years before final design to confirm that the required yield will, in fact, be available.

In cold regions, particularly in the Arctic, a significant proportion of the precipitation is in the form of snow. Due to winds, however, it does not necessarily remain where it falls initially. This can actually be turned to advantage by inducing the occurrence and growth of snowdrifts to increase the annual water yield of a small watershed (Tabler, 1980; Ryan and Crissman, 1990). Figure 5-7 shows the snow fence constructed in Shismaref to increase watershed yield (Wheaton, 1980; Farmwald and Crum, 1986).

Design criteria for snow fences have been derived from several different projects.

Location	Yield m^3/lin. m (thousand gal./lin. ft.)	Height of Fence m (ft)
Barrow, Alaska	103.0 (8.3)	1.21 (4)
Wainwright, Alaska	146.5 (11.8)	2.4 (8)
Shishmaref, Alaska	31.0 (2.5)	2.4 (8)
Kotzebue, Alaska (design study only)	45.9 (3.7)	3.6 (12)
Kipnuk, Alaska	?	2.4 (8)
Baker Lake, NWT	0.3	5.5 (18)

An analysis of the Baker Lake snow fences provided the following cost information. The 5.5 m (18 ft) high snow fence cost $398 per metre (Cdn. 1993) to construct. This included material and labor including piling foundation and wind bracing. The materials for the fence were purchased in 1990/1991.

Off-stream storage may be an economic means for reducing problems of quantity or quality. Water storage in a lake was used in Inuvik, NWT to meet community water needs during freeze-up and break-up. This method can also be used to meet summer requirements when concentrations of sediment or other contaminants are high. (See Section 7 for more information on impoundments.)

5.2.2 Groundwater. Groundwater is usually the most desirable source of water in cold regions for several reasons:

- Normally, groundwater temperature is nearly constant and warmer than surface water in the winter.
- Mineral quality of groundwater is more constant than surface water.
- Groundwater from under the permafrost is almost always a year-round source of supply so that alternate or dual-source systems are often not needed.
- There is much less chance of contamination from surface activities than with surface water (especially deep groundwater).

However, the cost of exploring, drilling, developing, and maintaining wells in cold, remote areas can be high (Ryan and Crissman, 1990).

Groundwater in Permafrost Areas. Groundwater in areas of continuous permafrost may be found in three general locations;

- above permafrost, within the active layer (suprapermafrost);
- within permafrost in thawed areas (intrapermafrost); and
- under permafrost (subpermafrost).

Waters found in the active layer above the permafrost are generally not potable unless treated extensively. Such water is usually found within one to two metres of the surface and frequently has a high mineral or organic content, or both. Because they are shallow, such aquifers are also subject to contamination from privies, septic tanks, and animals. The quantity of water from this source is often small and unreliable and not available in the winter. A suprapermafrost water collection system developed for Point Hope, Alaska (McFadden and Collins, 1978) is shown in Figure 5-8.

Intrapermafrost water is quite rare and usually highly mineralized. Such water must contain high concentrations of impurities to depress the freezing point below that of the surrounding permafrost. There is no reliable method to locate pockets of interpermafrost water with present state-of-the-art techniques (Smith et al., 1979). For these reasons it is not normally a suitable water source.

