11–4 ON-SITE DISPOSAL SYSTEMS

In less densely populated areas where lot sizes are large and houses are spaced widely apart it is often more economical to treat human waste on-site, rather than use a sewer system to collect the waste and treat it at a centralized location. On-site systems are generally small and may serve individual homes, small housing developments (clusters), or isolated commercial establishments, such as small hotels or restaurants. In the United States about 25% of the population is serviced by on-site wastewater treatment systems. In some states as much as 50% of the population uses on-site systems within rural and suburban communities (U.S. EPA, 1997). As many people chose to move to rural and outer suburban areas the number of decentralized systems is increasing. It is estimated that as much as 40% of new housing construction is taking place in areas that are not connected to municipal sewers.

Alternative On-Site Treatment and Disposal Systems with Water

Septic Tanks and Absorption Fields. About 85–90% of the on-site wastewater disposal systems are conventional septic systems. A conventional septic system consists of three parts: the **septic tank,** a distribution box, and an absorption field (also called a leach or drain or tile field) (Figure 1). The septic tank and tile field are a unit. Neither part will function as intended without the other.

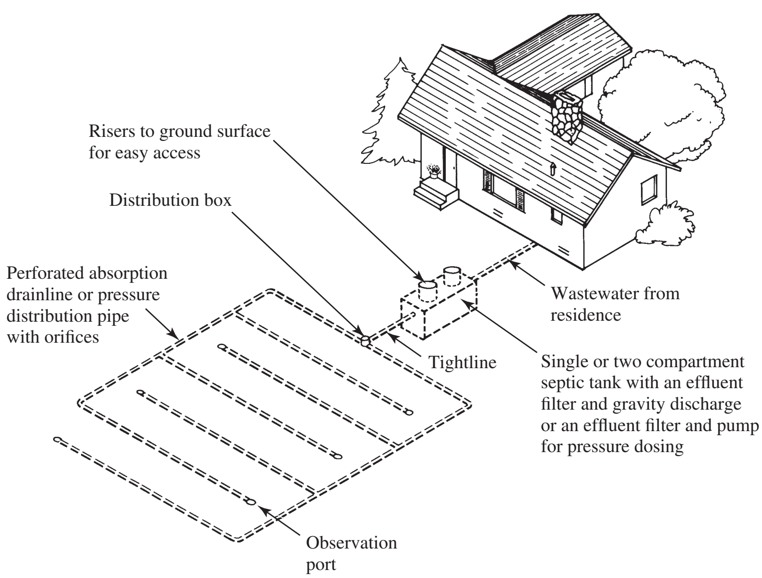
The main function of the septic tank (Figure 2) is to remove large particles and grease, which would otherwise clog the tile field. Heavy solids settle to the bottom where they undergo biological decomposition. Grease floats to the surface and is trapped. It is only slightly decomposed.

The size of the tank depends on the expected wastewater flow. The tank should be large enough to accommodate a holding time for water in a septic tank of at least 24 h. For individual homes the following guidelines can be used: 3 m^3 tank minimum; 4 m^3 for a three-bedroom house; 5 m^3 for a four-bedroom house, and 6 m^3 for a five-bedroom house.

Bacterial action in the tank helps to degrade the organic matter in the wastewater. The BOD_5 of the wastewater is also reduced by the separation of the solids from the liquid. For domestic systems, the BOD_5 of the influent is typically 210 $mg \cdot L^{-1}$. The septic tank effluent has a BOD_5 of about 180 $mg \cdot L^{-1}$ without an effluent filter and about 130 $mg \cdot L^{-1}$ if an effluent filter is used in the system. Usually the BOD_5 limit to allow wastewater to be discharged to surface waters is 20 $mg \cdot L^{-1}$ or less, so the BOD_5 of a septic effluent is too high to allow for surface water

FIGURE 1

Schematic of a conventional septic system.



