezing and to inhibit density currents. A continuously heated building is not necessary to maintain treatment efficiency. Operator comfort and convenience are the only justifications for such energy inputs. If the incoming sewage is 50 degrees F or warmer, there is sufficient heat in the liquid to sustain a protected treatment process. A

standby heat source and emergency power are recommended for extended power failures and other emergencies.

7.4.3.3.2 EXTENDED AERATION. Extended aeration units have been successfully operated with liquid temperatures as low as 33 degrees F and have still produced high quality effluent. Design organic loadings (food/microorganism ratio) of up to 0.08 lb BOD (biochemical oxygen demand)/lb MLSS/day, and mixed liquor suspended solids (MLSS) concentrations of 3000-40000 mg/L are recommended for low temperature operation. Small packaged treatment units must be covered and must be protected from the wind. Pumps, motors, blowers, external pipes, valves and similar appurtenances will require heat as well as a protective shelter. These systems must not be oversized or overdesigned with respect to hydraulic capacity because low organic loadings usually result in poor performance. Dual units are required for low, intermittent flows at remote installations. Only one unit is operated during low flow periods. This unit is operated with a MLSS concentration. Sludge is then transferred to the second unit during peak flow periods allowing an immediate start-up. Figure 10 illustrates the special features of an oxidation ditch in the Subarctic. The aeration basin has vertical sidewalls and a vertical central divider. This reduces exposed surface area and heat losses by about 32% as compared to the conventional ditch with sloping sidewalls and center island. The only heated space in this treatment system is the office/laboratory clarifier equipment, and aeration brushes are housed in simple concrete block construction. Condensation and ice form on the interior surfaces of exterior walls. Thus switches, control panels, etc., must be located on dry interior walls. These features are not unique to oxidation ditches and can usually be incorporated into other systems as well.

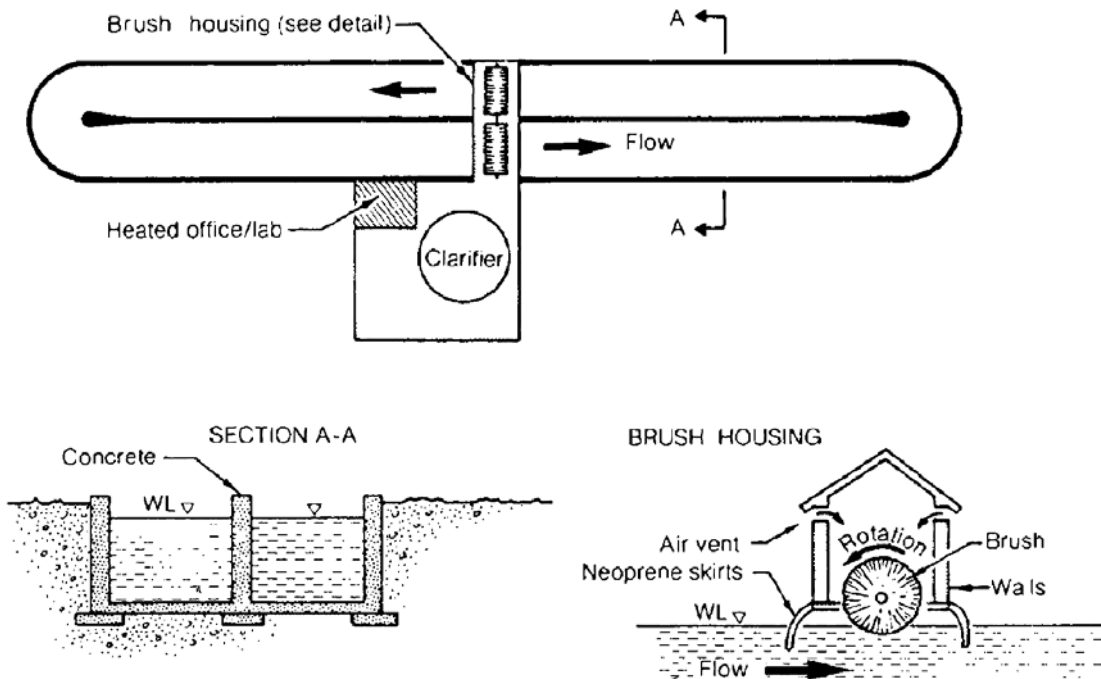


Figure 10

Oxidation ditch for the subarctic

7.4.3.4 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. Criteria from the professional literature will be used for the design, along with the temperature coefficients given in Table 4. The need for additional heat in the protective structure will depend on the temperature of incoming waste-water and on the degree of treatment required.

7.5 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. Typical values for systems in use in the cold regions are presented in Table 5. Thickening, digestion and dewatering of sludge all follow temperate zone practice as defined in the professional literature.