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

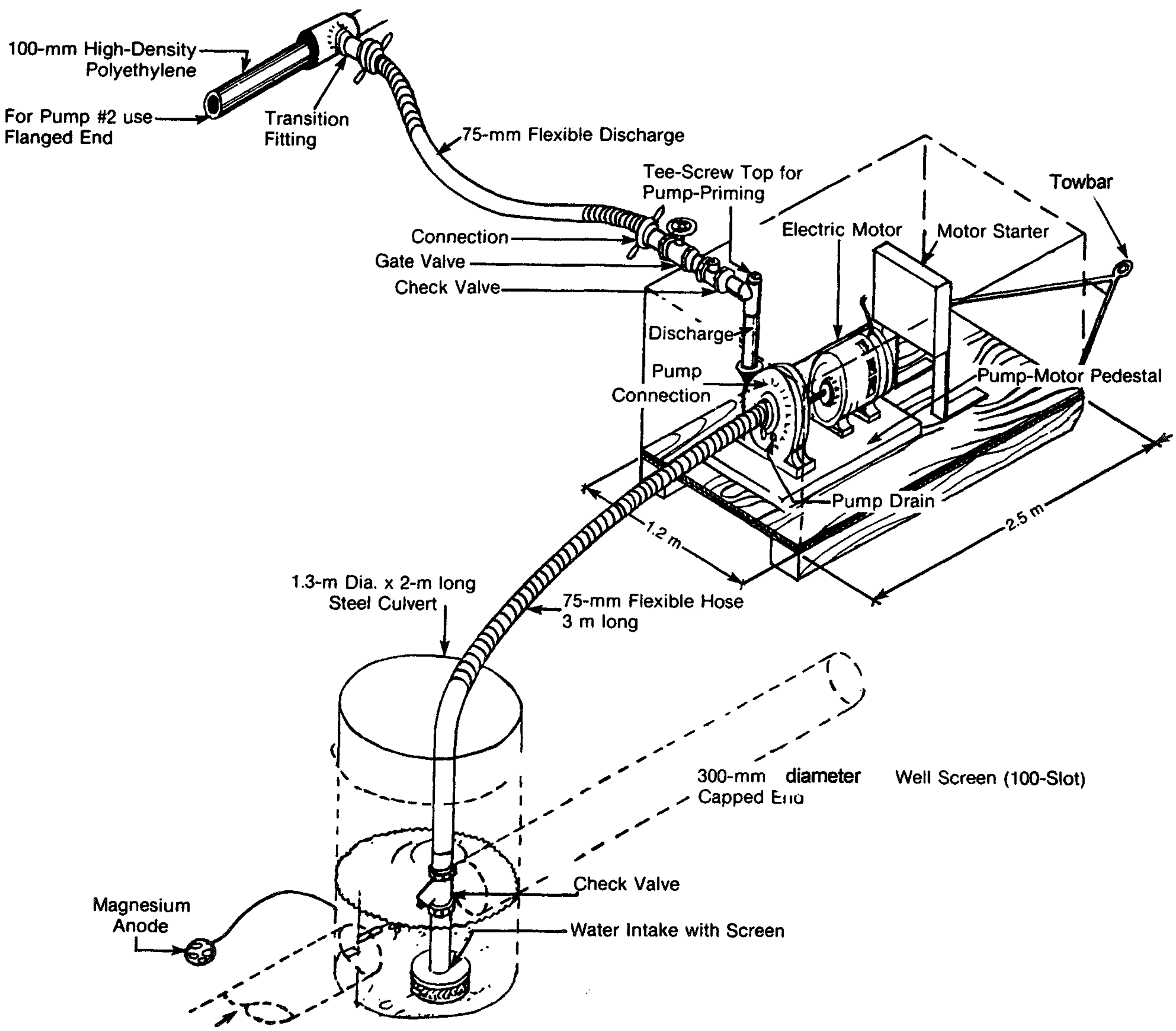

FIGURE 5-8 SUPRAPERMAFROST WATER SOURCE PUMP SYSTEM AND INFILTRATION GALLERY

Subpermafrost groundwater is generally deficient in dissolved oxygen. As a result, high concentrations of some minerals, such as iron and manganese, which are soluble under these conditions, are present. Higher concentrations of polyvalent cations (hardness) are also common in subpermafrost groundwater. Occasionally this groundwater contains dissolved organic substances as well.

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

Groundwater in Intermittent Permafrost Areas. The construction and operation of wells in intermittent permafrost areas requires special consideration of the thermal conditions. In such regions the permafrost is generally warmer than in the continuous region. Thermal disturbance of the surface by drilling a well or by the well itself can result in thawing and, perhaps, well failure (Linell, 1973).

In these regions the potential for successful well development is also much higher. Thawed "windows" permit more water to move from the surface to the groundwater. This can also result in a better quality of water. In areas where buried or surficial organics are slowly decomposing, the quality of the groundwater can be poor.

Groundwater in Deep Seasonal Frost Areas. The volume of groundwater in these areas is seriously influenced by frost conditions. The amount of water moving from the surface to the water table is restricted during the period of frozen ground. If the percolation rate is low and the water pumping rate is high, water mining may occur.