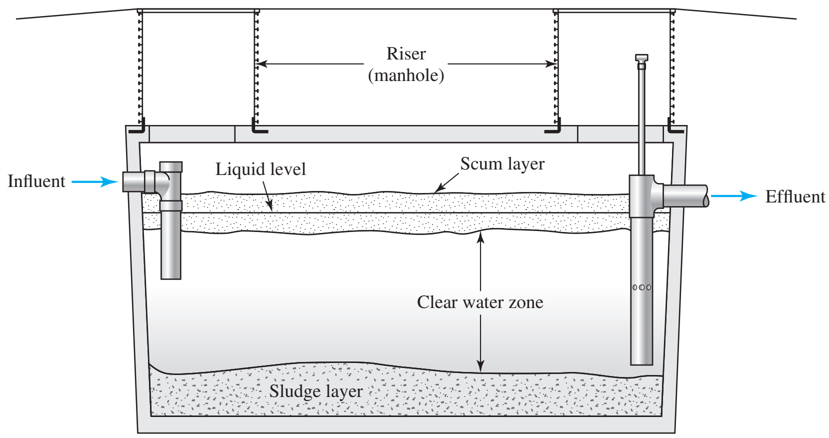


FIGURE 2

Definition sketch for the sludge, clear water, and scum zones that form in a septic tank.

discharge. However, as further treatment occurs in the soil, absorption fields can be used to safely dispose of the partially treated septic tank effluent. A distribution box is used to distribute the septic tank effluent throughout the absorption field. The absorption field usually consists of a series of trenches that contain perforated PVC pipes that are about 10 cm in diameter. The pipes are placed over a 15-cm deep layer of drainrock and then buried with an additional layer of drainrock. The drainrock is covered with building fabric or building paper (which helps to prevent the migration of fines into the drainrock), and finally the trench is filled in using native soil (Figure 3). The trenches should be separated by a distance of at least 2 m.

When the system is operational, bacteria produce a slime layer at the bottom of the trench. This layer, commonly called the **clogging mat,** creates a barrier that slows the movement of water into the surrounding soil, which allows the flow in the surrounding soil to remain unsaturated, permitting air to move through the soil. This maintains aerobic conditions, which are essential to proper treatment of the effluent.

The size of the absorption area depends on the wastewater flow and the permeability of the surrounding soil. The permeability of the soil is determined by a percolation (or perc) test. The perc test is conducted by digging a hole of a prescribed size, filling it with water, and measuring the rate at which the water disappears into the soil. A preferred method for determining the suitability of the site is to dig one or more trenches in the area proposed for the absorption field and visually inspect them. An inspector looks for unsuitable soils such as clays and the presence of **mottled soils,** that is, those having blotches of different color. Mottled soils are an indication that the groundwater table has, at some time, risen to a level where it may interfere with the absorption field.

Most septic systems will fail eventually. The normal lifetime of an absorption field is 20–30 years. After that time the soil around the field becomes clogged with organic matter and

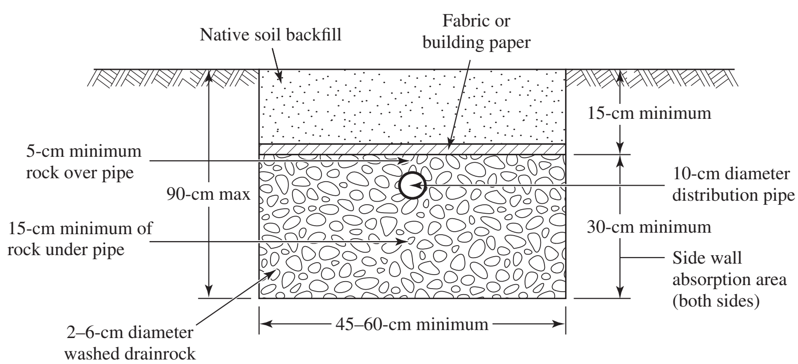


FIGURE 3

Typical cross section through conventional absorption trench.

the system will not operate properly. Many factors can cause the system to fail prematurely. Roots can block pipes, or the pipes may be crushed if a vehicle is driven over the field. The system may also fail if the absorption field is hydraulically overloaded or if substances that are toxic to soil bacteria, such as solvents, paints, pesticides, or softener salt are disposed of down the drain. However, the most common reason for premature failure is improper maintenance. Because the rate of biodegradation in septic tanks is slow, the solids that settle in the tank tend to accumulate over time. If these solids are not removed, the clear water zone between the sludge layer and the scum layer becomes too small, leading to an increased carry over of solids to the absorption field. If too many solids reach the absorption field then it can become clogged, resulting in premature failure of the field. To prevent the accumulation of too much sludge and scum in a septic tank they should be periodically removed. The rate of accumulation of sludge depends on the use of the system. It is suggested that the level of sludge in the tank be checked annually, though usually a domestic system will only need to be pumped out once every 2–3 years.

