United States Environmental Protection Agency
Office of Water Washington, D.C.
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Decentralized Systems Technology Fact Sheet
Aerobic Treatment

DESCRIPTION

Natural treatment of biological waste has been practiced for centuries. However, engineered aerobic biological treatment of wastewater has been practiced in the United States, on a large scale, for only a few decades. In fact, in 1925, 80 percent of all cities in the United States with populations of over 100,000 had no treatment systems at all (Linsley 1972). The basic aerobic treatment process involves providing a suitable oxygen rich environment for organisms that can reduce the organic portion of the waste into carbon dioxide and water in the presence of oxygen. With the ever increasing development of land, both suburban and rural, large central sewerage systems have not always been cost-effective or available. Many homeowners still rely on individual septic tank or other systems to treat and dispose of household wastewater onsite.

Historically, aerobic treatment was not feasible on a small scale, and septic tanks were the primary treatment device, but recent technology advances make individual aerobic treatment systems efficient and affordable. Aerobic systems are similar to septic systems in that they both use natural processes to treat wastewater. But unlike septic (anaerobic) treatment, the aerobic treatment process requires oxygen. Aerobic treatment units, therefore, use a mechanism to inject and circulate air inside the treatment tank. Because aerobic systems use a higher rate process, they are able to achieve superior effluent quality. The effluent can be discharged to the subsurface as in a septic tank leach field or, in some cases, discharged directly to the surface.

Current Technologies

Individual aerobic systems have been in place since the 1950's, however, these early systems consisted of little more than an aerator placed in a traditional septic tank. They were prone to noise, odor and maintenance complaints, and were used only where standard septic tanks were not feasible. The newer aerobic treatment units are pre-engineered and operate at a high level of efficiency. The demand for these units and the desire for direct surface discharge of the treated waste stream has led to a certification process by the National Sanitation Foundation (NSF). This certification (NSF Standard 40 for Individual Wastewater Treatment Plants) applies to plants with capacities of up to 1,500 gallons per day, and leads to approval as a Class I or Class II plant. A Class I certification indicates performance to EPA Secondary Treatment Guidelines for three parameters: BOD, suspended solids and pH. Noise levels, odors, oily films and foaming are also measured.. The Class II criteria require that not more than 10% of the effluent $CBOD_5$ values exceed 60 mg/L and that TSS not exceed 100 mg/L.

As of June 2000, 15 manufacturers carry NSF 40 Class I Certification with available capacities ranging from 1514.2 Liters/day to 5,678.1 Liters/day (400 to 1,500 gallons per day). Table 1 provides a list of the certified manufacturers, the number of models available, and the range of flows treated. It is important to note that the NSF certified Product Listing is continually changing. The NSF should be contacted directly to confirm the status of the listing provided in Table 1. Table 2 shows the NSF Class I effluent performance limits.

TABLE 1 MANUFACTURERS CARRYING NSF CLASS I CERTIFICATION*

Company	Location	Number of Certified Models	Flow Range (gpd)
Alternative Wastewater Systems, Inc.	Batavia, IL	5	500-1500
American Wastewater Systems, Inc.	Duson, LA	1	500
Aquarobic International	Front Royal, VA	24	500-1500
Bio-Microbics	Shawnee, KS	4	500-1500
Clearstream Wastewater Systems, Inc.	Beumont, TX	10	500-1500
Consolidated Treatment Systems, Inc.	Franklin, OH	10	500-1500
Delta Environmental Productss	Denham Springs, LA	9	400-1500
H.E. McGrew, Inc.	Bossier City, LA	4	500-750
Hydro-Action, Inc.	Beaumont, TX	7	500-1500
Jet, Inc.	Cleveland, OH	6	500-1500
Microseptec, Inc.	Laguna Hills, CA	2	600-1500
National Wastewater Systems, Inc.	Lake Charles, LA	1	500
Nordbeton North America, Inc.	Lake Monroe, FL	1	600
Norweco, Inc.	Norwalk, OH	10	500-1500
Thomas, Inc.	Sedro Woolley, WA	6	500-1000

* As of June 19, 2000. This list is continually changing. Please contact NSF to confirm the status of any listing.
Source: National Sanitation Foundation, 2000

TABLE 2 NSF CLASS I EFFLUENT PERFORMANCE LIMITS

BOD & SS	pH	Color	Odor	Foam	Noise
#30mg/L (2.504 x 10^{-7} lb/gal) (Monthly Average)	6.0-9.0 Units	15 Units	Non-Offensive	None	<60dbA @20 feet

Source: NSF Evaluation of JET Model J-500 (1998).

APPLICABILITY

Although there have been small scale "home aerobic systems" in the United States for more than 50 years, their use has been fairly limited, in part, because of the widespread use of septic systems, which are relatively inexpensive and easy to maintain. They are the most common onsite wastewater treatment systems in rural areas. However, many households may not be well suited for septic systems.

For example, septic systems are not suitable for all decentralized wastewater treatment applications. In fact, approximately two-thirds of all land area in the United States is estimated to be unsuitable for the installation of septic systems (Linsley 1972). Some homes may not have enough land area or appropriate soil conditions to accommodate the soil absorption drainfield. In some communities, the water table is too high to allow the drainfield to give adequate treatment to the wastewater before it is returned to the groundwater.

Other site-related concerns include homes located on wooded lots or on lots close to a body of water. Homeowners in wooded areas may not want to clear enough land to install a septic tank and drainfield, and wastewater treated by a septic system is often not of high enough quality to be discharged near a body of water.

One of the most common reasons to select aerobic wastewater treatment units is to replace failing septic systems, which are a major source of groundwater pollution in some areas. If a failed septic system needs to be replaced or if a site is inappropriate for a septic system, aerobic wastewater treatment may be a viable option.

ADVANTAGES AND DISADVANTAGES

Advantages:

- Can provide a higher level of treatment than a septic tank
- Helps protect valuable water resources where septic systems are failing
- Provides an alternative for sites not suited for septic systems
- May extend the life of a drainfield
- May allow for a reduction in drainfield size
- Reduces ammonia discharged to receiving waters

Disadvantages:

- More expensive to operate than a septic system
- Requires electricity
- Includes mechanical parts that can break down
- Requires more frequent routine maintenance than a septic tank
- Subject to upsets under sudden heavy loads or when neglected
- May release more nitrates to groundwater than a septic system

DESIGN CRITERIA

On-site aerobic processes typically produce a higher degree of treatment than septic tanks, but periodic carryover of solids due to sludge bulking, chemical disinfection addition, or excessive sludge buildup can result in substantial variability of effluent quality. Regular, semi-skilled operation and maintenance are required to ensure proper functioning of moderately complex equipment. Inspections every two months are recommended. Power is required to operate aeration equipment and pumps. Absorption beds are dependent upon site and soil conditions, and are generally limited to sites with percolation rates less than 2.4 minutes/millimeter (60 minutes/inch), depth to water table or bedrock of 0.61 to 1.2 meters (2 to 4 feet), and level or slightly sloping topography.

Two aerobic primary systems have been adapted for onsite use: suspended growth and fixed film. In suspended growth systems, the microorganisms responsible for the breakdown of wastes are maintained in a suspension with the waste stream. In fixed film systems, the microorganisms attach to an inert medium. Very few commercially produced fixed film systems are available for onsite application, and they include a variety of proprietary devices, making it difficult to prescribe design guidelines. In many cases, however, design guidelines for fixed film systems are similar to those applied to suspended growth systems.

Configuration

Most aerobic treatment units designed for individual home application range in capacity from 1514 to 5678 Liters (400 to 1,500 gallons), which includes the aeration compartment, settling chamber, and in some units, a pretreatment compartment. Based upon average household flows, this volume will provide total hydraulic retention times of several days.

Pretreatment

Some aerobic units provide a pretreatment step to remove grease, trash and garbage grindings. Pretreatment devices include trash traps, septic tanks, comminutors, and aerated surge chambers. The use of a trash trap or septic tank before the extended aeration process reduces problems with floating debris in the final clarifier, clogging of flow lines, and plugging of pumps. Pretreatment is required in fixed film systems to prevent process malfunction.

Flow Mode

Suspended growth aerobic treatment plants may be designed as continuous or batch flow systems. The simplest continuous flow units provide no flow equalization and depend upon aeration tank volume and/or baffles to reduce the impact of hydraulic surges. Some units use more sophisticated flow dampening devices, including air lift or float-controlled mechanical pumps to transfer the wastewater from aeration tank to clarifier. Still other units provide multiple-chambered tanks to attenuate flow. The batch (fill and draw) flow system eliminates the problem of hydraulic variation. This unit collects and treats wastewater over a period of time (usually one day), then discharges the settled effluent through pumping at the end of the cycle. Fixed film treatment plants operate on continuous flow.

Method of Aeration

Oxygen is transferred to the waste stream by diffused air, sparged turbine, or surface entrainment devices. When diffused air systems are used, low pressure blowers or compressors force the air through diffusers on the bottom of the tank. The sparged turbine uses a diffused air source and external mixing, usually from a submerged flat-bladed turbine. The sparged turbine is more complex than the simple diffused air system. A variety of surface entrainment devices are used in package plants to aerate and mix the wastewater. Air is entrained and circulated in the mixed liquor through violent agitation from mixing or pumping. Oxygen transfer efficiencies for these small package plants are normally low (3.4 to 16.9 kg O_2/MJ or 0.2 to 1.0 lb O_2/hp/hr) as compared with large-scale systems which may transfer 50.7 kg O_2/MJ or more (3+ lbs O_2/hp/hr). This difference is primarily due to the high power inputs to the smaller units. Normally, there is sufficient oxygen transferred to produce high oxygen levels. In an attempt to reduce power requirements or enhance nitrogen removal, some units use cycled aeration periods. Care must be taken to avoid developing poor settling biomass when cycled aeration is used.

Mixing the aeration tank contents is also an important consideration in the design of oxygen transfer devices. Rule of thumb requirements for mixing in aeration tanks range from 0.465 to 0.931 kW/m^3 (0.5 to 1 hp/1,000 ft^3) depending upon reactor geometry and type of aeration or aeration system configuration. Commercially available package units are reported to deliver mixing inputs ranging from 0.005 to 2.8 kW/m^3 (0.2 to 3 hp/1,000 $ft^{3)}$. Solids deposition problems may develop in units with lower mixing intensities.

Biomass Separation

The clarifier is critical to the successful performance of the suspended growth process. A majority of commercially available package plants provide simple gravity separation. Weir and baffle designs have not been given much attention in package units. Weir lengths of at least 12 in. (30 cm) are preferred and sludge deflection baffles (Stamford baffles) should be included as a part of the outlet design. The use of gas deflection barriers is a simple way to keep floating solids away from the weir area.

Upflow clarifier devices have been used to improve separation, but hydraulic surges must be avoided in these systems. Filtration devices have also been employed in some units, but they are very susceptible to clogging.

Controls and Alarms

Most aerobic units are supplied with some type of alarm and control system to detect mechanical breakdown and to control the operation of electrical components. They do not normally include devices to detect effluent quality or biomass deterioration. These control systems are subject to corrosion because they contain electrical components. All electrical components should be waterproofed and regularly serviced to ensure their continued operation.

Additional Construction Features

Typical onsite extended aeration package plants are constructed of noncorrosive materials, including reinforced plastics and fiberglass, coated steel, and reinforced concrete. The unit may be buried as long as there is easy access to all mechanical parts, electrical control systems, and appurtenances requiring maintenance such as weirs, air lift pump lines, etc. Units may also be installed above ground, but should be properly housed to protect against severe climatic conditions. Installation should be in accordance with the manufacturers specifications.

Appurtenances for the plant should be constructed of corrosion-free materials including polyethylene plastics. Air diffuser support legs are normally constructed from galvanized steel or an equivalent. Large-diameter air lift units should be used to avoid clogging problems. Mechanical units should be waterproofed and/or protected from the elements.

For fixed film systems, synthetic packing or attachment media are preferred over naturally occurring materials because they are lighter, more durable, and provide better void volume-surface area characteristics.

Since blowers, pumps, and other prime movers are abused by exposure to severe environments, lack of attention, and continuous operation, they should be designed for heavy duty use. They should be easily accessible for routine maintenance and tied into an effective alarm system.

PERFORMANCE

In extended aeration package plants, long hydraulic and solids retention times (SRT) are maintained to ensure a high degree of treatment at minimum operational control, to hedge against hydraulic or organic overload to the system, and to reduce sludge production. Since waste of accumulated solids is not routinely practiced in many of these units, SRT increases to a point where the clarifier can no longer handle the solids, which will be uncontrollably wasted in the effluent. Treatment performance (including nitrification) normally improves with increasing hydraulic retention time and SRT to a point where excessive solids build-up will result in high suspended solids washout. This is one of the biggest operational problems with these extended aeration units, and is often the reason for poor performance.

Dissolved oxygen concentrations in the aeration tank should exceed 2 mg/L (1.669×10^{-8} pounds/gallon) to insure a high degree of treatment and a good settling sludge. Normally, onsite extended aeration plants supply an excess of dissolved oxygen due to minimum size restrictions on blower motors or mechanical drives. An important element of aeration systems is the mixing provided by the aeration process. Package units should be designed to provide sufficient mixing to ensure good suspension of solids and mass transfer of nutrients and oxygen to the microbes.

Wastewater characteristics may also influence performance of the process. Excess amounts of certain cleaning agents, grease, floating matter, and other detritus can cause process upsets and equipment malfunctions.

Process efficiency may also be affected by temperature, generally improving with increasing temperature.

The clarifier is an important part of the treatment process. If the biomass cannot be properly separated from the treated effluent, the process will fail. Clarifier performance depends upon the settleability of the biomass, the hydraulic overflow rate, and the solids loading rate. Hydraulic surges can result in serious clarifier malfunctions. As mentioned previously, high solids loadings caused by accumulation of mixed liquor solids result in eventual solids carryover. Excessively long retention times for settled sludges in the clarifier may result in gasification and flotation of these sludges. Scum and floatable material not properly removed from the clarifier surface will also impair effluent quality.

Generally, extended aeration plants produce a high degree of nitrification since hydraulic and solids retention times are high. Reductions of phosphorus are normally less than 25 percent. The removal of indicator bacteria (fecal coliforms) in onsite extended aeration processes is highly variable and not well documented. Reported values of fecal coliforms appear to be about two orders of magnitude lower in extended aeration effluents than in septic tank effluents.

Aerobic units can achieve higher BOD_5 removals than septic tanks, but suspended solids removals, which are highly dependent on solids separation methods, are similar. Nitrification is normally achieved, but little reduction in phosphorus is accomplished. NSF studies indicate that suspended growth units can provide from 70 to 90 percent BOD_5 and SS reductions for combined household wastewater, yielding effluent BOD_5 and suspended solids concentrations as low as 20 mg/l.

OPERATION AND MAINTENANCE

General Plant Operation

The activated sludge process can be operated by controlling only a few parameters; the aeration tank dissolved oxygen, the return sludge rate, and the sludge wasting rate. For onsite package plants, these control techniques are normally fixed by mechanical limitations so that very little operational control is required. Dissolved oxygen is normally high and cannot be practically controlled except by "on or off" operation. Experimentation with the process may dictate a desirable cycling arrangement using a simple time clock control that results in power savings and may also achieve some nitrogen removal.

The return sludge rate is normally fixed by pumping capacity and pipe arrangements. Return sludge pumping rates often range from 50 to 200 percent of the incoming flow. They should be high enough to reduce sludge retention times in the clarifier to a minimum (less than one hr), yet low enough to discourage pumping of excessive amounts of water with the sludge. Time clock controls may be used to regulate return pumping.

Sludge wasting is manually accomplished in most package plants, usually during routine maintenance. Through experience, the technician knows when mixed liquor solids concentrations become excessive, resulting in excessive clarifier loading. Usually 8 to 12-month intervals between wasting is satisfactory, but this varies with plant design and wastewater characteristics. Wasting is normally accomplished by pumping mixed liquor directly from the aeration tank. Wasting of approximately 75 percent of the aeration tank volume is usually satisfactory. Wasted sludge must be handled properly.

Start-up

Prior to actual start-up, a dry checkout should be performed to insure proper installation. Seeding of the plant with bacterial cultures is not required as they normally develop within a 6 to 12-week period. Initially, large amounts of white foam may develop, but will subside as mixed liquor solids increase. During start-up, it is advisable to return sludge at a high rate. Monitoring by qualified maintenance personnel is desirable during the first month of startup.

Routine Operation and Maintenance

The maintenance process for suspended growth systems is more labor-intensive than for septic systems and requires semi-skilled personnel. Based upon field experience with these units, 12 to 48 man-hours per year plus analytical services are required to ensure reasonable performance. Power requirements are variable, but range between 2.5 to 10 kWh/day (8,530.8 to 34,123.2 Btu/day). Maintenance for fixed film systems is less labor-intensive but still requires semi-skilled personnel. Based upon limited field experience, 8 to 12 man-hours per year plus analytical services are required for adequate performance. Power requirements depend upon the device employed, but range from 1 to 4 kWh/day (3,412.3 to 13,649.3 Btu/day). Maintenance for both types of aerobic treatment units is usually completed through routine contract services. No chemicals are required for either method unless chemical disinfection or additional nutrient removal (N and P) is required for surface discharge.

Operational Problems

Major mechanical maintenance problems for onsite treatment units include blower or mechanical aerator failure, pump and pipe clogging, electrical motor failure, corrosion and/or failure of controls, and electrical malfunctions. Careful attention to a maintenance schedule will reduce these problems and alleviate operational problems due to the biological process upset. Emphasis should be placed on adequate maintenance checks during the first 2 or 3 months of operation.

COSTS

Costs for both suspended growth and fixed film systems of between 1,892 and 5,678 Liters/day (500 to 1,500 gallons per day) are typically in the $2,500 to $9,000 cost range, installed. These costs have been updated using the ENR construction cost index (ENR=6076). These units need more frequent maintenance than a traditional septic tank, and quarterly servicing is recommended. This maintenance cost averages $350 per year. Since many of these systems are being installed to replace failed septic systems, additional costs may be incurred to account for site conditions and additional piping.

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Water Efficiency Technology Fact Sheet
Composting Toilets

DESCRIPTION

Originally commercialized in Sweden, composting toilets have been an established technology for more than 30 years, and perhaps longer in site-built forms. As they require little to no water, composting toilet systems can provide a solution to sanitation and environmental problems in unsewered, rural, and suburban areas and in both developed and underdeveloped countries.

A composting (or biological) toilet system contains and processes excrement, toilet paper, carbon additive, and sometimes, food waste. Unlike a septic system, a composting toilet system relies on unsaturated conditions where aerobic bacteria break down waste. This process is similar to a yard waste composter. If sized and maintained properly, a composting toilet breaks down waste 10 to 30% of its original volume. The resulting soil-like material called "humus," legally must be either buried or removed by a licensed septage hauler in accordance with state and local regulations.

Public health professionals are beginning to recognize the need for environmentally sound human waste treatment and recycling methods. The composting toilet is a nonwater-carriage system that is well-suited for (but is not limited to) remote areas where water is scarce, or areas with low percolation, high water tables, shallow soil, or rough terrain. Because composting toilets eliminate the need for flush toilets, this significantly reduces water use and allows for the recycling of valuable plant nutrients.

Although there are many different composting toilet designs that continue to evolve, the basic concept of composting remains the same.

The primary objective of composting toilet systems is to contain, immobilize, or destroy pathogens, thereby reducing the risk of human infection to acceptable levels without contaminating the environment or negatively affecting the life of its inhabitants. This should be accomplished in a manner that is consistent with good sanitation (minimizing the availability of excrement to disease vectors, such as flies, and minimizing human contact with unprocessed excrement), thus producing an inoffensive and reasonably dry end-product that can be handled with minimum risk.

A composting toilet is a well-ventilated container that provides the optimum environment for unsaturated, but moist, human excrement for biological and physical decomposition under sanitary, controlled aerobic conditions. Some are large units that require a basement for installation. Others are small self-contained appliances that sit on the floor in the bathroom. In the composting process, organic matter is transformed by naturally occurring bacteria and fungi that break down the excrement into an oxidized, humus-like end-product. These organisms thrive by aeration, without the need for water or chemicals. Various process controls manage environmental factors—air, heat, moisture—to optimize the process.

The main process variations are continuous or batch composting. Continuous composters (including such brands as CTS, Clivus Multrum, Phoenix, Biolet, SunMar, etc.) are single chambers where excrement is added to the top, and the end-product is removed from the bottom. Batch composters (including Carousel, Vera, and nearly all of the site-built composters worldwide) are actually two or more composters that are filled and then allowed to cure without the continuous addition of new potentially pathogen contaminated excrement. Alternating concrete double-bins are the most common batch system, although several systems use polyethylene 55-gallon drums that contain the process.

APPLICABILITY

Composting toilet systems can be used almost anywhere a flush toilet can be used. They are typically used for seasonal homes, homes in remote areas that cannot use flush toilets, or recreation areas, etc. Application advantages for composting toilet systems are listed below:

- It is more cost-effective to treat waste on-site than it is to build and maintain a central sewer system to which waste will need to be transported.
- Water is not wasted as a transport medium to flush toilets.
- Nutrients (nitrogen and phosphorus) are kept in tight biological cycles without causing problems to receiving waters.

There have been many reports of successful use of waterless (composting, incinerator, chemical, and privy) toilets. Below are some examples of successful stories.

Replacement of Existing Disposal Systems

A family of four had a failing wastewater disposal system in their urban home. They lived on a small lot with insufficient land area to construct a disposal system for their water use. A waterless toilet was installed in conjunction with a 35% smaller disposal system to handle the remaining graywater.

Rejuvenation of an Existing Disposal System

A disposal system in a residential neighborhood had a history of surface breakouts due to overloading. The load was reduced when a waterless toilet was installed along with water conservation devices on plumbing fixtures.

Remodeling

A waterless toilet was installed in a basement near a family room because it was more practical than installing plumbing and a pump to lift the waste to a septic tank.

Waterless, Solar Toilets in Colorado Park

The Colorado Health Board was faced with the task of providing adequate toilets to the outlying portions of a 18,000-acre recreation area. The options considered were running a sewer and water line or installing chemical toilets and vault latrines. However, these options added to the problem with continual maintenance requirements, high chemical costs, expensive excavations and pump-outs, and the potential to pollute groundwater. Faced with this dilemma, the Colorado Health Board installed composting toilets to decompose wastes without water, chemicals, pollution, or odor.

The compost produced from the decomposed waste was similar to topsoil and reduced considerably in volume. Directly below the toilet chute was a large tank in which organic material such as lawn clippings, paper, and leaves was placed. The waste decomposed slowly along the tank floor by the natural bacteria present in the waste material. A fan powered by a small photovoltaic cell on the roof of each brick and concrete restroom was installed to draw out all vapors produced in the tank. Both the men's and the women's stalls were accommodated by a tank unit each to handle up to 40,000 uses per year, thus providing much-needed toilet facilities in outlying areas.

ADVANTAGES AND DISADVANTAGES

Some advantages and disadvantages of composting toilet systems are listed below:

Advantages

- Composting toilet systems do not require water for flushing, and thus, reduce domestic water consumption.

- These systems reduce the quantity and strength of wastewater to be disposed of onsite.

- They are especially suited for new construction at remote sites where conventional onsite systems are not feasible.

- Composting toilet systems have low power consumption.

- Self-contained systems eliminate the need for transportation of wastes for treatment/disposal.

- Composting human waste and burying it around tree roots and nonedible plants keeps organic wastes productively cycling in the environment.

- Composting toilet systems can accept kitchen wastes, thus reducing household garbage.

- In many states, installing a composting toilet system allows the property owner to install a reduced-size leachfield, minimizing costs and disruption of landscapes.

- Composting toilet systems divert nutrient and pathogen containing effluent from soil, surface water, and groundwater.

Disadvantages

- Maintenance of composting toilet systems requires more responsibility and commitment by users and owners than conventional wastewater systems.

- Removing the finished end-product is an unpleasant job if the composting toilet system is not properly installed or maintained.

- Composting toilet systems must be used in conjunction with a graywater system in most circumstances.

- Smaller units may have limited capacity for accepting peak loads.

- Improper maintenance makes cleaning difficult and may lead to health hazards and odor problems.

- Using an inadequately treated end-product as a soil amendment may have possible health consequences.

- There may be aesthetic issues because the excrement in some systems may be in sight.

- Too much liquid residual (leachate) in the composter can disrupt the process if it is not drained and properly managed.

- Most composting toilet systems require a power source.

- Improperly installed or maintained systems can produce odors and unprocessed material.

DESIGN CRITERIA

The main components of a composting toilet (see Figure 1) are:

- A composting reactor connected to a dry or micro-flush toilet(s).

- A screened air inlet and an exhaust system (often fan-forced) to remove odors and heat, carbon dioxide, water vapor, and the by-products of aerobic decomposition.

- A mechanism to provide the necessary ventilation to support the aerobic organisms in the composter.

- A means of draining and managing excess liquid and leachate (optional).

- Process controls to optimize and facilitate management of the processes.

- An access door for removal of the end-product.

The composting unit must be constructed to separate the solid fraction from the liquid fraction and produce a stable, humus material with less than 200 MPN per gram of fecal coliform. Once the leachate has been drained or evaporated out of the unit, the moist, unsaturated solids are decomposed by aerobic organisms using molecular oxygen. Bulking agents can be added to provide spaces for aeration and microbial colonization.

The compost chamber in some composting toilets is solar or electrically heated to provide and maintain optimum temperature requirements for year-round usage.

PERFORMANCE

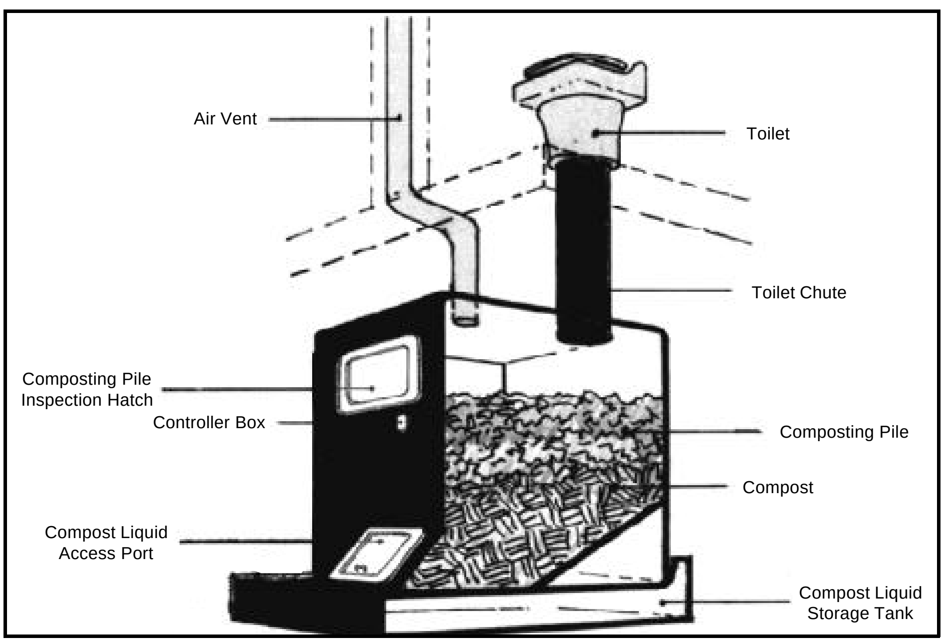
There are several factors that affect the rate of composting. Discussed below are the predominant factors:

- Microorganisms: The microbiology is dominated by the presence of a mixed population of bacteria and fungi. The presence of these microorganisms is directly related to the environmental conditions in the compost material.

- Temperature: As the microorganisms grow, heat is generated by the energy released during aerobic microbial respiration. The temperature of the compost is significant from a public health perspective because of the need for destruction of pathogens. Temperatures typically never become high enough to rapidly destroy pathogens, so time and optimum environmental factors are more significant.