Estimation of Groundwater Yield. The predictable yield of groundwater from a watershed may be estimated in a manner similar to that in warmer regions where the permafrost layer essentially acts as a confining layer. Once a proper well has been installed, well testing to determine the safe yield follows normal practice. The point of discharge must be selected so that the pumped water has the least possible effect on the surrounding ground.

Because of the effects of permafrost as a confining layer, and the limited recharge during the winter months, longer periods of test pumping are recommended to assist in obtaining information on long-term yields and quality. Variations in recharge have also led to seasonal changes in water quality, which can be assessed by sampling at different time periods.

Well Construction and Design. Location, siting and design of water wells in cold regions follow the same procedures and principles as in other locations but additional considerations are needed (Ryan and Crissman, 1990). Critical factors include:

- Considering bulk fuel storage and fuel fill line locations to minimize the potential for contamination.
- Drop pipes should be provided with drainback valves at least to a level below the deepest expected frost penetration.
- Heat tracing should be used if no drainback is used or for wells which penetrate permafrost to prevent freezing, however overheating must be avoided.
- The top of the casing should be insulated, and consideration should be given to providing a building at the well head for location of controls and other components and to assist in the operation and maintenance of the facility under adverse weather conditions.
- Seasonal frost can damage the well casing through frost jacking. Bentonite is usually used to grout the annular shape around the casing in the seasonal frost region. Concrete grout, as used in warmer climates, bonds tightly to the steel casing and the frost heaving can pull the casing apart, ruining the well.
- The increasing depth of the active layer during the winter can increase the pressure on the groundwater beneath the advancing freezing front. A well using this source can become artesian or even flowing artesian as winter progresses. There are several recorded instances where this pressure has caused large amounts of water to flow out of the well causing considerable damage to structures. This process is similar to the method of icing (aufeis) formation by streams.

5.2.3 Other Water Sources. Snow, ice and rain catchments are potential water sources which may be considered for small or temporary establishments. See Section 14 for detailed information.

Seawater. Desalinated seawater has been used for domestic supplies but the associated operation and maintenance problems can be considerable. Intakes in the ocean or on the beach are subject to ice forces of great magnitude. Ice scour during fall and spring can be serious. Along the Arctic Ocean, scour can occur at any time. During the winter months, shore-fast ice and frozen beaches pose special problems.

Brackish Water. Brackish water with total dissolved solids (TDS) of 10,000 mg/L or less is occasionally the only source available. Such waters may be treated by reverse osmosis or distillation, but significant problems must be anticipated with small installations. Treatment methods are discussed in Section 6.

Harvesting Snow and Ice. Snow and ice can be melted for water. Most larger communities and camps in the North American Arctic have developed groundwater or surface water sources and snow or ice is only used in isolated homes or temporary hunting, trapping, or oil exploration camps. In Antarctica, however, major settlements melt snow for their water supply. Snow is usually gathered with front-end loaders and transported to melters which operate on fuel oil and/or waste heat collected from the engines used for electrical power generation. Because of the possible exhaust contamination from the generators and heating boilers, the snow to be collected must be carefully selected, usually upwind from the camp. The soot from the engines tends to give the melted water an oily taste. Antarctica experience indicated the snow often contained volcanic ash which created turbidity and taste problems. Thus, the melted snow needed to be thoroughly filtered and disinfected. It takes over one litre of fuel to produce the heat to melt 100 litres of ice (more if melting snow), therefore, snow and ice are usually a last resort. On the Greenland icecap, a cavern is often formed in the ice cap by injecting steam into a drilled hole around 45 m deep. The thawed water is then pumped out for use in the camp. This method has produced better quality water than melting snow, but is still very expensive.

Water Reuse. In the absence of ample supplies of fresh water, water reuse may be considered. In Alaska, bath and laundry wastewaters are often reclaimed and used at several locations for toilet flushing and other nonpotable purposes. Reclamation of wastewater for conversion to potable water is not a commonly used technology in northern regions. Yet the effluent from existing secondary or tertiary sewage treatment plants is nearly free from suspended materials and should be more economical to treat than seawater. Seawater contains approximately 35 times more dissolved solids than domestic sewage.

5.3 Water Requirements

Determining the quantity of water needed and rate of flow is an initial step in the design of analysis of a water supply. Data on existing usage and projections of future needs are necessary.