Septic Tank and Absorption Field Modifications. As mentioned earlier, often the reason for the failure of absorption fields in poorly draining soils is excessive growth of the clogging mat. Reduction of the BOD of the wastewater can reduce the rate of growth of the mat. Two types of treatment systems commonly used to reduce the wastewater BOD are aerobic treatment systems and sand filters.

Aerobic Systems. A wide range of aerobic treatment systems are available. The common feature of these units is the use of some mechanism to inject or circulate air inside the treatment tank. If sufficient air is introduced, then aerobic conditions can be achieved in the wastewater. Because aerobic degradation is rapid, good removal of BOD can be achieved under these conditions, which reduces the rate of growth of the clogging mat and extends the life of the absorption field.

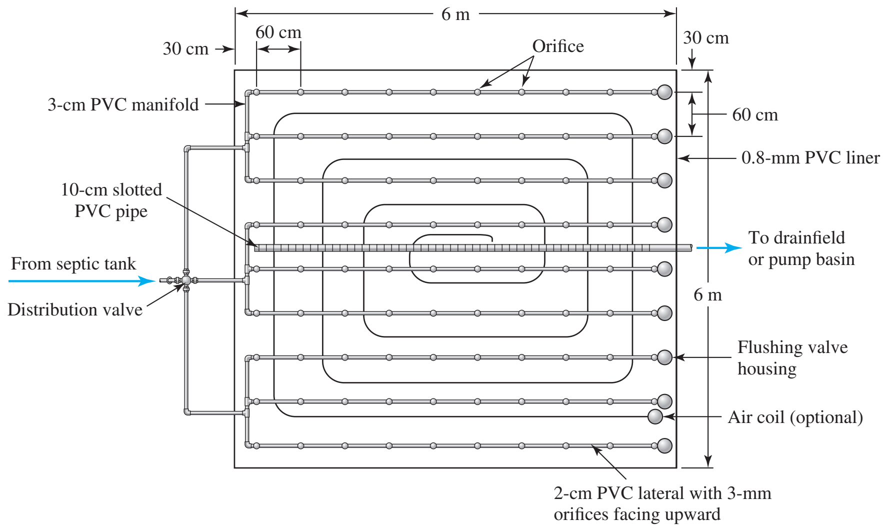
Sand Filter Systems. The sand filter is also an aerobic treatment system. The components of a typical sand filter are illustrated in Figure 4. The filter consists of a bed of granular material (usually sand, but other materials such as anthracite can be used). The surface of the bed is intermittently dosed with wastewater that percolates through the sand to the bottom of the filter. The sand bed is dosed anywhere from 12 to 72 times a day. The size of the dose should be such that the sand bed does not become saturated. This allows the wastewater to flow as a thin film around the sand particles, so good contact between the wastewater and the air can be achieved. Sand filters may be single-pass or multipass. Single-pass sand filters are commonly called **intermittent sand filters** (ISFs). In a single-pass system the wastewater is collected in the underdrain and passed onto an absorption field or other disposal system. In a multipass system a portion of the treated wastewater is recycled back through the sand bed. Recirculation dilutes the wastewater coming from the septic tank. By diluting the strength of the effluent, higher application rates can be used. Recirculating sand filters require one-fifth to one-third the area of single-pass sand filters. Also, better nitrogen removal is achieved in recirculating sand filters due to nitrification–denitrification (see Chapter 5 and Figure 8–9).

Dosing Systems. Another solution to the clogging problem can be to replace the conventional absorption trenches with a disposal system that is less prone to failure. In a conventional absorption field the effluent flows by gravity into the trenches. The gravity system may be replaced by a dosing system, similar to that used in a sand filter. This helps to maintain unsaturated conditions in the soil surrounding the trench.

