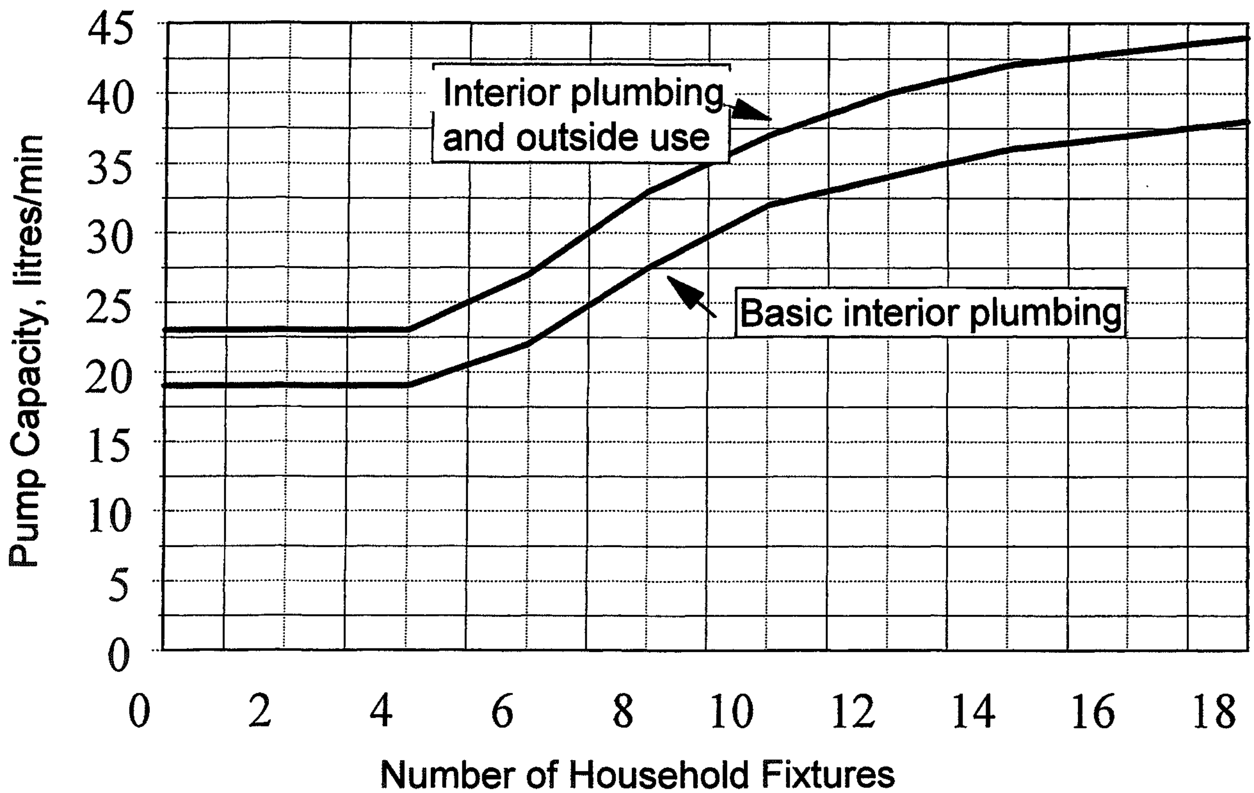

FIGURE 14-2 RECOMMENDED PUMP CAPACITY

are such that the use of subpermafrost wells for individual buildings requires special attention, artesian wells in particular. Recovery of water from a deep well requires electrical power and the use of a pump of appropriate capacity. Submersible pumps are most commonly used for this service.

In much of the Arctic, the permafrost is 100 m or more thick, and the active layer freezes down to the top of the permafrost. Shallow wells are obviously not effective. Shallow wells can be functional in permanently thawed alluvial soils adjacent to existing water bodies or in former stream beds. Design features of drilled wells are illustrated in Figure 14-1. Especially important is a small-diameter "weep" hole in the riser pipe at a location below the frost line and above the check valve. The weep hole prevents the water from freezing in the riser by allowing it to drain back between pump uses. Driven wells using a slotted well point are also effective for shallow water-bearing formations. Provision for air bleed is needed in buildings that use sealed bladder pressure tanks, to allow air flow in and out of the system to allow drain-back.

The needed capacity of the pump depends on the number of fixtures to be served. Figure 14-2 can be used to estimate recommended pump capacity for a household based on the number of fixtures it contains. For example, a house with two sinks, a toilet, and a shower, i.e., four fixtures, should have a pump capacity of at least 20 L/min. The lower curve is for interior household uses only. If in addition, exterior uses such as agriculture or some fire protection or both are desired, then the upper curve should be used. These curves are based on the use of conventional fixtures with no water conservation measures employed; they represent the maximum requirement for cold-region applications.

The capacity of a well or spring is often less than the values indicated in Figure 14-2. In those cases, the well pump should be compatible with well capacity and deliver the water to in-house gravity storage. The gravity storage must be large enough to permit in-house pressure pumping and distribution at the rate indicated in Figure 14-2 for conventional services.