- Moisture: Moisture enables microorganisms to hydrolize complex organic compounds into simpler compounds before they are metabolized. The moisture should be maintained within the range of 40 to 70%, with the optimum being about 60%.

- pH: In composting toilet systems, pH is not typically a concern to the owner/operator, although the pH will initially drop as organic acids are formed. Other biochemical processes buffer the final end-product, bringing it to a neutral level. In general, the optimum pH is between 6.5 and 7.5.



Source: Adapted from Clivus Multrum, Inc., 1994.

FIGURE 1 COMPOSTING TOILET

- Carbon to nitrogen ratio (C/N): For complete utilization of the nitrogen in urine, an adequate amount of carbon (about 30 parts of carbon for each part of nitrogen) is required. However, as most urine drains to the bottom of the composter and is removed, this is less of a problem than is usually reported in literature.

- Aeration: Maintaining an aerobic environment in the composting chamber is the most important factor for the growth of microorganisms, reducing high moisture content, and minimizing nitrogen loss through ammonia volatilization. Aeration can be improved by mechanical mixing or by adding wood chips or sawdust to the composting material.Management: As with all wastewater treatment systems, management is critical to the efficiency of the system.

The two main parameters in the composting process that account for the destruction of pathogens are:

- Antibiosis: Microbial and other higher order aerobic organisms develop in the compost pile during the decomposition process, resulting in the synthesis of substances that are toxic to most pathogens.

- Time: When exposed to an unfavorable environment for an extended period of time, most pathogenic microorganisms will not survive. However, caution is essential when using the compost end-product and liquid residual in case some pathogens survive. Table 1 gives typical pathogen survival times at 20 to 30°C in various environments.

The standard governing minimum materials, design, construction, and performance of composting toilet systems is the American National Standard/NSF International Standard ANSI/NSF 41-1998: Non-Liquid Saturated Treatment Systems.

TABLE 1 TYPICAL PATHOGEN SURVIVAL TIMES AT 20 TO 30°C IN VARIOUS ENVIRONMENTS

	Survival Time, Days		
Pathogen	**Fresh Water and Wastewater**	**Crops**	**Soil**
Bacteria			
Fecal coliforms[a]	< 60 but usually < 30	< 30 but usually < 15	< 120 but usually < 50
Salmonella (spp.)[a]	< 60 but usually < 30	< 30 but usually < 15	< 120 but usually < 50
Shigella[a]	< 30 but usually < 10	< 10 but usually < 5	< 120 but usually < 50
Vibrio cholerae[b]	< 30 but usually < 10	< 5 but usually < 2	< 120 but usually < 50
Protozoa			
E. histolytica cysts	< 30 but usually < 15	< 10 but usually < 2	< 20 but usually < 10
Helminths			
A. lumbricoides eggs	Many months	< 60 but usually < 30	< Many months
Viruses[a]			
Enteroviruses[c]	< 120 but usually < 50	< 60 but usually < 15	< 100 but usually < 20

a In seawater, viral survival is less and bacterial survival is very much less than in fresh water.
b *V. cholerae* survival in aqueous environments is a subject of current uncertainty.
c Includes polio, echo, and coxsackie viruses.

Source: Adapted from: Crites and Tchobanoglous, 1998.

OPERATION AND MAINTENANCE

Handling raw waste has historically been a problem from a management standpoint. Removing vault or pit type waste has led to accidental spills and is always a difficult task. This is why managers appreciate the concept of composting human waste.

Management considerations for composting toilets include gathering information on how much maintenance is needed annually, administration and operation, quality control and assurance, record-keeping, and training.

In general, operation and maintenance (O&M) for composting toilet systems does not require trained technicians or treatment plant operators. However, regular O&M is of the utmost importance since any system depends on responsible administration. In cold climates, all composting toilet systems should be heated to levels specified by the manufacturer or designer.

Composting toilet systems may require organic bulking agents to be added, such as grass clippings, leaves, sawdust, or finely chopped straw. The agents composting by providing a source of carbon for the bacteria, as well as keeping the pile porous for proper air distribution. If the facility is used every day, it is recommended to add bulking material at least every other day. Periodic mixing or raking is suggested for single-chamber continuous systems.

The other required maintenance step is removing the finished end-product (anywhere from every 3 months for a cottage system to every 2 years for a large central system). If proper composting has taken place, the end-product should be inoffensive and safe to handle. Adequate precautions should be taken while handling the humus material. All waste materials should be disposed of in accordance with the state and local regulations.

COSTS

The cost of a composting toilet system depends on the manufacturer and their type of design. Although the principle of waste treatment is the same, there are design variations in the containment of the waste, aeration, and other features of the system. The main factors that determine costs are the cost of the equipment, the building foundation, electrical work, and installation labor.

For a year-round home of two adults and two children, the cost for a composting toilet system could range anywhere between $1,200 and $6,000, depending on the system. Cottage systems designed for seasonal use range from $700 to $1,500. Large-capacity systems for public facility use can cost as much as $20,000 or more. However, site-built systems, such as cinder-block double-vault systems are as expensive as their materials and construction labor costs. A septic tank and soil absorption or subsurface irrigation system to manage graywater will usually be required.

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ADDITIONAL INFORMATION

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Wastewater Technology Fact Sheet

Disinfection for Small Systems

DESCRIPTION

The impact of untreated and partially treated domestic wastewater on rivers and community water sources continues to raise health and safety concerns. The organisms of concern in domestic wastewater include enteric bacteria, viruses, and protozoan cysts. Table 1 summarizes the most common microorganisms found in domestic wastewater and the types of human diseases associated with them. Based on health and safety concerns associated with microorganisms present in wastewater, EPA has increased its efforts to address the wastewater treatment needs of all communities across the United States. As a result, small community wastewater treatment needs are an EPA priority.

According to the EPA, a small system can either be a septic system, sand filter, or any system that serves individual houses or groups of homes, strip malls, or trailer parks. These systems can handle flows from 3.8 to 76 m^3/d (1,000 - 20,000 gpd). EPA estimates that more than 20 million homes in small communities are not connected to public sewers and that nearly one million homes in small communities across the United States have no form of sewage treatment at all (USEPA, 1999). In addressing small community needs, disinfection is considered a primary mechanism for inactivating/destroying pathogenic organisms and preventing the spread of waterborne diseases to downstream users and the environment. Some of the most commonly used disinfectants for decentralized applications include chlorine, iodine, and ultraviolet (UV) radiation.

Wastewater must be adequately treated prior to disinfection in order for any disinfectant to be effective. Reduction of suspended solids (SS) and biological oxygen demand (BOD) is recommended prior to disinfection. SS may absorb UV radiation, shield microorganisms, and increase chlorine demand. Removing SS also reduces the number of microorganisms present. Organic compounds associated with BOD also consume added chlorine.

TABLE 1 INFECTIOUS AGENTS POTENTIALLY PRESENT IN UNTREATED DOMESTIC WASTEWATER

Organism	Disease Caused
Bacteria	
Escherichia coli	Gastroenteritis
Leptospira (spp.)	Leptospirosis
Salmonella typhi	Typhoid fever
Salmonella (=2100 serotypes)	Salmonellosis
Shigella (4 spp.)	Shigellosis (bacillary dysentery)
Vibrio cholerae	Cholera
Protozoa	
Balantidium coli	Balantidiasis
Cryptosporidium parvum	Cryptosporidiosis
Entamoeba histolytica	Amebiasis (amoebic dysentery)
Giardia lamblia	Giardiasis
Helminths	
Ascaris lumbricoides	Ascariasis
Taena solium	Taeniasis
Trichuris trichiura	Trichuriasis
Viruses	
Enteroviruses (72 types) e.g., polio echo and coxsackie viruses	Gastroenteritis, heart anomalies, meningitis
Hepatitis A virus	Infectious hepatitis
Norwalk agent	Gastroenteritis
Rotavirus	Gastroenteritis

Source: Adapted from Crites and Tchobanoglous (1998), with permission from The McGraw-Hill Companies.

This fact sheet focuses on the use of UV disinfection and chlorination to disinfect small community septic systems.

APPLICABILITY

Chlorination and UV radiation can be used to inactivate potentially infectious organisms. As a result, communities and homeowners should carefully select a disinfection technology. A number of factors to consider when choosing a disinfection system are presented in Table 2.

The effectiveness of a UV disinfection system depends on the characteristics of the wastewater, the intensity of UV radiation, the amount of time the microorganisms are exposed to the radiation, and the reactor configuration. Disinfection success in any decentralized system is directly related to the concentration of colloidal and particulate constituents in the wastewater.

The most common UV system used for small systems is a low-pressure, low-intensity system. Low-pressure signifies the pressure of the mercury in the lamp, which is typically 13.8 Pa (0.002 lbs/in^2). The term intensity refers to the lamp power. Standard low-pressure, low-intensity lamps typically have a power of 65 watts. These lamps are generally efficient in producing germicidal wavelengths necessary for damaging DNA in bacteria. The low-pressure, low-intensity lamp typically has 40 percent of its output at 253.7 nm, which is within the ideal range for inactivating bacteria. This type of system can be configured vertically or horizontally. This allows systems to be configured to fit the available space. Safety considerations associated with UV disinfection include UV light itself, and potential release of mercury from lamp bulbs if damaged.

Chlorine is one of the most practical and widely used disinfectants for wastewater. Chlorination is commonly used because it can kill disease-causing bacteria and control nuisance organisms such as iron-reducing bacteria, slime, and sulfate-reducing bacteria. Chlorine destroys target organisms by oxidizing the cellular material of bacteria. Chlorine can be supplied in many forms and in liquid, solid, or gaseous phases. Common chlorine-containing disinfection products include chlorine gas,

TABLE 2 APPLICABILITY OF CHLORINATION AND UV RADIATION

Consideration	Chlorination	UV Radiation
Size of plant	All sizes	Small to medium[1]
Applicable level of treatment prior to disinfection	All levels, but chlorine required will vary	Secondary
Equipment reliability	Good	Fair to good
Process control	Well developed	Fairly well developed
Relative complexity of technology	Simple to moderate	Simple to moderate
Transportation on site	Substantial	Minimal
Bactericidal	Good	Good
Virucidal	Poor	Good
Cysticidal	Poor	Variable[2]
Fish toxicity	Potentially toxic	Nontoxic
Hazardous byproducts	Yes	No
Persistent residual	Long	None
Contact time	Long	Short
Contribute dissolved oxygen	No	No
Reacts with ammonia	Yes	No
Increased dissolved solids	Yes	No
pH dependent	Yes	No
Operation and maintenance sensitive	Minimal	Moderate
Corrosive	Yes	No

Source: Adapted from U.S. EPA, 1986.

[1] Early installations of UV disinfection facilities took place primarily in small to medium size plants because the technology was relatively new. Plants currently in design or construction phases tend to be larger.

[2] Recent studies have shown that UV radiation may be effective against oocysts.

hypochlorite solutions, and chlorine compounds in solid or liquid form. Liquid sodium hypochlorite and solid calcium hypochlorite tablets are the most common forms of chlorine used for small systems because they are less hazardous than chlorine gas.

ADVANTAGES AND DISADVANTAGES

UV Radiation

Advantages

C Effective inactivation of most viruses, bacteria, and spores. May be effective against some cysts.

C Physical process rather than a chemical disinfectant.

C No residual effect that could harm humans or aquatic life.

C Equipment requires less space than other methods.

Disadvantages

C Low dosages may not effectively inactivate some viruses, spores, and cysts.

C Turbidity and total suspended solids (TSS) in the wastewater can render UV disinfection ineffective.

C May require a large number of lamps.

Chlorination

Advantages

C Chlorine is reliable and effective against a wide spectrum of pathogenic organisms.

C Chlorine is more cost-effective than UV or ozone disinfection.

C The chlorine residual that remains in the wastewater effluent can prolong disinfection even after initial treatment and can be measured to evaluate the effectiveness.

C Dosing rates are flexible and can be controlled easily.

Disadvantages

C The chlorine residual is toxic to aquatic life and the system may require dechlorination, even when low concentrations of chlorine are used.

C All forms of chlorine are highly corrosive and toxic. Thus, storage, shipping, and handling chlorine poses a risk and requires increased safety - especially in light of the new Uniform Fire Code.

C Chlorine reacts with certain types of organic matter in wastewater, creating hazardous compounds (e.g., trihalomethanes).

C Chlorine residuals are unstable in the presence of high concentrations of chlorine-demanding materials (BOD). Thus, wastewater with high BOD may require higher chlorine doses for adequate disinfection.

DESIGN CRITERIA

UV Radiation

A UV disinfection system consists of mercury arc lamps, a contact vessel, and ballasts. The source of UV radiation is either a low- or a medium-pressure mercury arc lamp with low or high intensity. Medium- pressure lamps are generally used for large facilities. The optimum wavelength to effectively inactivate microorganisms is in the range of 250 to 270 nm. The intensity of the radiation emitted by the lamp dissipates as the distance from the lamp increases. Low-pressure lamps emit essentially monochromatic light at a wavelength of 253.7 nm. Standard lengths of the low-pressure lamps are 0.75 and 1.5 m (2.5 and 5.0 ft), with diameters of 15 to 20 mm (0.6-0.8 inches). The ideal lamp wall temperature is between 35 and 50EC (95-122EF). The United States Public Health Service requires that UV disinfection equipment have a minimum UV dosage of 16,000 FW·s/cm^2.

There are two types of UV disinfection reactor configurations: contact and noncontact. In both types, wastewater can flow either perpendicular or parallel to the lamps. In the contact reactor, a series of mercury lamps are enclosed in quartz sleeves to minimize the cooling effects of the wastewater. Flap gates or weirs are used to control the level of the wastewater. In the noncontact reactor, UV lamps are suspended outside a transparent conduit which carries the wastewater to be disinfected. In both types of reactors, a ballast—or control box—provides a starting voltage for the lamps and maintains a continuous current.

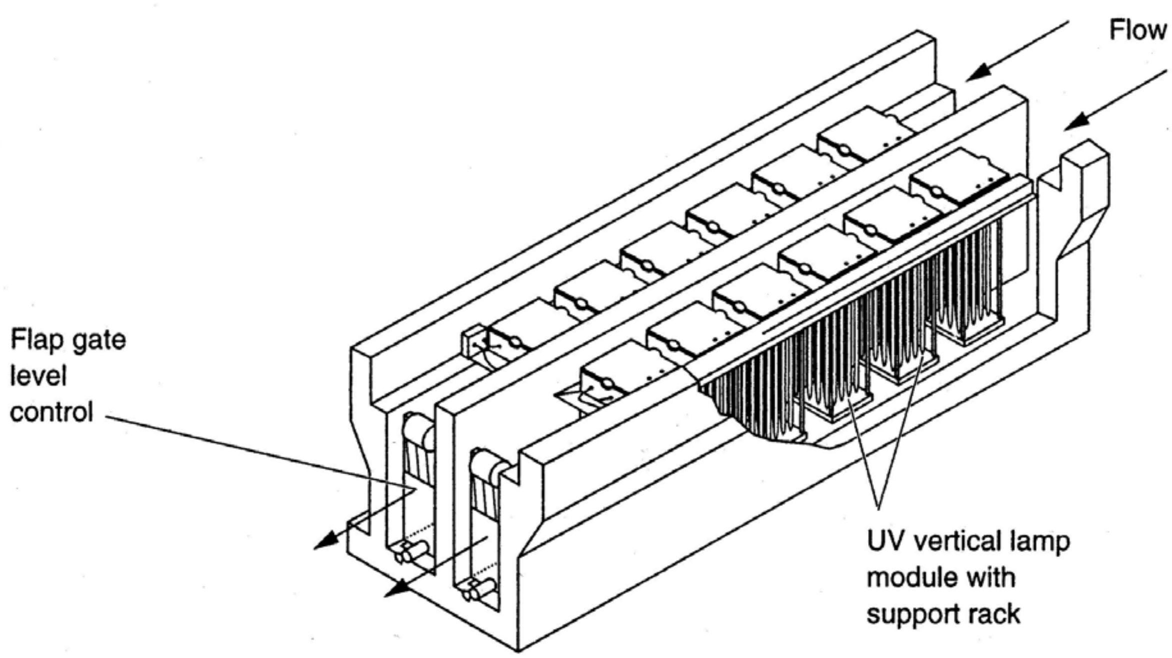
Because of capital cost advantages at low flow rates and the ease of managing a system with a small number of lamps, the majority of UV systems handling less than 0.4 m^3/s (1 MGD) are low-pressure, low-intensity systems. A 0.4 m^3/s (1 MGD) system should have fewer than 100 low-pressure lamps, so the impact of further reducing the number of lamps will not be substantial. Figure 1 presents a schematic of a low pressure contact UV disinfection system.

Several wastewater characteristics must be evaluated before selecting UV disinfection as a treatment method. The following list of characteristics can affect the performance and design of a UV disinfection system:

- Flow Rate: Wastewater flow can vary daily and seasonally, affecting the required size of a UV disinfection facility. As a result, the peak hourly flow rate typically is used as the design flow rate. The applied UV dosage is a function of UV intensity and the duration of exposure; the dosage rate achieved is directly proportional to flow rate.

- UV Transmittance: UV transmittance is a measure of the quantity of UV light at the characteristic wavelength of 253.7 nm transmitted through wastewater per unit depth. Historically, a 50 percent UV transmittance has been accepted as the minimum transmittance for which UV disinfection is practical. High turbidity and/or high concentrations of BOD, certain metals, TDS, TSS, and color may decrease transmittance, lessening the effectiveness of UV radiation.

- TSS Concentration: TSS levels significantly affect UV disinfection because UV light can be blocked by suspended solids. This can



Source: Crites and Tchobanoglous, 1998.

FIGURE 1 LOW PRESSURE CONTACT UV DISINFECTION SYSTEM

shield microorganisms from the disinfecting effects of the light. As a result, measuring the particle size distribution in wastewater can be helpful in determining the feasibility of this disinfection technology. Particles with a diameter of <10 microns allow for easy UV penetration. Particles with diameters between 10 and 40 microns can be completely penetrated, but with increased UV demand.

- Microorganism Concentration: UV disinfection performance evaluations indicate that the microorganism density remaining after exposure to a given UV dose is proportional to initial microorganism density. As a result, it is beneficial to consider the concentration of microorganisms before disinfection.

- Hardness: Carbonate deposition (scaling) on lamp sleeves becomes an issue when handling wastewater with high levels of hardness. Carbonate accumulation on lamp sleeves reduces the intensity of UV light reaching the wastewater.

- Iron Concentration: Dissolved iron concentrations in wastewater can absorb UV light, reducing the light intensity reaching the microorganisms. Adsorbed iron on suspended solids may also shield microorganisms from UV light. Iron hydroxides may precipitate on lamp bulbs, decreasing their intensity.

- Organics: Dissolved organics or oils and grease can reduce UV transmittance. The size of the organic compounds is important in determining whether they will interfere with the UV transmittance: the larger the molecular weight of the compounds, the more they will interfere. This effect is primarily the result of increasing color and/or turbidity in the water.

- Inorganics: Some inorganic salts (e.g., bromide) can absorb UV light and thereby reduce UV effectiveness.

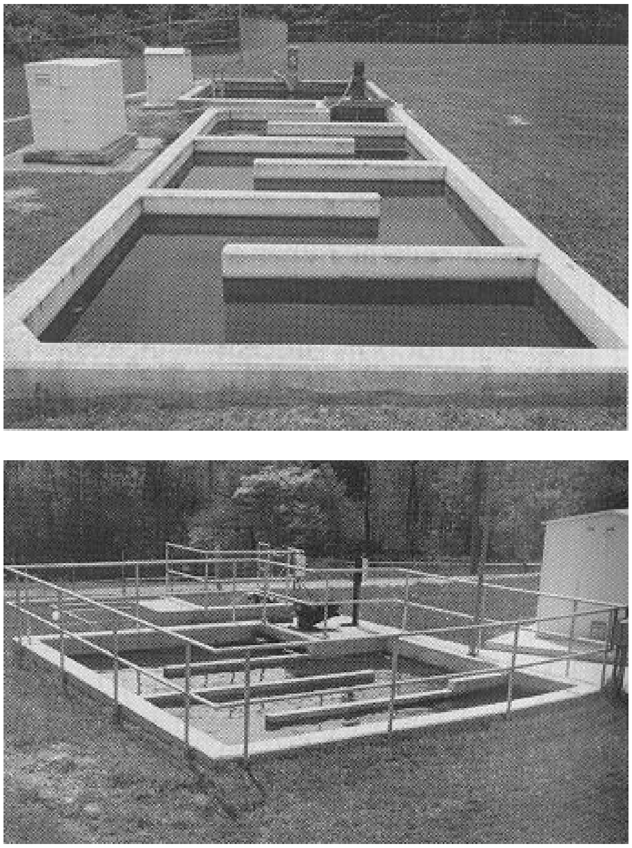
Systems using an aerobic household wastewater treatment system are usually installed at or below grade level and the effluent pipe may be as much as 60 cm (24 in) below grade. To maintain gravity flow, the UV unit must be below grade and must have very low flow resistance. During construction, the components of an underground UV system must be easily accessed for service and low voltage should be used for safety.

Chlorination

For optimum performance, a chlorine disinfection system should provide rapid initial mixing and a plug flow contact regime. The goal of proper mixing is to enhance disinfection by initiating a reaction between free chlorine and ammonia nitrogen. This helps to prevent free chlorine from reacting with organic carbon compounds and forming hazardous byproducts. In order to allow appropriate time for the disinfection reaction, the contact chamber should be designed with rounded corners to eliminate dead flow areas. It should also be baffled to minimize short-circuiting. This design allows for adequate contact time between the microorganisms and a minimal chlorine concentration for a specific period of time. Figure 2 illustrates plug flow chlorine contact basins.

Chemical feed systems are used for adding sodium and/or calcium hypochlorite solutions. For sodium hypochlorite, the basic components of a chemical feed system include a plastic or fiber glass storage reservoir, metering pumps, and an injection device to inject the hypochlorite solution into a contact tank or pipeline. Calcium hypochlorite can typically be added to the wastewater either by mixing calcium hypochlorite powder in a mixing device and then injecting it into the wastewater stream, or by immersing chlorine tablets in the wastewater using a tablet chlorinator. Tablet chlorinator systems are described in more detail below.

A typical calcium hypochlorite tablet chlorinator consists of a cylindrical PVC tank with a diameter ranging from 230 to 610 mm (9-24 in) and a height ranging from 0.6 to 1.2 m (24-48 in). A sieve plate



Source: Crites and Tchobanoglous, 1998.

FIGURE 2 TYPICAL PLUG FLOW CHLORINE CONTACT BASINS FOR SMALL FLOWS

with holes supports the 80 mm (3-in) diameter calcium hypochlorite tablets. Tablet chlorinator systems can typically provide between 1 and 295 kg (2-650 lbs) of chlorine per day. A side stream from the main flow is piped into the chlorinator at the bottom of the tank. The flow rises through the holes in the sieve plate, contacting and eroding the bottom layer of tablets. The tablets erode at a predictable rate based on the amount of water that enters the chlorinator. An accurate chlorine dosage can be achieved by controlling the water flow rate through the chlorinator. The chlorinator effluent is returned to the main stream, providing the desired level of available chlorine to meet operational requirement.

The required degree of disinfection can be achieved by varying the dose and the contact time for any chlorine disinfection system. Chlorine dosage will vary based on chlorine demand, wastewater characteristics, and discharge requirements. The dose usually ranges from 5 to 20 mg/L. Table 3 describes some common wastewater characteristics and their impact on chlorine. Several other factors

TABLE 3 WASTEWATER PROPERTIES AFFECTING CHLORINATION AND UV DISINFECTION PERFORMANCE

Property	Effects on Chlorination	Effects on UV Disinfection
Ammonia	Forms chloramines when combined with chlorine.	Minor effect, if any.
Nitrite	Reduces effectiveness of chlorine and results in THMs.	At high concentrations may absorb UV light and reduce transmittance.
Nitrate	Minor effect, if any.	At high concentrations may absorb UV light and reduce transmittance.
Bio-chemical oxygen demand (BOD)	Organic compounds associated with BOD can consume added chlorine.	Minor effect, if any. If a large portion of the BOD is humic and/or unsaturated (or conjugated) compounds, then UV transmittance may be diminished.
Hardness	Minor effect, if any.	Affects solubility of metals that can absorb UV light. Can lead to the precipitation of carbonates on quartz tubes.
Humic materials, Iron	Minor effect, if any.	High absorbency of UV radiation.
pH	Affects distribution between hypochlorous acid and hypochlorite ions and among the various chloramine species.	Affects solubility of metals and carbonates, and thus scaling potential.
TSS	Shielding of embedded bacteria and chlorine demand.	Absorbs UV radiation and shields embedded bacteria.

Source: Adapted from Darby, et al., 1995, with permission from the Water Environment Research Foundation.

ensure optimum conditions for disinfection, including temperature, alkalinity, and nitrogen content. Wastewater pH affects the distribution of chlorine between hypochlorous acid and hypochlorite. A lower pH favors hypochlorous acid, which is a better disinfectant. High concentrations of hypochlorous acid, however, may result in production of chlorine gas, which may be hazardous.

PERFORMANCE

Performance of chlorination and UV disinfection varies between facilities based on maintenance techniques and wastewater characteristics. Researchers at Baylor University are evaluating existing on-site systems using different disinfection units.

OPERATION AND MAINTENANCE

UV Radiation

A routine operation and maintenance (O&M) schedule should be developed and implemented for any disinfection system. A proper O&M program for a UV disinfection system should ensure that sufficient UV radiation is transmitted to the organisms to inactivate them. All surfaces between the UV radiation and the target organisms must be cleaned, while ballasts, lamps, and the reactor must be functioning properly. Inadequate cleaning is one of the most common causes of ineffective UV systems. The quartz sleeves or Teflon tubes should be cleaned regularly, either manually or through mechanical methods. Common cleaning methods include mechanical wipers, ultrasonic baths, or chemicals. Cleaning frequency is site-specific.

Chemical cleaning is most commonly performed with citric acid or commercially available cleaning solutions. Other cleaning agents include mild vinegar solutions and sodium hydrosulfite. A combination of cleaning agents should be tested to find those that are most suitable for the specific wastewater characteristics without producing harmful or toxic by-products. Non-contact reactor systems are most effectively cleaned with sodium hydrosulfite.

Average lamp life ranges from 8,760 to 14,000 working hours (between approximately 12 and 18 months of continuous use), but lamps are usually replaced after 12,000 hours of use. Operating procedures should be set to reduce the on/off cycles of the lamps, because repeated cycles reduce their effectiveness. In addition, spare UV lamps should be kept on hand at all times along with accurate records of lamp use and replacement. The UV output gradually decreases over the life of the lamp and the lamp must be replaced based on the hours of use or a UV monitor. The quartz sleeves that fit over the lamps will last about 5 to 8 years but are generally replaced every 5 years.

The ballast must be compatible with the lamps and should be ventilated to prevent excessive heating, which may shorten its life or even result in fires. The life cycle of ballasts is approximately 10 to 15 years, but they are usually replaced every 10 years.

Operation and maintenance of an on-site system is usually the responsibility of the homeowner, but some home sewage systems are sold with service contracts that call for a trained serviceman to inspect the system and perform necessary maintenance every six months. As a result, it is necessary to determine who is responsible for operation and maintenance of the UV system.

Chlorination

O&M for a chlorine disinfection system should include the following activities:

- Follow all manufacturer recommendations and test and calibrate equipment as recommended by the manufacturer.
- Disassemble and clean system components, including meters and floats, every six months.
- Inspect and clean valves and springs annually.
- If the system includes metering pumps, maintain pumps on a regular basis.

- Remove iron and manganese deposits with muriatic acid or other removal agents.

- If gaseous chlorine is stored on-site, develop an emergency response plan in case of accidents or spills.