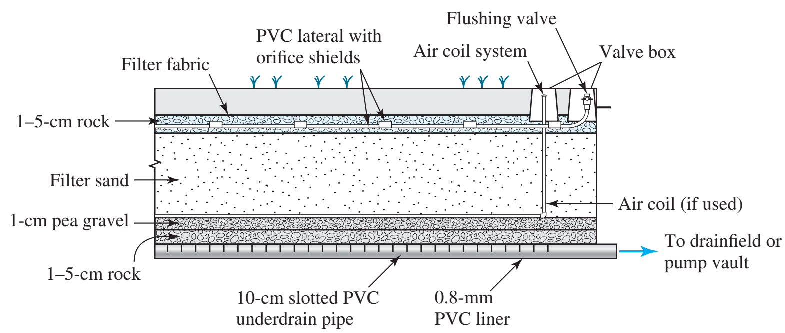
Shallow Absorption Fields. In these systems the distribution piping is often covered with large half pipe rather than gravel. The trenches are only about 0.25 m deep. Better treatment can be achieved, as the upper soil layers have a higher concentration of microbes.

FIGURE 4

Schematic of modern intermittent sand filter: **(a)** plan view and **(b)** typical cross section.



(a) Plan view



(b) Typical cross section

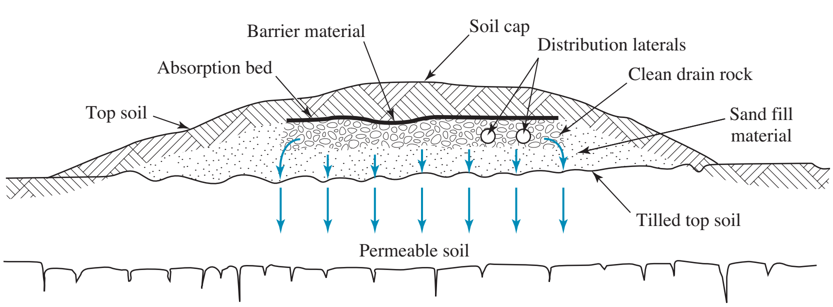
On-Site Treatment and Disposal Systems for Unfavorable Site Conditions

Where site conditions are unfavorable for conventional septic systems, alternative treatment–disposal systems may be required. Among the limitations that might preclude the installation of a conventional system are high groundwater tables, shallow limiting layers of bedrock, very slowly or rapidly permeable soils, close proximity to surface water, and small lot size.

Mound Systems. Mounds were first developed at the North Dakota Agricultural College in the 1940s and were known as NODAK systems. The components of a typical mound system are illustrated in Figure 5. Mounds are both treatment and disposal systems because the effluent from

FIGURE 5

Typical cross section through mound effluent disposal system.



the mound percolates directly into the native soil. The design overcomes certain site restrictions such as slowly permeable soils, shallow permeable soils over porous bedrock, and permeable soils with high water tables. A mound system is a pressure-dosed absorption system that is elevated above the natural soil surface. Effluent from the septic tank is pumped or siphoned to the elevated absorption area and distributed through a piping network located in the coarse aggregate at the top of the mound. The effluent then passes through the aggregate and infiltrates the sand fill. Treatment occurs in the sand and in the fill below the sand bed. As the water percolates downward it spreads out over a large area. The size of the mound must be such that the area of native soil under the mound, called the **basal area,** is large enough that wastewater does not seep out of the base or sides of the mound. During construction of mound systems, special attention should be given to ensure that the basal area of the system is properly scarified, and that compaction of the basal area by earthmoving equipment is minimal. Compaction of the top layer of the soil can greatly reduce the rate of infiltration into the soil.

Barriered Landscape Water-Renovation System (BLWRS). In the summer of 1969, Dr. A. Earl Erickson demonstrated the efficacy of using a BLWRS (pronounced "blowers," like "flowers") to denitrify water containing 100 mg $\cdot$ L^{-1} of nitrate. Subsequently, he and his associates demonstrated that the BLWRS could be used to renovate both dairy cow and swine feedlot wastewater (Table 1) (Erickson et al., 1974). The system is, of course, equally applicable to domestic wastewater.