Large-capacity pumps are not required for in-house distribution from water storage tanks that are on a vehicle delivery system. The lower curve on Figure 14-2 provides adequate supply for in-house use. Figure 14-3 shows a typical pump system used for buildings in Alaska. The pump unit for a conventional house complete with plumbing fixtures would

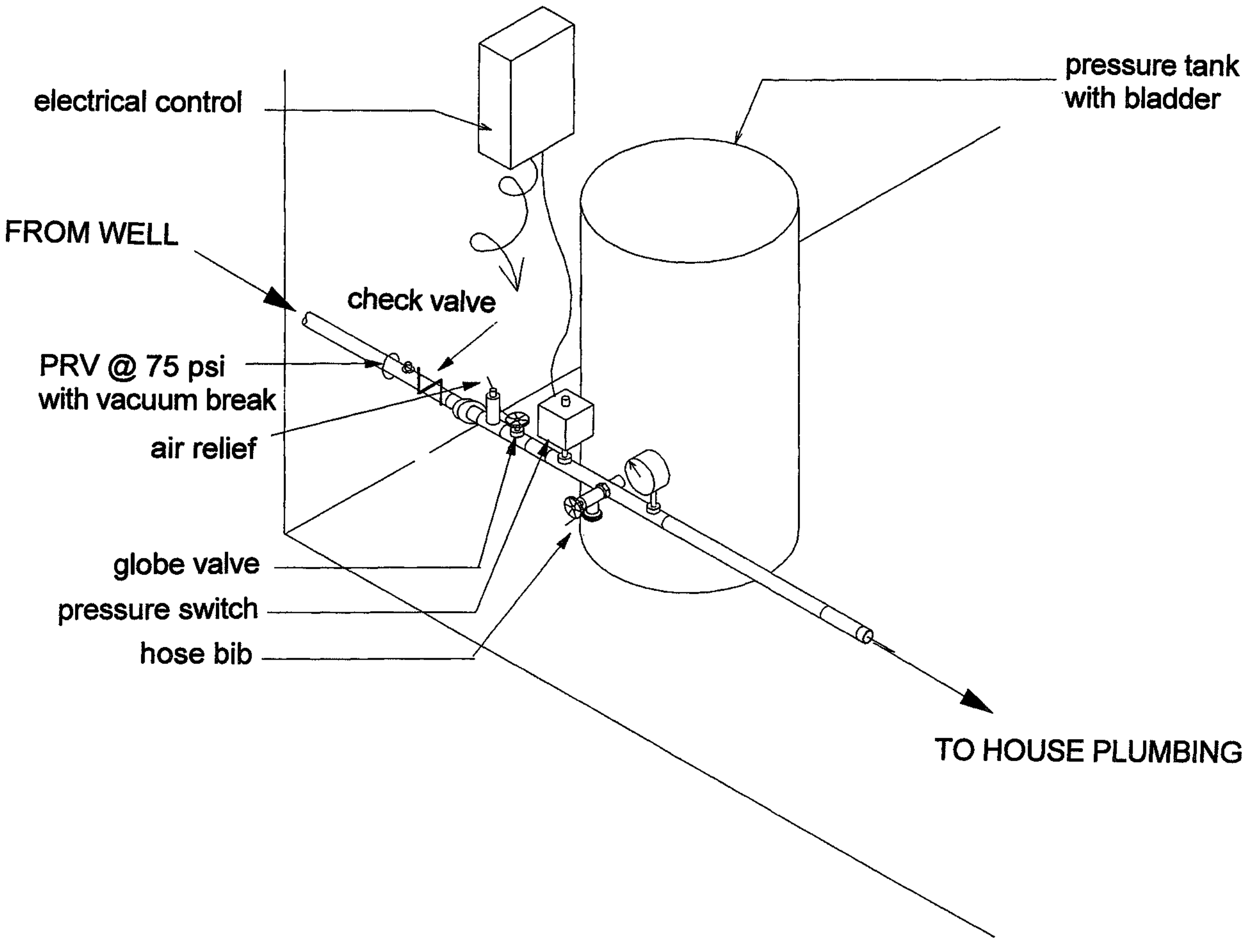

FIGURE 14-3 TYPICAL PUMP PRESSURE SYSTEM WITH WELL LINE DRAINBACK

typically combine a 190 watt pump with a pressure tank.

Springs. Natural springs may be available in the subarctic and may be developed into adequate on-site water supplies. The spring box structure is only provided to physically protect the spring and the quality of the water. It should be constructed of concrete or some other durable, relatively watertight material. The spring water should be admitted freely into the structure, but surface drainage must be excluded. There should be no openings in the structure for animal access. The top cover or access hole cover should be secured. Before constructing the spring box, the site should be excavated sufficiently to locate the true spring openings and to ensure a firm foundation. An insulated, screened overflow pipe should be provided. A service pipe which allows either gravity or pumped flow to the building should be installed in the lower portion of the structure. Valves are needed to allow draining before maintenance. The housing is not usually sized to provide a significant amount of storage. If storage is needed, it is usually provided in the house or in a tank elsewhere. Thermal elements, such as insulation on the sides and cover as well as insulation and heat tape on the overflow and supply pipe are essential if winter operation is expected. The use of a perforated pipe in the water-bearing strata is suggested in aquifers with marginal productivity. Simpler construction is possible for aquifers with higher productivity; for example, the spring housing needs only to be an open-bottom container with impermeable walls. A variation of the construction can be used as a small-scale infiltration gallery next to rivers and streams (U.S. Public Health Service, 1980).

The open nature of some springs may limit the natural purification. A spring should not be used as a domestic supply without first determining suitable quality by taking a series of bacteriological tests. Periodic sampling should continue for the life of the spring. An increase in turbidity during break-up or after storms may indicate that surface runoff is reaching the spring.

Cisterns and Holding Tanks. The collection and storage of rainwater or snow meltwater is possible as a seasonal or a supplemental water source. It is a limited source since the amount of precipitation in the Arctic and subarctic is small. In central Alaska, for example, the rainfall in the warm months of the year averages about 160 mm. A minimal water usage of 10 L/(p•d) would require a catchment surface of 23 m^2/p to supply the annual needs. Assuming no losses due to evaporation or other factors, the above equation can be used to estimate the minimum catchment area required:

$$A = \frac{q \bullet N \bullet d}{P}$$

where,

A = minimum catchment area required, m^2

q = daily water usage, L/(p•d)

N = number of people

d = number of days during which water service is required, d/a

P = annual rainfall at the site (mm/a).