It is essential to properly and safely store all chemical disinfectants when using chlorine. The storage of chlorine is strongly dependent on the compound phase. Heat, light, storage time, and impurities such as iron accelerate the degradation of sodium hypochlorite. Calcium hypochlorite is unstable under normal atmospheric conditions and should be stored in a dry location. Hypochlorites are destructive to wood, corrosive to most common metals, and will irritate skin and eyes if there is contact. For further details on the safe use and storage of chlorine refer to the Material Safety Data Sheets (MSDS) for the specific chemicals of interest. MSDSs are readily available from the internet by doing a search on the chemical name.

COSTS

The costs associated with chlorination and UV treatment are predominantly dictated by dosage, which in turn is related to peak flows, suspended solids, temperature and bacterial counts. The following summaries describe some of the costs that a homeowner and/or community may encounter when considering chlorination or UV treatment to disinfect wastewater.

UV Radiation

Table 4 provides capital cost summaries for UV systems. Systems include the wastewater channel, UV module assemblies with lamps and quartz sleeves, and ballasts. The ballasts include meters for run times and UV intensity. The last two systems in the table also include costs for delivery of the equipment to the site.

TABLE 4 UV SYSTEM COSTS

UV System description	Cost
Peak flow: 19 m^3/d (5,000 gpd)	$2,500[1]
Peak flow: 95 m^3/d (25,000 gpd)	$3,750[1]
Peak flow: 49 m^3/d (12,960 gpd)	$4,000[2]
Peak flow: 98 m^3/d (25,920 gpd)	$4,700[2]

Sources:

[1] Tipton Environmental International, Inc., 2003.

[2] Infilco Degremont, Inc., 1999.

Chlorination

Most decentralized systems use chlorine tablets to disinfect their wastewater because they are simple to use, and they are less expensive than liquid chlorine. These units can range from $325-$700, depending on the flow to be chlorinated. Tablets are sold in tablets or drums based on weight. For example, a 100 kg (45 lb) pail of tablets ranges in cost from $69-$280, depending on the vendor.

Liquid chlorinators are more complex because the liquid must be pumped into the system. A hypochlorinator system sized to treat a flow range of 9.5 to 76 m^3/d (2,500 to 20,000 gpd), consisting of one 210-L (55-gal) polyethylene drum, two metering pumps, and injector valve, costs approximately $4,200.

Cost Comparison

Cost comparisons between UV and chlorination disinfection systems are difficult because of the cost differences based on the volume of flow. In addition, while the initial capital costs of one system may be low relative to another system, subsequent operation and maintenance costs for each type of system must be evaluated before the overall cost-effectiveness of one system vs. another can be determined. For example, while the capital costs of a chlorination system may be low compared to the capital costs for a UV system, dechlorination equipment and supplies will increase the overall cost associated with this disinfection method.

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EPA 832-F-03-024
September 2003

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Decentralized Systems Technology Fact Sheet

Septic Tank Effluent Screens

DESCRIPTION

A septic tank is a traditional wastewater treatment technology that uses an underground tank to hold and treat wastewater. As wastewater flows into the tank, heavier materials settle to the bottom and form a sludge layer, while lighter greases and fats float to the top, forming a scum layer. Clarified effluent is piped from the center of the tank and into a drainfield, where it percolates into the surrounding soil.

An effluent screen (Figure 1) is a physical device that is placed on the outlet pipe of the septic tank to enhance solids removal from the septic tank effluent. In addition, by preventing excess solids from flowing out into the drainfields with the clarified effluent, these screens help to prevent blockages that can damage the drainfield. Finally, in some cases, a thin layer of organic growth called a "biomat" may build up on the screen. This biomat is rich in anaerobic bacteria, which can help to remove viruses and pathogens from the effluent.

FIGURE 1 EFFLUENT SCREEN

APPLICABILITY

The use of effluent screens in septic tanks is becoming more common in the U.S. Installation of effluent screens on septic tanks is mandatory in more than 50 counties nationwide, as well as in the states of Florida, Georgia, North Carolina, and Connecticut.

ADVANTAGES AND DISADVANTAGES

The two primary benefits of using effluent screens in septic systems are that screens improve the quality of the effluent and extend the life of the leach field. Additional advantages and disadvantages of using effluent screens in septic systems are listed below.

Advantages

- Helps prevent solids from clogging the drainfield.
- Keeps non-biodegradeable objects from entering the drainfield.
- Can be placed in existing or new septic tanks.
- Requires little routine maintenance because there are no moving parts.
- Units are relatively inexpensive.

Disadvantages

- Regular clean-out of the effluent screen is required to maintain optimal total suspended solids removal.
- Requires surface access for servicing.

DESIGN CRITERIA

The two primary design considerations for septic tank effluent screens are the location of the screen and the flow area of the screen relative to the size of the tank.

Effluent screens can be placed directly in the septic tank's outlet tee, or in a separate housing unit. When the screen is placed in a housing unit (Figure 2), the housing unit can act as a second settling chamber, increasing the clarity of the effluent before it goes through the screen.

If the effluent screen is located in the outlet tee within the septic tank, it should be placed in the clear-water zone beneath the scum layer and above the sludge layer (Figure 3). The bottom of the screen should extend into the liquid a distance equal to 40 percent of the liquid depth. This should ensure that neither scum nor sludge will be transferred onto the screen, and will therefore maximize the clarity of the effluent flowing out of the tank.

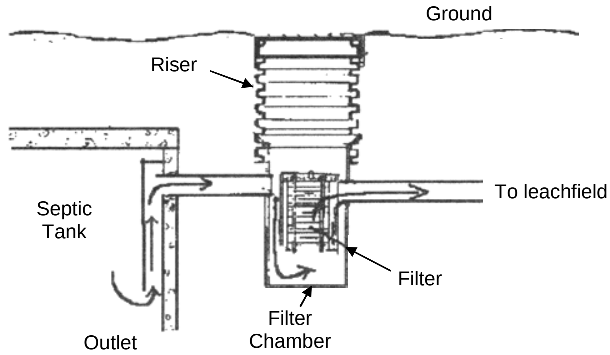

FIGURE 2 EFFLUENT SCREEN LOCATED OUTSIDE THE SEPTIC TANK

Source: Barnstable County (Mass.) Department of Health and Environment (use of Zabel filter), 2003.

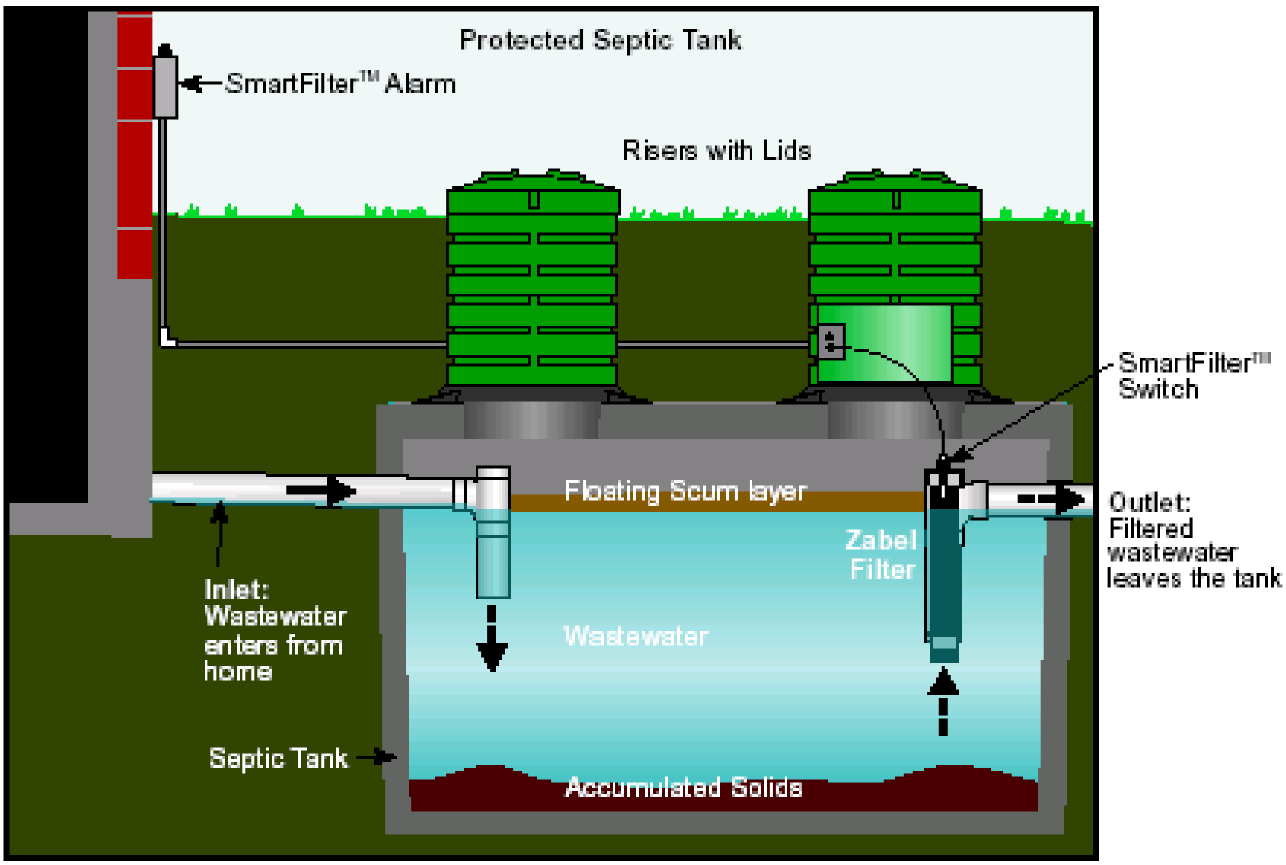

FIGURE 3 FILTER PLACEMENT BETWEEN THE SCUM AND SLUDGE LAYERS

Source: Zabel, 2003.

The other major design consideration is ensuring that the flow area (the combined area of the perforations or openings in the screen through which liquid passes) is sufficient for the flow rate and the solids concentrations in the system. Screens placed in systems with high flow rates and/or high solids content will need higher flow areas to avoid screen clogging. Some screens have an alarm to alert the owner if the filter becomes clogged. This can allow the owner to clean the effluent screen before effluent backs up in the tank.

PERFORMANCE

As described above, effluent screens are designed to remove solids. Most effluent screens have the capability to retain solids that are greater than 3 mm (⅛ in) in diameter. However, solids removal performance for any given septic tank effluent screen will depend on a number of factors, the most important of which is daily flow. The higher the flow, the more likely it is to overload the filter, even at average solids loadings. Larger systems may require multiple filters in a manifold arrangement to treat the daily flow.

Effluent screens can also enhance the decomposition of solids within the tank. Effluent passes through the effluent screen through vertical inlet holes, while larger particles are retained in the tank. As these particles settle in the tank, further decomposition of organic materials occurs.

OPERATION AND MAINTENANCE

Because of their lack of moving parts, effluent screens require minimal maintenance. Nonetheless, lack of attention will lower their overall efficiency, and regular maintenance is important to ensure efficient screen operation.

The primary maintenance activity is cleaning the screen to prevent plugging. When an effluent screen plugs, liquid backs up and cannot exit the tank. To avoid this problem, effluent screens must be cleaned on a regular basis. The cleaning frequency will be dependent on the size of the screen, environmental conditions, and the type of material entering the septic system. Smaller flow areas and smaller effluent screen openings increase the need for maintenance. Most manufacturers recommend cleaning the screen every one to three years, depending on site characteristics.

COSTS

Effluent screens cost from $70-$300 per unit. Installation and servicing add additional costs.

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September 2000

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September 2000

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Agency

Office of Water
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EPA 816-F-01-021
July 2001

Source Water Protection Practices Bulletin

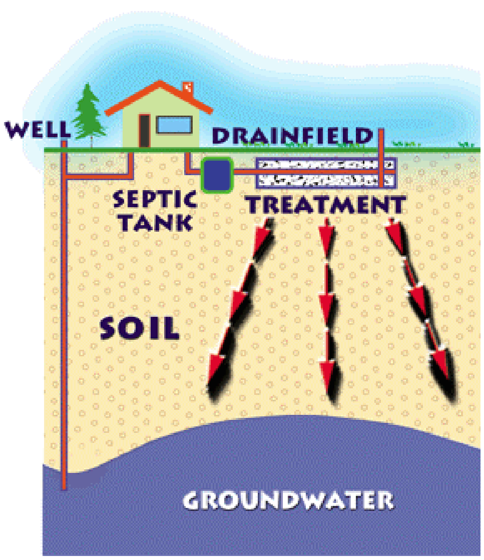
Managing Septic Systems to Prevent Contamination of Drinking Water

Septic systems (also known as onsite wastewater disposal systems) are used to treat and dispose of sanitary waste. When properly sited, designed, constructed, and operated, they pose a relatively minor threat to drinking water sources. On the other hand, improperly used or operated septic systems can be a significant source of ground water contamination that can lead to waterborne disease outbreaks and other adverse health effects.

This fact sheet discusses ways to prevent septic systems from contaminating sources of drinking water. Septic systems that receive non-sanitary wastes (e.g., industrial process wastewater) are considered industrial injection wells, and are not the primary focus of this fact sheet. Other fact sheets in this series address prevention measures for contamination sources such as fertilizers, pesticides, animal feeding operations, and vehicle washing.

SOURCES OF SEPTIC SYSTEM EFFLUENT

About 25 percent of U.S. households rely on septic systems to treat and dispose of sanitary waste that includes wastewater from kitchens, clothes washing machines, and bathrooms. Septic systems are primarily located in rural areas not served by sanitary sewers.



A typical household septic system consists of a septic tank, a distribution box, and a drain field. The septic tank is a rectangular or cylindrical container made of concrete, fiberglass, or polyethylene. Wastewater flows into the tank, where it is held for a period of time to allow suspended solids to separate out. The heavier solids collect in the bottom of the tank and are partially decomposed by microbial activity. Grease, oil, and fat, along with some digested solids, float to the surface to form a scum layer. (Note: Some septic tanks have a second compartment for additional effluent clarification.)

The partially clarified wastewater that remains between the layers of scum and sludge flows to the distribution box, which distributes it evenly through the drain field. The drain field is a network of perforated pipes laid in gravel-filled trenches or beds. Wastewater flows out of the pipes, through the gravel, and into the surrounding soil. As the wastewater effluent percolates down through the soil, chemical and biological processes remove some of the contaminants before they reach ground water.

Large capacity septic systems are essentially larger versions (with larger capacities and flow rates) of single family residential septic systems, but they may have more than one septic tank or drain field for additional treatment capacity. In some cases, an effluent filter may be added at the outlet of the large capacity septic tank to achieve further removal of solids. Many large systems rely on pumps rather than gravity to provide an even flow distribution into the drain field.

WHY IS IT IMPORTANT TO MANAGE SEPTIC SYSTEMS NEAR THE SOURCES OF YOUR DRINKING WATER?

Septic systems are a significant source of ground water contamination leading to waterborne disease outbreaks and other adverse health effects. The bacteria, protozoa, and viruses found in sanitary wastewater can cause numerous diseases, including gastrointestinal illness, cholera, hepatitis A, and typhoid.

Nitrogen, primarily from urine, feces, food waste, and cleaning compounds, is present in sanitary wastewater. Consumption of nitrates can cause methemoglobinemia (blue baby syndrome) in infants, which reduces the ability of the blood to carry oxygen. If left untreated, methemoglobinemia can be fatal for affected infants. Due to this health risk, a drinking water maximum contaminant level (MCL) of 10 milligrams per liter (mg/l) or parts per million (ppm) has been set for nitrate measured as nitrogen. Even properly functioning conventional septic systems, however, may not remove enough nitrogen to attain this standard in their effluent.

AVAILABLE PREVENTION MEASURES TO ADDRESS SEPTIC SYSTEMS

Septic systems can contribute to source water contamination for various reasons, including improper siting, poor design, faulty construction, and incorrect operation and maintenance. Most States and localities regulate siting, design, and construction of septic systems and only regulate operation and maintenance for large capacity septic systems. Some of the more widely used prevention measures are described below. Your local health department should be able to advise you on specific requirements for your community.

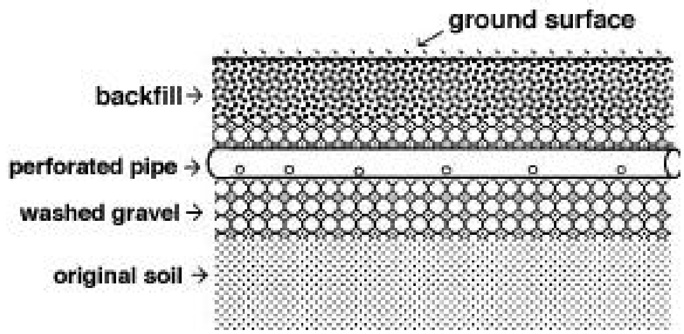
Please keep in mind that individual prevention measures may or may not be adequate to prevent contamination of source waters. Most likely, individual measures should be combined in an overall prevention approach that considers the nature of the potential source of contamination, the purpose, cost, operational, and maintenance requirements of the measures, the vulnerability of the source water, the public’s acceptance of the measures, and the community’s desired degree of risk reduction

Siting

Most jurisdictions have adopted, for septic systems, ***minimum horizontal setback distances*** from features such as buildings and drinking water wells and ***minimum vertical setback distances*** from impermeable soil layers and the water table. Septic systems should be located a safe distance from drinking water sources to avoid potential contamination. Areas with high water tables and shallow impermeable layers should be avoided because there is insufficient unsaturated soil thickness to ensure sufficient treatment. ***Soil permeability must be adequate*** to ensure proper treatment of septic system effluent. If permeability is too low, the drain field may not be able to handle wastewater flows, and surface ponding (thus contributing to the contamination of surface water through runoff) or plumbing back-ups may result. If permeability is too high, the effluent may reach ground water before it is adequately treated. As a result, alternative systems may be necessary in karst areas. Well-drained loamy soils are generally the most desirable for proper septic system operation. In making siting decisions, local health officials should also evaluate whether soils and receiving waters can absorb the combined effluent loadings from all of the septic systems in the area.

Design and Construction

Septic tanks and ***drain fields should be of adequate size*** to handle anticipated wastewater flows. In addition, soil characteristics and topography should be taken into account in designing the drain field. Generally speaking, the lower the soil permeability, the larger the drain field required for adequate treatment. Drain fields should be located in relatively flat areas to ensure uniform effluent flow.



Septic drain field

Effluent containing excessive amounts of grease, fats, and oils may clog the septic tank or drain field and lead to premature failure. The installation of ***grease interceptors*** is recommended for restaurants and other facilities with similar wastewater characteristics.

Construction should be performed by a ***licensed septic system installer*** to ensure compliance with applicable regulations. The infiltration capacity of the soil may be reduced if the soil is overly compacted. Care should be taken not to drive heavy vehicles over the drain field area during construction or afterward. Construction equipment should operate from upslope of the drain field area. Construction should not be performed when the soil is wet, or excessive soil smearing and soil compaction may result.

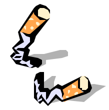
Operation and Maintenance

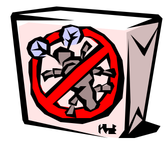
Proper operation and maintenance of septic systems is perhaps the most crucial prevention measure to preventing contamination. Inadequate septic system operation and maintenance can lead to failure even when systems are designed and constructed according to regulation. Homeowners associations and tenant associations can play an important role in educating their members about their septic systems. In commercial establishments such as strip malls, management companies can serve a similar role. Septic system owners should continuously monitor the drain field area for signs of failure, including odors, surfacing sewage, and lush vegetation. The septic tank should be ***inspected annually*** to ensure that the internal structures are in good working order and to monitor the scum level.

Many septic systems fail due to hydraulic overloading that leads to surface ponding. Reducing wastewater volumes through ***water conservation*** is important to extend the life of the drain field. Conservation measures include using water-saving devices, repairing leaky plumbing fixtures, taking shorter showers, and washing only full loads of dishes and laundry. Wastewater from basement sump pumps and water softeners should not be discharged into the septic system to minimize hydraulic load. In addition, surface runoff from driveways, roofs, and patios should be directed away from the drain field.

If an excessive amount of sludge is allowed to collect in the bottom of the septic tank, wastewater will not spend a sufficient time in the tank before flowing into the drain field. The increased concentration of solids entering the drain field can reduce soil permeability and cause the drain field to fail. Septic tanks should be pumped out every two to five years, depending on the tank size, wastewater volume, and types of solids entering the system. Garbage disposals increase the volume of solids entering the septic tank, requiring them to be pumped more often.


Household chemicals such as solvents, drain cleaners, oils, paint, pharmaceuticals, and pesticides can interfere with the proper operation of the septic system and cause ground water contamination. Homeowners should take advantage of ***local hazardous waste collection programs*** to dispose of these wastes whenever possible. Grease, cooking fats, coffee grounds, sanitary napkins, and cigarettes do not easily decompose, and contribute to the build-up of solids in the tank. The use of additives containing yeast, bacteria, enzymes, and solvents has not been proven to improve the performance of septic systems, and may interfere with their normal operation. Bacterial "starters" are not necessary because a wide range of bacteria are normally present in sewage entering the tank. Additives containing solvents or petrochemicals can cause ground water contamination.




Vehicles and heavy equipment should be kept off the drain field area to prevent soil compaction and damage to pipes. Trees should not be planted over the drain field because the roots can enter the perforated piping and lead to back-ups. Last, any type of construction over the drain field should be avoided. Impervious cover can reduce soil evaporation from the drain field, reducing its capacity to handle wastewater.

FOR ADDITIONAL INFORMATION

For information on septic system regulations in your community, contact your state or local health department. The information sources below contain information on measures to prevent septic system failures. All of the documents listed are available free of charge on the Internet.

Numerous documents on septic systems are available for download from U.S. Department of Agriculture Cooperative State Research, Education, and Extension Service State Partners. Links to the various State Partners can be found at http://www.reeusda.gov/1700/statepartners/usa.htm. Several examples of these documents are presented below:

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The National Small Flows Clearinghouse has developed a series of brochures on septic systems. They can be found at http://www.estd.wvu.edu/nsfc/NSFC_septic_news.html.

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United States Environmental Protection Agency | Office of Water Washington, D.C. | EPA 832-F-00-033 September 2000

Decentralized Systems Technology Fact Sheet
Evapotranspiration

DESCRIPTION

Evapotranspiration (ET) is a method of onsite wastewater treatment and disposal that offers an alternative to conventional soil absorption systems for sites where protection of the surface water and groundwater is essential. An ET system disposes of wastewater into the atmosphere through evaporation from the soil surface and/or transpiration by plants, without discharging wastewater to the surface water or groundwater reservoir. ET can offer flexibility by combining seepage with evaporation when absolute protection of the groundwater or surface water is not required.

An ET system is a feasible option in semi-arid climates where the annual evaporation rate exceeds the annual rate of precipitation. The amount that evaporation exceeds precipitation is the wastewater application capacity. The different design configurations of ET are discussed in more detail in the sections that follow.

Process

Evapotranspiration is the net water loss caused by evaporation of moisture from the soil surface and transpiration by vegetation. Three conditions must be met for continuous evaporation. First, it requires latent heat of approximately 590 cal/g of water evaporated at 15 °C. Second, a vapor pressure gradient between the evaporative surface and the atmosphere must exist to remove vapor by diffusion, convection, or a combination of the two. Third, there must be a continuous supply of water to the evaporative surface.

Evapotranspiration is also influenced by vegetation on the disposal field. Theoretically, ET can remove high volumes of effluent in the late spring, summer, and early fall, especially if large silhouette and good transpiring bushes are present.

There are three main types of evapotranspiration systems; ET, evapotranspiration/absorption (ETA), and mechanical.

The first type, an ET system, is the most common. The main components are a pretreatment unit (usually a septic tank or an aerobic unit) used to remove settleable and floatable solids and an ET sand bed with wastewater distribution piping, a bed liner, fill material, monitoring wells, overflow protection, and a surface cover. Vegetation must be planted on the surface of the bed to enhance the transpiration process.

The septic tank effluent flows into the lower portion of a sealed ET bed equipped with continuous impermeable liners and carefully selected sands. Capillary action in the sand causes the wastewater to rise to the surface and escape through evaporation as water vapor. In addition, vegetation transports the wastewater from the root zone to the leaves, where it is transpired as a relatively clean condensate. This design allows for complete wastewater evaporation and transpiration with no discharge to nearby soil.

Figure 1 shows a cross-sectional view of a typical ET bed. Although this design may be acceptable in certain sites, local and state regulations should be checked to ensure approval.

The second type of evapotranspiration system is known as ETA. In addition to evaporation and transpiration, percolation also occurs through an unsealed bed. This design provides discharge to both the atmosphere and to the subsurface.

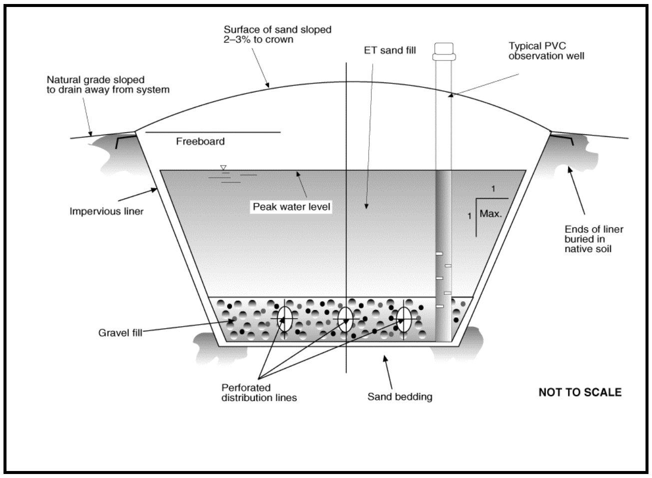

FIGURE 1 CROSS SECTIONAL VIEW OF A TYPICAL EVAPOTRANSPIRATION BED

The third type of evapotranspiration system, which involves the use of mechanical devices, is still under development. There are two types of mechanical evaporation systems, both of which require a septic tank for pretreatment and storage tank. The first type consists of a rotating disk unit, in which the disks rotate slowly, providing a large surface area for the wastewater to evaporate.

The second type of mechanical ET system is a concentric cylinder unit, where forced air enters the center of the cylinder, moves outward through wetted cloth wraps, and is discharged as vapor.

Mechanical systems use little electricity and require minimal maintenance, which makes them attractive options for individual home wastewater disposal in regions where evaporation exceeds precipitation.

APPLICABILITY

Onsite systems with ET disposal are appropriate in locations with a shallow soil mantle, high groundwater, relatively impermeable soils, absence of fractured bedrock, or other conditions that put the groundwater at risk. ET systems perform well in semi-arid and arid locations. In certain parts of the United States, ET systems are feasible for homes, outdoor recreation areas, and highway rest areas. It is important to note that assessment of the reliability of the system requires micro-climatic data.

Boyd County Demonstration Project

A demonstration site was set up about five miles from the Huntington Airport in Kentucky, in an area with low population density and rough topography. Approximately 60 families live in the sanitary district. The demonstration project serves 47 families, with 36 individual home aeration treatment plants and two multi-family aeration plants which serve 11 families. Six manufacturers provided 16 stream discharge units, two spray irrigation units, one ET unit, and 19 subsurface field discharge units. Four recycle units serving five homes produced clear, odorless water.

The ET unit is 2,000 square feet (two 1,000 square foot beds) designed for disposing effluent from a Cromaglass model C-5 aeration plant. The beds are sealed with plastic to keep the high ground water at the site from flooding them. They contain 8 inches of gravel, 18 inches of sand, and are covered with topsoil and planted with grass and junipers. They are crowned to shed rainwater.

The Kentucky test provided valuable data on how the system handles variations in loading rates. Although the ET beds were designed for a family of four, seven people lived at the site which increased water usage, yet the ET system continued to perform well with only one small modification to the distribution box. Before installation of the ET beds, raw sewage pooled in the yard of this house from a nonfunctioning septic tank and soil absorption field. Despite high rainfall, the ET system continues to perform satisfactorily.

