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OFF-GRID PLUMBING DESIGN

BY E. W. BOB BOULWARE, PE

COMPOSTING TOILETS AND LEACH FIELDS OFFER ALTERNATIVES TO TRADITIONAL PLUMBING SYSTEMS.

When a facility is located beyond the service area of water and sewer utilities, the traditional solution for plumbing systems is a well and septic tank. If electricity is not available to power a pump, the soil is poor, or the water table is high, applying conventional thinking can be expensive and possibly nonfunctional. Composting toilets to handle black water, in concert with a leach field for graywater, can provide a convenient, economical, and sanitary alternative.

Contrary to popular thinking, a strong argument can be made that composting toilets are more sanitary than conventional systems because they do not pollute groundwater or waterways. While flush toilets conveniently carry wastewater away from its source, the wastewater becomes someone else's problem downstream. Composting the waste on-site provides an environmentally friendly and effective solution for waste management.

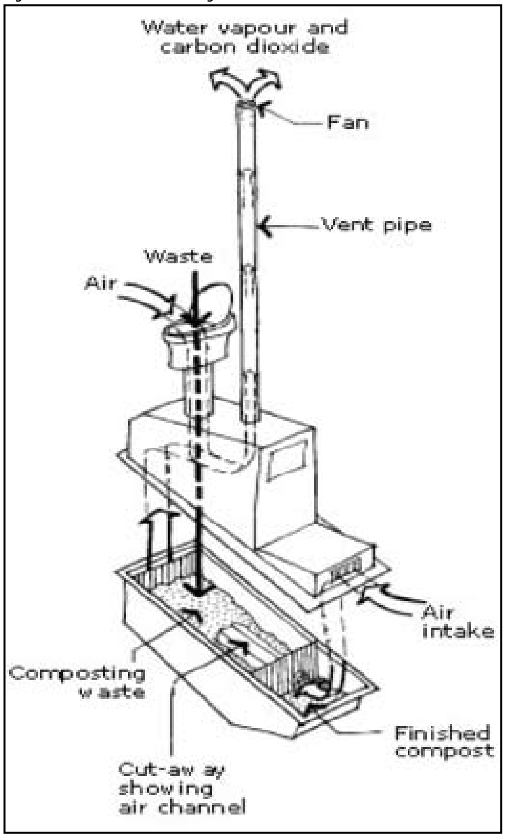
HISTORY OF COMPOSTING TOILETS

Composting toilets have existed for centuries. The initial form was the latrine, which eventually evolved into the classic outdoor privy (see Figure 1), common to every rural farmhouse in the mid-1900s. The design concept of the traditional outhouse is simple: It uses no power or water, is inexpensive to build, and is somewhat easy to relocate if necessary. However, significant downsides include odor in the summer and the necessary trek outside in all weather conditions.

Figure 1 Classic outdoor privy

In 1939, Rikard Lindström, a Swedish engineer, developed the original composting toilet by overcoming the major disadvantages of an outhouse that allowed the concept to be moved indoors. Eventually, in 1962, the system was patented, and in 1964 the first commercial model was constructed out of fiberglass. Many of the advantages of the classic design were maintained in what is known as the Clivus Multrum design (see Figure 2).

Figure 2 Clivus Multrum design



Source: Clivus Multrum

The name Clivus Multrum means "sloping chamber" in Swedish and describes the system design. The original system used a single-chamber, sloped-bottom design and was constructed of concrete. The chief advantage of this style of toilet is the concept of aerobic digestion, in which the primary products of decomposition are relatively odorless carbon dioxide and water vapor as contrasted with the methane, hydrogen sulfide, and ammonia produced under anaerobic digestion, which is common with the standard privy.

To maintain aerobic digestion, the composting toilet utilizes exhaust fan operation and occasional stirring of the waste stack to oxygenate the mix to avoid anaerobic digestion. Waste volume is reduced approximately 70 percent per year with a composting toilet, with a humus-like material being removed periodically for use as landscape fertilizer. Properly sized, these units can last several years before pumping out is necessary. They are approved by NSF International for public restrooms and commonly are used in state parks.

