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.	Pipes laid in sawtooth profile to fit into utilidor. Can be used with any low flush toilet. One interface valve can serve a large school or motel. Requires a vacuum station for every 200 to 500 services. Pumps at vacuum station deliver sewage to treatment plant. Can separate blackwater and graywater. Uses 76-, 101-, and 152-mm pipe. 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.	Water saving if low-water-use fixtures are installed. High health and convenience improvement. No central facility needed; units in individual buildings. No infiltration. Uses small pipes.

Daily collection has been found to be the most desirable. Each system has two buckets; the used one is replaced by a clean, newly-lined bucket (Smith 1986). The bags are hauled to the disposal point by trucks or snow machines. The usual application of a community-run container system is for a population of 200 people or less.

Disposal. Disposal of the bags and their contents by burial in a pit is not a good solution. The most desirable procedure is to deposit the contents in a conventional waste treatment system and to burn the bags. However, the waste is very concentrated and cannot be treated in that form. It is necessary that there be enough liquid from a sewer system or other source of water for dilution. Other methods of disposal that have been used are ocean dumping and placing in a lagoon, composting, or septic system.

Even when a treatment system is available to process the wastes, the bags themselves are a problem. After emptying, the bags must be burned or buried.

The container system has many undesirable aspects. It is esthetically unappealing and it requires constant attention of citizens determined to make it work. From the public health standpoint, studies have shown that containers are only slightly better than a collection of privies (Heinke 1985). Its primary merit, besides its low initial and operating costs, is that it is a first step in providing a sanitation system for small population centers.

10.7.2 Tank Storage and Tanker Haul

A tank storage and haul system is a refinement of the container technique. Each dwelling has a sewage holding tank below the floor. The household wastes from the cooking, bathing, and toilet facilities flow into the tank by gravity flow (Figure 10.8). The holding tank is pumped out periodically into a tanker collection vehicle. The tanker then transports the liquid wastes to the central disposal plant. The system depends on a fairly abundant supply of flowing water so it usually is installed after or at the same time as a community-wide water supply system. Communities with populations of about 500 or more are usually capable of operating such a system effectively.

Holding tanks of sufficient size are needed in each building to reduce the frequency of cleaning them out. The Cold Climate Utilities Manual (Smith 1986) recommends that the tanks hold at least 1,000 liters. A rule of thumb is that the waste holding tanks should hold about twice as much as the fresh water tank. Quick-disconnect hoses should be used and the size of the sewage pipe should be different from the fresh water pipes to avoid the possibility of a cross connection. The pumpout pipe should slope back toward the house to prevent leakage from running down the pipe to freeze outside.

The tanks must be provided with a manhole access to allow cleaning and they must have an outside outlet for removal of the wastes.

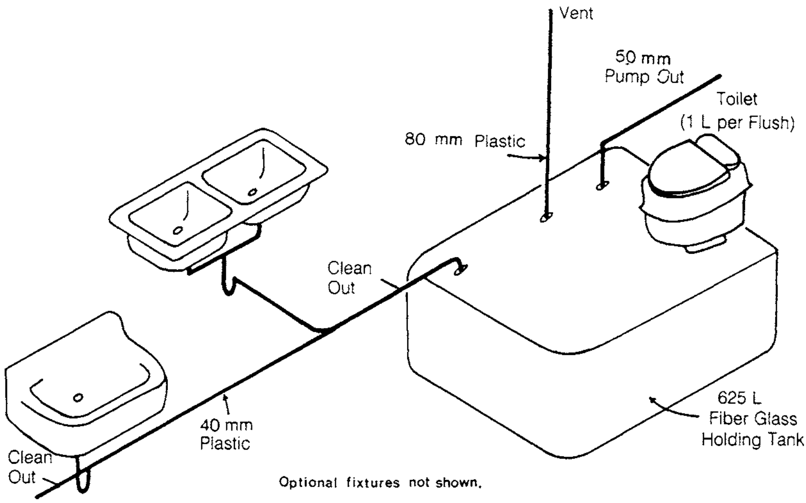

FIG. 10.8 Wastewater Plumbing for a House on a Truck-Hauled Sewage System (from Smith 1986, Courtesy of Canadian Society for Civil Engineering)