5.3.1 Variations in Water Use. Short-term and seasonal variations in flow include daily, weekly, and monthly fluctuations. Average daily rates of water use can be determined from utility records, with at least two years of data reviewed. Alternatively, typical values depending on geographic location and type of system can be used.

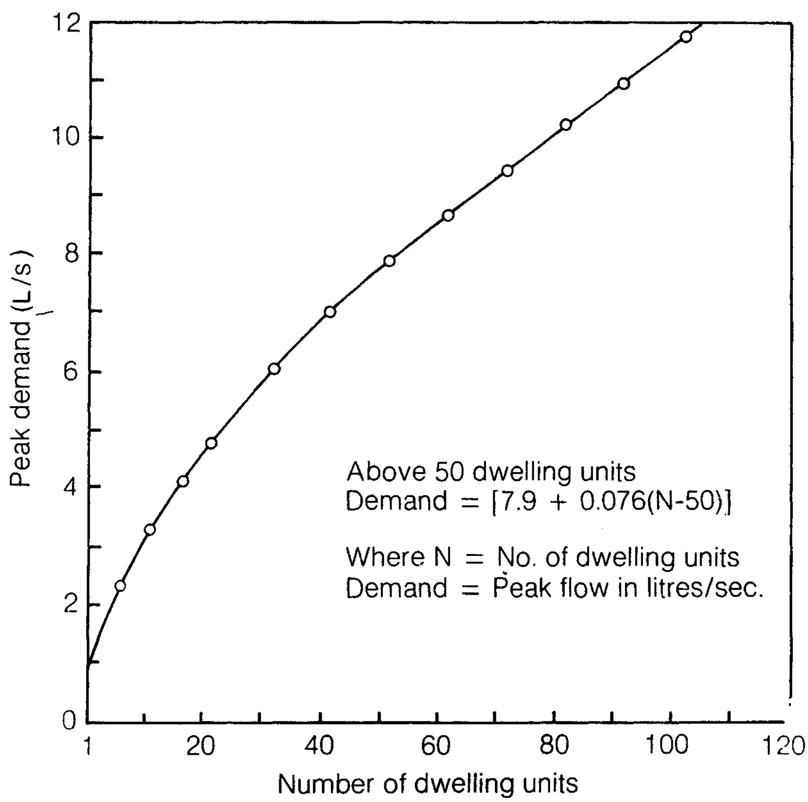

FIGURE 5-9 HOURLY PEAK WATER DEMAND IN SMALL COLD-CLIMATE COMMUNITIES

TABLE 5-2 RECOMMENDED DESIGN WATER DEMAND

	Water Consumption, L/(p•d)	
	Average	Normal Range
Households		
1. Self-haul from watering point	10	5 to 25
2. Truck system		
a. Nonpressure water tank, bucket toilet and central	10	5 to 25
b. Nonpressure water tank, bucket toilets and no central	25	10 to 50
c. Nonpressure water tank, waste holding tank	45	20 to 70
d. Pressure water system[1], waste holding tank, and normal	90	40 to 250
e. Pressure water system, waste holding tank, low flush	60	
3. Piped system[2] (gravity sewers)	225	100 to 400
Piped water supply and trucked sewer pumpout	110	
4. Piped system (vacuum or pressure sewers)	145	60 to 250
5. Well and septic tank and tilefield	160	80 to 250
Trucked water delivery and individual septic tanks	100	
Institutions (piped system)		
Day student school	10	2 to 18
Boarding school student	100	100 to 400
Nursing station or hospital (per bed)	100	
Hotels per bed	100	
Restaurants, bars, per customer	5	
Offices	10	
Showers (two per person per week)	10	
Laundry (two loads per family per week)	7	
Camps		
Base camp	200	
Drilling pad	130	
Temporary, short-duration camps	100	
Greenland Guidelines for New Water Works[3]		
Water collected in buckets		30 to 80
Water supplied by trucks or piped to nonsewered houses		80 to 150
Piped to sewered houses		150 to 200
USSR Guidelines for Systems in Permafrost Regions[4]		
Building with hydrant columns only		30 to 50
Building with running water and sewers, no baths		125 to 160
Building same with baths and local water heaters		160 to 230
Building same with central hot-water supply		250 to 350

Notes:

[1] Conventional flush toilets are strongly discouraged with truck system in NWT

[2] The figures for piped systems do not make allowances for the practice of letting fixtures remain open in cold weather to provide continuous flow in water mains to prevent freezing. Water use under that practice used only in older systems may be as high as several 1,000 L/(p•d).