MODERN COMPOSTING TOILETS

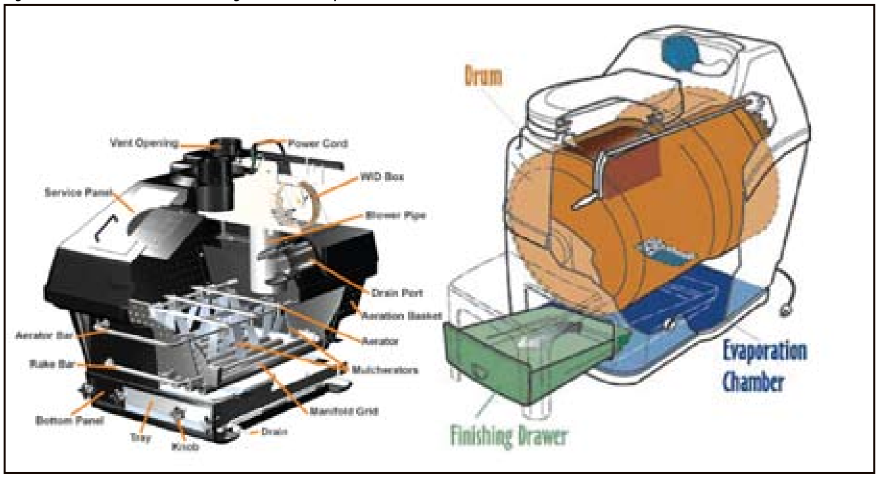
Modern composting toilets are more convenient in their operation, and their appearance is similar to flushing water closets, thus making them a more acceptable alternative. Although they require the occasional addition of peat moss or wood shavings to the composter to assist the decomposition process, electronic controls make the operation invisible to the user.

Common to all composting toilets is the use of a fan to drive moisture from the waste, which reduces the volume by about

95 percent. The key difference from previous systems is that the waste is maintained in an aerobic condition by maintaining a constant oxygen level within the mix. This maintains carbon dioxide as a by-product and avoids the methane and hydrogen sulfide odor associated with anaerobic decomposition. On modern composting toilets, this mixing process is integral to the design. Figure 3 shows how various manufacturers accomplish this task. Sancor uses a raking mechanism that is operated manually. Sun-Mar uses a barrel to tumble the waste/peat moss/oxygen mix to accelerate decomposition. A third manufacturer, BioLet, uses paddles to keep the mix oxygenated.

Of the three, Sun-Mar is approved by NSF International, while it is important to know the testing conditions because optimum composting occurs between 60°F and 100°F and between 40 and 70 percent relative humidity. Deviation from these conditions requires either adjusting the capacity or product loading or including a temperature control device within the composting toilet.

Figure 3 View of internal waste agitation techniques



Source: Sun-Mar and Envirolet

STYLES OF COMPOSTING TOILETS

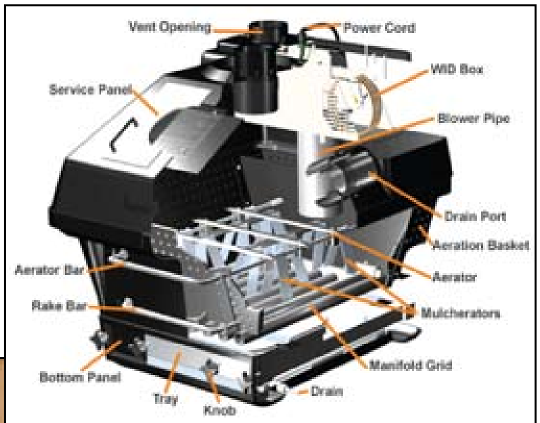
Two common styles of composting toilets are available: a "dry" operation toilet, desirable where freezing is possible (see Figure 4) and an ultra-low-flow version that uses a pint of water for the flushing operation (see Figure 5). The dry and ultra-low-flow models each come in self-contained and remote composting options. Because the ultra-low-flow toilets use water to assist waste conveyance, the toilet does not need to be directly above the composter, which allows multiple toilets to be installed on a single composter. The end product from the decomposition process is odorless, has the composition of potting soil, and can be used in gardens. Depending on toilet use, the task of emptying the composter can occur on a quarterly or even annual basis. Available to all are the options of manual operation, 12 volts (battery) for solar power, and 120 volts for utility-based power.