The catchment area from which rainwater is collected is usually the roof of the dwelling. The cistern is most feasible for schools and similar isolated structures with a relatively large roof area and limited summer water needs.

The quality of the water may be affected by the roof surface material, the collection gutters, and if used, the filtering devices. The first flow from the roof carries the maximum concentration of wind-blown particles. Manual or automatic devices to provide for the bypassing of this water should be used.

It is prudent to use filtering devices to remove suspended matter which may cause taste, odor, or color problems. Self-contained, prefabricated pressure filters are readily available in various capacities for home or similar on-site application. Precautions must be taken for filters for the removal of microbial contamination due to concerns over regrowth and breakthrough. Therefore, the holding tank or cistern should be disinfected periodically and the cartridge filters changed frequently (Bouthillier, 1950).

Melted Water. Snowmelting as an on-site water source in winter has been reported (Coutts, 1976). Snow collection can be labor-intensive. Water yield from melted snow or ice and the energy requirements for the melting depend on the density and temperature of the original material (Table 14-2). About 3.0 L of diesel fuel is required for each cubic metre of snow (at 0°C), if the snow melt is 100 percent efficient. One cubic metre of snow (0°C) produces about 300 L of water. At a water use rate of 10 L/(p•d), about 38 L of diesel fuel per person per annum would be required. To meet the energy requirements, the use of a heat source that would otherwise be wasted should be encouraged; for example, exhaust gases or chimneys provide a good source of heat which is typically wasted. Snow- or ice-melting should only be considered as a last resort or as a standby emergency system.

TABLE 14-2 ENERGY REQUIREMENTS AND WATER YIELD FROM ICE AND SNOW

Form	Density Yield* (g/m^3)	Water Required** (L/m^3)	Energy Required** (MJ/m^3)	Volume Diesel (L)
Snow, new, loose*	85	85	29.8	0.8
Snow, on ground*	300	300	10.52	2.7
Snow, drifted and compacted	500	500	175.4	4.5
Ice at 0°C	900	900	315.7	8.0
Ice at -40°C	900	900	391.1	10.0

* Assume 0°C and temperature elevated to 4°C.
** Assume no evaporation loss and 100% efficient heat exchange.

Surface Water. Freshwater ponds, lakes, and streams can be used for all or part of the year if available. If the water body does not completely freeze, an infiltration gallery similar to that used for springs may be used. Winter use of pond water drawn from under the ice may be limited because of the deteriorated water quality. Sometimes filling storage tanks during the summer months for winter use may be the best alternative.

Water from surface water sources should be filtered and disinfected prior to use. Occasionally chemical treatment for removal of suspended solids or color-causing materials may be required.

14.2.2 Water Quality. The quality of these on-site water sources is generally the same as that described in Section 5. Surface sources can be turbid and periodically contaminated by animals, birds or upstream human users. This is why filtration and disinfection should always be practiced. Groundwater sources often contain significant quantities of iron, manganese, and other minerals as well as naturally occurring organic compounds that make treatment difficult. Both surface water and groundwater sources tend to be low in temperature, which decreases the efficiency of chemical treatment and filtration. Readily available conventional equipment that was designed for use in temperate zones has been used including: water softeners, pressure filters often combined with potassium permanganate chemical feed for iron removal, disinfection equipment, and reverse osmosis units for demineralization. Households on vehicle delivery systems would not normally require individual treatment units since it is more economical to use a centralized community water treatment system of the types described in Section 5. Concern has been expressed over health effects of point of use home treatment units that contain activated carbon; they may serve as a media for microorganism growth unless properly maintained and serviced. Some health authorities do not allow point of use filters for domestic service.

14.2.3 Storage Tanks, Plumbing, and Piping. Storage tanks for water and wastewater are required for buildings on vehicle-haul systems. As indicated previously, gravity storage with pressure pumps for water tanks may also be necessary where the on-site water source has a low flow rate. In these cases the storage is sized to meet the daily need; and the low, but continuous, flow refills the tank during non-use periods.

Tanks can be buried where site conditions allow. Ice-rich, fine-grained permafrost soils generally require tank construction above ground for stability. Tanks located above ground require thermal protection. The preferred locations for both water and sewage tanks are within the heated envelope of the dwelling, not only to take maximum advantage of the thermal protection but also to provide easy access for service and maintenance. Installation within the house imposes certain criteria to ensure maximum efficiency and cost effectiveness. The most critical criterion is the use of water conservation measures whenever possible.

Providing a vehicle delivery system to meet the commonly assumed water use rates (about 1,000 L/d for a family of four) for conventional facilities in warm climates is not feasible. At the usage rates shown in Table 14-1, the storage tank capacity should range from about 1,000 to 3,600 L to supply water for up to one week for four persons. Minimum single-family tank sizes can be estimated as follows, assuming twice weekly service:

Minimum water tank size = 675 x no. of bedrooms

Minimum sewage tank size = 1.5 x water tank size

In determining the frequency of service, the total cost of the vehicle delivery needs to be minimized. This total cost includes both the cost to provide service and the cost of the tanks. Delivering water every day will minimize the size and the cost of the building water tank but result in high delivery costs. Conversely, delivering water once per month will reduce the number of visits, but the customers would have to have larger, more expensive water tanks.