The tank must be vented to the outside to allow odors to escape as the tank fills. It is mandatory to guard against freezing. By locating the tank beneath the house, a benefit can be gained from the house heat loss. Heat loss analysis should be made to determine the need for insulation or added heating or both. In permafrost areas, the tank must not melt the permafrost nor can it be allowed to freeze. The weight of a full tank is large enough that the supporting structure or soil must be analyzed to insure stability.

The tanker vehicles that haul away the wastes represent a major cost of this system. The vehicles must be large enough to carry the contents of several dwellings, be equipped with a pump and extraction hose, and be insulated against freezing. To be able to travel on muddy roads in spring and in snow in winter, the vehicles should be all-wheel-drive. Initial and operational costs for this type of vehicle are high. Tracked vehicles can travel to locations that do not have roads but their costs are much greater than for wheeled vehicles. Details of the vehicles and their operation are given in the Cold Climate Utilities Manual (Smith 1986).

10.7.3 Gravity-Flow Pipe System

Most wastewater collection systems rely on gravity to propel the water through the pipes. In temperate climates and on terrain that is not too steeply sloping, this means of collection is the lowest cost alternative. An important requirement is that the grade line of the pipes be neither too steep nor too flat and not have sags. In cold regions applications, the pipes must be kept from freezing, which adds complexity and cost. The planning, design, and construction of a gravity-flow wastewater collection system calls upon the full range of cold regions skills and expertise. The system requires detailed knowledge of the geotechnical characteristics of the site for foundations and support of the pipelines, thorough analysis of the thermal and energy requirements of the proposed layout, and attention to details in construction.

If gravity sewers can be installed at a site without excessive construction costs, this type of collection will be the lowest cost and most reliable of the alternatives. All fixtures, fittings, and appurtenances are the same as for installations in temperate climates. However, some additional work must be done to insulate and seal the components against infiltration. Maintenance is more likely to be done and to cost less when standard components and technology are employed.

Surface drainage, either from rains or melting snow, should not be allowed to enter wastewater lines in cold regions. These waters are usually rather cold and will lower the temperature of the wastewater stream. The sudden influx of surface water can overload treatment facilities and bring in excessive amounts of sand and grit.

Above-Ground Lines. Most gravity sewer lines and pipe materials are not tolerant of settlements or distortion. Gravity sewers in cold regions must be placed below the active layer to avoid frost heave and consequent pipe breakage. Also, they must be placed above ice-rich permafrost to prevent the warm pipe from causing melting and settlement. In many situations, it is not possible to meet both requirements and maintain an acceptable grade. If the soil on site is non-frost-susceptible, insulated pipes can be buried.

When the site conditions prevent simple burial of the collector pipes, they are placed above the ground surface. In order to maintain the grade, the pipe must be elevated along the path to the treatment facility. This is done by placing the line on piles or on an embankment of non-frost-susceptible soil. Careful planning of the layout must be done to minimize the number of times the line must cross a road or walkway. Each such crossing requires a structure to allow the line to either pass under or over the road. In any event, above-ground lines are unsightly and disruptive to access (Figure 10.9).