The key limitation of composting toilets appears to be social acceptance of their use as an alternative to the traditional porcelain flush toilet. Because modern composting toilets are comparable to flush toilets in appearance and operation, a little experience usually brings acceptance. Also, in a world concerned about freshwater shortages, an important benefit of composting toilets is reduced water use, with the added benefit of protecting the water that is available by reducing downstream pollution

WHAT TO DO WITH GRAYWATER?

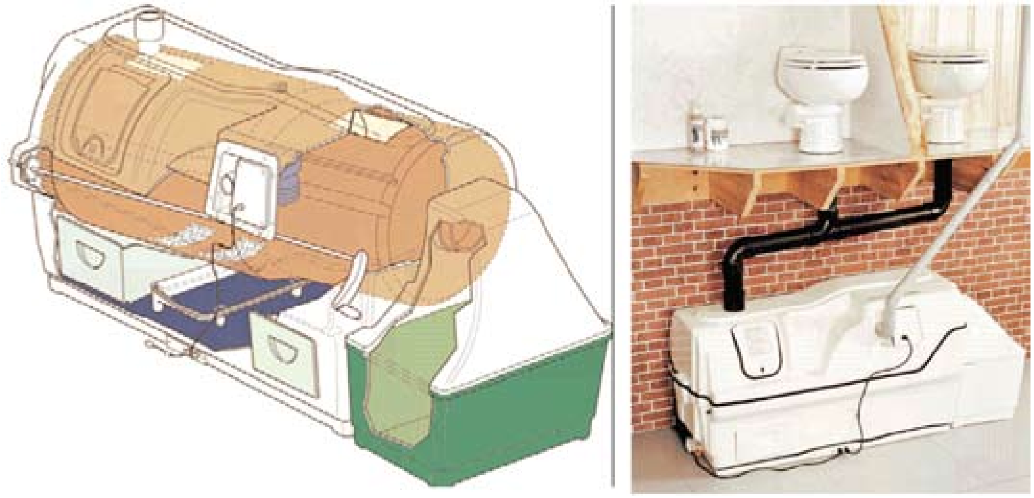
The other wastewater from a building—the water from the lavatory, shower, and kitchen—is called graywater. Also spelled gray water, grey water, or greywater, this water can be routed to a leach field, a waterway with hyacinths or other biodegrading plants, a dry well/French drain application, or even a decorative planting bed. The chief difference between a leach field and a septic field is that a leach field does not handle black water. However, some municipalities do not differentiate between graywater and conventional septic systems, which requires an organized design procedure to

Figure 4 Waterless remote toilets



Source: Envirolet and Sun-Mar

Figure 5 Ultra-low- ow toilet



Source: Sun-Mar

avoid problems. The recommended steps in designing a leach field for graywater management are as follows:

1. Investigate the permit process.
2. Prepare the plan.
3. Design the graywater system.
4. Submit the plan for review and approval.
5. Install the system.
6. Arrange for inspection and approval.
7. Use, monitor, and maintain the system.

More often than not, the authority having jurisdiction will assign the same methodology to leach field design as to a septic field. This means that the resultant leach field will be assumed to handle black water and therefore will be sized according to the number of bedrooms in a house or the total number of fixture units in a commercial building.

Some jurisdictions are more open to engineered systems than others. To their credit, those who balk at engineered systems are concerned that failure of an installation would reflect badly on public health agencies by relinquishing control to a new technology. You can help address their concerns by showing competence and thoroughness in your methodology.