Determining a frequency of service to minimize the total cost is difficult because the cost varies with the water use, the cost of the water tanks, the cost of vehicle operation, relative building location, and other factors. As water use varies with each building, setting a fixed frequency of delivery is difficult. For single-family homes, a smaller range in water use as well as lower quantity of use occurs. By assuming a water consumption of 450 L per day for a household of five persons, it is possible to develop a relative cost chart (Cameron, 1996). Figure 14-4 shows one example of such an analysis. In this case, the lowest total cost occurs when water is delivered twice per week. The frequency of service to minimize the total cost of vehicle service to other buildings will vary with tank size and water use rate. Some general guidelines to determine the optimum schedule include the following:

- Service more than twice per week is only economical when water use in the building is sig-

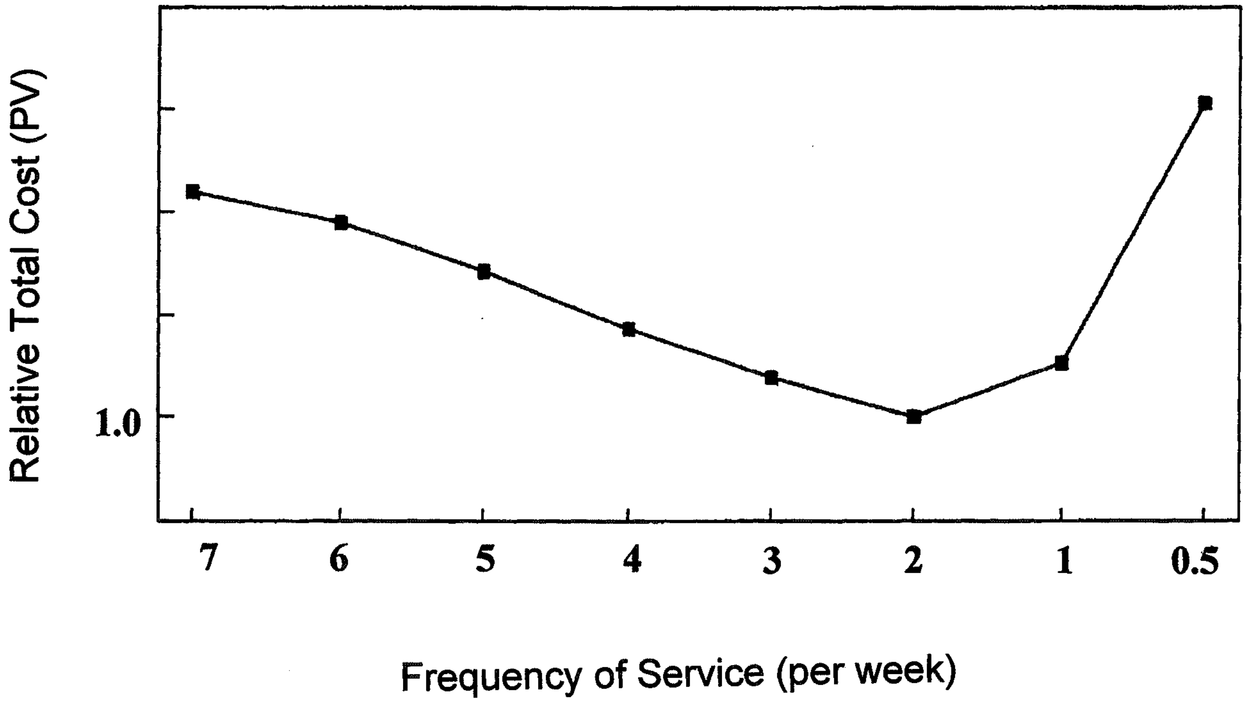

FIGURE 14-4 RELATIVE TOTAL COST FOR VEHICLE HAUL VS. FREQUENCY OF SERVICE

nificantly higher than that of a single-family dwelling.

- The lowest service cost occurs when a full truck load of water can be delivered for each service. The service cost does not decline any further once the frequency is long enough such that a full truckload of water is dropped off with each servicing. For example, it costs the same to deliver five truckloads of water during one day as one truckload on each of five separate days.
- Specifying the frequency of service as opposed to providing whatever frequency of service is requested will result in a minimum overall system cost.

To reduce pumping requirements, the in-house water tank should be located as high as possible, and the wastewater tank as low as possible. Both tanks should be made of corrosion-resistant materials. The water tank should not impart tastes or odors to the contents. Plastic materials, particularly fiberglass or high density polyethylene, should be suitable for use with potable water, and meet established national standards.

The technical specifications for water and wastewater storage tanks at Galena, Alaska, include the following provisions: 5.0 mm nominal thickness fiberglass, one-piece unit, contact mold construction method, 13 mm radius of curvature at intersections of tank surfaces; tensile strength 36.6 MPa, flexural strength 40.0 MPa, impact strength 61.4 MPa; water tank fabrication with an isophthalic acid resin during lamination to eliminate taste and odors, and a paraffin surfacing wax for a curing agent on all interior surfaces; the wastewater tank will have a resin-rich interior surface for corrosion resistance. The location of these storage tanks and the related plumbing facilities of this Galena installation are shown in Figure 14-5.

The water tank fill line runs to a quick-connect fitting on the house exterior for connection to the hose from the water delivery vehicle. The pumpout line for the wastewater tank runs to a similar but different size fitting.

As shown in Figure 14-6, the wastewater tank is supported by the basic house flooring and decked over with plywood. Alternatively, the tank may be an insulated steel or plastic tank located outside the house. A low-water-use toilet (1.0 L/flush) is connected directly to the tank. Since the village may have public showers and public laundry, the fixtures in most buildings are limited to sinks and the low-water-use toilet.