The BLWRS differs from the NODAK mound system in that the mound of soil is underlain by an impervious water barrier (Figures 6a and 6b). As the renovated water passes beyond the edge of the barrier, it may be collected in drains or be allowed to recharge the aquifer. The mound is constructed of a fine sand. The dimensions of the BLWRS depend on the soil texture and expected wastewater application rates. A 0.15-m layer of topsoil is used to cover the sand. A water-hardy grass (quack grass or volunteer weed cover) must be established on the surface and banks to maintain the soil's permeability and stability.

The wastewater is spread on the top of the mound by a sprinkler. As the wastewater percolates down, the organic particles are filtered out and remain on the surface. The particles are oxidized by soil microorganisms. The soluble organic compounds and other ions move into the

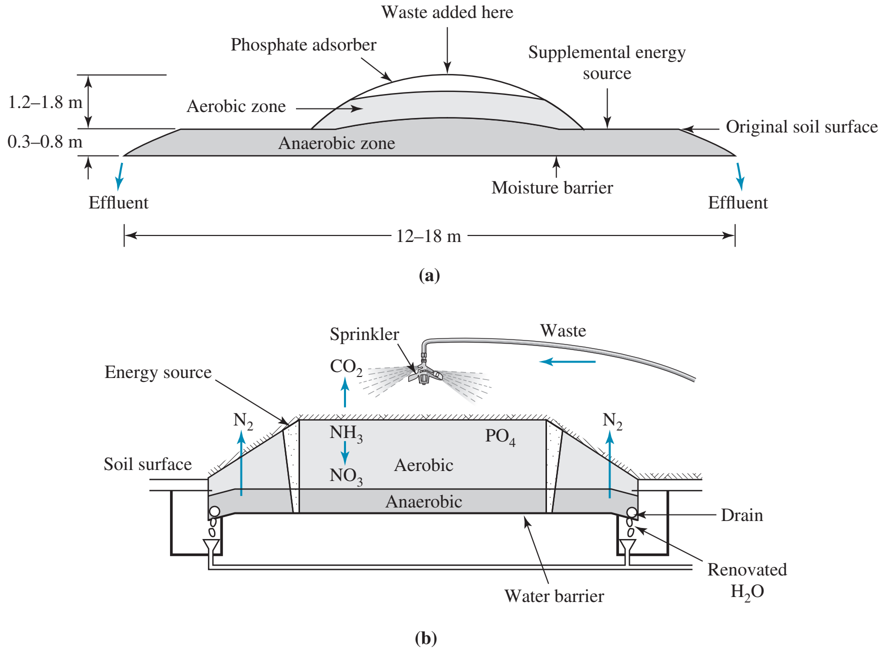
TABLE 1 BLWRS Wastewater Renovation Efficiencies

	Average Influent Concentration (mg · L^{-1})	Average Effluent Concentration (mg · L^{-1})	Efficiency (%)
Swine waste[a]			
BOD$_5$	1131	8.9	98.3
P	18	0.02	99.9
Suspended solids	3000	NIL	≈100.0
TKN	937	187.4	80.0
Dairy waste[b]			
BOD$_5$	1637.0	18.9	98.8
P	38.5	0.22	99.4
Suspended solids	4400.0	NIL	≈100
TKN	917.0	27.5	97.0

[a]Average application rate of 15 mm · day^{-1} for 503 days.
[b]Average application rate of 8.8 mm · day^{-1} for 450 days.
Source: Data taken from Erickson et al., 1974.

FIGURE 6

(a) Common dimensions of barriered landscape water-renovation system (BLWRS); **(b)** water chemistry change in a BLWRS.



aerobic soil zone. Most of the soluble organic matter is oxidized by bacteria in the highly active aerobic soil. The phosphate ions are held on the clay fraction of the soil and sand bed. [Iron slag or limestone (or both) can be used to enhance the phosphorus adsorption capacity.] The ammonium ions are held on the soil until they are nitrified to nitrate. The downward movement of the nitrified water is stopped by the barrier. The water then is forced to move laterally through the anoxic layer. Denitrification occurs as the waste passes out of the carbon source.

The BLWRS must be operated in a cyclic fashion to allow the soil microorganisms time to degrade the waste and to maintain aerobic conditions in the soil. Application rates between 9 and 18 mm of wastewater per day may be used provided that the BLWRS is "rested" for one-third of the time. The physical conditions of the soil govern the application rates. Ponding on the surface indicates excessive application rates.