Leigh Marine Laboratory, University of Auckland, New Zealand

Leigh Marine Laboratory, a research institution on the New Zealand coastline about 62 miles north of Auckland, has an ETA system which was installed in 1982. It has a design load to support 35 persons (including residents and day visitors) at 4,565 L/d (1,180 gallons per day) total flow. Three septic tanks feed a sump pump that discharges through a 400 m rising force main, to an ETA bed system on an exposed grass ridge 70 m above the laboratory complex.

There is a loading factor of 1.0, an ETA loading rate of 10 mm per day for beds, and an areal rate (including spaces between beds) of 3.75 mm per day. This system includes extensive groundwater and surface water drainage controls. The total bed area is 450 m^2 divided into 20 beds, each 15 m by 1.5 m, arranged in four groups of five beds, with each group dose loaded for one week and rested for three.

Since their commissioning, the ETA beds have performed as predicted: in the summer, capillary action in the sand draws effluent to support vigorous grass growth; in the winter, the effluent gradually accumulates for storage and disposal during drier weather. The system is currently loaded between 80 and 90 percent of its capacity and is performing successfully.

ADVANTAGES AND DISADVANTAGES

Listed below are some advantages and disadvantages of ET systems.

Advantages

- ET systems may overcome site, soil, and geological limitations or physical constraints of land that prevent the use of subsurface wastewater disposal methods.
- The risk of groundwater contamination is reduced with ET systems that have impermeable liners.
- Costs are competitive with other onsite systems.
- ET systems can be used to supplement soil absorption for sites with slowly permeable shallow soils with high water tables.
- ET systems can be used for seasonal application, especially for summer homes or recreational parks in areas with high evaporation and transpiration rates, such as in the southwestern United States.
- Landscaping enhances the aesthetics of an ET system as well as beautifies the area.

Disadvantages

- ET systems are governed by climatic conditions such as precipitation, wind speed, humidity, solar radiation, and temperature.
- ET systems are not suitable in areas where the land is limited or where the surface is irregular.
- ET systems have a limited storage capacity and thus cannot store much winter wastewater for evaporation in the summer.
- There is a potential for overloading from infiltration of precipitation.
- The bed liner must be watertight to prevent groundwater contamination.
- ET systems are generally limited to sites where evaporation exceeds annual rainfall by at least 24 inches (i.e., arid zones).
- Transpiration and evaporation can be reduced when the vegetation is dormant (i.e., winter months).
- Salt accumulation and other elements may eventually eliminate vegetation and thus transpiration.

DESIGN CRITERIA

There are several variables that determine the size requirement of an ET system. The flow rate of domestic wastewater is site-specific. Accurate estimates (daily, weekly, or monthly) of flow rates must be calculated as part of the design process to prevent overloading associated with undersizing or the excessive cost of oversizing a system. The design flow rate should also include a safety factor to account for peak flows or increased site use in the future.

Like other disposal methods that require area-intensive construction, the use of ET systems can be constrained by limited land availability and site topography. For year-round, single-family homes, ET systems generally require about 4,000 to 6,000 square feet of available land. However, the use of water conservation plumbing devices could reduce the bed area requirements.

The maximum slope that an ET system can be used on has not yet been determined, although a slope greater than 15 percent could be used if terracing, serial distribution, and other necessary design features are incorporated.

PERFORMANCE

By far the most important performance consideration of any ET system is the rate of evaporation. This is largely affected by climatic conditions such as precipitation, wind speed, humidity, solar radiation, and temperature. Since these factors are variables, evaporation rates can vary significantly, a factor which must be considered in the design of an ET system.

Although most precipitation will be absorbed into the ET bed, hydraulic overloading could occur if more water enters the system than is evaporated. Provisions for long-term storage of excess water can be expensive. Thus, the evaporation rate must exceed the precipitation rate. This makes an ET system suitable for areas with relatively low rainfall, such as the western and southwestern parts of the United States. Climate requirements are not as well defined for ETA systems, although the soils must be able to accept all of the influent wastewater if net evaporation is zero for a long period of time.

In addition to the climate, other factors influence the performance of an ET system. These are discussed below.

Hydraulic Loading

If the hydraulic loading is too high, wastewater could seep out from the system. However, if a loading rate is too low, it can result in a lower gravity (standing) water level in the bed and insufficient evaporation. This situation can be solved by sectional construction in level areas to maximize the water level in a particular section of the bed.

Sand Capillary Rise Characteristics

The sand must be fine enough to draw the water up from the saturated zone to the surface by capillary action. The potential for capillary rising must be slightly more than the depth of the bed. However, if the sand is too fine, the bed can be clogged by solids from the wastewater.

Cover Soil and Vegetation

The vegetation used in an ET system must be able to handle the varying depths of free water surface in the bed. Grasses, alfalfa, broad-leaf trees, and evergreens are types of vegetation used in ET beds. They have been known to increase the average annual evaporation rate from an ET bed to a rate higher than that for bare soil. However, grasses and alfalfa also result in nearly identical or reduced evaporation rates as compared to bare soil during winter and spring, when evaporation rates are normally at a minimum. Similarly, topsoil has been shown to reduce evaporation rates. Some evergreen shrubs have resulted in slightly higher evaporation rates than bare soil throughout the year. Water seekers with hair roots, such as berries, are not recommended because they may clog the distribution pipes.

Construction Techniques

Although ET system performance is generally affected less by construction techniques than most subsurface disposal methods, some aspects of ET construction can affect performance. For ET systems, main considerations are to ensure that the impermeable liner is watertight and that the sand has sufficient potential for capillary rise.

Salt Accumulation (for ET only)

As wastewater is evaporated during dry weather, salt and other elements build up at the surface of the ET bed. Precipitation distributes the salt throughout the bed. For nonvegetated ET systems, salt accumulation is generally not a problem, but systems with vegetation may experience negative effects over time.

Soil Permeability (for ETA only)

Soil permeability affects the performance of ETA beds that use seepage into the soil in addition to evaporation. A portion of pretreated wastewater is absorbed and treated by the soil. As a general rule, the wastewater must travel through two to four feet of unsaturated soil for adequate treatment before reaching the groundwater.

OPERATION AND MAINTENANCE

Regular operation and maintenance (O&M) of ET and ETA systems is usually minimal, involving typical yard maintenance such as trimming the vegetation. If a septic tank is used for pretreatment, it should be checked for sludge and scum buildup and periodically pumped to avoid carryover of solids into the bed. Recommended maintenance practices include:

- Ensuring that all stormwater drainage paths/pipes are not blocked and that stormwater drains away from the system.
- Using high transpiration plants suitable for the wetness at ground level.
- If there is more than one bed, alternating the bed loading as necessary.
- Installing additional beds as required.

If an ET or ETA system is properly installed on a suitable site, maintenance is rarely needed.

COSTS

The cost of an ET system depends on the type of system, site, and wastewater characteristics. The construction cost of an ET bed is determined by its surface area, which is a function of the design loading rate. (For non-discharging, permanent home ET units located in suitable areas, the loading rate ranges from approximately 1.0 mm per day to 3.0 mm per day.) Other cost considerations include the availability of suitable sand, the type and thickness of the liner, use of a retaining wall (if needed), and vegetation (usually native to the area).

Typical costs for a three-bedroom residence with a septic tank and ET system run about $10,000 (minimum) yet may be higher depending on site conditions.

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United States Environmental Protection Agency
Office of Water Washington, D.C.
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Decentralized Systems Technology Fact Sheet
Low Pressure Pipe Systems

DESCRIPTION

Although not an alternative to all unsuitable soils, the low-pressure pipe (LPP) system has proven to be useful for some specific conditions, where conventional systems frequently fail. Less than one-third of the land area in the U.S. has soil conditions suitable for conventional soil absorption systems. Numerous innovative alternatives to the conventional septic tank soil absorption system have evolved in response to the demand for an environmentally acceptable and economical means of disposing domestic wastewater onsite and contending with the restrictive soil conditions common in many states.

Originating in North Carolina and Wisconsin, a LPP system is a shallow, pressure-dosed soil absorption system with a network of small diameter perforated pipes placed 25.4 to 45.7 cm (10 to 18 inches) deep in narrow trenches, 30.5 to 45.7 cm (12 to 18 inches) wide.

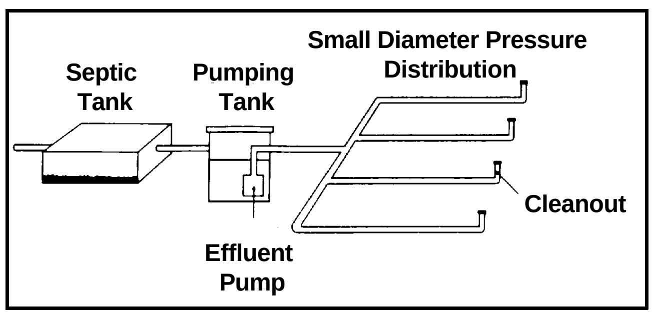
LPP systems were developed as an alternative to conventional soil absorption systems to eliminate problems such as: clogging of the soil from localized overloading, mechanical sealing of the soil trench during construction, anaerobic conditions due to continuous saturation, and a high water table. The LPP system has the following design features to overcome these problems:

- Shallow placement.
- Narrow trenches.
- Continuous trenching.
- Pressure-dosed with uniform distribution of the effluent.
- Design based on areal loading.
- Resting and reaeration between doses.

Process

The main components of a LPP system are (see Figure 1):

- A septic tank or an aerobic unit.
- A pumping (dosing) chamber (a submersible effluent pump, level controls, a high water alarm, and a supply manifold).
- Small diameter distribution laterals with small perforations (holes).



Source: USEPA, 1992.

FIGURE 1 LOW-PRESSURE PIPE SYSTEM

The septic tank is where settleable and floatable solids are removed and primary treatment occurs. Partially clarified effluent then flows by gravity from

tank to a pumping chamber, where it is stored until
which activates the pump. The level controls are set
a specific pumping sequence of 1 to 2 times daily,
lateral pipe volume, which allows breaks between
for the soil to absorb the effluent. The pump turns
the lower float control. However, the dosing
anism and frequency may vary for different systems.
provide excess storage of at least one day's capacity

failure or pump malfunction. If the pump or level
should fail, the effluent would rise to the
level of the alarm control, turning the alarm on.

pump moves the effluent through the supply line
trenches under a low pressure 0.91 to 1.5 meters
3 to 5 feet of pressure head). These laterals are
perforated holes, usually 0.4 to 0.64 centimeters
in diameter and spaced at 0.76 to
dimensions are determined for each system).

The
trenches 254. To 46 centimeters (10 to 18 inches)
(5 feet) apart.
The
so that the depth of the effluent does not exceed 5.1
7.6 centimeters (2 or 3 inches) of the total trench
depth during each dosing cycle.

Chatham County, North Carolina

A study was
Carolina, to evaluate the effectiveness of a sand
system in slowly permeable soils of a
Triassic Basin.
evaluate the operation and functioning of system
assess treatment effectiveness of a buried
hydraulic capacity and wastewater treatment

The system included a 3785-liter (1,000-gallon)
eptic tank, a Tyson flow splitter, two 3785-liter (1,000-gallon)
buried sand filter, and two similar side-by-side LPP
fields. One drain field was dosed with septic tank
sand filter effluent. This system was designed for a
house and began operating in August 1988.

of the effluent from the septic tank flowed into
Effluent from the sand filter drained into a dosing
and was then pumped to the first drain field. The
Pump Tank 2, which dosed the other LPP field.
LPP system consisted of lateral pipes (PVC) 3.2
and 0.36 centimeter (5/32 and 9/64 inch) holes and
in trenches 25.4 centimeters (10 inches) wide.
.005 meters cubed per day per meters squared (0.13
per day per square foot), and each drain field contained
centers.

It
and mechanical components performed quite well.
was excellent removal of fecal coliform orga
both drain fields, and little to no NO_3-N and NH -N were
LPP drain field receiving sand filter effluent. The
xcellent nitrogen removal resulted from the nitrification
denitrification that occurred due to shallow

The system performed well except for some partial
of the pressure distribution systems, breakage
perched water into the tanks. Extensive flushing of
and fecal coliform occurred with large rainfall events
associated with a hurricane). These observations
that the tanks should be watertight and require
conventional systems.

ADVANTAGES AND DISADVANTAGES

Some advantages and disadvantages of LPPs are listed below:

Advantages

- Shallow placement of trenches in LPP installations promotes evapotranspiration and enhances growth of aerobic bacteria.
- Absorption fields can be located on sloping ground or uneven terrain that are otherwise unsuitable for gravity flow systems.
- Improved distribution through pressurized laterals disperses the effluent uniformly throughout the entire drain field area.
- Periodic dosing and resting cycles enhance and encourage aerobic conditions in the soil.
- Shallow, narrow trenches reduce site disturbances and thereby minimize soil compaction and loss of permeability.
- LPPs allow placement of the drain field area upslope of the home site.
- LPPs have reduced gravel requirements.
- There is a significant reduction in land area required for the absorption system.
- Costs are comparable to other alternative typical distribution systems.
- LPPs overcome the problem of peak flows associated with gravity-fed conventional septic systems.

Disadvantages

- In some cases, the suitability could be limited by the soil, slope, and space characteristics of the location.
- A potential exists for clogging of holes or laterals by solids or roots.
- LPPs have limited storage capacity around their laterals.
- There is the possibility of wastewater accumulation in the trenches or prolonged saturation of soil around orifices.
- LPPs could experience moderate to severe infiltration problems.
- Regular monitoring and maintenance of the system is required; lack of maintenance is a sure precursor to failure.

DESIGN CRITERIA

Soil requirements

According to state/local regulations, a LPP system should be located in soils that have suitable or provisionally suitable texture, depth, consistence, structure, and permeability. A minimum of 0.3 meters (12 inches) of usable soil is required between the bottom of the absorption field trenches and any underlying restrictive horizons, such as consolidated bedrock or hardpan, or to the seasonally high water table. Also, a minimum of 0.5 to 0.76 meters (20 to 30 inches) of soil depth is needed for the entire trench.

Space requirements

The distribution network of most residential LPP systems utilizes about 93 to 465 meters squared (1,000 to 5,000 square feet) of area, depending on the soil permeability and design waste load. An area of equal size must also be available for future repair or replacement of the LPP system. If the space between the lateral lines will be used as a repair area, then the initial spacing between the lateral lines must be 10 feet (3 meters) or wider to allow sufficient room for repairs. Although size requirements for a LPP system vary depending on the site, in general, an undeveloped lot smaller than one acre may not be suitable for a LPP system.

The septic tank, pumping chamber, and distribution
should not be located in areas where hydraulic
overloading could occur from surface runoff.

critical drainage requirements are surface
water
waters upslope of the system. These conditions are
important on sites with concave or lower slope
positions
the surface. If this condition exists, surface water
perched groundwater must be diverted away
from the LPP system.

There are special design considerations for LPP
fields located on slopes. The
distribution
pumping chamber so that gravity does not cause the
to flow out of the pumping chamber and
into
operating. If the topography does not allow for
then the LPP system must be designed to
ensure
chamber when the pump is turned off (e.g., use of
anti-siphon hole or other control in the discharge
piping in the pumping chamber).

Two critical factors that affect the performance of a

effluent. The first factor, the dosing and resting
helps maintain aerobic conditions in the soil
and
cycles back and forth between aerobic and anaerobic
which can lead to favorable conditions
for nitrification and denitrification. During the
bic resting period, nitrification occurs. When
the
conditions result in denitrification.

The
cannot be overemphasized in the performance of
LPP system. The effluent must be distributed
evenly
hydraulically overloading it.

The
soil, slope, available space, and anticipated

OPERATION AND MAINTENANCE

A
requires very little ongoing maintenance. However,
inspection and maintenance by professional
operators
documented a 40 to 50 percent failure rate when
was left to the homeowners rather than
professionals.
minimum monitoring frequency of every 6 months

The septic tank and pumping chamber should be
for sludge and scum buildup and pumped
as
solids from escaping from the septic tank.
some solids may accumulate at the end of
the
year. Turnups installed at the distal ends of laterals

The manufacturer's recommendations should be

ensure longer life and proper function of the pumps
other mechanical/electrical components of the
system.
cleaning and inspection. Pump replacements should
selected based on the specific system design
rather
be checked for signs of oil leakage, worn or broken
or for damaged parts that need to be
rep
level switches to ensure proper operation. An
run-time meter and pump impulse counter
should
facilitate system troubleshooting and monitoring of

In the event of a power failure or pump malfunction,
visible and audible alarm is activated when the
effluent rises to the level of the alarm control.
alarm should be located at the control panel to
testing by the professional operator.
Listed
maintenance (O&M) tasks for large LPP systems.

Although the LPP system overcomes many of the problems associated with the conventional septic tank system, there has been documentation of some operational problems with small, poorly maintained, onsite LPP systems in North Carolina. Large LPP systems in North Carolina were shown to have similar problems as well, but on a larger scale because of the size of the systems. Careful site-specific designs and regular maintenance by trained, professional operators are essential for overcoming these problems. Large LPP systems can have problems such as:

- Excess infiltration: Drain fields are very susceptible to hydraulic overloading due to infiltration. In areas with improper drainage, leaky pump tanks can become sinks for nearby groundwater. Large systems that include extensive collection sewers have a higher probability of inflow/infiltration. Watertight septic tanks and pumping chambers are essential for system performance.

- Faulty hydraulic design: For optimum performance of the system, the pumps, supply lines, manifold, laterals, and orifices must be properly designed, sized, and located. Improper hydraulic design can result in problems such as localized overloading, excessive head loss, and nonuniform distribution. The dosing volume must be large enough (5 to 10 times the lateral pipe volume) to adequately pressurize the pipe network. The manifold should feed the highest lateral first in order to improve effluent distribution to the drain field.

- Drainage: Surface runoff must be diverted away from the LPP system. If the water table becomes high in level sites, groundwater beneath community-scale LPP systems can mound up into soil absorption field trenches and cause failure. The trenches on sloping fields can experience hydraulic overloading due to subsurface flow from higher areas.

- Improper installation: Since the performance of a LPP system is sensitive to any variations in hydraulic design, proper installation is essential. Some common installation problems are; incorrect orifice size and spacing, installation of undersized substitute pumps, incorrect adjustment of level control floats and pressure head, installation of laterals at incorrect elevations, and failure to install an undisturbed earth dam in each trench where the manifold feeds each lateral. Earth dams are used at the beginning of each lateral trench to prevent redistribution of effluent from higher trenches to those lower on the landscape. Dams are not used elsewhere in the trenches.

- Orifice and lateral clogging: Poor septic tank maintenance can result in solids reaching the soil absorption field and clogging the orifices. In some older LPP systems, it was observed that slime had built up in long supply lines, manifolds, and laterals. Current practice includes sleeving the small diameter laterals within a 10.2 centimeter (4-inch) diameter corrugated drainage tubing or drain field pipe and laying the small diameter distribution laterals such that the perforations point upward.

TABLE 1 GENERAL MAINTENANCE SCHEDULE

Component	O&M Requirement
Collection system	Check for I/I and blockages.
Septic tank	Check for solids accumulation, blockages, or damage to baffles, and excess I/I.
Pump septage as required.	
Pumping chamber	Check pumps, controls, and high water alarm. Check for solids accumulation and pump as required; check for I/I.
Supply lines	Check for pipe exposure and leakage in force mains.
Soil absorption field	Provide maintenance of field and field's vegetative cover; repair broken lateral turnups.
Check for erosion and surfacing of effluent.	

Source: Marinshaw, printed with permission, 1988.

COSTS

The
contractor, the manufacturers, the site, and the
of the wastewater. The overall cost of
capital and O&M expenses. The annual operating
ts for LPPs include power consumption for the pumps,
repair, replacement of the components, and

In a 1989 study of LPP use among different

$2,600 to install a LPP system for a three-bedroom
The average installation cost across counties ranged
related to the extent of LPP use within a county.
are installed
within a community, the less the cost per system.

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United States Environmental Protection Agency
Office of Water Washington, D.C.
EPA 832-F-99-079 September 1999

Decentralized Systems Technology Fact Sheet
Recirculating Sand Filters

DESCRIPTION

A recirculating sand filter (RSF) system is a modified version of the old-fashioned, single-pass open sand filter. It was designed to alleviate the odor problems associated with open sand filters. The noxious odors were eliminated through recirculation, which increases the oxygen content in the effluent that is distributed on the filter bed.

RSFs are a viable addition or alternative to conventional methods of treatment when soil conditions are not conducive to proper treatment or wastewater disposal through percolative beds/trenches. Sand filters can be used on sites that have shallow soil cover, inadequate permeability, high groundwater, and limited land area. RSFs commonly serve subdivisions, mobile home parks, rural schools, small municipalities, and other generators of small wastewater flows.

Sand filters remove contaminants in wastewater through physical, chemical, and biological processes. Although the physical and chemical processes play an important role in the removal of many particles, the biological processes play the most important role in sand filters.

Figure 1 shows the three basic components of a RSF system. These three components are a pretreatment unit, a recirculation tank, and an open sand filter.

Wastewater first flows into a septic tank (or in the

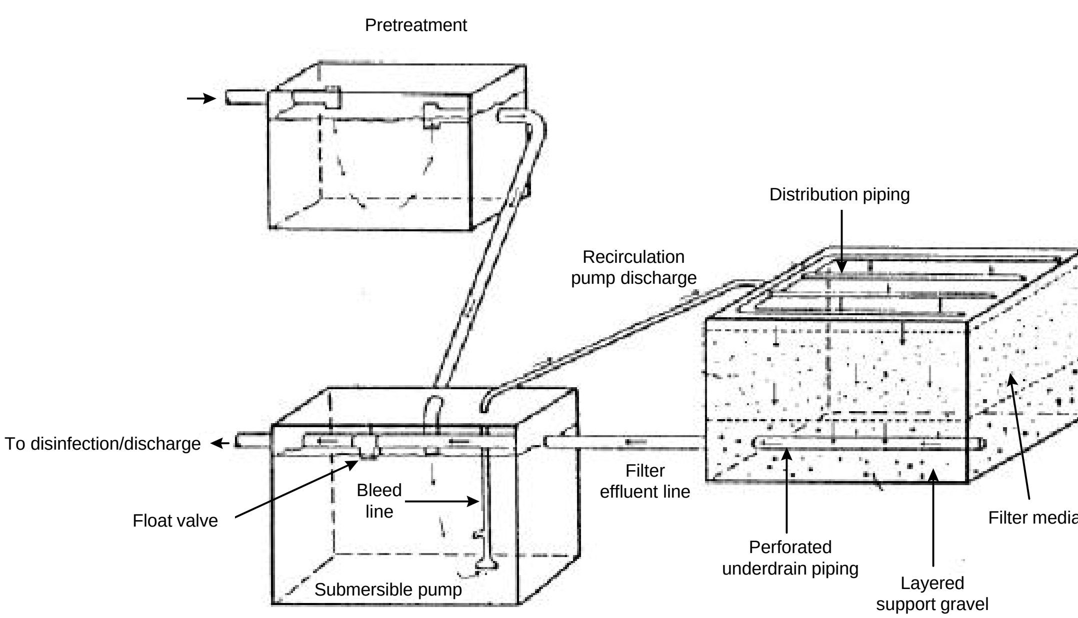

FIGURE 1 TYPICAL RECIRCULATING SAND FILTER

Sources: Hines, 1998 and NSFC, 1997.

case of a clustered or community system, a number of septic tanks) for primary treatment. A standard concrete or fiberglass septic tank can be used, with size being relative to the home/facility served.

The partially clarified effluent from the pretreatment tank then flows into a recirculation tank. The volume of the recirculation tank should be equivalent to at least 1 day's raw wastewater flow (or follow local jurisdiction requirements). In the recirculation tank, raw effluent from the septic tank and the sand filter filtrate are mixed and pumped back to the sand filter bed.

APPLICABILITY

Stonehurst Development in Martinez, California

The Stonehurst development is a small residential subdivision near the City of Martinez in Contra Costa County, California. This subdivision is located in a hilly, rural area that did not have a wastewater collection system. Thus, an innovative decentralized wastewater system was designed to provide for wastewater collection, treatment, disinfection, and reuse.

The innovative system combines the use of septic tanks, screened effluent filter vaults, high-head effluent pumps, small-diameter variable grade sewers, pressure sewers, a recirculating granular medium filter, an ultraviolet (UV) disinfection unit, a subsurface drip irrigation system for wastewater reuse, and a community soil absorption field for wintertime disposal. The principle elements for treatment consisted of two sections of recirculating granular filter followed by disinfection.

Each filter was 24 inches deep with 3 millimeter gravel (washed and rounded with less than 2% fines) sandwiched between layers of drain rock, which was coarse, washed gravel approximately 1 to 2.5 inches in diameter. The wastewater was pumped from the recirculating tank to the filters for five minutes every half hour, and circulated approximately five times through the filter. Since one half of the filter was used during the time the study was conducted, the hydraulic loading was 1.2 gal/ft^2.

Performance data was calculated for 28 months from June 1994 to September 1996, based on an average of at least two samples per month for five-day BOD, and at least four samples per month for TSS, chemical oxygen demand (COD), pH, and total coliform. Table 1 summarizes the performance data of effluent samples that passed through the recirculating gravel filter and the UV system.

To date, the Stonehurst decentralized wastewater system has exceeded all expectations by performing beyond required standards.

TABLE 1 PERFORMANCE DATA FOR STONEHURST WASTEWATER TREATMENT SYSTEM

Constituent	Range
BOD_5	0 - < 5 mg/L
COD	1 - 18 mg/L
TSS	2 - 15 mg/L
pH	6.96 - 8.65 unitless
Total coliform	< 2 - 12.5 MPN/100 mL
NH_4	0 - 15 mg/L
NO_3	3.55 - 37 mg/L
TKN	0 - 3 mg/L
Oil and grease	0 - 12 mg/L
TDS	340 - 770 mg/L
EC	433 - 1,200 μmhos/cm

* TDS - total dissolved solids, EC = electrical conductivity, μmhos/cm - micro mhos per centimeter

Source: Crites et al., 1997.

Elkton, Oregon

A RSF system was installed and monitored for a community in Elkton, which is located on the Umpqua River in Southwestern Oregon. The population of this community was 350, mostly residential with some commercial establishments. The wastewater generated from stores, restaurants, schools, and about 100 residences was first pretreated and screened in individual septic tanks. Partially clarified effluent was then collected and conveyed by an effluent pressure sewer system to a RSF and finally pumped to a drainfield for final treatment and disposal.

The sand filter was 60 feet x 120 feet with four cells, 36 inches deep, and designed to treat 30,000 gallons per day (gpd). A recirculation tank of 29,500-gallon capacity was used with four one-horsepower pumps. Each pump dosed one cell at the rate of 130 gallons per minute. Two pumps alternately dosed during each cycle. The actual recirculation ratio was 3.2:1, and during low periods, a motorized valve allowed 100% recirculation.

Effluent quality data obtained from February 1990 through October 1997 are presented in Table 2.

It was concluded from this study that the RSF produced a high quality effluent, thus protecting the river nearby at an affordable cost. Capital costs for RSFs range from $3 to $10 per treated gallon. The annual operating costs are very low. For example, at Elkton, the annual O&M cost for the RSF is less than $5,000, which includes $780 for electricity.

Use of a smaller media (< 3.0 nm) would have resulted in better nitrification, but this was not a concern when the design was made.

TABLE 2 ELKTON'S RSF EFFLUENT QUALITY DATA

Wastewater Characteristics	Influent (mg/L)	Effleunt (mg/L)
BOD	123	4
TSS	37	9
NH_3-N	51	10
NO_3-N	2	26

Source: Orenco Systems, Inc., 1998.