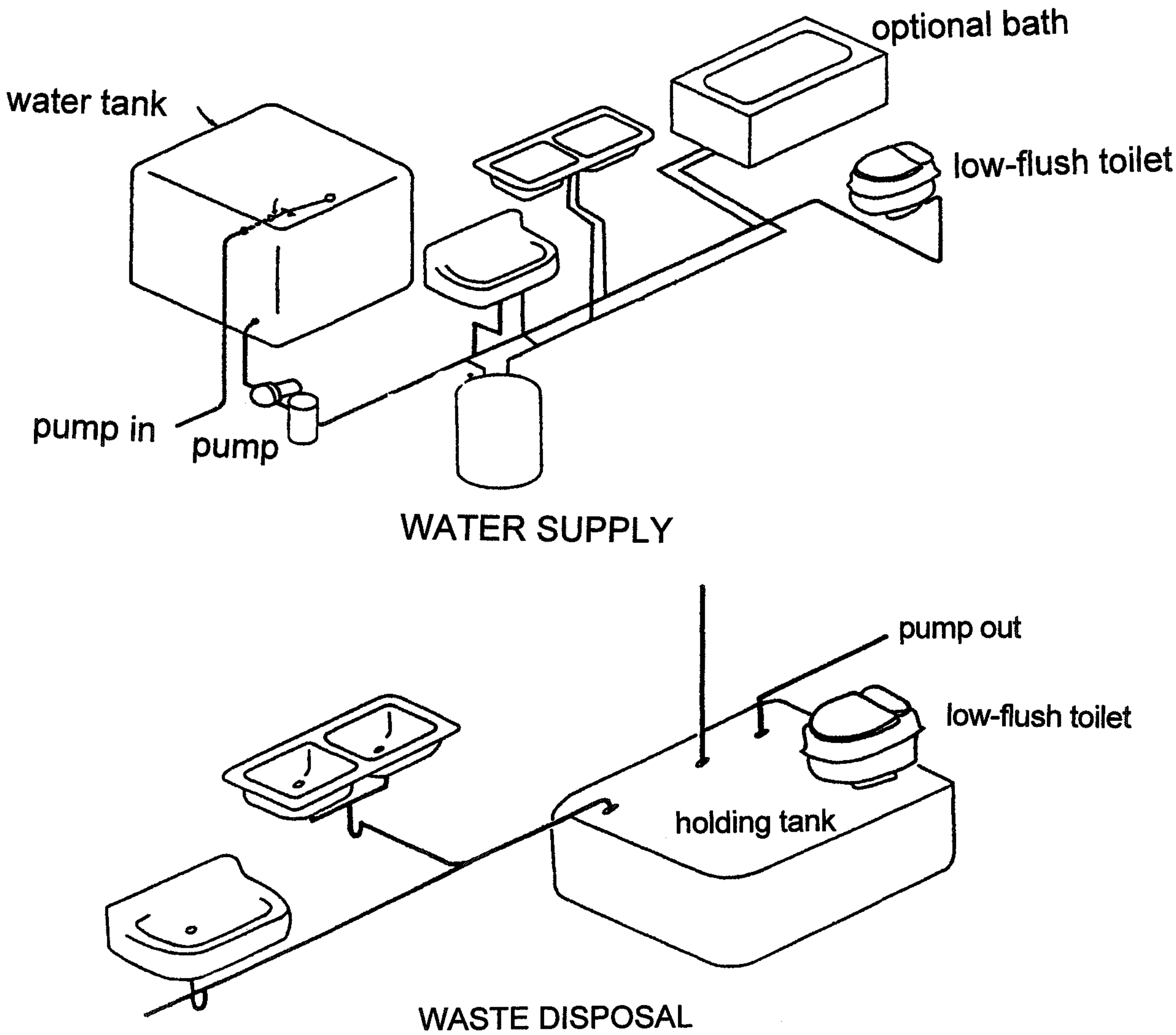

FIGURE 14-5 WATER SUPPLY AND WASTEWATER PLUMBING – VEHICLE-HAUL SYSTEM

The plumbing details shown in Figure 14-5 are typical for cold-region installations. Copper lines, polyethylene, or polybutylene are commonly used for water service, and plastic with solvent-welded or compression joints, for wastewater.

All such plumbing should be located along interior walls, if at all possible, for maximum thermal protection. The water lines should be provided with drains at the low spots so that the system can be emptied during extended periods of cold or power loss or both, in the building. In addition to the normal sink traps, the wastewater lines should have clean-outs at critical locations in the system. Exterior walls must be penetrated so that the integrity of the wall insulation and vapor barrier remains sound. These exterior connections must be dry and empty when not in use. Exterior connections to on-site wells or springs must be insulated and heat traced. Figure 14-7 shows methods of making exterior connections of sewer pipes to on-site disposal systems or to community sewers.