DESIGNING GRAYWATER EVAPORATION FIELDS

Assuming a calculated approach to determining water volume is accepted, following is a guide discussing the fundamentals for designing graywater evaporation fields and how to determine the size required to handle a typical graywater application in concert with a composting toilet installation.

System Terminology

Three concepts interrelate to handle graywater: evaporation, absorption, and transpiration. The local rate of evaporation from the soil to atmosphere is a function of relative humidity and wind velocity. Such information typically can be found at local university agronomy departments. A soils engineer can determine the rate of absorption of graywater into the soil, usually after analysis of a soil sample. Horticulture or agriculture sources can relay the transpiration of water into plants as part of their growing process.

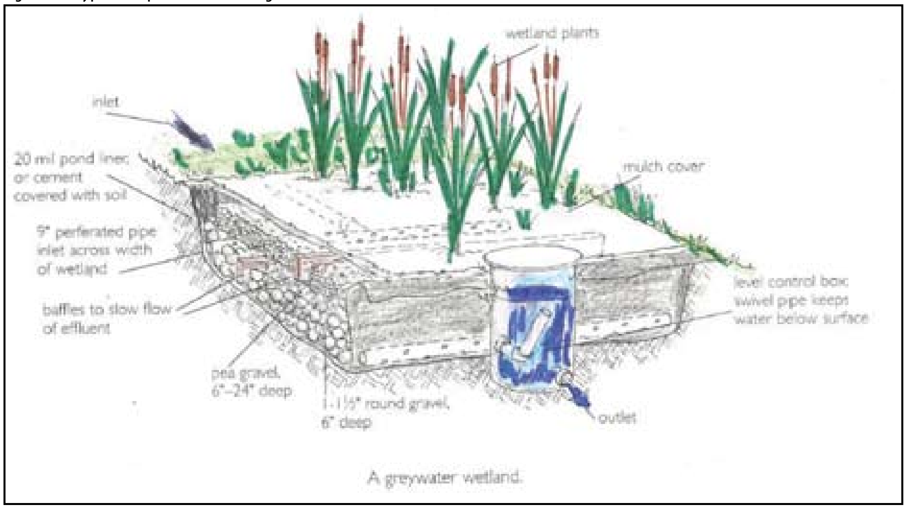
You will hear these terms in combination (e.g., evaporation, evapotranspiration, and evapoabsorption), each referring to the primary method of handling graywater. Absorption into the soil, which is how a septic field works, may not be possible due to soil conditions, water table, or proximity to a nearby body of water. In this case, a water barrier is used, and graywater is processed by evapotranspiration. Figure 6 shows a typical evaporation field design.

Determining System Demand

Determining the expected demand is the first step in sizing a leach field. Following is an example of the fundamentals involved in determining demand for a typical single-family house:

- The use of water is partly based on the flow rate of the domestic water supply pump. Most pumps are set at 40 pounds of pressure. At that pressure, the average shower uses about 1¼ to 1½ gallons per minute. Using that rate, you can determine that a 15-minute shower will use 22 gallons of water.

Figure 6 Typical evaporation field design



- Flush versions of composting toilets use only about 1 pint per flush. Therefore, this water can be evaporated in the composting system itself, resulting in no water discharge.
- The average person should use only about 1 gallon a day to wash up.
- Washing dishes should take only 2 gallons per day per person.
- A high-efficiency, front-loading washing machine uses about 15 gallons per load. A normal top-loader uses about 40 gallons and has less capacity. Using the high-efficiency machine and two loads of laundry per person per week equals 30 gallons per week, or about 2 gallons per day per person.

Thus, the total water use per person per day is approximately 27 gallons.

Sizing the Evaporation Field

Using these numbers, you can size the evaporation field. You first must determine the amount of water that will be used in the dwelling per month, which is based on the number of people who can sleep in the house, not the number of bathrooms.

If you conclude that each person's use is a minimum of 27 gallons per day, total usage is 810 gallons per person per month.

Local soil evaporation rates can be obtained from local university agronomy departments. (Agronomy departments gather this information as part of their efforts to monitor soil evaporation rates in conjunction with agricultural crop growth.) For instance, the evaporation rate in Miami is estimated to be 11.4 gallons per square foot per month. This is an average. The actual rate varies based on humidity levels during a particular month.