[3] Rauschenberger (1983)

[4] Fedorov and Zaborshchikov (1979)

Demand factors are needed to design sources and storage facilities. Maximum daily demand should be computed at 2.3 times the average daily demand. Maximum hourly demand should be computed at 4.5 times the annual average daily demand. Figure 5-9 is presented for estimating hourly peak water demand in small cold-climate communities.

5.3.2 Water Usage. The amount of water used by inhabitants of northern communities depends on several factors. Cultural background is particularly important, since many cold-climate communities in Alaska and Canada are populated by indigenous people. Traditionally, these people have not had access to large quantities of water and therefore tend to use water conservatively. As more water becomes available, however, it is used more freely. For information on water use in individual dwellings and construction camps see Sections 13 and 14. Water usage can also increase considerably with higher pressures in the delivery system. Pressures should range between 100 and 350 kPa and no higher.

The minimum amount of water considered adequate for drinking, cooking, bathing and laundry is 60 litres per person per day (L/(p•d)). Even this may be difficult to achieve where piped delivery is not practical or possible. In communities without residential piped water distribution systems, and which have honey-bag waste systems, water consumption is between 4 and 12 L/(p•d).

Analysis of data collected at Wainwright, Alaska, indicates that when more water was made available, water use in homes rose from about 2 L/(p•d) to about 5.5 L/(p•d) in a three-year period. Wainwright, however, has a central facility that provides for bathing and laundry away from the home. This water use has not been included in these figures. In spite of these apparently low quantities for household use, significant health benefits were observed in the village from improved water supply and sanitation facilities. This is consistent with information in Figure 2-1.

Table 5-2 lists water use factors for various types of communities in cold regions. General design information is also available for Greenland (Rauschenberger, 1983) and the USSR (Fedorov and Zaborshchikov, 1979).

Nonresidential Use. The total community water use varies with the extent of nonresidential activities (i.e., commercial, institutional and industrial) in the community. The nonresidential activities tend to increase in proportion to the population of the community. Unless specific data are available to estimate nonresidential water use in a community, for design purposes, the total water use per capita for both trucked and piped systems is calculated using the following equations in the NWT:

Total Community Population	Total Water Use Per Capita
0 to 2,000	RWU • [1.0 + (0.00023 • Population)]
2,000 to 10,000	RWU • [-1.0 + (0.323 • Ln (Population)]
>10,000	RWU • [2.0]

where,

RWU = Residential Water Use

Ln = natural logarithm

Water Conservation. Even though these recommended quantities are recognized as adequate, many communities in Alaska and Canada consume large quantities of water of which much is wasted. Table 5-3 gives examples of water use. In some cases water consumption is excessive. In many communities this is the result of water bleeding (see Section 8).

System designers must be alert to the possibilities for conserving water and potential reasons why systems sometimes encourage waste. Water and its treatment costs money, as do sewers and sewage treatment which must handle the hydraulic loads. Section 14.3 summarizes the various household water conservation fixtures, including those for toilet systems.

The City of Yellowknife, NWT, undertook initiatives to conserve water over the past ten years. Measures such as infrastructure upgrade, bleeder detection and elimination, water metering and leak detection surveys have resulted in substantial decreases in consumption and considerable monetary savings to the municipality. The City now estimates that actual use is about 280 L/(p•d), a figure that has stayed relatively constant since 1980. At one time, the City distributed approximately 560 L/(p•d). Water losses have been reduced 25% since they started their conservation program, a savings of nearly $860,000 (Cdn) annually.