The quick-connect connections and the hoses used for water and wastewater should be of different sizes to avoid the risk of cross-contamination. Both the water tank and the sewage tank must be vented to permit air movement during filling and pump-out. Household wastewater tanks have a typical capacity of 2,000 L, but some as large as 4,500 L have been used in Canada. It is common practice to install a wastewater tank from one and one-half up to twice the size of the water storage tank; although generally a tank volume of about 1,000 L or at least

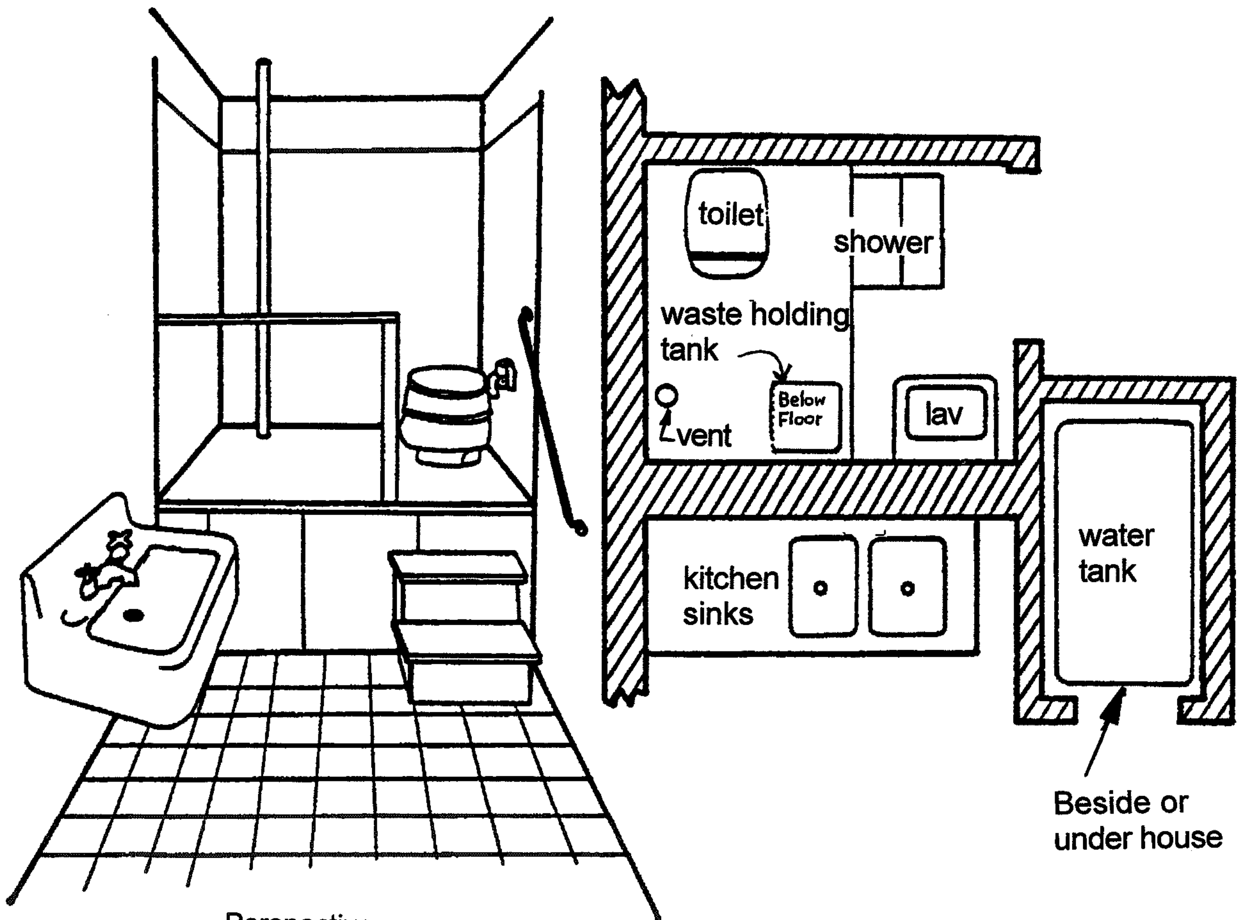

FIGURE 14-6 BASIC HOUSEHOLD FACILITIES FOR VEHICLE-HAUL SYSTEM

400 L larger than the water tank should give adequate service.

14.3 Water Conservation Alternatives

Water conservation measures can include simple flow-control orifices in sinks and shower piping to limit flow. Automatic spring-loaded supply valves on sinks, and low water use toilets may be used. The toilet provides the major opportunity for water conservation since the conventional units without any modifications consume about 40 percent of the household water. Personal bathing in conventional showers or tubs uses about 30 percent of the water supplied. The balance is used in laundry (15 percent), kitchen (13 percent) and miscellaneous (2 percent) (Cameron and Armstrong, 1979; Armstrong et al., 1981).

14.3.1 Toilets. Toilets use more water than any other single fixture within the home. Toilets, which typically use 13 L/flush or less, can be easily modified by the homeowner to reduce water consumption during flushing. Modifications range from simple homemade devices such as weights or plastic bottle inserts, to inexpensive manufactured dams or dual-flush attachments. A more expensive modification, applicable for piped systems, replaces the reservoir tank with a small pressure tank.

Also a number of toilets designed to use as little as 1.5 litres of water are available. These recirculating toilets use the smallest amount of fresh water. They require an initial charge of water and chemicals or other additives. A number of toilet alternatives that do not require any water at all are also available. It is important to note that not all toilets are applicable or appropriate to every situation. For example, some mechanical-seal toilets must be located directly over a receiving tank, and a 1.5 L toilet should only discharge into a tank less than 25 m away through a sewer line with at least a three percent slope.