If you divide the total usage of 810 gallons by the evaporation rate of 11.4 gallons per square foot, you get 71 square feet per person. That means you need an evaporation field that has a 71-square-foot surface area for each person living in our example house. Thus, you can estimate that a cottage with two people living full time would need an evaporation field of about 142 square feet, or 10 feet by 14¼ feet in dimension. Keep in mind that guests will boost system demand, so increasing evaporation field size for added capacity is advisable in some situations.

How to Boost Evaporation Rates

The evaporation rates we have used to calculate the field size are based on straight evaporation of water from the ground. If local climate allows, the rate can be boosted significantly by the use of broadleaf plants. Some studies have shown that plants with large leaves can expel water into the air at a rate five times faster than an open pool of water. Thus, if you design a system to cover just the two people living in the house, by planting a full field of plants, you should be able to boost capacity to evaporate enough water to accommodate any guests.

Note: Care must be taken to ensure that excessive rainwater does not get into your field. Evaporation rates take normal rainfall into account. They do not account for runoff draining into the field. Be sure to raise the ground around the field to prevent rainfall runoff from flowing into the field. Also, you can construct a plastic roof over the evaporation field. That will allow light for the plants and keep rainwater completely out of the field. (Do not allow rain runoff from the roof to fall in the field.) For proper operation of an evapotranspiration field, an important concept to remember is that evaporation per square foot must exceed rainfall per square foot where absorption into the soil does not occur.

Design of the Evaporation Field

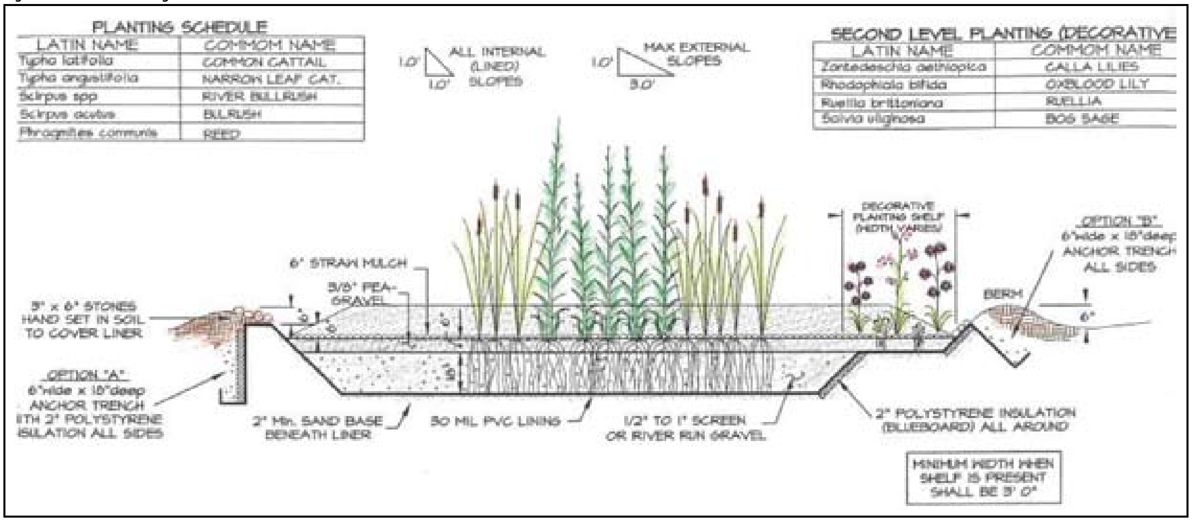
When building on dry land, graywater systems can be lined and constructed in the ground. The end result looks like any other garden, only greener because it is regularly watered with graywater. In a commercial building, with the use of waterless urinals and composting toilets, the resultant water from lavatories and air-conditioning condensate can be adequately handled by using flower planters as evaporation fields.