Bleeding. Bleeding is the practice of allowing water to run to prevent freeze-up of water service lines. There could be isolated instances where bleeding

TABLE 5-3 EXAMPLES OF ACTUAL WATER USE

City	Water Consumption (L/(p•d))	Approximate Number of People	Type of System
Alaska			
Allakaket (1993)	15	200	Watering point
Anchorage	890*	220,000	Conventional water and gravity sewers
Bethel	270	1,200	Circulating water and gravity sewers
Brevig Mission (1993)	50	137	Washeteria
Dillingham	2,300*		Conventional water and gravity sewer
Dot Lake	190	50	Central heat-conventional water (utilidors), individual sewer
Elim	170	196	Circulating piped; gravity sewer
Fairbanks	650*	25,000	Circulating water and gravity sewer
Galena (1980)	12	200	Truck delivery only. Showers and laundromat available elsewhere.
Golovin (1993)	70	146	Truck delivery; septic tanks
Gulkana (1993)	110	103	Circulating piped; gravity sewer
Holy Cross (1993)	280	275	Circulating piped
Homer	1,630*		Conventional water and gravity sewers
Kenai	380		Conventional water and gravity sewer
Kiana (1993)	170	410	Circulating piped; gravity sewer
Kotzebue (1980)	246	2,544	Circulating distribution system; gravity sewer
Kotzebue (1993)	280	3,500	Circulating piped; gravity sewer
Little Diomede (1993)	23	180	Washeteria
Metlakatla (1993)	1,000	900	Conventional piped; gravity sewer
Minto	190	180	Circulating water-gravity sewers
Nunapitchuk (1979-80)	17	312	Washeteria consumption
Palmer	760*		Conventional water and gravity sewer
Saxman (1993)	1,000	380	Conventional piped; gravity sewer
Seldovia	680*		Conventional water and gravity sewer

continued

TABLE 5-3 continued

City	Water Consumption (L/(p•d))	Approximate Number of People	Type of System
Seward	4,500**		Conventional water and gravity sewers (winter)
	2,300		(summer)
Shaktookik (1979-80)	20	160	Self-haul
	38		Washeteria plus self-haul
	68		Total summer use, summer distribution line; cluster septic tank
Shaktoolik (1993)	200	200	Circulating piped
Shishmaref (1993)	38	466	Washeteria
St. Michael (1993)	15	330	Watering point
Toksook Bay (1978-79)	136	317	Circulating piped
Toksook Bay (1993)	170	510	Circulating piped; gravity sewer
Tununak (1980)	22	283	Washeteria consumption
Unalakleet (1978)	352	600	Circulating water-gravity sewers
Wales (1993)	38	147	Washeteria
<u>Alberta</u>			
Edmonton	236	500,000	Conventional, residential only
<u>Denmark</u>			
Copenhagen (1972-73	115-253		Range for 33 multistory apartment building***
<u>Greenland</u>			
Godthab (1981)	123	9,423	Piped water and sewer
Julianehaab (1981)	232	2,574	Part piped, part self-haul
	340		Piped house only
	35		Self-haul only
Sukkertoppen (1981)	145	3,013	Piped
<u>Northwest Territories</u>			
Aklavik	32	797	Trucked delivery
	63		Summer piped system
Fort Franklin (1978)	45	472	Truck delivery
Fort Good Hope (1976-77)	32	440	Truck delivery
Fort McPherson	250	850	Piped portion of community; remainder trucker

continued

TABLE 5-3 continued

City	Water Consumption (L/(p•d))	Approximate Number of People	Type of System
Inuvik (1970)	20	1,300	Trucked water, honey bags
Inuvik (1976)	485 to 550	3,500	Circulating water and gravity sewer
Resolute Bay (1970)	163		Circulating water
Resolute Bay (1977)	23	160	Trucked water, honey bags
Sacks Harbour (1977)	22	180	Truck delivery
Yellowknife	485 to 560	10,000	Piped water, gravity sewer
	90		Trucked water, sewage pumpout
Yukon			
Clinton Creek	1,140*	381	Circulating water and gravity sewer
Dawson City	6,400*	745	Circulating water and gravity sewer
Faro	1,140*		Circulating water and gravity sewer
Mayo	1,700*	462	Circulating water and gravity sewer
Whitehorse	1,680*	11,217	Circulating water and gravity sewer

Notes:
* Some water bleeding to prevent freezing of service line.
** Leakage in old water pipes.
*** Rauschenberger (1983)

is economical, however, users must be discouraged from doing this where it is not required. This type of wastage is most common in the spring when frost penetration is greatest. To compound the problem, the amount of water available is lowest in early spring. Subarctic communities seem to be more prone to this situation, probably because service lines in the Arctic are designed for low temperatures and are usually heated or recirculated. Remedies for this problem are to educate water users, meter all service connections, provide inexpensive and quick methods of thawing frozen service lines, and construct service lines that are less apt to freeze. Constructing service lines that are less apt to freeze means:

- burying lines below frost line until within the thaw bulb of the house;
- insulating lines where the surrounding ground may freeze;
- recirculating the water in service lines;
- providing heat tapes on lines in the frost zone; and
- heating water in the distribution system.