14.3.2 Bathing. Depending on the habits of the user, showering usually requires less water than tub bathing, particularly if an inexpensive flow-restrict-

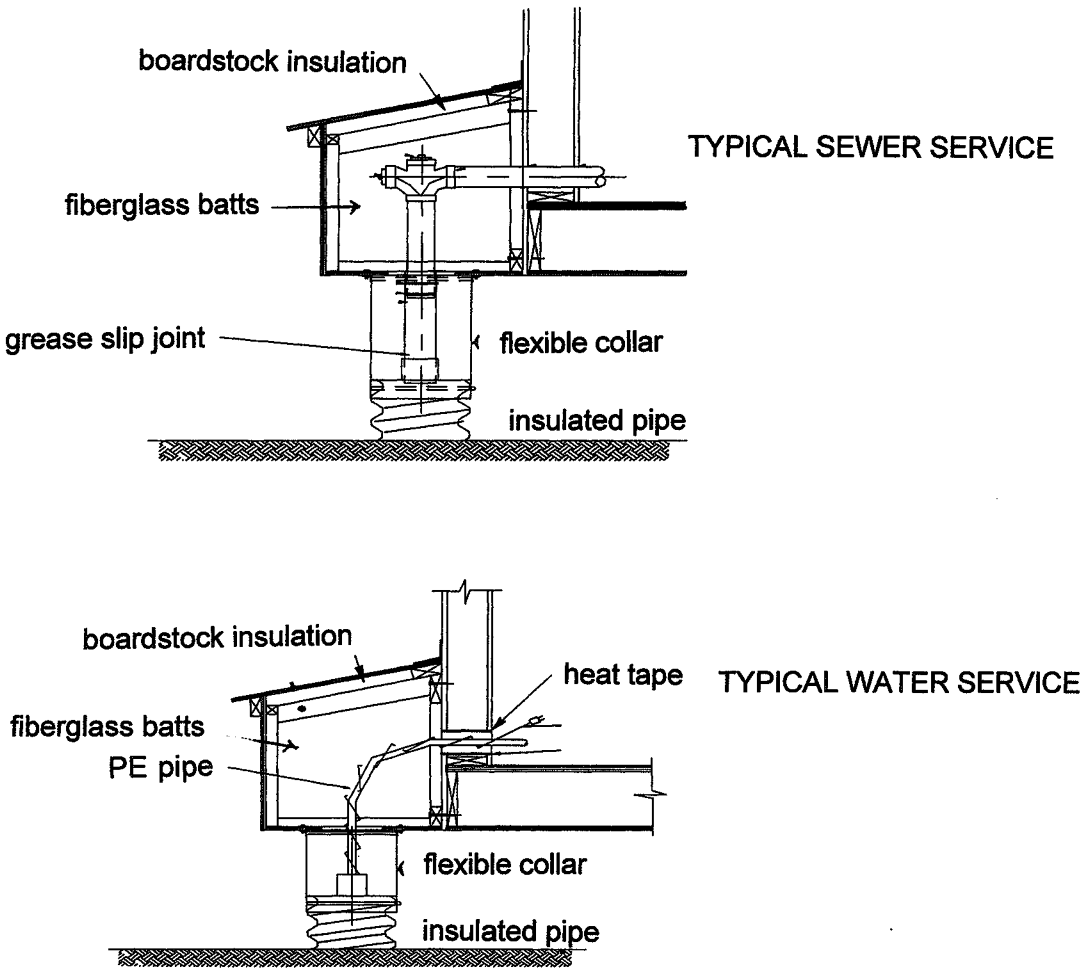

FIGURE 14-7 ARCTIC HOUSE UTILITY BOX INSTALLATION

ing insert or specially designed low-flow showerhead has been installed. Many low-flow showerheads give a satisfactory or even superior shower while saving a considerable amount of water along with the energy required for heating the water. Other specialty shower units or systems use very little water. Several add-on shower devices are available that can save water, and some increase convenience, comfort, and safety.

The use of hand-held showers can reduce water consumption by about 50 percent compared to the conventional fixed shower heads. A very significant saving in household energy use can be achieved by coupling a hand-held shower to an instant in-line water heater. The energy saving arises from the elimination of the conventional hot-water tank for heating and storing of water. The units are thermostatically controlled and provide instantaneous heating of water flowing through the unit. Both electrical and gas-fired units are commercially available. The gas-fired units claim at least a 25 percent fuel savings compared to a conventional hot-water tank system. Single heating units can be located in the house at each point of hot-water use or a larger heater unit can be located at a central point.

14.3.3 Laundry. Numerous different brands of top-loading, automatic washers are available; some of them use considerably less water than others. The more efficient tumble action of the front-load washer makes it the lowest hot- and total-water user of the automatic washers. They are, however, more expensive, and consumer acceptance has been poor.

14.3.4 Kitchen. In the kitchen, dishwashing uses the most water. Washing dishes by hand can be done with very little water but may entail some inconvenience and extra effort. If an automatic dishwasher is used and always loaded to capacity for each full cycle of operation, water use is comparable to dishwashing by hand in a filled sink and rinsing under a free-flowing stream of water. In-sink food waste disposal units are a modern convenience that, if judiciously used, does not significantly increase domestic water use. Other kitchen operations such as drinking and cooking use small, relatively fixed volumes of water. Reductions in the wasting of water can be achieved by adopting habits such as keeping a container of cold water in the refrigerator. Various faucet attachments reduce the amount of water flow and hence water wastage. Water flow reduction of faucets also has the added benefit of energy savings since approximately 50 to 75 percent of the flow is heated water. Where water is corrosive, all faucets should be flushed before taking water for consumption, until the system is modified to correct the water characteristics (GCDWQ, 1995).

14.3.5 Economics. There are practical and technical limitations to the economic selection of water conservation alternatives for an individual building. All capital and operating and maintenance (O&M) costs associated with an alternative need to be discounted to obtain its present worth. Since the costs depend upon the unit costs for water, sewerage, and energy, the number of uses or volume used, and the O&M costs, each new and retrofit situation is different. The marginal unit costs (net of any subsidies) should be used to arrive at costs, but these are often difficult or impractical to obtain. Nevertheless, the following measures of water conservation are recommended.