Instead of a septic tank, evaporation fields usually have a settlement tank. This serves to protect the evaporation field from being plugged by soaps and any garbage that goes down the drain. Trapping grease serves to protect and prolong the life of the graywater system. A settlement tank can be as simple as a 50-gallon drum bought locally or as complex as a plastic or concrete tank, which would be more appropriate in a commercial installation. The tank allows light soaps to rise to the top of the water, while solid, heavy wastes such as food scraps settle on the bottom. The exit pipe allows clean water from the center of the tank to move to the evaporation field. This prevents any waste from entering the evaporation field and plugging the drain holes in the perforated pipe. The settlement tank should have a removable lid for occasional cleaning and servicing.

The need to line the field depends on how close the field is located to sensitive areas. It is generally acceptable to perk wastewater into the soil if there is adequate separation from any wells, creeks, wetlands, or waterfront. In the United States, a separation of at least 100 feet from septic systems and any water source is required. If the groundwater level is near the surface, the system should be lined to avoid pumping graywater directly into the groundwater or allowing graywater to run off site.

If the groundwater is near the surface, the evaporation bed must be raised. This can be done two ways. You can dig until you are close to the water table and use the dirt taken out of the hole to build up the outside wall around the field. The field then is lined with a plastic membrane or clay to prevent the graywater from getting into the groundwater. The bed is filled with gradated sand and gravel until the inside depth is about 2½ feet. The bed then is topped with 4–6 inches of topsoil to support plant growth, as shown in the wetland design detail in Figure 7. Another option is to pour a concrete slab and cement walls 2 feet high to form a planter box of the size required. Whether in the ground or in a concrete box, the design of the field is the same.

Figure 7 Wetland design detail



Source: Dr. M.L. Robinson, University of Nevada Cooperative Extension, and Michael Ogden, Natural Systems

Review, Installation, and Approval

Careful documentation of the calculations and assumptions will be necessary if the system is considered an engineered system by the authority having jurisdiction. Also, the conventional certification of a soils scientist will be needed for review and approval.

At this point, installation could be the easy part, although careful inspection will be needed to ensure that the subtle design differences between a septic field and evapotranspiration field are followed.

The customary blessing of local authorities always is needed to ensure compliance with local health codes and that installation per the approved drawings has occurred.

Use, Monitor, and Maintain the System

Maintaining the system is the most important part. Following are a few pointers for successful operation:

- Use only biodegradable soaps and prevent garbage from being put down the drain. Do not throw any chemicals down the drains.
- Use of a weed screen is advised for the system. This prevents the topsoil from filtering down into the gravel. You can add more topsoil, but if the topsoil fills all the voids in the gravel, the field won't be able to hold as much graywater. The weed screen also prevents roots from invading the pipes and plugging the drain holes.
- Only use plants that have shallow root systems. Do not use trees, which can destroy the distribution piping. Supercharge the leach field by planting broadleaf plants whenever possible. The larger the leaves, the more water the plants can expel into the air.
- Protect the field from heavy rain runoff from hillsides and roofs. Mound the soil around the field to protect it. Even a plastic roof cover over the leach field can prevent rainstorms from adding water to the system.

Leach fields not only are applicable where no available waste management utility is available, but they also can be applied to conventional systems where the septic field has failed. Without the black water component, the efficiency of the septic field is improved significantly. Septic fields have been known to correct themselves where graywater is the only load. The system is simple to install and forgiving if undersized or if the load changes. To adjust the capacity, simply install an overflow line to an added field of whatever size you choose.

THE BENEFITS

Contrary to popular thinking, composting toilets working with a well-designed leach field can provide an economical, sanitary, and ecological solution to the problem of waste management. Applications also present themselves with poor percolating soil conditions, for temporary installations, and as alternatives to septic field installations based on the merits of reduced cost.

Off-grid plumbing techniques also serve to protect the environment. Less chemicals and energy are used at the wastewater treatment plant, and off-site water contamination is eliminated. Such solutions present an environmentally low-impact system with many applications. **PSD**

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A CASE STUDY

Composting toilets in concert with evaporation fields are popular in the Caribbean, where development progress is not waiting for municipal infrastructure to be provided. An extreme example of this can be seen in Figure 1a, which is a restroom installed on the water, with a shore-based leach field to handle graywater.