7.5.1 FREEZE-THAW DEWATERING. Sludges from water or waste water treatment operations can be flooded onto conventional open sand drying beds in layers and allowed to freeze. The depth of sludge that can be frozen (or thawed) is calculated with:

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

where:

X = depth of sludge that can be frozen, inches

m_S = proportionality coefficient for sludge, use 0.6 for sludge concentrations in the range of 0 to 7 percent solids (higher concentrations are difficult to spread on bed)

I_A = Air freezing (or thawing) index, in $(\text{deg F}\cdot\text{d})^{-1/2}$ (use warmest winter of record for freezing calculations)

7.5.1.1 Sludges with an undrainable jelly-like consistency will dewater immediately upon thawing and then have a granular consistency.

| Process | Dry solids lb/person/day | Solids content of wet sludge (%) |
|--|-----------------------------|--|
| Primary settling | 0.12 | 6 |
| Trickling filter (TF) Secondary | 0.04 | 4 |
| Primary plus TF Secondary | 0.16 | 5 |
| Conventional activated sludge (AS), secondary clarifier | 0.07 | 0.5-1 |
| Primary plus conventional AS secondary | 0.19 | 2-3 |
| Extended aeration | 0.09 | 2 |
| Lagoons | 0.13 | 20 ^b |

a Average, 24-hr values, from temperate climate experience.

b High value due to long-term consolidation of sludge on lagoon bottom. Data from partial-mix aerated lagoons in Alaska.

Table 5
Typical sludge production rates ^a

7.5.1.2 Solids concentrations of 20 to 25 percent immediately after thawing are typical and after a few more weeks of drying will approach 50 percent. The total depth of sludge that can be frozen is 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. The following equation can be used to estimate the potential total depth of sludge that could be frozen (applied in 3-inch layers) if the maximum depth of frost penetration for a site is known:

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

where:

ΣX = total depth of sludge that could be frozen in 3-inch layers, inches

f_p = maximum depth of frost penetration for area, inches

7.5.1.3 At most facilities it will 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, will determine 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. Polymer additions (in the summer only) will be necessary to condition alum and other metallic hydroxide sludges for conventional dewatering on the sand beds.

7.5.2 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 grounds prevent surface application or landfill operations.

7.6 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. Exposed outfall piping will be insulated and heat-traced. A submerged outfall is recommended wherever possible. However, in shallow streams the pipe must be protected from ice scour that can occur during spring breakup. If possible, the pipe will be installed 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 will be required. Figure 11 illustrates a typical elevated outfall detail. The support

piling will be designed 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 breakup. As shown in Figure 11, break-away couplings will be used to prevent complete destruction of the outfall structure. In general, elevated outfalls will be designed 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.

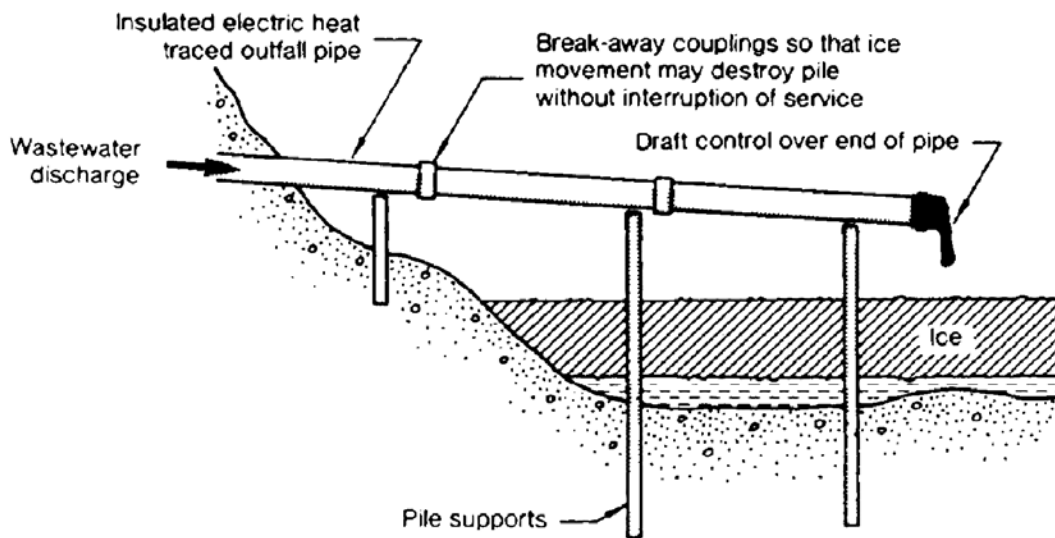


Figure 11

Example of an elevated outfall design

The pipe must be of sufficient height so that the ice mound does not plug the outlet. A dual outlet constructed as a wye with a valve on each branch has been successfully used to overcome this problem. When the ice mound approaches one outlet, discharge is shifted to the other leg for the remainder of the winter. Figure 8 illustrates design details for the buried outfall for a typical cold region lagoon. A submerged outfall will be similar in concept to the water intake.

7.7 ALTERNATIVES TO TREATMENT/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/disposal options discussed above. Small-scale on-site systems may be feasible for these situations and will be considered. 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; a 2-inch thickness of rigid polystyrene board will retain heat and is 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 will be required. Electric incinerator toilets have been successfully used since 1977 at remote Alaskan stations. These units are not recommended for recreational areas or for transient users. The “grey water” (kitchen, bath and laundry wastes) at these remote stations is discharged to a gravel pad on the ground surface.