For piped systems, toilets need not use over 6.0 L/flush. Low-flow showers and flow-control aerators are almost universally economical. Piped systems with preheating, excessive water pressures, or high treatment costs, and locations with very high electricity costs may find other devices economical.

For vehicle systems with marginal rates of $0.01 to $0.02/L, more restrictive alternatives are economical for households. Mechanical flush toilets should be used wherever possible. Where the sewage holding tank cannot be located directly below the toilet, recirculating toilets are usually the most economical despite the cost of chemicals. Toilets using over 6L/flush should not be installed. Low-flow showers, hand-held showers, flow-control aerators, mixing faucets, and a method to reduce hot-water pipe flushing, such as insulation, circulation, or a return line, are economical. Front-load laundry machines are economical for new installations and use minimal amounts of water.

Where utility costs are very high or where the water supply is limited, more severe steps are necessary. Even nongravity piped sewer systems do not control excessive water use that is inherent with vehicle systems and central facilities. In addition to the recommendations pertaining to vehicle systems, devices such as spray and self-closing faucets, specialty shower systems, and timers on showers can be used. Water conservation is usually more economical than greywater reuse. Greywater reuse should only be considered for central facilities and where other considerations such as zero pollution are paramount. Reuse must be approached with caution due to the complex treatment systems needed, the controls that are necessary, and the risk of disease transmission during a malfunction.

14.4 On-Site Wastewater Management

Community sewage collection systems (pipes, vehicle haul) are not always possible or economical. It is often necessary to provide for on-site wastewater treatment and disposal. Community treatment systems are designed to meet regulatory requirements for both the protection of public health and the environment at the discharge point. On-site treatment systems must meet the same objectives.

14.4.1 Direct Disposal. The alternatives for direct, on-site disposal without some type of preliminary treatment are bucket and chemical toilet dump pits, pit privies, and vaulted privies. The use of bucket or chemical toilets is frequently chosen because of convenience and privacy. In nonpermafrost and many intermittent permafrost areas, a suitable location can be found for the excavation of a disposal pit. Pit location criteria should conform with those used for septic tank leach fields. One such criterion is the separation distance of at least 35 m from the water supply point and other water bodies. Groundwater depth should also be determined to ensure adequate separation between the bottom of the pit and the highest annual groundwater table. In addition, ground freezing patterns, direction and rate of groundwater movement, and soil types should be examined to ensure that the leachate from the pit cannot migrate to a water source during adverse conditions. Another important consideration is surface and interflow water movement during spring break-up. The pit should be located to minimize seepage inflow. If necessary and when soil conditions permit, a diversion ditch around the pit can be excavated. The pit should be about one metre in

TABLE 14-3 TYPICAL DOMESTIC WASTEWATER CHARACTERISTICS

Constituent	g/(p•d)	mg/L at 90 L/(p•d)	mg/L at 200 L/(p•d)
BOD_5	81.7	910	410
Suspended solids	90.8	1010	450
Total nitrogen	12.3	140	60
Total phosphorus	3.6	40	18
Fecal coliform* (no./100 mL)	3.0×10^9	2.2×10^6	1.5×10^6

* based on 2.0×10^7 fecal coliform/g of feces and 150 g feces/capita/d.

diameter and as deep as soil conditions and groundwater table location permit. Odor reduction is possible with periodic additions of layers of ashes or lime. A pit 1 m in diameter and about 2.5 m in depth used for human waste only may last a four-member family two to three years. Replacement pits should be 2 to 4 m apart to ensure soil stability and reduce infiltration from the old pit.

The pit privy is one of the earliest methods of human waste disposal. The main features of concern in cold regions are the criteria for locating the pit and the elevation of the entrance to account for snow accumulation. The privy building should be relocatable and the pit chamber should be vented to the outside.

Where pumpout equipment is available, vault toilets may be suitable. Vault toilets can be used where land use, groundwater, soil conditions, or proximity to surface water bodies restrict the use of conventional pits. They are not common for single-family dwellings but are extensively used for on-site sanitation at parks, playgrounds, and similar recreational facilities. The use of four vertical walls and a separate liner is usually cheaper and easier than attempting to construct a complete watertight structure on site. Both reinforced Hypalon and the more rigid cross-linked polyethylene have been successfully used as liners. If the thinner and more flexible Hypalon is used, a thin layer of concrete should be placed on the bottom for protection during the cleaning operations. The vault should have a maximum capacity of about 1,900 L, unless the design analysis shows that a larger capacity is warranted. A large-diameter access hole is essential in the vault cover for access during cleaning. The vault should be pumped out at the end of the recreational season or more frequently if necessary. Some cleaning by hand tools may be necessary, since all sorts of undesirable objects tend to find their way into the vault and cannot be removed with the typical pumper vehicle.

14.4.2 On-Site Treatment. Individual facility wastewater treatment can be achieved by three different methods:

- composting;
- septic tanks (anaerobic); and
- aerobic units.

These processes are capable of treating different volumes and strengths of wastewater. Wastewater strength often varies with water use, as does the concentration of contaminants in wastewater. An estimate of the mass of waste contaminants generated by various sources in the home is detailed in Section 10. The average daily amounts are given in Table 14-3. These amounts can be divided by the amount of wastewater generated in the home to calculate concentrations. Concentrations based on 90 and 200 L/(p•d) are also listed in Table 14-3.

Composting. Non-water-carried treatment using a composting process can be accomplished with one of several different types of units. Some require electricity as they are electrically heated, or have ventilation blowers. Selection from the various types of composters requires careful evaluation for sizing, hydraulic loading, operation and maintenance requirements and cost of operations. Several types of units are described in the references. The composted material must be removed for disposal.