The evaporation field design in this situation prevents graywater from entering the water table or the ocean. Graywater kills coral, which in this area is the primary ecotourism attraction. To ensure that no graywater enters the ocean, the system was designed to be a closed-loop system. That means no water leaves the system unless it evaporates into the air. The graywater enters the evaporation field, where the plants drink all the water, thrive on the phosphates it provides, and expel the water back into the air. No contamination or pollution to the environment occurs. Figure 1b shows the worksheet for this graywater installation.

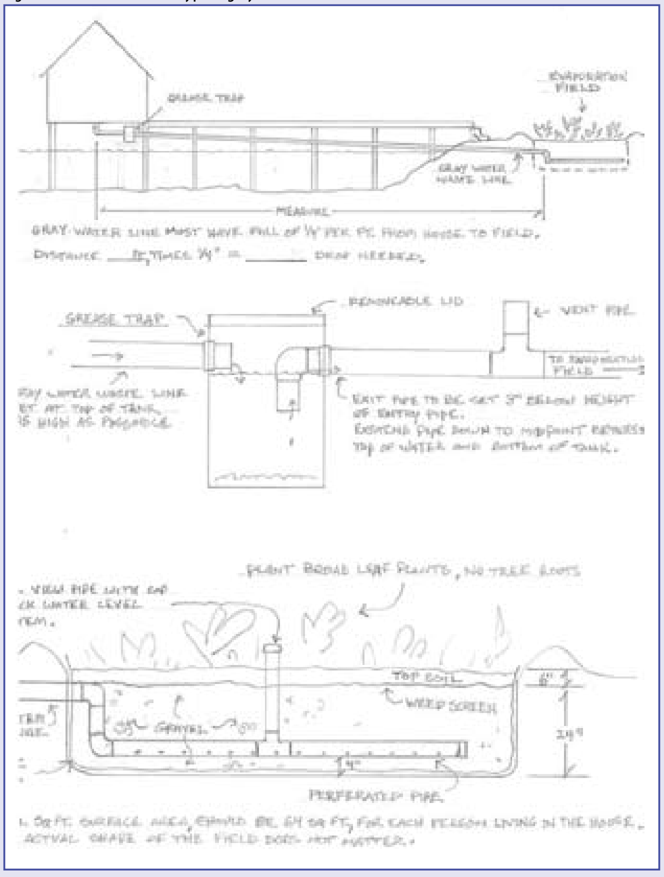
When building over the water, it is necessary to pipe the water to the land if the distance to the field is not too far. The drainpipe needs ¼ inch of fall per foot to drain to the field. If the house was 100 feet from the field, the drainpipe would need to drop about 2 feet.

If the building is too far offshore to reach a field or there is no access to land for the system, the field may be constructed over the water. In this case, you might consider constructing what would resemble a small swimming pool on stilts. The concrete box on concrete stilts is 2 feet deep and sized to the dimensions required for the application. It is made of concrete to guarantee a long life and to prevent leakage. The box can be any shape, as long as it has the required square-foot exposure for evaporation. It even can be designed as a long planter running along the walkway from the land to the house and built into the structure of the dock.

Figure 1a Restroom installed on water, with a shore-based leach field to handle graywater

Photo: E. W. Boulware

Figure 1b Worksheet for typical graywater installation



Source: David Miner, Cleanwater Construction

ONLINE EXCLUSIVE RESOURCES

Visit www.psdmagazine.org to access the following articles related to off-grid plumbing design:

- A dynamic view of composting toilet operation, illustrating the interaction of composting and waste accumulation over time
- A case study on LaGrange County, Indiana, which uses a variation of the evaporation field concept to handle waste from 300 homes
- More comprehensive discussions of evapotranspiration bed design
- General information on rainwater catchment, another off-grid plumbing design technique