ADVANTAGES AND DISADVANTAGES

Advantages

- No chemicals are required.
- RSFs provide a very good effluent quality with over 95% removal of biochemical oxygen demand (BOD) and total suspended solids (TSS).
- The treatment capacity can be expanded through modular design.
- RSFs are effective in applications with high levels of BOD.
- RSFs are easily accessible for monitoring and do not require a lot of skill to maintain.
- A significant reduction in the nitrogen level is achieved.
- If sand is not feasible, other suitable media could be substituted that may be found locally.
- Less land area is required (1/5 of the land area of a single-pass sand filter) for RSFs than for single-pass sand filters.

Disadvantages

- If appropriate media are not available locally, costs could be higher.
- Weekly maintenance is required for the media, pumps, and controls.
- Design must address extremely cold temperatures.

DESIGN CRITERIA

The RSF system is an open sand filter with a sand media depth of 2 feet. A layer of graded gravel (about 12 inches) is provided under the sand for support to the media and to surround the underdrain system. A portion of the mixture (septic tank effluent and sand filtrate) is dosed by a submersible pump through a distribution system that applies it evenly over the sand filter. The dosing frequency is controlled by a programmable timer in the control panels.

The filtrate from the sand filter is collected by underdrains that are located at the bottom of the bed. The filter discharge line passing through the recirculation tank is located near the top of the tank.

Figure 1 shows a ball float valve connected to a downturned "T" on the discharge line, in which is housed a rubber ball with a diameter slightly larger than that of the pipe. As the filter effluent rises in the tank, it forces the rubber ball firmly against the bottom of the downturned leg, thus discharging the effluent for further treatment or disposal. Other control mechanisms may be used, but care must be taken to ensure that the recirculation tank does not run dry.

Table 3 gives typical design specifications for RSFs.

In very cold climates, the RSF design must include elements that prevent freezing of standing water. Distribution lines must drain between doses and tanks, and the filter should be insulated.

PERFORMANCE

RSFs produce a high quality effluent with approximately 85% to 95% BOD and TSS removal. In addition, almost complete nitrification is achieved. Denitrification also has been shown to occur in RSFs. Depending on modifications in design and operation, 50% or more of applied nitrogen can be removed.

The performance of a RSF system depends on the type and biodegradability of the wastewater, the environmental conditions within the filter, and the design characteristics of the filter. Temperature affects the rate of microbial growth, chemical reactions, and other factors that affect the stabilization of wastewater within the RSFs.

Other parameters that affect the performance and design of RSFs are the degree of wastewater pretreatment, the media size, media depth, hydraulic loading rate, organic loading rate, and dosing techniques and frequency.

TABLE 3 TYPICAL DESIGN CRITERIA FOR RSFS

Item	Design Criteria
Pretreatment	Minimum level: septic tank or equivalent
Filter medium	
Material	Washed durable granular material
Effective size	1.0 to 3.0 mm
Uniformity coefficient	< 4.0
Depth	24 in
Underdrains	
Type	slotted or perforated pipe
Slope	0 - 0.1%
Bedding	Washed durable gravel or crushed stone (0.25 - 1.50 in)
Hydraulic loading	3.0 to 5.0 gpd/ft^2/ (forward flow)
Organic loading	0.002 - 0.008 lb/ft^2/day
Recirculation ratio	3:1 to 5:1
Recirculation tank	Volume equivalent to at least 1 day's raw wastewater flow
Distribution and dosing system	Pressure-dosed manifold distribution system and spray nozzles where permitted
Dosing	
Time on	< 2-3 minutes
Time off	Varies
Frequency	48-120 times/day or more
Volume/orifice	1-2 gal/orifice/dose

Source: Adapted from Crites and Tchobanoglous with permission from The McGraw-Hill Companies, 1998.

The effectiveness of a granular material as filter media is dependent on the size and uniformity of the grains. The size of the granular media affects how much wastewater is filtered, the rate of filtration, the penetration depth of particulate matter, and the quality of the filter effluent. The finer the grain, the slower the rate and higher the quality of the effluent.

High hydraulic loading rates are typically used for filters that receive higher quality wastewater. The accumulation of organic material in the filter bed affects the performance of RSFs. As with hydraulic loading, an increase in the organic loading rate results in shorter filter life.

OPERATION AND MAINTENANCE

RSFs require routine maintenance, although the complexity of maintenance is generally minimal. Primary O&M tasks include monitoring the influent and effluent, inspecting the dosing equipment, maintaining the filter surface, checking the discharge head on the orifices, and flushing the distribution manifold annually. The surface of the sand bed should be kept weed free.

In addition, the septic tank should be checked for sludge and scum buildup and pumped as needed. The recirculation tank should also be inspected and maintained.

The pumps should be installed with quick disconnect couplings for easy removal. A duplicate recirculation pump should be available for backup. Listed in Table 4 are the typical O&M requirements for RSFs.

TABLE 4 RECOMMENDED O&M FOR RSFS

Item	O&M Requirement
Pretreatment	Depends on process; remove solids from septic tank or other pretreatment unit
Dosing chamber	
Pumps and controls	Check every 3 months
Timer sequence	Check and adjust every 3 months
Appurtenances	Check every 3 months
Filter media	If continuous hydraulic or biological overloading occurs, the top portion of the media can clog and may need to be replaced if not corrected in time
Other	Weed as needed
	Monitor/calibrate distribution device as needed
	Prevent ice sheeting

Source: U.S. Environmental Protection Agency, 1980.

COSTS

The cost of RSFs depends on the labor, materials, site, capacity of the system, and characteristics of the wastewater. One of the most significant factors that affects the cost of sand filters is media cost. Therefore, using locally available materials for the media is usually the most cost-effective option.

Table 5 shows the costs for RSFs with sand media and black beauty sand media used in a facility treating 5,000 gpd. These are typical costs, actual costs will vary from site to site and among different designs. Local regulatory requirements and labor rates will affect cost as well. The cost data in Table 5 includes the labor and machinery necessary to install media, plumbing, and tankage in the excavation and landscape, the same should be noted for the recirculation tank (minus the media).

The cost of the pretreatment unit(s) for a RSF system will depend on the waste stream characteristics specific to the site application. Effluent sewer systems incorporate individual or community septic tanks to pretreat wastewater before it flows into the recirculation tank. Developments that include commercial establishments may require higher levels of pretreatment in the form of additional septic tank storage, surge capacity, grease traps, and possibly aerobic digestion.

Suggested maintenance for RSFs range from weekly inspections (15 to 30 minutes) to monthly inspections (for approximately 1 hour).

The Ashco Rock Filter Storage II (RFSII) sand filters consists of three different gradations of media; high spec black beauty sand, Ashco's Bottom Zone, and spray grids with spray nozzles to distribute the recycled filtrate evenly over the media, all contained in 75 square foot precast concrete cells.

TABLE 5 COST ESTIMATES FOR A 5,000 GPD FACILITY USING TWO DIFFERENT MEDIA

	Cost ($)	
Item	**Sand[1]**	**Black Beauty Sand[2]**
<u>Capital Costs</u>		
Construction costs		
Pretreatment	May vary	May vary
Recirculation tank and pumping system	10,000	9,000
Sand filter	10,000[a]	43,100
Non-component costs	May vary	May vary
Engineering	3,000	7,800
Contingencies	3,000	7,800
Land	May vary	May vary
Total Capital Costs	26,000	67,700
<u>Annual O&M Costs</u>		
Labor	20/hr	20/hr
Power	May vary	May vary
Sludge disposal @ 10 cents/gal	50/yr[b]	50/yr[b]

Note: Non-component costs include piping and electrical. Engineering and contingency each equal approximately 15% of construction costs. Costs toward land, labor, and power may be different from site to site and system to system.

[a] Design does not include precast concrete cells.
[b] Average pumping frequency is every 5 years.

Source: (1) Orenco Systems, Inc., 1998. and (2)

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United States Environmental Protection Agency
Office of Water Washington, D.C.
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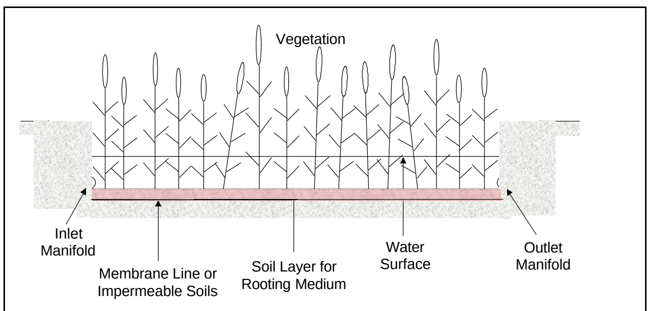
Wastewater Technology Fact Sheet
Free Water Surface Wetlands

DESCRIPTION

Free water surface (FWS) wetlands are defined as wetland systems where the water surface is exposed to the atmosphere. Most natural wetlands are FWS systems, including bogs (primary vegetation mosses), swamps (primary vegetation trees), and marshes (primary vegetation grasses and emergent macrophytes.) The observation of water quality improvements in these natural wetlands for many years led to the development of constructed wetlands in an effort to replicate the water quality and habitat benefits of natural wetlands in a constructed ecosystem. The majority of FWS constructed wetlands designed for wastewater treatment are marshes, but a few operating examples of bogs and swamps exist. In FWS treatment wetlands, water flows over a vegetated soil surface from an inlet point to an outlet point. In some cases, water is completely lost to evapotranspiration and seepage within the wetland. A diagram of FWS wetland is shown in Figure 1.



Source: Adapted from drawing by S.C. Reed, 2000.

FIGURE 1 FREE WATER SURFACE WETLAND

There are relatively few examples of the use of natural wetlands for wastewater treatment in the United States. Because any discharge to a natural wetland must satisfy National Pollutant Discharge Elimination System (NPDES) limits, these wetlands are typically used for advanced wastewater treatment (AWT) or tertiary polishing. The design goals for constructed wetlands range from an exclusive commitment for basic treatment functions to systems which provide advanced treatment and/or combine with enhanced wildlife habitat and public recreational opportunities. The size of the FWS wetland systems ranges from small on-site units designed to treat septic tank effluents to large units with more than 16,188 hectares (40,000 acres). A large system is being used to treat phosphorus from agricultural storm water drainage in south Florida. Operational FWS wetlands designed for municipal wastewater treatment in the United States range from less than 3785 liters per day (1,000 gallons per day) to more than 75,708 m^3/day (20 million gallons per day).

Constructed FWS wetlands typically consist of one or more shallow basins or channels with a barrier to prevent seepage to sensitive ground waters and a submerged soil layer to support the roots of the selected emergent macrophyte vegetation. Each system has appropriate inlet and outlet structures to ensure uniform distribution and collection of the applied wastewater. The most commonly used emergent vegetations in constructed FWS wetlands include cattail (*Typha* spp.), bulrush (*Scirpus* spp.), and reeds (*Phragmites* spp.). In systems designed primarily for treatment, it is common to select only one or two species for planting. The plant canopy formed by the emergent vegetation shades the water surface, preventing growth and persistence of algae, and reduces wind-induced turbulence in the water flowing through the system. Perhaps most important are the submerged portions of the living plants, the standing dead plants, and the litter accumulated from previous growth. These submerged surfaces provide the physical substrate for the periphytic-attached growth organisms responsible for much of the biological treatment in the system. The water depth in the vegetated portions of these systems ranges from a few inches to two feet or more.

The influent to these wetlands spreads over a large area of shallow water and emergent vegetation. The subsequent low velocity and essentially laminar flow provides for very effective particulate removal in the front part of the system. This particulate material, characterized as total suspended solids (TSS), contains Biochemical Oxygen Demand (BOD) components, fixed forms of total nitrogen (TN) and total phosphorus (TP), and trace levels of metals and more complex organics. The oxidation or reduction of these particulates releases soluble forms of BOD, TN, and TP to the wetland environment, which are available for adsorption by the soils and removal by the active microbial and plant populations throughout the wetland. Oxygen is available at the water surface, microsites on living plant surfaces, and on root and rhizome surfaces, allowing some aerobic activity the wetland. It is, however, prudent to assume that the bulk of the liquid in the FWS wetland is anoxic or anaerobic. The lack of oxygen can limit the biological removal of ammonia nitrogen (NH_3/NH_4 - N) via nitrification, but the FWS wetland is still effective for removal of BOD, TSS, trace metals, and some complex organics because the treatment of these occurs under both aerobic and anoxic conditions.

If nitrogen removal and/or enhancement of wildlife habitat is a project goal, consideration should be given to alternating shallow water emergent vegetated zones with deeper (greater than 1.83 meters or six feet) water zones containing selected submerged vegetation. Deeper water zones provide a completely exposed water surface for atmospheric re-aeration and submerged vegetation provides an additional source of oxygen for nitrification. The deeper water zones will also attract and retain a large variety of wildlife, particularly ducks and other water birds. This concept, in use at Arcata, California, and Minot, North Dakota, can provide excellent treatment on a year-round basis in warm climates and on a seasonal basis in colder climates where low temperatures and ice formation occur. The hydraulic residence time (HRT) in each of the open water zones should be limited to about three days at design flow to prevent the re-emergence of algae. Such systems should always start and end with shallow emergent vegetation zones to ensure retention and treatment of particulate matter and to minimize wildlife toxicity in the open water zones. The use of FWS constructed wetlands has increased significantly since the late 1980's. The systems are widely distributed in the United States and are found in about 32 states.

Common Modifications

In the United States, it is routine to provide some preliminary treatment prior to a FWS wetland. The minimal acceptable level is the equivalent of primary treatment which can be achieved with septic tanks, with Imhoff tanks for smaller systems, or with deep ponds with a short HRT. About 45 percent of operational FWS wetland systems use facultative lagoons for preliminary treatment, but these systems have also been used behind other treatment systems. For example, some of the largest FWS systems, in Florida and Nevada, were designed for tertiary effluent polishing and receive effluent from mechanical AWT plants.

Non-discharging, total retention FWS systems have been used in arid parts of the United States where the water is completely lost through a combination of seepage and evapotranspiration. These systems require that attention be paid to the long term accumulation of salts and other substances which might become toxic to wildlife or plants in the system. While it is impossible to exclude wildlife from FWS wetlands, it is prudent to minimize their presence until the water quality approaches secondary levels of treatment. This can be accomplished by limiting open water zones to the latter part of the system and using dense stands of emergent vegetation in the front part of the wetland. Selecting vegetation with little food value for animals or birds may also help. In colder climates or where large land areas are not available for wetland removal of nitrogen, a smaller wetland system can be designed for BOD/TSS removal. Nitrogen removal can be achieved with a separate process. Wetland systems in Kentucky and Louisiana successfully use an integrated gravel trickling filter for nitrification of wastewater ammonia. Seasonally operated FWS wetlands are also used in very cold climates, in which the wastewater is retained in a lagoon during the winter months and discharged to the wetland at a controlled rate during the warm summer months.

APPLICABILITY

FWS wetlands require a relatively large land area, especially if nitrogen or phosphorus removal is required. The treatment is effective and requires little in the way of mechanical equipment, energy, and skilled operator attention. Wetland systems can be a most cost effective treatment alternative where suitable land is available at reasonable cost. They also provide enhanced habitat and recreational values. Land requirements and costs tend to favor application of FWS technology in rural areas.

FWS wetland systems reliably remove BOD, Chemical Oxygen Demand (COD), and TSS. With a sufficiently long HRT, they can also produce low levels of nitrogen and phosphorus. Metals are also removed and a reduction in fecal coliforms of about a one log can be expected. In addition to municipal wastewaters, FWS systems are used to treat mine drainage, urban storm water, combined sewer overflows, agricultural runoff, livestock and poultry wastes, landfill leachates, and for mitigation purposes. Because the water is exposed and accessible to humans and animals, the FWS concept of receiving partially treated wastewater may not be suited for use in individual homes, parks, playgrounds, or similar public facilities. A gravel bed subsurface flow (SF) wetland is a choice for these applications.

ADVANTAGES AND DISADVANTAGES

Some advantages and disadvantages of FWS wetlands are listed below:

Advantages

- FWS wetlands offer effective treatment in a passive manner, minimizing mechanical equipment, energy, and skilled operator requirements.
- FWS wetlands may be less expensive to construct, and are less costly to operate and maintain than conventional mechanical treatment systems.
- Year-round operation for secondary treatment is possible in all but the coldest climates. Year-round operation for advanced or tertiary treatment is possible in warm to moderately temperate climates.
- Wetland systems provide a valuable addition to the "green space" in a community, and include the incorporation of wildlife habitat and public recreational opportunities.
- Wetland systems produce no residual biosolids or sludges requiring subsequent treatment and disposal.
- The removal of BOD, TSS, COD, metals, and persistent organics in municipal wastewaters can be very effective with a reasonable detention time. The removal of nitrogen and phosphorus can also be effective with a significantly longer detention time.

Disadvantages

- The land area required for FWS wetlands can be large, especially if nitrogen or phosphorus removal are required.
- The removal of BOD, COD, and nitrogen are biological processes and essentially continuously renewable. The phosphorus, metals, and some persistent organics removed by the system are bound in the wetland sediments and accumulate over time.

- In cold climates low winter temperatures reduce the rate of removal for BOD and the biological reactions responsible for nitrification and denitrification. An increased detention time can compensate for this, but the increased wetland size required in extremely cold climates may not be cost effective or technically feasible.

- The bulk water in most constructed FWS wetland systems is essentially anoxic, limiting the potential for rapid biological nitrification of ammonia. Increasing the wetland size and, therefore, the detention time, may compensate for this, but may not be cost effective. Alternate methods for nitrification in combination with a FWS wetland have performed successfully.

- Mosquitoes and other insect vectors can be a problem.

- The bird population in a FWS wetland can have adverse impacts if an airport is nearby.

- FWS constructed wetlands can remove fecal coliforms by at least one log from typical municipal wastewaters. This may not be sufficient to meet discharge limits in all locations and supplemental disinfection may be required. The situation is further complicated because birds and other wildlife in the wetland produce fecal coliforms.

DESIGN CRITERIA

Published models for the pollutant removal design of FWS wetland systems have been available since the late 1980's. More recent efforts have produced three textbooks containing design models for FWS wetlands (Reed, et al., 1995; Kadlec & Knight, 1996; Crites & Tchobanoglous, 1998) All three models are based on first order plug flow kinetics but provide different results based on the use of different databases. The Water Environment Federation (WEF) presents a comparison of the three approaches in the Manual of Practice on Natural Systems (WEF, 2000.) Another comparison is found in the U.S. EPA design manual on wetland systems (U.S. EPA, 2000.) This manual also includes design models developed by Gearheart and Finney. The designer of a FWS wetland system should consult these references and select the method best suited for the project under consideration. A preliminary estimate of the land area required for an FWS wetland can be obtained from Table 1 of typical areal loading rates presented below. These values can also be used to check the results from other references.

The pollutant requiring the largest land area for removal determines the necessary treatment area for the wetland, which is the bottom surface area of the wetland cells. The wastewater flow must be uniformly distributed over the entire surface for that area to be 100 percent effective. This is possible with constructed wetlands by careful grading of the bottom surface and the use of appropriate inlet and outlet structures. Uniform distribution of wastewater is more difficult when natural wetlands are used for treatment or polishing. The existing configuration and topography are typically retained in these natural wetlands, which can result in significant short circuiting of flow. Dye tracer studies in such wetlands have shown that the effective treatment area can be as little as 10 percent of the total wetland area. The total treatment area should be divided into at least two cells for all but the smallest systems. Larger systems should have at

TABLE 1 TYPICAL AREAL LOADING RATES

Constituent	Typical Influent Conc. (mg/L)	Target Effluent Conc. (mg/L)	Mass Loading Rate (lb/ac/d)*
Hydraulic Load (in/d)	0.4 - 4**		
BOD	5 - 100	5 - 30	9 - 89
TSS	5 - 100	5 - 30	9 - 100
NH_3/NH_4 as N	2 - 20	1 - 10	1 - 4
NO_3 as N	2 - 10	1 - 10	2 - 9
TN	2 - 20	1 - 10	2 - 9
TP	1 - 10	0.5 - 3	1 - 4

least two parallel trains of cells to provide flexibility for management and maintenance.

Wetland systems are living ecosystems. The life and death cycles of the biota produce residuals which can be measured as BOD, TSS, nitrogen, phosphorus, and fecal coliforms. As a result, regardless of the size of the wetland or the characteristics of the influent, there will always be a residual background concentration of these materials in wetland systems. Table 2 summarizes these background concentrations.

Because removal of BOD and various nitrogen forms is temperature dependent, the temperature of the wetland must be known for proper design. The water temperature in large systems with a long HRT (greater than 10 days) will approach the average air temperature except during subfreezing weather in the winter. Methods to estimate the water temperature for wetlands with a shorter HRT (less than 10 days) can be found in the references cited.

TABLE 2 "BACKGROUND" FWS WETLAND CONCENTRATIONS

Constituent	Concentration Range
BOD_5 (mg/L)	1 - 10
TSS (mg/L)	1 - 6
TN (mg/L)	1 - 3
NH_3/NH_4 as N (mg/L)	< 0.1
NO_3 as N (mg/L)	< 0.1
TP (mg/L)	< 0.2
Fecal Coliforms (MPN/100mL)	50 - 500

Because living plants and litter provide significant frictional resistance to flow through the wetland , it is necessary to consider the hydraulic aspects of system design. Manning's equation is generally accepted as the model for the flow of water through FWS wetlands. Descriptive information is found in the references cited. Flow resistance impacts the configuration selected for the wetland cell: the longer the flow path, the higher the resistance. To avoid hydraulic problems, an aspect ratio (L:W) of 4:1 or less is recommended.

PERFORMANCE

A lightly loaded FWS wetland can achieve the "background" effluent levels shown in Table 2. In general, an FWS constructed wetland is designed to produce a specified effluent quality. Table 1 can be used to estimate the size of the wetland necessary to produce the desired effluent quality. The design models in the referenced publications provide a more precise estimate of required treatment area. Table 3 summarizes actual performance data for 27 FWS systems from a recent Technology Assessment (U.S. EPA, 2000).

In theory, the performance of a wetland system can be influenced by hydrological factors. High evapotranspiration (ET) rates may increase effluent concentrations, but may also increase the HRT in the wetland. High precipitation rates dilute the pollutant concentrations but also shorten the HRT in the wetland. In most temperate areas with a moderate climate, these influences are not critical for performance. Hydrological aspects only need to

TABLE 3 SUMMARY OF PERFORMANCE FOR 27 FWS WETLAND SYSTEMS

Constituent	Mean Influent (mg/L)	Mean Effluent (mg/L)
BOD_5	70	15
TSS	69	15
TKN as N	18	11
NH_3/NH_4 as N	9	7
NO_3 as N	3	1
TN	12	4
TP	4	2
Dissolved P	3	2
Fecal Coliforms (#/100mL)	73,000	1320

Source: U.S. EPA, 2000.

be considered for extreme values of ET and precipitation.

OPERATION AND MAINTENANCE

The routine operation and maintenance (O&M) requirements for FWS wetlands are similar to those for facultative lagoons. They include hydraulic and water depth control, inlet/outlet structure cleaning, grass mowing on berms, inspection of berm integrity, wetland vegetation management, mosquito and vector control (if necessary), and routine monitoring.

The water depth in the wetland may need adjustment on a seasonal basis or in response to increased resistance from the accumulating plant litter in the wetland channel. Mosquitoes may require control, depending on local conditions and requirements. The mosquito population in the treatment wetland should be no greater than in adjacent natural wetlands.

Vegetation management in FWS wetlands does not include the routine harvest and removal of the harvested material. Plant uptake of pollutants represents a relatively minor pathway, so harvest and removal on a routine basis does not provide a significant treatment benefit. Removal of accumulated litter may become necessary if there are severe restrictions to flow. Generally, this will only occur if the wetland channels have been constructed with very high aspect ratios (L:W > 10:1). Vegetation management may also include wildlife management, depending on the type of vegetation selected for the system. Animals such as nutria and muskrats have been known to consume all emergent vegetation in FWS constructed wetlands.

Routine water quality monitoring is required for all FWS systems with an NPDES permit. The permit specifies the monitoring requirements and frequency of monitoring. Sampling for NPDES monitoring is usually limited to untreated wastewater and the final system effluent. Since the wetland component is usually preceded by some form of preliminary treatment, the routine monitoring program does not document wetland influent characteristics. Periodic samples of the wetland influent should be obtained and tested for all but the smallest systems to provide the operator with an understanding of wetland performance and a basis for adjustments, if necessary.

COSTS

The major items included in the capital costs for FWS wetlands are similar to those for lagoon systems, including land, site investigation, site clearing, earthwork, liner, rooting media, plants, inlet and outlet structures, fencing, miscellaneous piping, engineering, legal, contingencies, and contractor's overhead and profit. The liner can be the most expensive item. For example, a plastic membrane liner can approach 40 percent of construction costs. In many cases, compaction of the in-situ native soils provides a sufficient barrier for groundwater contamination. Table 4

TABLE 4 CAPITAL AND O&M COSTS FOR 100,000 GAL/D FWS WETLAND

Item	Cost ($)* Native Soil Liner	Cost ($)* Plastic Membrane Liner
Land Cost	16,000	16,000
Site Investigation	3,600	3,600
Site Cleaning	6,600	6,600
Earthwork	33,000	33,000
Liner	0	66,000
Soil Planting Media	10,600	10,600
Plants	5,000	5,000
Planting	6,600	6,600
Inlets/Outlets	16,600	16,600
Subtotal	98,000	164,000
Engineering, legal, etc.	56,800	95,100
Total Capital Cost	154,800	259,100
O&M Costs ($/year)	6,000	6,000

* June 1999 Costs, ENR CCI = 6039

Source: Water Environment Federation, 2000.

summarizes capital and O&M costs for a hypothetical 378,500 liters per day (100,000 gallon per day) FWS constructed wetland, required to achieve a 2 mg/L ammonia concentration in the effluent. Other calculation assumptions include the following: influent NH_3 = 25 mg/L; water temperature = 20°C (68°F); water depth = 0.46 meters (1.5 ft); porosity = 0.75; treatment area = 1.3 hectares (3.2 ac); and land cost = $12,355/hectare ($5,000/ac).

Table 5 compares the life cycle costs for this wetland to the cost of a conventional sequencing batch reactor (SBR) treatment system designed for the same flow and effluent water quality.

TABLE 5 COST COMPARISON FOR FWS WETLAND AND CONVENTIONAL WASTEWATER TREATMENT

Cost Item	Process	
	Wetland	SBR
Capital Cost ($)	259,000	1,104,500
O&M Cost ($)	6,000/yr	106,600/yr
Total Present Worth Costs* ($)	322,700	2,233,400
Cost per 1000 gal treated ** ($)	0.44	3.06

*Present worth factor 10.594 based on 20 years at 7 percent interest

**Daily flow rate for 365 d/yr for 20 yr, divided by 1000 gal.

Source: Water Environment Federation, 2000.

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United States Environmental Protection Agency | Office of Water Washington, D.C. | EPA 832-F-00-047 September 2000

Wastewater Technology Fact Sheet
High-Efficiency Toilets

INTRODUCTION

In 1992, Congress passed legislation requiring that all toilets sold in the United States meet a new water conservation standard of 1.6 gallons per flush (gpf). By 1992, in response to the growing need for conservation of drinking water supply resources, a number of metropolitan regions and 17 states had already instituted water conservation programs which included high-efficiency toilet requirements.

A national water use standard for a high-efficiency toilet was necessary to address the problems with different states and communities having established different toilet water use standards. A national standard eliminated the need for plumbing fixture firms to manufacture, stock, and deliver different products, and the difficulty for states in preventing the importation of high-water-use fixtures.

High efficiency designs have significantly improved since they were first introduced. Despite the improvements, the industry continues to refine this technology. Based on consumer surveys, the majority of users are satisfied with the performance of the current designs.

Because toilets use is the largest proportion of indoor water used in a household, high-efficiency toilets achieve real water savings.

The national high-efficiency toilet standard brings a range of questions and concerns for. This fact sheet is intended to assist in answering the questions that the consumer, property manager, plumbing contractor, and utility manager might have about the high-efficiency toilet standards.