Other On-Site Treatment and Disposal Options

Constructed wetlands can be used for on-site wastewater treatment and disposal. The use of these systems is more common in warmer climates. In arid areas, evapotranspiration beds are an alternative to conventional absorption beds. In an evapotranspiration system, water-tolerant vegetation is planted in a shallow sand bed. The plant roots draw the water up through the sand and it is evaporated or transpired to the atmosphere.

Treated domestic wastewater can be reused. However, because of the risks posed by pathogens in the water the reuse of domestic wastewater in on-site systems is not common. Some alternatives for reuse are drip irrigation and toilet flushing.

Alternative On-Site Treatment–Disposal Systems Without Water

In areas away from population centers, such as national or state parks, remote roadside rest areas, or vacation homes, there may be no reliable water supply. The absence of a water supply or water scarcity may preclude the use of flush toilets. In this case, other systems for the disposal of human waste need to be considered. Commonly used systems are the pit privy and vault, chemical, and composting toilets. Vault, chemical, and composting toilets are closed systems, so there is "zero" discharge from these systems on-site. The waste produced is collected and disposed of elsewhere.

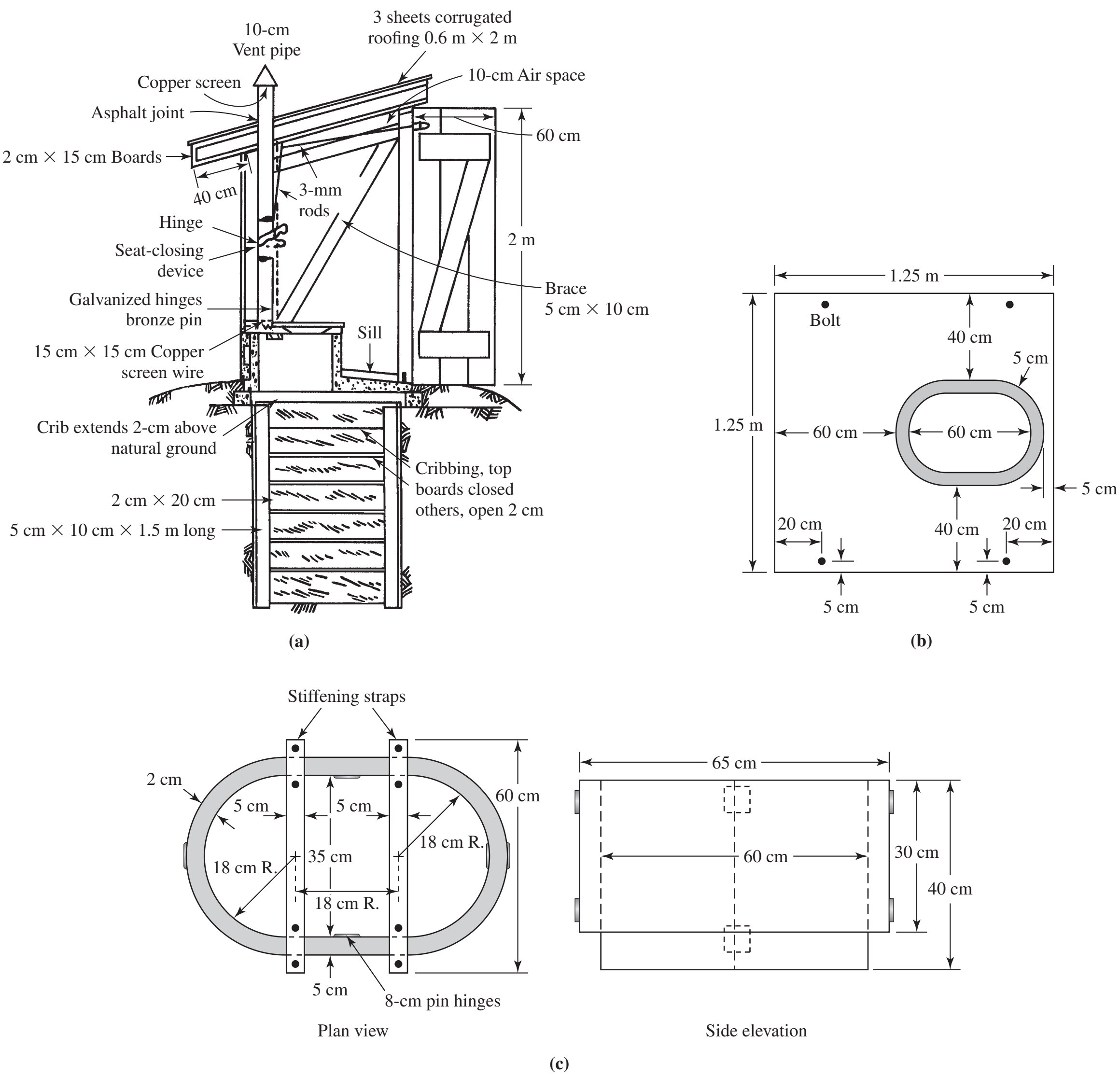
For this reason, these systems may also be used in environmentally sensitive areas where the discharge of wastewater may be environmentally unacceptable.