Leakage. A lot of water is wasted not only because of leakage from old or broken service lines and mains but also because of poorly-maintained plumbing within buildings. Possible methods of minimizing losses of this kind are to:

- maintain pressure in mains at the lowest pressure necessary (approximately 170 kPa);
- promptly repair all leaks in mains and service lines;
- check the system for leaks frequently by isolating sections and pressure testing;
- inform users about the causes of leaks, and train them to repair leaking fixtures such as faucets and toilets; and
- install water meters on all services.

5.3.3 Water Quality. The concern for the quality of the water source is based primarily on the ease with which the water may eventually be treated to make it potable, and the cost of the required treatment. Reliability in quality is as important as reliability in quantity.

Surface Water Quality. Surface waters are more readily polluted by people and animals; thus emphasis should be placed on bacteriological and biological quality of the water and watershed. Cysts, bacteria, and viruses live for long periods in cold waters, and pose a potential health problem for long distances downstream from their entry point.

Water sources should be selected and the watershed protected in a manner acceptable in any climate.

Group I water may be used as public water supplies without treatment (deep groundwater supplies) (disinfection in the distribution system is always required);

Group II water may be used after disinfection only (groundwater under the influence of surface water); and

Group III waters require either complete conventional treatment (including coagulation, sedimentation, filtration and disinfection) or direct filtration and disinfection (Malcolm Pirnie, Inc. and HDR Engineering, Inc., 1990).

Because of the high probability of contamination of surface water by animals harboring various helminth eggs and protozoan cysts, all surface waters must now be coagulated, filtered and disinfected before use in the public water supply in the United States (see Section 6).

Surface water sampled for quality during warm weather may yield misleading values. The sun's ultraviolet light can reduce concentrations of microbial constituents in the water. Freeze rejection of minerals and other impurities during ice formation causes remaining liquid to be of significantly poorer quality. Lakes in cold regions also "turn over" in the fall (Ryan and Crissman, 1990). This process is caused by the decreasing temperature of the lake's surface with the start of winter and the fact that the density of fresh water is greatest at 4°C. Sudden increases in the total dissolved solids and suspended solids will result. Also, during the summer, runoff filters through the mosses and lichens collecting color and organics. These can increase water treatment needs, especially if trihalomethanes are formed during disinfection.

Groundwater Quality. Suprapermafrost water must be considered of questionable quality, since contamination by pit privies, septic systems, and animals can easily occur. Subpermafrost waters are generally unpolluted, but may contain high concentrations of minerals such as iron (as high as 175 mg/L), manganese, magnesium, and calcium as well as organics. Concentrations of iron below 7 mg/L and hardness below 150 mg/L are reasonably easy to reduce by treatment and do not significantly detract from the value of the source. In the highly mineralized areas of Alaska, some groundwaters have been found to contain unacceptably high quantities of arsenic. High concentrations of nitrates have been observed in other groundwaters near Fairbanks, Alaska, and on Nunivak Island.

Quality Improvement of Lake Water. The quality of water in a small saline pond or lake can often be improved by pumping out the concentrated brines which remain under the ice near the end of winter and allowing fresh runoff to replace it. Repeated one or more times, this method may permit the use of an initially unacceptable water body as a source of supply. The U.S. Public Health Service, in developing an improved water source for Barrow, Alaska, used this method with good results. Total dissolved solids concentration in the pond, when the ice cover had fully developed, was about 7,000 mg/L. The range of total dissolved solids in the pond is shown in Figure 5-10. Soil salinity and brine pockets in the soil beneath the impoundment may limit the amount of improvement which can be realized from this technique.

5.4 Structures

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

This discussion does not intend to provide a guide for detailed design of any facility but rather to point out features that may require special attention in cold climates. Designs should be prepared by experienced engineers, qualified to work in cold regions.

5.4.1 River Intakes. Intake structures may be either temporary or permanent. Permanent structures are the most desirable, because they permit a certain freedom from attention during such critical times