Single or Combined Lines. Because of the larger temperature differential between the inside and the outside of the pipe, heat losses in above-ground lines are approximately three times greater than for similar buried pipes. It is possible to minimize total heat loss by inclosing sanitary piping, along with fresh water, electrical, and heating pipes, in a single, large, insulated utilidor (Chapter 9). However, the advantage in terms of thermal efficiency for small systems is not great. The U.S. Navy tested utilidors enclosing multiple lines of freez-

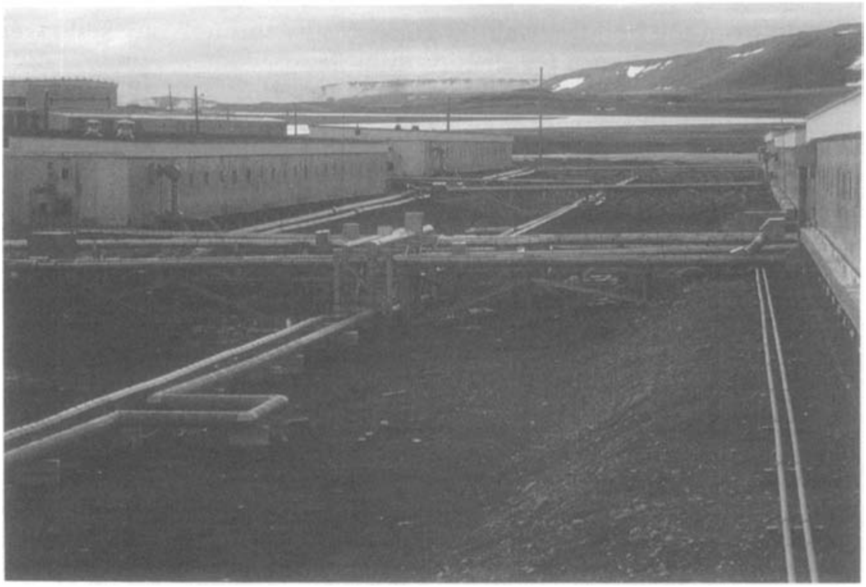

FIG. 10.9 Utilidor System Can Create an Unappealing Complex of Pipes (CRREL photo, D. R. Freitag)

able liquids and one pipe carrying a heated liquid to supply heat for all (Hoffman 1971, Smith 1970). The data indicate that if the utility system consists of four or fewer pipes it is more efficient to insulate and heat trace each pipe separately than to construct, insulate, and heat a utilidor to enclose them. For a greater number of lines, the difference was so small that the choice of single lines or utilidors could be made on the basis of other factors such as convenience, appearance, and whether the utilidor would serve an added purpose such as a walkway. The design and layout of utilidors are taken up in some detail in Chapter 9.

Line Layout. Gravity sewers must maintain sufficient flow velocity to suspend and move the wastes. The recommended minimum velocity in collection mains is 0.6 m/s (2 ft/sec). The mains do not flow full so the proper grade and size relation for a line must be determined from application of Manning's equation. In cold regions, relatively steep slopes are desirable as a greater velocity will allow less opportunity for lines to freeze. If possible the line grid should be arranged so that large users are at the ends of the laterals. This practice helps maintain sufficient flow volume to minimize icing and clogging.

Service lines from a building to the main should be 100 mm (4 in.) diameter pipe and be laid at a slope of 2.0% (Smith 1986). The connection from the building should go vertically through any soil layer to minimize the chance for distortion by frost action. Representative service line connections are shown in Figures 10.10 and 10.11. Of the two, the through-the-wall style is preferred because it can tolerate more relative movement, and all building plumbing can be kept above floor level. When the service connection must be made to above-ground lines, the service lines should be as short, flexible, and steeply sloping as possible. The lines are insulated and heat-traced and provision made for thawing if freezing occurs (and almost inevitably at some time it will).

10.7.4 Pressurized Lines

There are many locations in the far north that do not lend themselves well to gravity-flow collection. Irregular terrain or a widely dispersed population lead to high construction cost which is magnified for an isolated location. Permafrost in the foundation soils requires that the lines be placed above ground in a maze of pipes or in utilidors, either above or below ground. Above-ground lines are unsightly and are an impediment to travel around the community. Also, the demand for water to keep the sewers flowing may be too much for a marginal water supply.