The Pit Privy. Although most modern environmental engineering and science texts would skip this subject, the mere existence of 10,000 of these or their modern equivalent in the United States is just too much for us to ignore. Furthermore, junior engineers and environmental scientists are the most likely candidates for designing, erecting, operating, dismantling, and closing the beasts.

Figure 7 provides most of the information you will ever need about the construction of an outhouse. The slab is usually poured over flat ground on top of roofing paper. The riser hole is formed using 12-gauge galvanized iron. Once the slab has set, it is lifted into place over the pit. The concrete is a 1:2:3 mix, that is, one part Portland cement, two parts sand, and three parts gravel less than 25 mm in diameter.

FIGURE 7

Construction details of the pit privy: **(a)** cross section; **(b)** plan of concrete slab; and **(c)** details of riser form.



The principle of operation of the pit privy is that the liquid materials percolate into the soil through the cribbing (an open lattice box) and the solids "dry out." A pit of the dimensions shown in Figure 7 should last a family of four about 10 years. Rainwater is to be prevented from entering the pit. A cup of kerosene at weekly intervals discourages mosquito breeding, and odors can be reduced by the use of a cup of hydrated lime. Unfortunately, the lime also slows the decomposition of paper, so its use is not encouraged. Disinfectants should never be used.

The Vault Toilet. This is the modern version of the pit privy. Its construction is the same as that of the pit privy with the exception that the pit is formed as a watertight vault. A special truck (fondly called a "honey wagon") is used to pump out the vault at regular intervals. Because of the liquefying action of the bacteria and biological decomposition in the liquid (rather than in the soil as occurs with the pit privy), vault toilets are much more odiferous than the old pit privies. Many masking agents (perfumes) and disinfectants are available to mitigate the stench. Unfortunately, most of them have unpleasant odors themselves. If electricity is at hand, an ozone generator, set to vent into the gas space above the waste, are very effective in odor reduction.

The Chemical Toilet. The airplane toilet, the coach-bus toilet, and the self-contained toilets of recreation vehicles are all versions of the chemical toilet. The essence of the system is a strong disinfectant chemical used to carry the waste to a holding tank and render it inoffensive until it can be pumped. Although these vehicular systems are quite effective, the chemical must be selected taking into account its effect on the treatment system that ultimately must receive it. The chemical toilet has not found wide acceptance in permanent installations due to the cost of the chemical and to the impracticality of maintenance.

The Composting Toilet. A composting toilet consists of a large tank located directly below the toilet room. Wastes enter the tank through a large-diameter chute that connects to the toilet. No water is used for the toilet, but a bulking agent (such as wood shavings) is added to improve liquid drainage and aeration. A small fan draws air through the tank and up the vent pipe to ensure adequate oxygen for decomposition and odorless operation. The liquid in the waste is evaporated leaving a compost. The finished compost can be removed from the lower end of the tank about once each year. It can be used as a fertilizer. Power requirements for the system are very low, so if power from an electrical grid is not available, the electrical requirements can be met from an independent generating system, such as a photovoltaic system.