ENVIRONMENTAL, PUBLIC, AND CONSUMER BENEFITS

Studies indicate that converting to water efficient toilets, showers and clothes washers, results in a household water savings of about 30% compared to conventional fixtures. A change to high-efficiency toilets alone, reduces toilet water use by over 50% and indoor water use by an average of 16%. This translates into a savings of 15,000 to 20,000 gallons per year for a family of four. Furthermore, more efficient plumbing products result in lower wastewater flow and increase the available capacity of sewage treatment plants and onsite wastewater disposal systems.

The general public also benefits directly from water conservation measures. Practiced on a wide basis, efficient use of water resources helps reduce the potential need during drought periods for water restrictions such as bans on lawn watering and car-washing. Savings to the consumer from lower water bills, depending on local water rates and actual use, can range from $50 to $100 per year. Many hotels, motels, and office buildings are finding that new fixtures are saving them 20 percent on water and wastewater costs.

DESCRIPTION OF THE TECHNOLOGY

The principles of high-efficiency toilet design and operation reflect the shift from remvoing waste by using flushwater *volume* to increasing flushwater *velocity* to remove waste.

The design of the bowl contour became more vertical design to achieve the necessary increased downward velocity. Nevertheless, the bowl contour must ensure a shallow but large water surface towards the front of the bowl for adequate waste immersion. Many consumers notice that high-efficiency bowl designs result in a flush that tends to swirl less than their previous toilet. This is because the drag, or friction, resulting from swirling water reduces the essential velocity.

Some manufacturers use an enhanced front jet towards the bottom of the bowl to assist in waste removal. But other toilets that have received top consumer survey ratings use no jet at the bottom.

Gravity-flow or pressure-assisted?

Two types of technology are available for both residential and commercial uses. The most widely available is a high-efficiency modification of the conventional gravity flow toilet. The other, the pressure-assisted toilet, utilizes pressurized air in the tank to achieve additional force.

The choice between gravity and pressurized toilets usually hinges on two factors: noise, and the distinction between whether the maintenance is provided by the homeowner or by a building manager. Pressure-assisted toilets are much less likely to clog than even the older, 3.5 gpf gravity toilets. While many of the more recent models of high-efficiency gravity toilets perform as well as pressure-assisted models in tests, maintenance issues for heavy-duty use, or responsibility for maintaining multiple toilets, may lead to the decision to install pressure-assisted toilets. Some states, such as New Jersey, require pressure-assisted toilets in commercial use.

Gravity toilets in buildings with cast-iron waste lines may clog more readily, because of the roughness of the interior of the pipe. New buildings use PVC pipe, through which waste flows more easily. Choosing pressure-assisted toilets for buildings served by cast-iron pipe may reduce maintenance needs.

However, the greater noise from pressure-assisted toilets is a factor to consider when locating toilets near sleeping or working quarters. And the pressure-assisted toilet is generally more costly than gravity-flow.

Gravity-flow toilets achieve the necessary enhanced water velocity largely through coordinated improvements of the siphoning features of the fixture. Indeed, some of the early experiences with high-efficiency toilets that clogged too easily were the result of designs that increased siphoning by choking down on the trap size. Manufacturers responded by re-sizing the trap diameter nearer its original dimensions, and instead are coordinating the rim dimensions, bowl contour, and trap size to work in concert to enhance the force of the water and the siphoning function.

Pipe slope standards

The issue has been raised as to whether existing pipe slope standards are adequate to carry these reduced flows. American Society of Mechanical Engineers (ASME) tests indicate that the existing standards exceed performance requirements for drainline carry minimums. Field studies similarly report very few complaints, representing problems with a few individual buildings. The standards are under constant review, and any changes indicated would be recommended through normal procedures.

HIGH-EFFICIENCY TOILET PERFORMANCE

Consumer surveys, performed by utilities that have been implementing high-efficiency toilet programs (such as rebates), have shown that the vast majority of 1.6 GPF, high-efficiency toilets work well. For example, 90 percent of San Diego, CA, customers, and 95 percent of Austin, TX, customers reported that they were "satisfied" or "very satisfied" with their high-efficiency toilets; 91 percent of Tampa, FL, ratepayers said they would purchase the 1.6 gallon toilet again. A review of multiple metropolitan area customer satisfaction surveys for the 1995-1998 period shows that, while performance among individual high-efficiency toilet models varied, the large majority were rated at least satisfactory in performance, with most rated better than satisfactory.

Some brands and models have drawn more positive responses from consumers than others, with specific models being withdrawn and added as research and design progress. Since 1992, when the national law was first passed, plumbing products have gone through several cycles of improvements, with each new generation bringing improved product performance and customer acceptance. The marketplace has responded to the move to the high-efficiency toilet standard so as to better serve customer requirements.

The two complaints most often made against the high-efficiency fixture are somewhat more frequent clogging, and the perceived need for more frequent double-flushing. A 1996 survey in New York City on customer satisfaction reported that building managers--who are responsible for maintaining a number of toilets--reported more frequent clogging, probably due to the smaller trap size of the toilet (designed to increase siphoning). The high-efficiency toilet designs, as discussed in the section on operation and maintenance, cannot accommodate extraneous waste materials and non-flushables such as paper towels. Building managers should communicate this to their tenants.

In a study of 100 homes in each of 12 North American cities, the incidence of double-flushing was virtually the same for homes with high-efficiency toilets as for those with conventional toilets.

LIMITATIONS

The consumer choice of a particular high-efficiency toilet model must take into account the specifics of the application. Key considerations include:

- To be sure the new toilet will cover the area, check the dimensions of the space in which the toilet is to be installed, including the ‘footprint’ of the old toilet.
- If the drainlines are made of cast-iron rather than PVC pipe, the toilet may be more likely to clog. Ensure adequate maintenance, or consider a pressure-assisted model.
- Pressure-assisted models tend to be more noisy than gravity-flush, so use caution when installing this type adjacent to sleeping quarters.
- Ensure the availability of electricity for electric-assisted models.
- Some toilets have a taller seat height, which should be evaluated based on anticipated users (some higher seats will be less accessible to children).
- Users in areas with high mineral content in the water should check rim hole dimensions, or consider a toilet with a holeless rim.

CONSUMER TIPS

Purchase: The buyer of the high-efficiency toilet should carry out the same type of research necessary for any significant purchase intended to be used for a long time. Refer to current issues of consumer magazines that evaluate water-efficient toilets (frequently under article listings for water conservation fixtures). Your water utility, individual plumbers, and the local plumbers' union or association may also be able to recommend certain models. Look for manufacturers' guarantees. By following these tips, purchasers of water conservation toilets can be fairly assured of getting a satisfactory product.

Installation: Proper installation is especially important for high-efficiency toilets. Licensed plumbers who guarantee their work will make sure fixtures are installed correctly. It is very important to follow the manufacturer’s instructions. The proper flow cycle for high-efficiency toilets is shorter--usually about 45 seconds--than previous models.

If installing a water-conserving toilet to replace an old one, use new mounting bolts of the proper length, and be sure the old wax seal is completely removed before installing the new one. Check and clear drain lines while accessibility is open.

Operation and Maintenance: The common advice "Don't use your toilet as a trash bin" is especially important. High-efficiency toilets will not perform well if non-flushables, such as paper towels, are sent down the fixture. There has always been a need for plungers and plumbing "snakes," and their use should be considered first when the toilet overflows or does not refill completely.

Since flapper valves require replacement about every five years, proper selection of replacement valves is a key maintenance consideration. A study conducted by the Metropolitan Water District of Southern California found that proper flapper valve model selection is essential for continued performance. Of the physically compatible replacement flapper valves, half the models left a toilet with *less* than 1.6 gpf--and the resulting incomplete flush had insufficient water to do the job the toilet was designed to do. Since most hardware stores can stock only a few brands, there is no guarantee of compatibility. Industry standards groups are working to insure that after-market flappers will perform properly. Getting the right replacement flapper value is worth the effort.

A key problem affecting 1.6 gpf toilets is a result of the use of chemical in-tank toilet cleaners. All U.S. toilet manufacturers recommend against the use of chemical in-tank toilet cleaners, as the strong chemicals degrade the works within the toilet. Even with current toilets that include chemical-resistant materials, chemical cleaners still increase the specific gravity of water and slow flushing velocity, interfering with performance.

NOTE: Most major toilet manufacturers maintain 1-800 number Consumer Hotlines (call the distributor or 1-800-555-1212). These hotlines are set up to address both non-technical and technical questions relating to installation, operation, and maintenance of high-efficiency toilets.

COSTS

A wide range of toilets that perform well are available in all price ranges, although very inexpensive (less than $100) imports may not carry the American National Standards Institute (ANSI) design standard (different from the water conservation 1.6 gpf standard) and not function properly. In most cases, there is little relationship between price and performance. The consumer choice recommendations listed above under "Limitations" will help customers select the right model for them.

The choice to retrofit based on cost recovery from water savings can be easily calculated at the local level based on water rates and the price of the toilet. For average water/sewer rates, household savings for a typical four-person household is about $50/year.

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United States Environmental Protection Agency | Office of Water Washington, D.C. | EPA 832-F-99-072 September 1999

Water Efficiency Technology Fact Sheet
Incinerating Toilets

DESCRIPTION

Incinerating toilets are self-contained units consisting of a traditional commode-type seat connected to a holding tank and a gas-fired or electric heating system to incinerate waste products deposited in the holding tank. The incineration products are primarily water and a fine, non-hazardous ash that can be disposed of easily and without infection hazard.

APPLICABILITY

Though traditional water-flushing toilets are widely used throughout developed regions of the world, their use is not always feasible. For example:

- In rural areas where no municipal sewage system exists, or where installation of septic systems is impractical or prohibitively expensive due to shallow soils, steep slopes, high groundwater levels, or extreme cold weather conditions.
- For remotely located roadside rest areas, where connection to a piped sanitary system is impractical and the cost unjustifiable.
- For work crews operating in areas where permanent toilets are not available.
- In marine vessels, for which discharge of untreated waste into bodies of water is prohibited; human wastes must either be stored in tanks while at sea or be treated prior to discharge.
- In areas where water is scarce due to drought or other environmental conditions and the need to conserve water motivates consideration of alternative, water-free toilet systems.
- Where community, environmental, and health organizations have concerns regarding existing sewage disposal practices, especially seepage of contaminants into local water supplies from improperly functioning septic or other treatment systems, or exposure of residents to improperly dumped waste products from rudimentary collection pails called "honey buckets."

All of these situations are potentially suited to the use of incinerating toilets which are portable, water-free, and sanitizing.

ADVANTAGES AND DISADVANTAGES

Often touted as a "pollution-free" technology, incinerating toilets have some clear advantages over many traditional methods of sewage disposal. There are also disadvantages that should be considered.

Advantages

- Uses no water.
- Incineration cycle produces a fine, sterile ash that can be thrown in the trash.
- Ash is space-saving; as little as one tablespoon of ash is generated on average per use.

- Incinerating toilet systems are portable, simple to install, and easy to use. Can be installed in remote areas, either for temporary or permanent use. Can be installed in unheated shelters, even in freezing temperatures.

- Relatively odorless in comparison to more commonly used storage-in-disinfectant portable toilets.

- In most areas, can be used in unheated shelters without fear of freezing.

Disadvantages

- Incinerating process destroys nutrients in the waste; ash is inadequate for replenishing soil nutrients.

- Incinerating requires energy, resulting in higher average energy costs for users.

- Units are not entirely pollution-free; both portable electric generation (for remote locations) and propane fuel burning produce some air pollutants.

- Anti-foam agents, catalysts or other additives are typically required for use.

- Some models cannot be used while the incineration cycle is in progress.

DESIGN CRITERIA

Specific design criteria depend on the type of energy used for incineration. Incinerating toilets are designed with a chamber that receives and stores human wastes until ready for incineration. The incinerating chamber is typically composed of stainless steel or a cast nickel alloy. The chamber is accessed through a toilet seat support—part of a housing made of non-corroding fiberglass reinforced plastic or similar material—having a sealable receiving opening for introduction of wastes into the chamber. Vapor and products of combustion are fed by blower fan to a venting system which may be as simple as an exhaust pipe, or which may also incorporate an afterburner or other odor control system. Not all units can be used during the incinerating cycle. Some units require initiation of an incinerating cycle after each use while others allow for multiple uses before an incineration cycle takes place.

Electric Incinerating Toilets

The Incinolet electric incinerating toilet (Blankenship/Research Products, 1999) is designed with a paper-lined upper bowl that collects newly deposited waste. To "flush," a foot pedal is pressed causing an insulated chamber cover to lift and swing to the side while the bowl halves separate, dropping the paper liner and its contents into the chamber. When the foot pedal is released, the chamber is resealed and the bowl halves return to normal position.

Incineration is initiated by pressing a "start" button after each use of the toilet. The manufacturer does *not* recommend using the toilet multiple times between incineration cycles. The toilet can continue to be used while incineration is in progress. Once the "start" button is pressed, an electric heating unit cycles on-and-off for 60 minutes while a blower motor draws air from the chamber over a heat-activated catalyst bed designed to remove odor components. Upon leaving the catalyst bed, the air is forced out through a vent line. Makeup air for the chamber is drawn from the room in which the toilet is operating. The blower motor continues to operate after the heating cycle to cool the unit. A complete cycle takes from 1.5 to 1.75 hours.

Five models of the Incinolet electric toilet are available: two for fixed locations (one four-person capacity and one eight-person capacity); two mobile- location units for motor homes, trailers and boats (one four-person and one eight-person); and a urinal (eight-person). The smaller capacity units are designed for 120 volt service, while the larger units require 240 volts. All models retain the same fundamental design principles described above.

Gas-Fired Incinerating Toilets

Propane or natural gas-burning incinerating toilets are manufactured by Storburn International, Inc. (Storburn, 1999; Lake Geneva A&C Corp, 1977.)

These units are equipped with a three gallon storage chamber which can accommodate 40 to 60 uses before initiation of an incinerating cycle. To initiate the cycle, an anti-foaming agent is manually added to the chamber, a pilot is lit using a built-in piezo-electric igniter, and the burner is activated. This procedure automatically locks down the unit so it cannot be used while the burner is in operation. A complete incineration cycle takes approximately 4.5 hours for a full chamber.

PERFORMANCE

Evaluation of 19 On-Site Waste Treatment Systems in Southeastern Kentucky.

A comparative "blackwater" (human excrement waste) treatment study, known as the Appalachian Environmental Health Demonstration Project (AEHDP), was conducted in southeastern Kentucky during the 1970s (U.S. EPA 1980.) As part of the year study, twenty prototype systems representing several alternative treatment technologies were installed in private residences in southeastern Kentucky during 1970 and 1971, including six incinerating toilets. The region used for the study was mountainous, characterized by shallow soils, steep slopes and high groundwater, having a demonstrated need for alternative treatment methods. Further, the study was performed in a low-income area where cost of installation and operation was a critical consideration.

Two of the six toilets used in the study were Incinolet brand units and the remaining four were Destroilet brand propane-fired toilets. Since the Destroilet is no longer on the market, and was significantly different in design from propane-fired toilets available today, findings related to the Destroilet are not relevant to this Fact Sheet. Results pertaining to the Incinolet electric toilet, however, are still pertinent.

The two users of Incinolet toilets complained of incomplete waste incineration. Scraping of partly burned feces from the walls of the incinerating chamber was periodically necessary. One household using the Incinolet deemed the operating cost excessive, and abandoned the incinerating toilet in favor of their outdoor privy after approximately six months. The second household used the Incinolet for approximately three years; however, toilet use was intermittent over this period and the outdoor privy was preferred because of incomplete incineration of waste products. The second household installed a septic system to replace both the Incinolet and the privy. The study acknowledges that the Incinolet manufacturer subsequently added catalyst as an incineration aid, but notes that the basic configuration of the unit was unchanged.

Cold Weather Operation Study of a Storburn Propane Combustion Toilet

Researchers from the Alaska Area Native Health Service and from the University of Alaska, Anchorage, conducted an examination of Storburn propane combustion toilets whereby honey bucket waste was collected over nearly a month and burned in a Storburn toilet using various batch sizes and burn cycle times (Ritz and Schroeder, 1994.) All burn cycles were conducted while the toilet and propane fuel tank were located outdoors, with ambient temperatures reaching as low as -11°C. Anti-foam reagent was added to the contents of the combustion chamber before each cycle to prevent boil-over of liquid waste.

The Storburn was found to effectively reduce human wastes to ash, even at low ambient temperatures. On the coldest day tested, the exhaust temperature was measured going from -11°C to 100°C (the boiling point of water) only one minute after ignition. On average, the ash remaining after incineration amounted to 2.23 percent of the total weight of waste treated in the Storburn. Moreover, microbiological examination of the resulting ash revealed no fecal contamination. The coldest temperatures tested did adversely impact incineration, however, because the contents of the propane tank could not vaporize properly. To maintain an optimal fuel supply to the toilet, the authors of the study recommend keeping propane tanks sheltered or heated when used in sub-zero conditions.

OPERATION AND MAINTENANCE

Incinerating toilets are generally simple to operate, either involving the press of a button to begin the operating cycle or the activation of a burner. The degree of maintenance required depends on the model used. Storburn gas-fired toilets have no moving parts and routine maintenance involves periodic cleaning of the burner and regular removal of ash.

Maintenance for the electric incinerating toilet involves:

- Regular emptying of the ash collection pan.
- Cleaning of the outer stainless steel surfaces including the bowl halves.
- Periodic (every 90 days) cleaning of the blower motor with occasional replacement of the blower wheel.
- Cleaning and lubrication of the foot pedal mechanism.
- Removal of bits of paper and dust from the combustion chamber.
- Annual inspection of the catalyst.

COSTS

According to Incinolet product literature (Research Products/Blankenship), a four-user electric incinerating toilet costs $2,300; an eight-user toilet costs $2,700. The purchase cost of a propane-burning Storburn is $2,550; a natural gas-burning unit costs is $2,590. Vent kits for both types of toilet are not included in these costs.

The cost of electricity varies widely according to the location of service. Domestic retail energy prices can vary from $0.05 to $0.15 per kilowatt-hour. The Incinolet electric toilet is claimed by the manufacturer to use 2 kw-h per cycle. Assuming four users, each using the toilet every 1.5 hours for a use period of 10 hours, the electric toilet would consume approximately 53 kw-h of energy per day, or about 1,600 kw-h per month. At $0.10 per kw-h, this amounts to $160.00 per month or $1,920 annually.

According to the manufacturer, maintenance costs for the Incinolet include $0.08 per bowl liner used (one per use), a new heating coil every one to three years ($89.10 each), and a new blower fan every two years ($8.95 each). Using the same assumptions for frequency of use and replacing parts every two years, the annual maintenance cost is approximately $828.

Assuming a total purchase and installation cost of $4,000, for a 10-year service life, the average annual cost (including purchase, installation, operation and maintenance averaged over 10 years) is $3,148 in 1999 dollars for the Incinolet electric toilet.

Ritz and Schroeder performed a life-cycle cost analysis for the Storburn propane toilet (Ritz and Schroeder, 1994.) The authors calculated the annual operational cost per adult to be $233.60 and the average annual maintenance cost to be $150. Assuming a purchase and installation price of $4,000, the annual cost for four adult users averaged over a 10-year service life is $1,484 in 1994 dollars. In 1999 dollars (assuming 5 percent inflation per year), this figure is equivalent to $1,894. Since this estimate reflects unit operation under cold-weather conditions, it may be assumed that this represents the high end of the cost range; the unit would require less energy for each burn cycle when used indoors or in warmer climates, with correspondingly lower energy costs.

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United States Environmental Protection Agency
Office of Water Washington, D.C.
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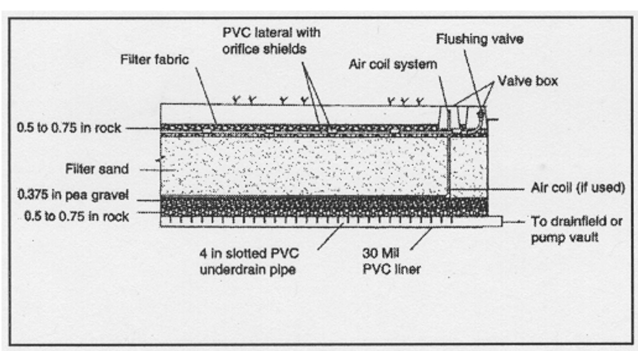
Wastewater Technology Fact Sheet
Intermittent Sand Filters

DESCRIPTION

Intermittent Sand Filters (ISFs) have 24-inch deep filter beds of carefully graded media. Sand is a commonly used medium, but anthracite, mineral tailings, bottom ash, etc., have also been used. The surface of the bed is intermittently dosed with effluent that percolates in a single pass through the sand to the bottom of the filter. After being collected in the underdrain, the treated effluent is transported to a line for further treatment or disposal. The two basic components of an ISF system are a primary treatment unit(s) (a septic tank or other sedimentation system) and a sand filter. Figure 1 shows a schematic of a typical ISF.



Source: Orenco Systems, Inc., 1998.

FIGURE 1 TYPICAL CROSS SECTION OF AN INTERMITTENT SAND FILTER

ISFs remove contaminants in wastewater through physical, chemical, and biological treatment processes. Although the physical and chemical processes play an important role in the removal of many particles, the biological processes play the most important role in sand filters.

ISFs are typically built below grade in excavations 3 to 4 feet deep and lined with an impermeable membrane where required. The underdrain is surrounded by a layer of graded gravel and crushed rock with the upstream end brought to the surface and vented. Pea gravel is placed on top of the graded gravel, and sand is laid on top of the pea gravel. Another layer of graded gravel is laid down, with the distribution pipes running through it. A flushing valve is located at the end of each distribution lateral. Lightweight filter fabric is placed over the final course of rock to keep silt from moving into the sand while allowing air and water to pass through. The top of the filter is then backfilled with loamy sand that may be planted with grass. Buried ISFs are usually designed for single homes. Some common types of these sand filters are listed below.

Gravity Discharge ISFs

The gravity discharge ISF is usually located on a hillside with the long axis perpendicular to the slope to minimize the excavation required. Because the effluent leaving the sand filter flows out by gravity, the bottom of the sand filter must be several feet higher than the drainfield area. To achieve that difference in elevations, a sand filter may be constructed partially above ground.

Pumped Discharge ISFs

The pumped discharge sand filter is usually sited on level ground. Its location in relation to the drainfield is not critical since a pump located within the sand filter bed allows effluent to be pumped to a drainfield at any location or elevation. Discharge piping goes over—not through—the sand filter liner, so the integrity of the liner is protected.

Bottomless ISFs

The bottomless ISF has no impermeable liner and does not discharge to a drainfield, but rather directly to the soil below the sand.

Table 1 shows the typical design values for ISFs. These values are based on past experience and current practices and are not necessarily optimum values for a given application.

ADVANTAGES AND DISADVANTAGES

TABLE 1 TYPICAL DESIGN CRITERIA FOR ISFs

Item	Design Criteria
Pretreatment	Minimum level: septic tank or equivalent
Filter medium	
Material	Washed durable granular material
Effective size	0.25-0.75 mm
Uniformity coefficient	< 4.0
Depth	18 - 36 in
Underdrains	
Type	Slotted or perforated pipe
Slope	0-0.1%
Size	3-4 in
Hydraulic loading	2-5 gal/ft^2/day
Organic loading	0.0005-0.002 lb/ft^2/day
Pressure distribution	
Pipe size	1-2 in
Orifice size	1/8-1/4 in
Head on orifice	3-6 ft
Lateral spacing	1-4 ft
Orifice spacing	1-4 ft
Dosing	
Frequency	12-48 times/day
Volume/orifice	0.15-0.30 gal/orifice/dose
Dosing tank volume	0.5-1.5 flow/day

Source: Adapted from: U.S. EPA, 1980 and Crites and

Some advantages and disadvantages of ISFs are listed below:

Advantages

- ISFs produce a high quality effluent that can be used for drip irrigation or can be surface discharged after disinfection.
- Drainfields can be small and shallow.
- ISFs have low energy requirements.
- ISFs are easily accessible for monitoring and do not require skilled personnel to operate.
- No chemicals are required.
- If sand is not feasible, other suitable media can be substituted and may be found locally.
- Construction costs for ISFs are moderately low, and the labor is mostly manual.
- The treatment capacity can be expanded through modular design.
- ISFs can be installed to blend into the surrounding landscape.

Disadvantages

- The land area required may be a limiting factor.
- Regular (but minimal) maintenance is required.
- Odor problems could result from open filter configurations and may require buffer zones from inhabited areas.
- If appropriate filter media are not available locally, costs could be higher.
- Clogging of the filter media is possible.

- ISFs could be sensitive to extremely cold temperatures.

- ISFs may require a National Pollutant Discharge Elimination System (NPDES) Permit when the effluent is surface discharged.

PERFORMANCE

Sand filters produce a high quality effluent with typical concentrations of 5 mg/L or less of biochemical oxygen demand (BOD) and suspended solids (SS), as well as nitrification of 80% or more of the applied ammonia. Phosphorus removals are limited, but significant fecal coliform bacteria reductions can be achieved.

The performance of an ISF depends on the type and biodegradability of the wastewater, the environmental factors within the filter, and the design characteristics of the filter. The most important environmental factors that determine the effectiveness of treatment are media reaeration and temperature. Reaeration makes oxygen available for the aerobic decomposition of the wastewater. Temperature directly affects the rate of microbial growth, chemical reactions, and other factors that contribute to the stabilization of wastewater within the ISF. Filter performance is typically higher in areas where the climate is warmer compared to areas that have colder climates.

Discussed below are several process design parameters that affect the operation and performance of ISFs.

The Degree of Pretreatment

An adequately sized, structurally sound, watertight septic tank will ensure adequate pretreatment of typical domestic wastewater.

Media Size

The effectiveness of the granular material as filter media is dependent on the size, uniformity, and composition of the grains. The size of the granular media correlates with the surface area available to support the microorganisms that treat the wastewater. This consequently affects the quality of the filtered effluent.

Media Depth

Adequate sand depth must be maintained in order for the zone of capillarity to not infringe on the upper zone required for treatment.

Hydraulic Loading Rate

In general, the higher the hydraulic load, the lower the effluent quality for a given medium. High hydraulic loading rates are typically used for filters with a larger media size or systems that receive higher quality wastewater.

Organic Loading Rate

The application of organic material in the filter bed is a factor that affects the performance of ISFs. Hydraulic loading rates should be set to accommodate the varying organic load that can be expected in the applied wastewater. As with hydraulic loading, an increase in the organic loading rate results in reduced effluent quality.

Dosing Techniques and Frequency

It is essential that a dosing system provide uniform distribution (time and volume) of wastewater across the filter. The system must also allow sufficient time between doses for reaeration of the pore space. Reliable dosing is achieved by pressure-dosed manifold distribution systems.

OPERATION AND MAINTENANCE

The daily operation and maintenance (O&M) of large filter systems is generally minimal when the ISF is properly sized. Buried sand filters used for residential application can perform for extended periods of time.

Primary O&M tasks require minimal time and include monitoring the influent and effluent, inspecting the dosing equipment, maintaining the filter surface, checking the discharge head on the orifices, and flushing the distribution manifold annually. In addition, the pumps should be installed with quick disconnect couplings for easy removal. The septic tank should be checked for sludge and scum buildup and pumped as needed. In extremely cold temperatures, adequate precautions must be taken to prevent freezing of the filter system by using removable covers. Table 2 lists the typical O&M tasks for ISFs.

TABLE 2 RECOMMENDED O&M FOR ISFs

Item	O&M Requirement
Pretreatment	Depends on process; remove solids from septic tank or other pretreatment unit
Dosing chamber	
Pumps and controls	Check every 3 months
Timer sequence	Check and adjust every 3 months
Appurtenances	Check every 3 months
Filter media	
Raking	As needed
Replacement	Skim sand when heavy incrustations occur; replace sand to maintain design depth
Other	Weed as needed
	Monitor/calibrate distribution device as needed
	Prevent ice sheeting

APPLICABILITY

An assessment conducted in 1985 by the U.S. Environmental Protection Agency of ISF systems revealed that sand filters are a low-cost, mechanically simple alternative. More recently, sand filter systems have been serving subdivisions, mobile home parks, rural schools, small communities, and other generators of small wastewater flows.