In these situations, a pressure-flow system can be a satisfactory alternative. Because the fluids are moved by the internal pressure differential instead of gravity, such systems need not conform to a grade specification and can be laid on the ground surface or just

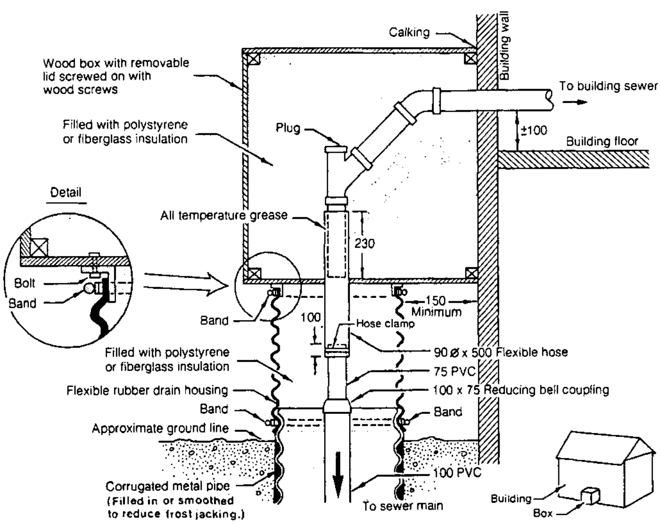

FIG. 10.10 Details of Sewer Connection through Wall (from Smith 1986, Courtesy of Canadian Society for Civil Engineering)

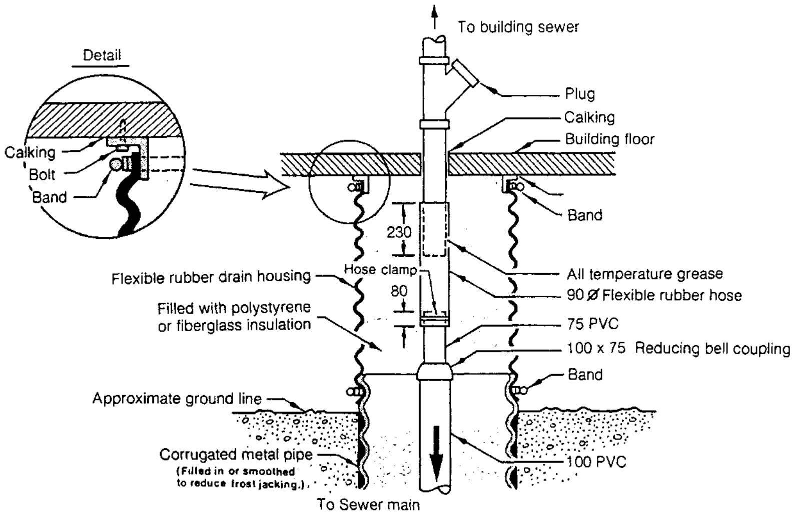

FIG. 10.11 Details of a Sewer Connection through Floor (from Smith 1986, Courtesy of Canadian Society for Civil Engineering)

below. Furthermore, vertical movements, that may be caused by soil settlements or frost heave and do not result in actual breakage, have no adverse effect on the ability of the lines to move wastes. There is no concern for infiltration in a pressurized underground line as the internal pressure will prevent inflow. Pipe sizes in a pressurized collection system are much smaller than for comparable capacity in a gravity system.

Pressurized systems have the attribute of being compatible with conventional gravity-fed systems. Pressurized lines can be used for that portion of the total system for which they are best suited and, at a collection point, the wastes can be inserted into the lines of a gravity main. Pressure systems can use either conventional or low-water-use toilets and fixtures.

Pumps. A pressure system requires that each building (or small group of buildings) be served by a pump-grinder unit. Wastes and wastewater from a building pass through the grinder and go into a holding tank. At intervals determined by the level in the tank, the wastes are pumped out and into a collector line. The pumps are positive displacement pumps with relatively steady pumping rates over a broad range of heads. With a household water-use rate of 190 L/p·d (50 gal/p·d) and a typical pump-grinder unit rated at 750 W (1 hp), the pump would operate for about one minute three times per day for each person in the household (Smith 1986). Systems are designed to pump against the design head plus a 40% overload. It is recommended that each unit have redundant controls and pumps so breakdowns do not render the installation inoperable. The overall collection system, being composed of a number of independent installations, is relatively unaffected by the failure of one or a few units.

Sump. The holding tank or sump in which wastes are stored between pump actions must be made of corrosion-resistant material. Glass fiber-resin material is commonly used. It has a good service record and its light weight saves on shipping costs. The tanks should be large enough to store several hours of accumulation. For dwellings, this probably should be of the order of 500 L (130 gal). The on-off switches for the pumps must be pressure sensors as the float type have been found to fail quickly.

Lines. Pressure sewers are sized to maintain a velocity of 1.0 m/s (3 ft/sec) to keep the lines clean. The minimum size for a collection line is 32 mm ($1^1/_4$ in.) which will handle a single pump unit. If additional units are placed on a collector line, the pressure and the velocity will increase. This does not degrade the system effectiveness but does use more energy than necessary. It is better to use an undersized pipe rather than an oversized one. An undersized pipe will always function but an oversized one may not be capable of producing flow velocities high enough to prevent clogging. The collection lines are made of PVC pipe with standard or drain-waste-vent (DWV) fittings. Solvent welding works satisfactorily for joining the pipes. The lines should drain to low points for emptying and check valves should be located in horizontal sections. Arrangement should be made for cleaning and maintaining the parts of the system without shutting down the whole.

Design of a pressure sanitary system is different in some important aspects from a conventional gravity line. Manufacturers' literature and reports such as Barber and Gray (1982) should be consulted.

10.7.5 Vacuum Collection Systems

A vacuum sewer system has most of the advantages of a pressure system. Vacuum, like pressure, allows the line to be laid without having to maintain a particular grade and it also uses small-diameter pipe. For some locations, a great advantage of the vacuum system is that special toilets are available that function using only about $^1/_{10}$ as much water as a conventional flush toilet. Low-water-use toilets are also an option.

Operation Principle. In the vacuum collection system, each household is connected to a main in which a vacuum is maintained by pumps at a central collection point. Within each dwelling, wastewater is conveyed by gravity from the source to a small sump. From the sump, the wastes are conveyed to the collection mains through a special entry valve that opens automatically when enough sewage has collected. The valve closes again after a timed interval sufficient for the wastes to be drawn into the main by the air pressure differential. The sewage mixes with air to create a watery foam for transport through the mains. A vacuum potential is maintained by the pumps at the central collection point. From the collection point, the waste is transferred to the sewer lines to the treatment plant. Transport in the vacuum system is intermittent, taking place only when a vacuum interface is open. When the vacuum is off, the waste in the system sits in a "slug" at lift pockets constructed at intervals along the mains. Like the pressure system, vacuum collection lends itself readily to connection to a final conventional gravity-flow collector.

System Classes. Vacuum systems are installed in three different configurations: single pipe, single pipe with vacuum toilets, and two pipes. The single-pipe system collects sewage and wastewater from conventional fixtures into a single vacuum pipe. The vacuum lines need not enter the building. All vacuum system components can be placed in the service right-of-way. The single pipe with vacuum toilets differs from the single pipe in that specially designed vacuum toilets (VWC) are connected directly to the vacuum main. All other wastewater goes into the sump first as for the single-pipe system. In a two-pipe system the toilet wastes (black water) are transported in one pipe and other wastewater (gray water) in another. This technique allows the treatment facility to process the very strong black water separately from the very dilute gray water, thereby saving on the cost of the overall system.