Sand filters are a viable addition/alternative to conventional methods when site conditions are not conducive for proper treatment and disposal of wastewater through percolative beds/trenches. Sand filters can be used on sites that have shallow soil cover, inadequate permeability, high groundwater, and limited land area.

Placer County, California

Placer County, California, in the last 20 years has had to develop their land with on-site systems due to the popularity of their rural homes at elevations of 100 to 4,000 feet. The county extends along the western slope of the Sierra Nevada Mountains from Lake Tahoe through the foothills and into the Great Central Valley. Large areas of the county have marginal soil quality, shallow soil depth, and shallow perched groundwater levels.

In 1990, a program was initiated to permit the use of the Oregon-type ISF system on an experimental basis to evaluate their performance and other related factors.

The ISF system used in this study had the following components: a conventional septic tank followed by a separate pump vault; a plywood structure with a 30 mm PVC liner for the filter and appurtenances; 24 inches deep of carefully graded and clean sand; a gravel over-layer and under-layer containing the pressurized piping manifold to distribute the septic tank effluent over the bed; and a collection manifold to collect the wastewater. The dimensions of the filter (for both three- and four-bedroom homes) were 19 feet x 19 feet at a design loading rate of 1.23 gal/ft^2/day. Summarized below in Table 3 are the results obtained from 30 ISF systems serving single-family homes during warm and cold weather.

The results of this study indicate that ISF systems showed a marked improvement in their effluent quality over septic tanks. Although the systems performed well, nitrogen and bacteria were not totally removed, which indicates that ISF systems

TABLE 3 COMPARISON OF EFFLUENTS FROM SINGLE-FAMILY, RESIDENTIAL SEPTIC TANKS AND ISFs FOR 30 SYSTEMS IN PLACER COUNTY

Effluent Characteristic	Septic Tank Effluent	ISF Effluent	% Change
$CBOD_5$	160.2 (15)*	2.17 (44)*	98
TSS	72.9 (15)*	16.2 (44)*	78
NO_3-N	0.1 (15)*	31.1 (44)*	99
NH_3-N	47.8 (15)*	4.6 (44)*	90
TKN	61.8 (15)*	5.9 (44)*	90
TN	61.8 (15)*	37.4 (44)*	40
TC	6.82 x 105 (13)*	7.30 x 102 (45)*	99 (3 logs)
FC	1.14 x 105 (13)*	1.11 x 102 (43)*	99 (3 logs)

*Number of samples

$CBOD_5$, TSS, and nitrogen expressed as mg/L; arithmetic mean. Fecal and total coliform expressed as geometric mean of MPN/100 mL.

Source: Cagle and Johnson (1994), used with permission from the American Society of Agricultural Engineers.

should be used only where soil types and separations from the groundwater are adequate. Other findings show that early involvement of stakeholders is vital to the program's success; effective system maintenance is essential; and the local learning curve allows errors that adversely affect system performance.

Boone County, Missouri

A pressure-dosed ISF was installed and monitored on the site of a three-bedroom single-family residence in Boone County, Missouri. The sand filter, followed by a shallow drainfield, replaced a lagoon and was installed to serve as a demonstration site for the county. The soil condition at this site is normally acceptable for septic tank effluent, but the top 30 to 35 cm had been removed to construct the original sewage lagoon.

The existing septic tank was found to be acceptable and was retrofitted with a pump vault and a high-head submersible pump for pressure dosing the sand filter. The sand filter effluent drained into the pump vault in the center of the sand filter, which then pressure dosed two shallow soil trenches constructed with chambers. The system was installed in October 1995, and the performance was monitored for 15 months.

The sand filter used in this study consistently produced a high quality effluent with low BOD, SS, and ammonia nitrogen (NH_4-N). Table 4 lists the various parameters studied. The aerobic environment in the sand filter is evident from the conversion rate of NH_4-N to nitrate nitrogen (NO_3-N) that also resulted in no odor problems. The fecal coliform numbers were consistently reduced by four log units.

The average electricity use by this system was 9.4

TABLE 4 EFFLUENT CHARACTERISTICS OF THE ISF IN BOONE COUNTY, MO

Parameter	Septic Tank	Sand Filter	% Change
BOD (mg/L)	297	3	99.0
TSS (mg/L)	44	3	93.2
NH_4-N (mg/L)	37	0.48	98.7
NO_3-N (mg/L)	0.07	27	384.71
Fecal coliform (#/100 mL)	4.56E+05	7.28E+01	99.9

Source: Sievers; used with permission from the American Society of Agricultural Engineers, 1998.

kWh/month, and the cost of operating two pumps in the system has been less than 70 cents per month. The high quality effluent produced by the sand filter also reduced the size of the absorption area.

The cost of an ISF system depends on the labor, materials, site, capacity of the system, and characteristics of the wastewater. The main factors that determine construction costs are land and media, which are very site-specific. Table 5 is an example of a cost estimate for a single-family residence.

Energy costs are mostly associated with the pumping of wastewater onto the filter. The energy costs typically range between 3 to 6 cents per day. Consequently, the energy costs of sand filters are lower than most small community wastewater processes, except for lagoons.

TABLE 5 COST ESTIMATES FOR SINGLE-FAMILY RESIDENCE

Item	Cost ($)
Capital Costs	
Construction costs, 1,500-gallon single compartment septic/pump tank @ 57 cents/gallon	850
ISF complete equipment package (includes dual simplex panel, pump pkg., tank risers, lids, liner, lateral kit, orifice shields, etc.)	3,200
Non-component costs	750
Engineering (includes soils evaluation, siting, design submittal, and construction inspections)	2,000
Contingencies (includes permit fees)	1,000
Land	May vary
Total Capital Costs	**10,800**
Annual O&M Costs	
Labor @ $65/hr. (2 hrs./yr.)	130/yr.
Power @10 cents/kWh	May vary
Sludge disposal	*25/yr.

*Septic tank pumping interval based on 7 years with five occupants.

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United States Environmental Protection Agency
Office of Water Washington, D.C.
EPA 832-F 99-074
September 1999

Decentralized Systems Technology Fact Sheet
Mound Systems

DESCRIPTION

The mound system was originally developed in North Dakota in the late 1940s and called the NODAK disposal system. Some soil types are unsuitable for conventional septic tank soil absorption systems. As a result, alternative systems such as the mound system can be used to overcome certain soil and site conditions.

The mound design in predominate use today was modified from the NODAK design by the University of Wisconsin-Madison in the early 1970s. Although there are now many different mound designs in use, this fact sheet will focus on the Wisconsin design. The Wisconsin mound has been widely accepted and incorporated into many state regulations.

The three principle components of a mound system are a pretreatment unit(s), dosing chamber and the elevated mound. Figure 1 illustrates a Wisconsin mound system.

APPLICABILITY

Mounds are pressure-dosed sand filters that discharge directly to natural soil. They lie above the soil surface and are designed to overcome site restrictions such as:

- Slow or fast permeability soils.
- Shallow soil cover over creviced or porous bedrock.
- A high water table.

The main purpose of a mound system is to provide sufficient treatment to the natural environment to produce an effluent equivalent to, or better than, a conventional onsite disposal system.

ADVANTAGES AND DISADVANTAGES

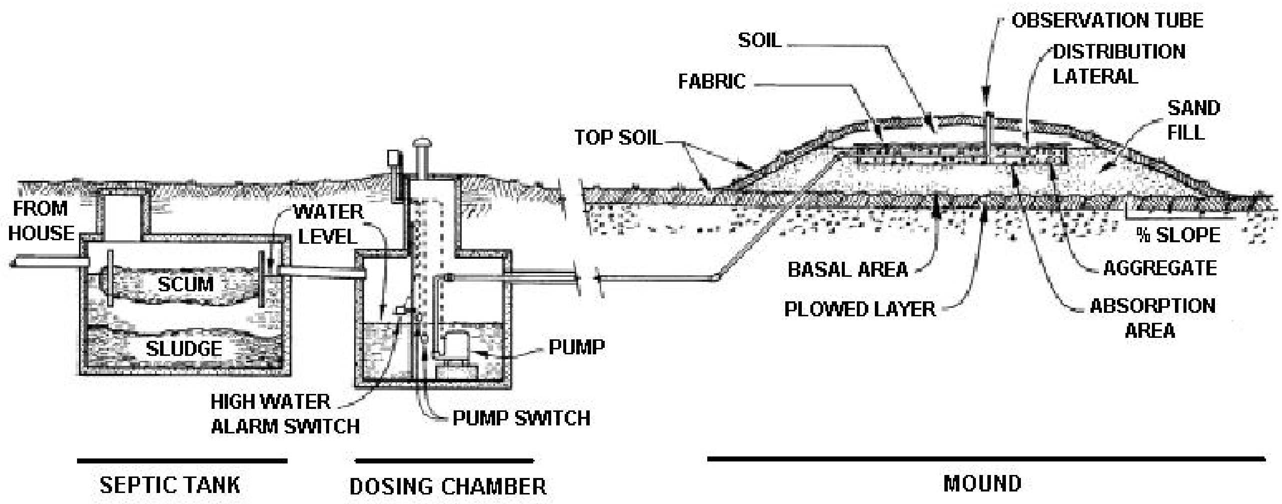
Listed below are some advantages and disadvantages of mound systems when compared to other alternative onsite systems.

Advantages

- The mound system enables use of some sites that would otherwise be unsuitable for in-ground or at-grade onsite systems.
- The natural soil utilized in a mound system is the upper most horizon, which is typically the most permeable.
- A mound system does not have a direct discharge to a ditch, stream, or other body of water.
- Construction damage is minimized since there is little excavation required in the mound area.
- Mounds can be utilized in most climates.

Disadvantages

- Construction costs are typically much higher than conventional systems.



Source: Converse and Tyler, Copyright © by the American Society of Agricultural Engineers, reprinted with permission, 1987.

FIGURE 1 SCHEMATIC OF A WISCONSIN MOUND SYSTEM

- Since there is usually limited permeable topsoil available at mound system sites. Extreme care must be taken not to damage this layer with construction equipment.
- The location of the mound may affect drainage patterns and limit land use options.
- The mound may have to be partially rebuilt if seepage or leakage occurs.
- All systems require pumps or siphons.
- Mounds may not be aesthetically pleasing in unless properly landscaped.

DESIGN CRITERIA

Two factors that determine the size and configuration of a mound are; how the effluent moves away and the rate at which it moves away from the system. The prediction of the movement and rate of movement is done from studies of the soil and site information obtained. To ensure proper performance of the mound system, the following concepts must be included in the design and construction process:

- 1) Leaving the topsoil in place but plowing it before placement of the fill.
- 2) Using a coarse sand fill meeting grain size distribution specifications.
- 3) Using pressure to uniformly distribute the effluent over the seepage area.

Soil Depth

A suitable depth of soil is required to treat the effluent before it reaches the limiting condition, such as bedrock, a high water table, or a slowly permeable soil layer. Although the separation distance varies, it is usually between 1 and 4 feet.

Site and Design

To date, siting and design experience at sites suitable for mound systems indicates that absorption systems should be long and narrow and should follow the contour (i.e., level). The more restrictive the site, the narrower and longer the system. Table 1 gives the soil criteria for a Wisconsin mound based on research and field experience.

TABLE 1 RECOMMENDED SOIL AND SITE CRITERIA FOR THE WISCONSIN MOUND SYSTEM BASED ON RESEARCH AND FIELD EXPERIENCE

Parameter	Value
Depth of high water table (permanent or seasonal)	10 in.
Depth to crevice bedrock	2 ft.
Depth to non-crevice bedrock	1 ft.
Permeability of top 10 in.	Moderately low
Site slope	25%
Filled site	Yes[a]
Over old system	Yes[b]
Flood plains	No

a Suitable according to soil criteria (texture, structure, consistence).
b The area and backfill must be treated as fill because it is a disturbed site.

Source: Converse and Tyler, 1990.

High Water

The high water table is determined by direct observation (soil boring), interpretation of soil mottling, or other criteria. The bedrock should be classified as crevice, non-crevice semi-permeable, or non-crevice impermeable. This will determine the depth of sand media required.

Percolation and Loading

Percolation tests are used in some jurisdictions to estimate the soil permeability because they are empirically related to the loading rate. Loading rates should be based on the soil texture, structure, and consistence, using the percolation test only to confirm morphological interpretations.

Mounds

Mounds can be constructed on sites with slopes up to 25%. The slope limitation is primarily for construction safety, because it is difficult to operate equipment on steep slopes, and they pose a construction hazard. From a hydraulic perspective, mounds can be positioned on steep slopes.

Sites

In the case of filled sites, fill material is placed on top of the natural soil and may consist of soil textures ranging from sand to clay. Sufficient time must be allowed for the soil structure to stabilize before constructing a system. Many more observations are required for filled areas.

When evaluating the soil loading rate for a mound over an old or failing in-ground system, the soil over the system must be considered to be disturbed, and thus, treated as a filled site. If a mound is to be placed over a large in-ground system, a detailed evaluation of the effluent movement should be done.

Mounds should not be installed in flood plains, drainage ways, or depressions unless flood protection is provided. Another siting consideration is maintaining the horizontal separation distances from water supply wells, surface waters, springs, escarpments, cuts, the boundary of the property, and the building foundation. Sites with trees and large boulders can make it difficult in preparing the site. Trees should be cut to the ground surface with tilling around stumps. The size of the mound should be increased to provide sufficient soil to accept the effluent when trees and boulders occupy a significant amount of the surface area.

The actual size of a mound system is determined by estimating the sand fill loading rate, soil (basal) loading rate, and the linear loading rate. Once these values are established, the mound can be sized for the site. The final step is to design the effluent distribution network and the pumping system.

PERFORMANCE

One factor that determines good performance is the type of sand fill material. A suitable sand is one that can adequately treat the wastewater. Suitable sand should contain 20% or less material greater than 2.0 mm and 5% or less finer than 0.053 mm. It should also have a size distribution that meets certain sieve analysis specifications, ASTMC-33 specifications, or meets limits for effective diameter and coefficient of uniformity.

For design of residential mounds, the daily wastewater volume is determined by the number of bedrooms in a house. Typical design flow requirements for individual homes are up to 150 gallons per day (gpd) per bedroom. Design specifications for mound systems are usually the same for both large and small flows for typical domestic septic tank effluent. Higher strength wastes must be pretreated to the levels of domestic septic tank effluent, or lower hydraulic loading rates may be applied.

IMPLEMENTATION

In Wisconsin, the success rate of the mound system is over 95%, which is due to their emphasis on siting, design, construction and maintenance.

Years of monitoring the performance of mound systems have shown that mounds can consistently and effectively treat and dispose of wastewater. Studies have shown evidence that some nitrogen removal does occur in mound systems when approximately 2 feet of natural unsaturated soil is below the fill material.

Mound Systems in Wisconsin (State-Wide)

Using relatively conservative soil criteria, many states have accepted the Wisconsin mound system as an alternative when conventional in-ground trenches and beds are not suitable. The Wisconsin mound system has evolved into a viable onsite system for the treatment of wastewater from individual, commercial, and community systems by overcoming some of the site limitations and meeting code requirements and guidelines.

In 1978, an experimental study was initiated to evaluate soil/site limitations for the Wisconsin mound (see Converse and Tyler, 1987a). The objectives of this research study were to determine whether the existing soil/site limitations on mounds were too restrictive and to determine the minimum soil/site limitations under which the mounds would perform without affecting public health and the environment. The experimental approach was to design, construct, and evaluate sites with mound systems that currently did not meet code requirements due to failing systems.

The sites selected for this study had to fit the objectives of the research and generate a reasonable amount of wastewater to be mound treated. The sites selected had to have:

1. Fill soil placed over natural soil.

2. A high water table where the seasonal high water table level was less than 60 cm below the ground surface.

3. Slowly permeable soils that were rated slower than moderately permeable soils.

4. Steep slopes greater than 12%.

5. Mounds over existing failing systems.

6. A combination of the above.

Over 40 experimental mounds were constructed between 1979 and 1983 on sites that did not meet the code requirements; 11 of these mounds are described in detail in this study. Site evaluations were done by certified soil scientists, plans prepared by designers were reviewed and approved by the state, and licensed contractors installed the systems with inspections by county sanitarians during construction.

The study concluded that the overall performance of the mounds was very good. The systems functioned satisfactory on filled sites, on sites with a high water table (seasonal water table 25 to 30 cm from the ground surface), on steep slope sites (up to 20 to 25%), on sites with slowly permeable soil, and on top of failing systems. Leakage occurred at the base of the mound on some sites during extremely wet conditions, but the effluent quality was good, with fecal counts generally less than 10 colonies per 100 ml in saturated toe effluent. It was found that Wisconsin mound systems can be constructed on difficult sites if the system is designed using linear loading rates, which are established based on the horizontal and vertical acceptance rates of the soil for each system.

Failure of Mound System in Wisconsin

Expansion of a Wisconsin firm's mound system in 1978, resulted in a clogging and seepage problem. The system was originally built to handle 65 employees at 750 gpd and was now serving a staff of 165. This expansion created a failure of the mound system due to hydraulic overload. To solve this problem, the mound system was expanded and a water conservation program was initiated. The expansion of the mound increased the hydraulic capacity to 2,600 gpd (Otis, 1981.)

In November 1979, the mound system failed again—this time due to a biological clogging mat. The clogging mat was removed by using 450 gallons of a 10% solution of hydrogen peroxide. The mound system was operating successfully within 2 days. However, further research indicates that for structured natural soils other than sand, hydrogen peroxide may reduce the soil infiltration rate, and thus, may not be an effective procedure to eliminate soil clogging.

A third failure occurred in January 1980, again due to hydraulic overload. The firm had expanded its employee base to 215 employees, with an average daily flow of 3,000 gpd. There was no room available to expand the mound system itself, so the firm redesigned the pumping chamber to avoid large peak flows, allowing the mound system to receive optimum dosing without failure.

OPERATION AND MAINTENANCE

The septic tank and dosing chamber should be checked for sludge and scum buildup and pumped as needed to avoid carryover of solids into the mound. Screens or filters can be used to prevent large solids from escaping the septic tank. The dosing chamber, pump, and floats should be checked annually and replaced or repaired as necessary. It is critical that the septic tank and dosing chamber be watertight. In addition, electrical parts and conduits must be checked for corrosion. Flushing of the laterals annually is recommended.

When a mound system is properly installed and maintained, it should last for a long period of time. In general, the maintenance required for mounds is minimal. However, as with any system, poor maintenance could lead to early system failure. Possible problems that can occur in an improperly designed or constructed mound system include:

- Ponding in the absorption area of the mound.
- Seepage out of the side or toe of the mound.
- Spongy areas developing on the side, top, or toe of the mound
- Clogging of the distribution system.

Practices that can be used to reduce the possibility of failure in a mound system include:

- Installing water-saving devices to reduce the hydraulic overload to the system.
- Calibrating pumps and utilizing event counters and running time meters.
- Timed dosing to dose equally sized doses on regular intervals throughout the day.
- Diverting surface water and roof drainage away from the mound.
- Preventing traffic on the mound area.
- Installing inspection tubes in the mound to check for ponding.
- Keeping deep-rooted plants (shrubs and trees) off the mound.
- Planting and maintaining grass or other vegetative cover on the mound surface to prevent erosion and to maximize water uptake.
- Stand-by power for the pump.

Follow all instructions recommended by the manufacturer. All equipment must be tested and calibrated as recommended by the equipment manufacturer. A routine operation and maintenance (O&M) schedule should be developed and followed for any mound system in addition to checking local codes.

COSTS

The cost of a mound system is dependent on design costs, energy costs, the contractor used, the manufacturers, land, and the characteristics of the wastewater. Table 2 lists some typical capital and O&M costs for a mound system serving a three-bedroom single home at a flow rate of 450 gpd (150 gallons per bedroom). Septic tank costs were estimated at $1 per treated gallon. It should be noted however, that costs will vary from site to site. To keep construction costs to a minimum, use good quality and local materials, when available.

TABLE 2 TYPICAL COST ESTIMATE FOR A MOUND SYSTEM (SINGLE HOME)

Item	Cost ($)
Capital Costs	
Construction Costs	
Septic tank (1000 gallon concrete tank)	1,000
Dosing chamber (includes pump and controls)	2,000
Mound structure	6,000
Total Construction Costs	**9.000**
Non-Component Costs	
Site evaluation	500
Permits	250
Total Costs	**9,750**
Annual O&M Costs	
Labor @$20/hr.	20 per year
Power @8 cents/kWh	35 per year
Septic tank pumping	75 to 150 every 3 years

Source: Ayres Associates, Inc., 1997.

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United States Environmental Protection Agency | Office of Water Washington, D.C. | EPA 832-F-00-048 September 2000

Water Efficiency Technology Fact Sheet
Oil Recirculating Toilets

DESCRIPTION

Oil recirculating toilets are "non-water carriage" toilets, meaning that they do not require water to operate. Instead, human wastes are deposited into mineral oil, or another similarly non-aqueous medium. The water-based urine and the solid waste products are separated from the oil medium, which is then filtered and reused in the toilet. The waste is separated and contained in a holding tank until it can be disposed of at an approved facility.

APPLICABILITY

Oil recirculating toilets are not widely used in the United States. Nevertheless, they are an option for numerous situations, including:

- Rural areas where no municipal sewage system exists, especially where installation of septic systems is impractical or prohibitively expensive due to shallow soils, deep slopes, high groundwater levels or extremely cold weather conditions.
- Remotely located roadside rest areas, where connection to a piped sanitary system is impractical and the cost prohibitive.
- Large marine vessels, which are faced with a prohibition against discharging untreated waste into bodies of water and must either hold accumulated wastes in tanks or must treat before discharge.
- Areas where water is scarce, either due to drought or to other environmental conditions, and the need to conserve water motivates consideration of alternative, water-free toilet systems.
- Where community, environmental, and health organizations have concerns regarding existing sewage disposal practices, especially seepage of contaminants into local water supplies from improperly functioning septic or other treatment systems, or exposure of residents to improperly dumped waste products from rudimentary collection pails, or "honey buckets."

ADVANTAGES AND DISADVANTAGES

Advantages

- Requires no water.
- Coast Guard-approved for marine use.

Disadvantages

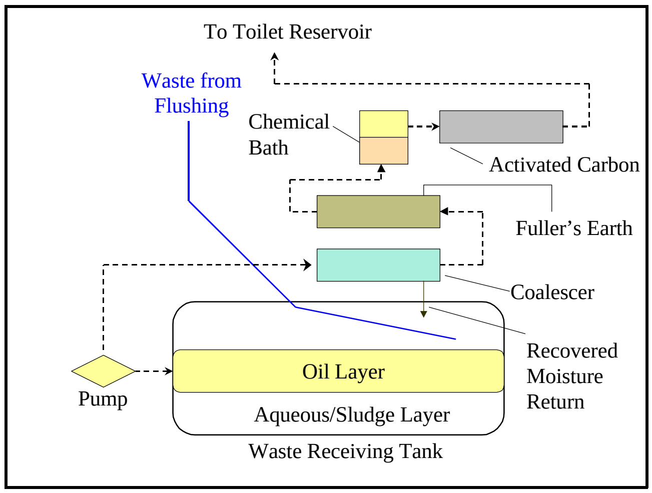
- Emulsion formation between oil and urine can cause an incomplete separation.
- Recycled flushing media can become discolored and unpleasant smelling with use.
- Flushing media eventually deteriorate and must be replaced.
- System requires a relatively large space for the holding tank and equipment for separation/purification.
- Disposal of separated waste products may be problematic due to oil content.

DESIGN CRITERIA

An oil recirculating toilet consists of a commode-type receptacle, a storage tank typically 53 cubic feet in size, and a recycling system (see Bishton *et. al*. for the following discussion). The flushing bowl is coated with Teflon or a similar coating product to minimize adherence of the waste products to the bowl. A closet reservoir with a float-controlled refilling mechanism is often attached to the toilet bowl for flushing, akin to conventional water-flushing systems. The simplest separation device simply relies on waste products settling to the bottom of the holding tank while the oil-based flushing medium floats to the top. The flushing medium can then be drawn from the top of the mixture for reuse, and waste products can be removed from the bottom periodically. In this way, waste products are stored in the same tank used for separation.

When the flushing medium is drawn from the reservoir for reuse, it is first directed to a coalescer, which is designed to remove suspended particulate matter and water droplets. Water and particulate matter thus removed are drained to the holding tank via a return line. The pump used to transfer liquid from the holding tank to the coalescer should be a reciprocating piston pump or other pump that will minimize break-up of aqueous droplets in the non-aqueous medium. From the coalescer, the flushing medium then passes through a filtering medium (such as Fuller's earth) to remove any residual water not caught by the coalescer. The fluid then passes through a disinfecting chemical bath, typically a hypochlorite solution, to treat odorous and pathogenic contaminants present. Following disinfection, the fluid is finally directed through another adsorbent medium (usually activated carbon) to remove non-water-borne dissolved contaminants.

To prolong the life of the adsorbent and filtering medium, it is desirable for the fluid drawn from the holding tank to be as water- and particle-free as possible before recycling begins. For this reason, commode-and-tank design should be configured so as to prevent mixing of the holding tank contents to the greatest extent possible. Ramping systems are often used to reduce the velocity of waste products entering the tank from the commode and to create an oblique angle of entry. Moreover, waste products from the commode should be deposited on the opposite side of the tank from the intake for fluid recycling and the intake point should be situated at the top-most liquid layer of the tank. Finally, the size of the holding tank relative to that of the commode, closet reservoir, and filtration system should be designed so that at least eight minutes of settling time is allowed in the holding tank between uses. For a five gallon toilet/closet reservoir capacity, and a filtration unit capacity of five gallons, the holding tank should have a capacity of twenty gallons. Figure 1 illustrates the primary components of a typical mineral oil recirculating toilet system.



Source: Parsons Engineering Science, 1999.

FIGURE 1 PRIMARY COMPONENTS OF A TYPICAL MINERAL OIL RECIRCULATING TOILET SYSTEM

PERFORMANCE

The Commonwealth of Virginia Department of Transporation (VDOT) installed oil recirculating toilets at four rest areas on the interstate highway I-64 in the late 1970s, all of which have been operative to date. According to VDOT's Director of Special Operations, complaints of odors and of discolored flushing medium have been common. A representative of the property management company responsible for maintaining the toilet systems, DTH Contract Services, stated that the oil recirculating systems require constant maintenance. Transport of the oil, which has a higher viscosity than water, causes pipe vibration with each flush leading to development of leaks on a regular basis. Moreover, the multi-component assembly of filters and cleansing solutions requires frequent checking and changing. During the high-traffic season, from April through October, a full-time operator needs to be on hand to repair leaks and tend to maintenance, taking approximately 5 hours per day. Pump-out of the holding tank must be performed approximately two to three times a week. In the off season, maintenance consumes approximately 2.5 hours per day. According to both the Commonwealth's Director of Special Operations and the property manager, plans are underway to remove the oil recirculating toilet systems and replace them with traditional, water-flushed toilets.

OPERATION AND MAINTENANCE

Removal of waste products from the tank bottom must be performed on a routine basis. For proper system functioning, the filtration and adsorbent media and chemical disinfection solution must be replaced when exhausted. Mineral oil flushing media lost through waste disposal must be replenished and the total volume of oil used must be replaced periodically because of breakdown.

COSTS

The cost of purchase and installation varies widely depending on the capacity of the system and application (shipboard versus land). Maintenance costs will include replacement of filters and sanitizing solutions, replacement of flushing medium lost through tank pump-out, and routine holding tank pump-out. Operation cost will include electricity to run the pumping system. The State of Virginia experienced additional maintenance costs associated with fixing leaks and other malfunctions.