Design. Vacuum lines are laid out in a vertical sawtooth pattern for level or upslope transport (Figure 10.12). Downslope sections have a uniform grade and flow is gravity driven. Pipes are PVC or ABS, Schedule 40, in sizes of 75, 100, or 150 mm (3, 4, or 5 in.) diameter. Transport pockets are created at the sawtooth by 45° bends with approximately 0.3 m (1 ft) elevation changes. Spacing between the transport pockets varies with pipe size and other transport factors but is of the order of 100 to 150 m (300 to 500 ft). A system may have as much as 3,000 meters (nearly 2 miles) of line between the vacuum source and the farthest interface valve. Total friction loss in a system can be as much as 4.0 m (13 ft). Some systems have as many as 3,000 valves and 12 vacuum systems (Smith 1986).

Because the waste is transported as a solids-water-air suspension the mechanics involved is somewhat different than for a pure hydraulic system. Designers must consult manufacturers' literature and references such as Pacheco et al. (1982).

10.8 ON-SITE WASTEWATER MANAGEMENT

There are many instances of habitations that cannot be linked to a community treatment system. These include very small communities,

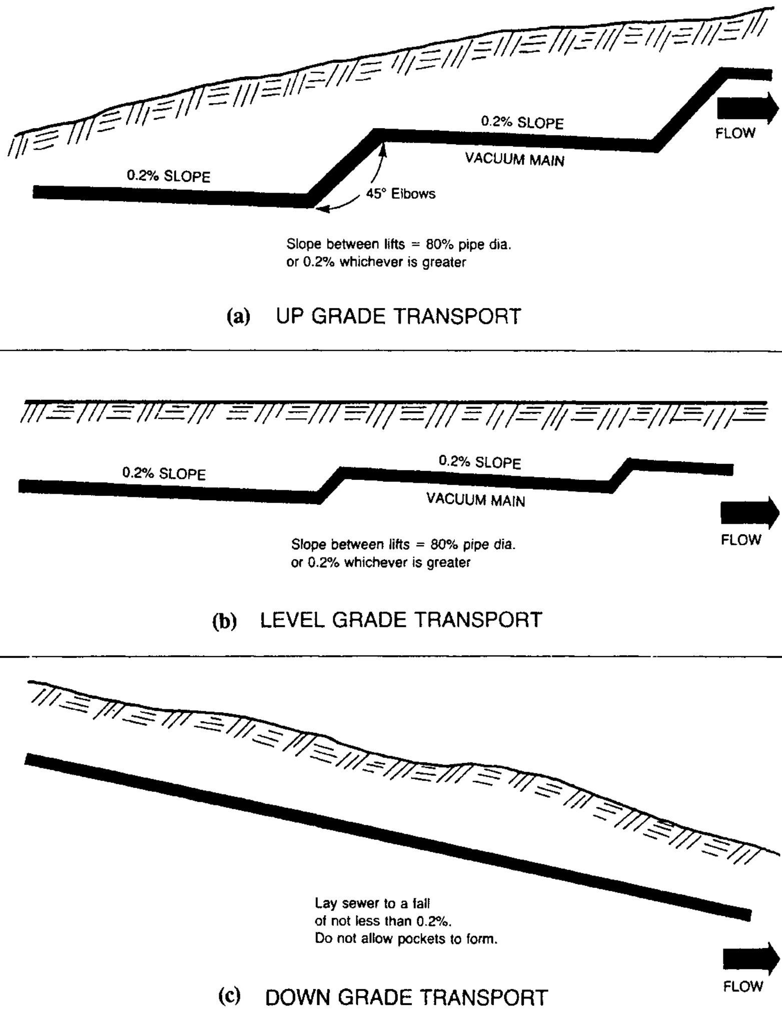

FIG. 10.12 Vacuum System Layout Patterns (from Smith 1986, Courtesy of Canadian Society for Civil Engineering)

widely dispersed individual dwellings, campgrounds, and parks and recreation areas that are lightly or sporadically used. At one time, users were willing to accept a simple privy for human wastes and ground dumping for graywater. Or, for the wintertime comfort of an indoor privy, the container system could be used. However, personal desires for better living conditions and pressures from regulatory agencies have led to increased interest in individual on-site treatment capabilities. The goals and objectives are to achieve the same quality of life, health, and environmental protection as for large central sys-