Most or possibly all of the U.S. companies that once made recirculating toilets have since discontinued production of these systems. As a result, cost estimates for package systems are currently not available.

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Other Related Fact Sheets

Incinerating Toilets
EPA 832-F-99-072
September 1999

Composting Toilets
EPA 832-F-99-066
September 1999

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United States Environmental Protection Agency | Office of Water Washington, D.C. | EPA 832-F-99-063 September 1999

Wastewater Technology Fact Sheet
Ozone Disinfection

DESCRIPTION

Disinfection is considered to be the primary mechanism for the inactivation/destruction of pathogenic organisms to prevent the spread of waterborne diseases to downstream users and the environment. It is important that wastewater be adequately treated prior to disinfection in order for any disinfectant to be effective. Table 1 lists some common microorganisms found in domestic wastewater and the diseases associated with them.

Ozone is produced when oxygen (O_2) molecules are dissociated by an energy source into oxygen atoms and subsequently collide with an oxygen molecule to form an unstable gas, ozone (O_3), which is used to disinfect wastewater. Most wastewater treatment plants generate ozone by imposing a high voltage alternating current (6 to 20 kilovolts) across a dielectric discharge gap that contains an oxygen-bearing gas. Ozone is generated onsite because it is unstable and decomposes to elemental oxygen in a short amount of time after generation.

Ozone is a very strong oxidant and virucide. The mechanisms of disinfection using ozone include:

- Direct oxidation/destruction of the cell wall with leakage of cellular constituents outside of the cell.
- Reactions with radical by-products of ozone decomposition.
- Damage to the constituents of the nucleic acids (purines and pyrimidines).
- Breakage of carbon-nitrogen bonds leading to depolymerization.

TABLE 1 INFECTIOUS AGENTS POTENTIALLY PRESENT IN UNTREATED DOMESTIC WASTEWATER

Organism	Disease Caused
Bacteria	
Escherichia coli (enterotoxigenic)	Gastroenteritis
Leptospira (spp.)	Leptospirosis
Salmonella typhi	Typhoid fever
Salmonella (=2,100 serotypes)	Salmonellosis
Shigella (4 spp.)	Shigellosis (bacillary dysentery)
Vibrio cholerae	Cholera
Protozoa	
Balantidium coli	Balantidiasis
Cryptosporidium parvum	Cryptosporidiosis
Entamoeba histolytica	Amebiasis (amoebic dysentery)
Giardia lamblia	Giardiasis
Helminths	
Ascaris lumbricoides	Ascariasis
T. solium	Taeniasis
Trichuris trichiura	Trichuriasis
Viruses	
Enteroviruses (72 types, e.g., polio, echo, and coxsackie viruses)	Gastroenteritis, heart anomalies, meningitis
Hepatitis A virus	Infectious hepatitis
Norwalk agent	Gastroenteritis
Rotavirus	Gastroenteritis

Source: Adapted from Crites and Tchobanoglous, 1998.

When ozone decomposes in water, the free radicals hydrogen peroxy (HO_2) and hydroxyl (OH) that are formed have great oxidizing capacity and play an active role in the disinfection process. It is generally believed that the bacteria are destroyed because of protoplasmic oxidation resulting in cell wall disintegration (cell lysis).

The effectiveness of disinfection depends on the susceptibility of the target organisms, the contact time, and the concentration of the ozone. A line diagram of the ozonation process is shown in Figure 1. The components of an ozone disinfection system include feed-gas preparation, ozone generation, ozone contacting, and ozone destruction.

Air or pure oxygen is used as the feed-gas source and is passed to the ozone generator at a set flow rate. The energy source for production is generated by electrical discharge in a gas that contains oxygen. Ozone generators are typically classified by:

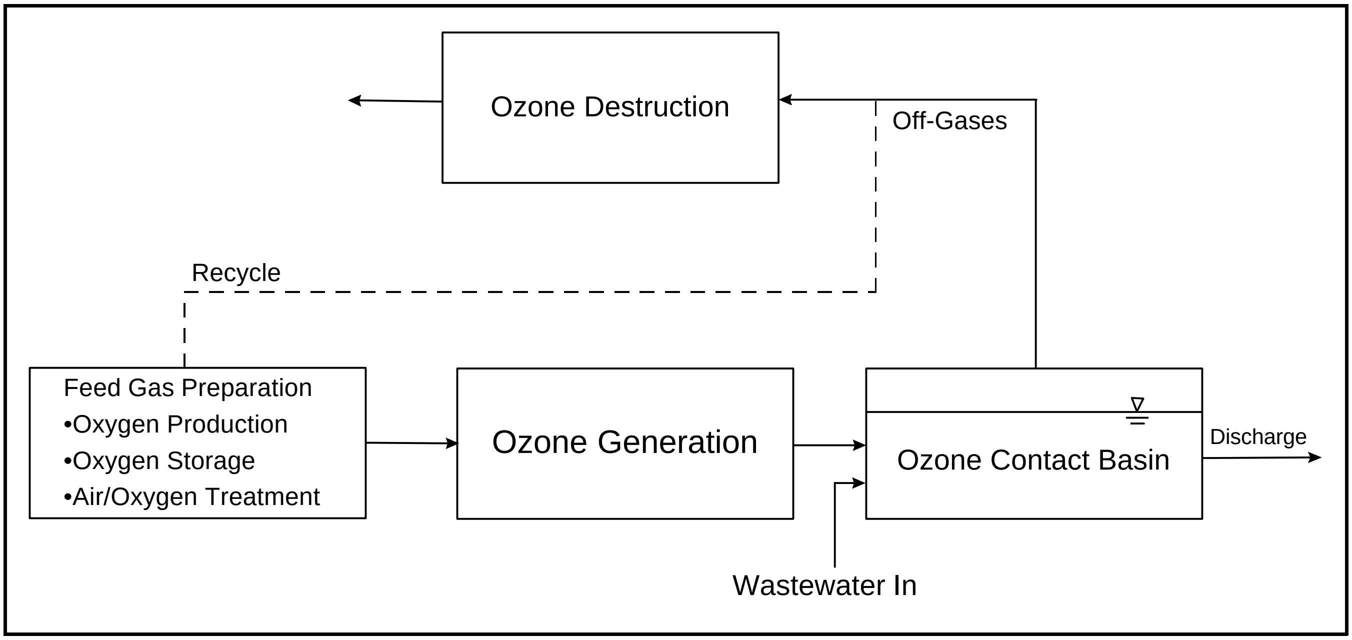
- The control mechanism (either a voltage or frequency unit).
- The cooling mechanism (either water, air, or water plus oil).
- The physical arrangement of the dielectrics (either vertical or horizontal).
- The name of the inventor.

However, generators manufactured by different companies have unique characteristics but also have some common configurations.

The electrical discharge method is the most common energy source used to produce ozone. Extremely dry air or pure oxygen is exposed to a controlled, uniform high-voltage discharge at a high or low frequency. The dew point of the feed gas must be -60°C (-76°F) or lower. The gas stream generated from air will contain about 0.5 to 3.0% ozone by weight, whereas pure oxygen will form approximately two to four times that concentration.

After generation, ozone is fed into a down-flow contact chamber containing the wastewater to be disinfected. The main purpose of the contactor is to transfer ozone from the gas bubble into the bulk liquid while providing sufficient contact time for disinfection. The commonly used contactor types diffused bubble (co-current and counter-current) are positive pressure injection, negative pressure (Venturi), mechanically agitated, and packed tower. Because ozone is consumed quickly, it must be contacted uniformly in a near plug flow contactor.

The off-gases from the contact chamber must be treated to destroy any remaining ozone before



Source: U.S. EPA, 1986.

FIGURE 1 OZONE PROCESS SCHEMATIC DIAGRAM

release into the atmosphere. Therefore, it is essential to maintain an optimal ozone dosage for better efficiency. When pure oxygen is used as the feed-gas, the off-gases from the contact chamber can be recycled to generate ozone or for reuse in the aeration tank. The ozone off-gases that are not used are sent to the ozone destruction unit or are recycled.

The key process control parameters are dose, mixing, and contact time. An ozone disinfection system strives for the maximum solubility of ozone in wastewater, as disinfection depends on the transfer of ozone to the wastewater. The amount of ozone that will dissolve in wastewater at a constant temperature is a function of the partial pressure of the gaseous ozone above the water or in the gas feed stream.

It is critical that all ozone disinfection systems be pilot tested and calibrated prior to installation to ensure they meet discharge permit requirements for their particular sites.

APPLICABILITY

Ozone disinfection is generally used at medium to large sized plants after at least secondary treatment. In addition to disinfection, another common use for ozone in wastewater treatment is odor control.

Ozone disinfection is the least used method in the U.S. although this technology has been widely accepted in Europe for decades. Ozone treatment has the ability to achieve higher levels of disinfection than either chlorine or UV, however, the capital costs as well as maintenance expenditures are not competitive with available alternatives. Ozone is therefore used only sparingly, primarily in special cases where alternatives are not effective.

ADVANTAGES AND DISADVANTAGES

Advantages

- Ozone is more effective than chlorine in destroying viruses and bacteria.

- The ozonation process utilizes a short contact time (approximately 10 to 30 minutes).

- There are no harmful residuals that need to be removed after ozonation because ozone decomposes rapidly.

- After ozonation, there is no regrowth of microorganisms, except for those protected by the particulates in the wastewater stream.

- Ozone is generated onsite, and thus, there are fewer safety problems associated with shipping and handling.

- Ozonation elevates the dissolved oxygen (DO) concentration of the effluent. The increase in DO can eliminate the need for reaeration and also raise the level of DO in the receiving stream.

Disadvantages

- Low dosage may not effectively inactivate some viruses, spores, and cysts.

- Ozonation is a more complex technology than is chlorine or UV disinfection, requiring complicated equipment and efficient contacting systems.

- Ozone is very reactive and corrosive, thus requiring corrosion-resistant material such as stainless steel.

- Ozonation is not economical for wastewater with high levels of suspended solids (SS), biochemical oxygen demand (BOD), chemical oxygen demand, or total organic carbon.

- Ozone is extremely irritating and possibly toxic, so off-gases from the contactor must be destroyed to prevent worker exposure.

- The cost of treatment can be relatively high in capital and in power intensiveness.

PERFORMANCE

Belmont and Southport Wastewater Treatment Plants in Indianapolis, Indiana

In 1985, the City of Indianapolis, Indiana, operated two-125 million gallons per day (mgd) advanced wastewater treatment plants at Belmont and Southport using ozone disinfection. The rated capacity of the oxygen-fed ozone generators was 6,380 pounds per day, which was used to meet geometric mean weekly and monthly disinfection permit limits for fecal coliforms of 400 and 200 per 100 ml, respectively.

Disinfection was required at both Indianapolis treatment plants from April 1 through October 31, 1985. Equipment performance characteristics were evaluated during the 1985 disinfection season and consequently, disinfection performance was optimized during the 1986 season. The capital cost of both ozone systems represented about 8% of the plants' total construction cost. The ozone system's Operation and Maintenance (O&M) cost represented about 1.9% and 3.7% of the total plant O&M costs at the Belmont and Southport plants, respectively.

In 1989, a disciplined process monitoring and control program was initiated. Records indicated a significant effect on process performance due to changes in wastewater flow, contactor influent fecal coliform concentration, and ozone demand.

Previously, ozone demand information was unknown. Several studies were conducted to enable better control of the ozone disinfection process. These included the recent installation of a pilot-scale ozone contactor to allow the plant staff to measure ozone demand on a daily basis. Also, tracer tests were conducted to measure contactor short-circuiting potential. Results demonstrated a noticeable benefit of adding additional baffles. Results also indicated operating strategies that could maximize fecal coliform removal, such as reducing the number of contactors in service at low and moderate flow conditions.

OPERATION AND MAINTENANCE

Ozone generation uses a significant amount of electrical power. Thus, constant attention must be given to the system to ensure that power is optimized for controlled disinfection performance.

There must be no leaking connections in or surrounding the ozone generator. The operator must on a regular basis monitor the appropriate subunits to ensure that they are not overheated. Therefore, the operator must check for leaks routinely, since a very small leak can cause unacceptable ambient ozone concentrations. The ozone monitoring equipment must be tested and calibrated as recommended by the equipment manufacturer.

Like oxygen, ozone has limited solubility and decomposes more rapidly in water than in air. This factor, along with ozone reactivity, requires that the ozone contactor be well covered and that the ozone diffuses into the wastewater as effectively as possible.

Ozone in gaseous form is explosive once it reaches a concentration of 240 g/m^3. Since most ozonation systems never exceed a gaseous ozone concentration of 50 to 200 g/m^3, this is generally not a problem. However, ozone in gaseous form will remain hazardous for a significant amount of time thus, extreme caution is needed when operating the ozone gas systems.

It is important that the ozone generator, distribution, contacting, off-gas, and ozone destructor inlet piping be purged before opening the various systems or subsystems. When entering the ozone contactor, personnel must recognize the potential for oxygen deficiencies or trapped ozone gas in spite of best efforts to purge the system. The operator should be aware of all emergency operating procedures required if a problem occurs. All safety equipment should be available for operators to use in case of an emergency. Key O&M parameters include:

- Clean feed gas with a dew point of -60°C (-76°F), or lower, must be delivered to the ozone generator. If the supply gas is moist, the reaction of the ozone and the moisture will yield a very corrosive condensate on the inside of the ozonator. The output of the generator could be lowered by the formation of nitrogen oxides (such as nitric acid).

- Maintain the required flow of generator coolant (air, water, or other liquid).

- Lubricate the compressor or blower in accordance with the manufacturer's specifications. Ensure that all compressor sealing gaskets are in good condition.

- Operate the ozone generator within its design parameters. Regularly inspect and clean the ozonator, air supply, and dielectric assemblies, and monitor the temperature of the ozone generator.

- Monitor the ozone gas-feed and distribution system to ensure that the necessary volume comes into sufficient contact with the wastewater.

- Maintain ambient levels of ozone below the limits of applicable safety regulations.

COSTS

The cost of ozone disinfection systems is dependent on the manufacturer, the site, the capacity of the plant, and the characteristics of the wastewater to be disinfected. Ozonation costs are generally high in comparison with other disinfection techniques.

Table 2 shows a typical cost estimate (low to medium) for ozone disinfection system used to disinfect one mgd of wastewater. The costs are based on the wastewater having passed through both primary and secondary treatment processes of a properly designed system (the BOD content does not exceed 30 milligrams per liter [mg/L] and the SS content is less than 30 mg/L). In general, costs are largely influenced by site-specific factors, and thus, the estimates that follow are typical values and can vary from site to site.

Because the concentration of ozone generated from either air or oxygen is so low, the transfer efficiency to the liquid phase is a critical economic consideration. For this reason, the contact chambers used are usually very deep and covered.

The overall cost of an ozonation system is also largely determined by the capital and O&M expenses. The annual operating costs for ozone disinfection include power consumption, and supplies, miscellaneous equipment repairs, and staffing requirements.

Another consideration for the cost is that each ozonation system is site specific, depending on the plant's effluent limitations. Chemical suppliers should be contacted for specific cost information.

TABLE 2 TYPICAL COST ESTIMATE OF AN OZONE DISINFECTION

Items	Costs
Capital Costs	
Oxygen feed gas and compressor	$245,500
Contact vessel (500 gpm)	$4,000-5,000
Destruct unit:	
Small (around 30 cfm)	$800
Large (around 120)	$1,000-1,200
Non-component costs	$35,000
Engineering	$12,000-15,000
Contingencies	30%
Annual O&M Costs	
Labor	$12,000
Power	90 kW
Other (filter replacements, compressor oil, spare dielectric, etc.)	$6,500

gpm = gallons per minute
cfm = cubic feet per minute

Source: Champion Technology, 1998.

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Wastewater Technology Fact Sheet
Package Plants

DESCRIPTION

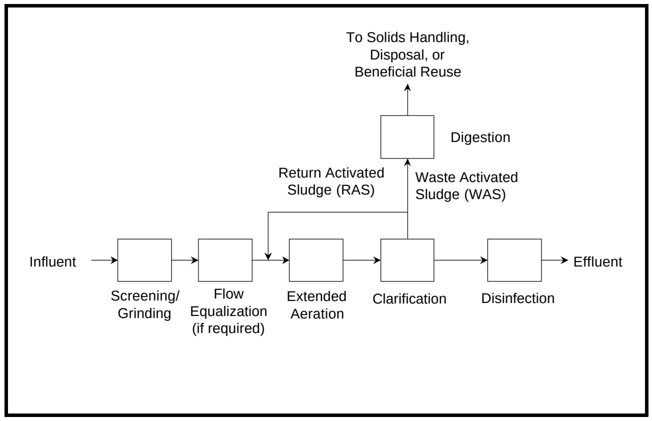
Package plants are pre-manufactured treatment facilities used to treat wastewater in small communities or on individual properties. According to manufacturers, package plants can be designed to treat flows as low as 0.002 MGD or as high as 0.5 MGD, although they more commonly treat flows between 0.01 and 0.25 MGD (Metcalf and Eddy, 1991).

The most common types of package plants are extended aeration plants, sequencing batch reactors, oxidation ditches, contact stabilization plants, rotating biological contactors, and physical/chemical processes (Metcalf and Eddy, 1991). This fact sheet focuses on the first three, all of which are biological aeration processes.

Extended aeration plants

The extended aeration process is one modification of the activated sludge process which provides biological treatment for the removal of biodegradable organic wastes under aerobic conditions. Air may be supplied by mechanical or diffused aeration to provide the oxygen required to sustain the aerobic biological process. Mixing must be provided by aeration or mechanical means to maintain the microbial organisms in contact with the dissolved organics. In addition, the pH must be controlled to optimize the biological process and essential nutrients must be present to facilitate biological growth and the continuation of biological degradation.

As depicted in Figure 1, wastewater enters the treatment system and is typically screened immediately to remove large suspended, settleable, or floating solids that could interfere with or damage equipment downstream in the process. Wastewater may then pass through a grinder to reduce large particles that are not captured in the screening process. If the plant requires the flow to be regulated, the effluent will then flow into equalization basins which regulate peak wastewater flow rates. Wastewater then enters the aeration chamber, where it is mixed and oxygen is provided to the microorganisms. The mixed liquor then flows to a clarifier or settling chamber where most microorganisms settle to the bottom of the clarifier and a portion are pumped back to the incoming wastewater at the beginning of the plant. This returned material is the return activated sludge (RAS). The material that is not returned, the waste activated sludge (WAS), is removed for treatment and disposal. The clarified wastewater then flows over a weir and into a collection channel before being diverted to the disinfection system.



Source: Parsons Engineering Science, 2000.

FIGURE 1 PROCESS FLOW DIAGRAM FOR A TYPICAL EXTENDED AERATION PLANT

Extended aeration package plants consist of a steel tank that is compartmentalized into flow equalization, aeration, clarification, disinfection, and aerated sludge holding/digestion segments. Extended aeration systems are typically manufactured to treat wastewater flow rates between 0.002 to 0.1 MGD. Use of concrete tanks may be preferable for larger sizes (Sloan, 1999).

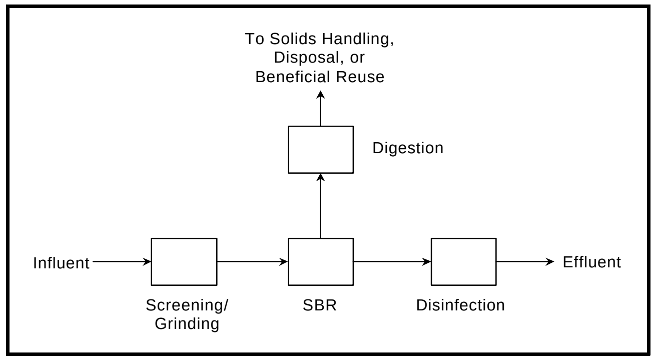
Extended aeration plants are usually started up using "seed sludge" from another sewage plant. It may take as many as two to four weeks from the time it is seeded for the plant to stabilize (Sloan, 1999).

Sequencing batch reactors

A sequencing batch reactor (SBR) is a variation of the activated sludge process. As a fill and draw or batch process, all biological treatment phases occur in a single tank. This differs from the conventional flow through activated sludge process in that SBRs do not require separate tanks for aeration and sedimentation (Kappe, 1999). SBR systems contain either two or more reactor tanks that are operated in parallel, or one equalization tank and one reactor tank. The type of tank used depends on the wastewater flow characteristics (e.g. high or low volume). While this setup allows the system to accommodate continuous influent flow, it does not provide for disinfection or holding for aerated sludge.

There are many types of SBR systems, including continuous influent/time based, non-continuous influent/time based, volume based, an intermittent cycle system (a SBR that utilizes jet aeration), and various other system modifications based on different manufacturer designs. The type of SBR system used depends on site and wastewater characteristics as well as the needs of the area or community installing the unit. Package SBRs are typically manufactured to treat wastewater flow rates between 0.01 and 0.2 MGD; although flow rates can vary based on the system and manufacturer.

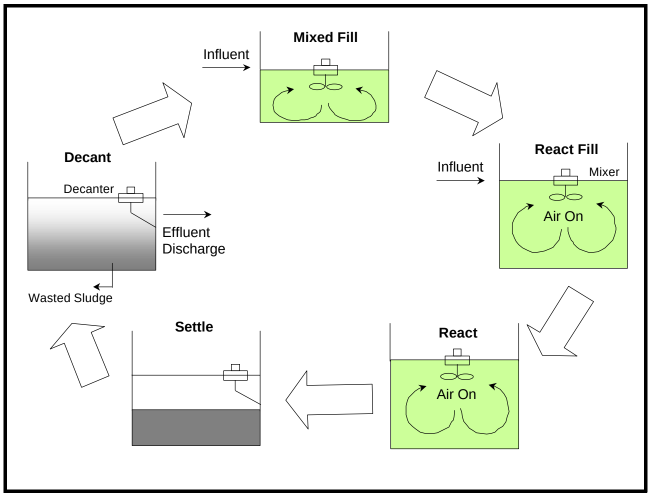
As seen in Figure 2, the influent flow first goes through a screening process before entering the SBR. The waste is then treated in a series of batch phases within the SBR to achieve the desired effluent concentration. The sludge that is wasted from the SBR moves on to digestion and eventually to solids handling, disposal, or beneficial reuse. The treated effluent then moves to disinfection. An equalization tank is typically needed before the disinfection unit in batch SBRs in order to store large volumes of water. If the flow is not equalized, a sizable filter may be necessary to accommodate the large flow of water entering the disinfection system. In addition, SBR systems typically have no primary or secondary clarifiers as settling takes place in the SBR.



Source: Parsons Engineering Science, 2000.

FIGURE 2 PROCESS FLOW DIAGRAM FOR A TYPICAL SBR

There are normally five phases in the SBR treatment cycle: fill, react, settle, decant, and idle. The length of time that each phase occurs is controlled by a programmable logic controller (PLC), which allows the system to be controlled from remote locations (Sloan, 1999). In the fill phase, raw wastewater enters the basin, where it is mixed with settled biomass from the previous cycle. Some aeration may occur during this phase. Then, in the react phase, the basin is aerated, allowing oxidation and nitrification to occur. During the settling phase, aeration and mixing are suspended and the solids are allowed to settle. The treated wastewater is then discharged from the basin in the decant phase. In the final phase, the basin is idle as it waits for the start of the next cycle. During this time, part of the solids are removed from the basin and disposed of as waste sludge (Kappe, 1999). Figure 3 shows this sequence of operation in an SBR.



Source: CASS Water Engineering, Inc., 2000.

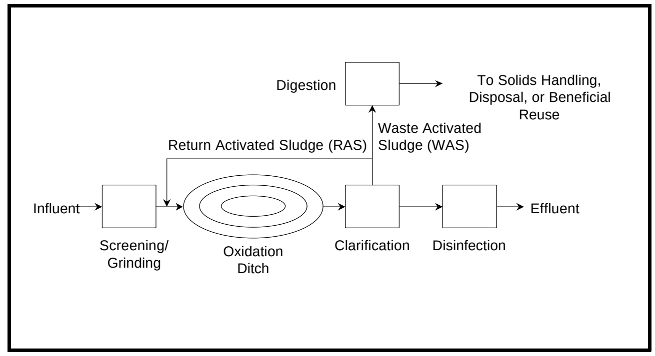
FIGURE 3 SBR SEQUENCE OF OPERATION

Sludge wasting is an important step in the SBR process and largely affects system performance. It is not considered a basic phase since the sludge is not wasted at a specific time period during the cycle. The quantity and rate of wasting is determined by performance requirements. An SBR system does not require an RAS system, as both aeration and settling occur in the same tank. This prevents any sludge from being lost during the react step and eliminates the need to return sludge from the clarifier to the aeration chamber (Metcalf and Eddy, 1991).

Oxidation ditches

An oxidation ditch, a modified form of the activated sludge process, is an aerated, long term, complete mix process. Many systems are designed to operate as extended aeration systems. Typical oxidation ditch treatment systems consist of a single or multi-channel configuration within a ring, oval, or horseshoe-shaped basin. Horizontally or vertically mounted aerators provide aeration, circulation, and oxygen transfer in the ditch.

Package oxidation ditches are typically manufactured in sizes that treat wastewater flow rates between 0.01 and 0.5 MGD. As seen in Figure 4, raw wastewater is first screened before entering the oxidation ditch. Depending on the system size and manufacturer type, a grit chamber may be required. Once inside the ditch, the wastewater is aerated with mechanical surface or submersible aerators (depending on manufacturer design) that propel the mixed liquor around the channel at velocities high enough to prevent solids deposition. The aerator ensures that there is sufficient oxygen in the fluid for the microbes and adequate mixing to ensure constant contact between the organisms and the food supply (Lakeside, 1999).



Source: Parsons Engineering Science, 1999.

FIGURE 4 PROCESS FLOW DIAGRAM FOR A TYPICAL OXIDATION DITCH

Oxidation ditches tend to operate in an extended aeration mode consisting of long hydraulic and solids retention times which allow more organic matter to break down. Treated sewage moves to the settling tank or final clarifier, where the biosolids and water separate. Wastewater then moves to other treatment processes while sludge is removed. Part of it is returned to the ditch as RAS, while the rest is removed from the process as the waste activated sludge (WAS). WAS is wasted either continuously or daily and must be stabilized prior to disposal or beneficial reuse.

APPLICABILITY

In general, package treatment plants are applicable for areas with a limited number of people and small wastewater flows. They are most often used in remote locations such as trailer parks, highway rest areas, and rural areas.

Extended aeration plants

Extended aeration package plants are typically used in small municipalities, suburban subdivisions, apartment complexes, highway rest areas, trailer parks, small institutions, and other sites where flow rates are below 0.1 MGD. These systems are also useful for areas requiring nitrification.

Sequencing batch reactors

Package plant SBRs are suitable for areas with little land, stringent treatment requirements, and small wastewater flows. More specifically, SBRs are appropriate for RV parks or mobile homes, campgrounds, construction sites, rural schools, hotels, and other small applications. These systems are also useful for treating pharmaceutical, brewery, dairy, pulp and paper, and chemical wastes. While constant cycles with time-fixed process phases are sufficient in most cases, phases should be individually adapted and optimized for each plant. SBRs are also suited for sites that need minimal operator attendance and that have a wide range of inflow and/or organic loadings.

Industries with high BOD loadings, such as chemical or food processing plants, will find SBRs useful for treating wastewater. These systems are also suitable for facilities requiring nitrification, denitrification, and phosphorous removal. Most significantly, SBRs are applicable for areas where effluent requirements can change frequently and become stricter, as these systems have tremendous flexibility to change treatment options. However, part of the economic advantage of the SBR process is lost when advanced treatment processes must be added downstream since intermediate equalization is normally required.

Oxidation ditches

Oxidation ditches are suitable for facilities that require nutrient removal, have limitations due to the nature of the site, or want a biological system that saves energy with limited use of chemicals unless required for further treatment. Oxidation ditch technology can be used to treat any type of wastewater that is responsive to aerobic degradation. In addition, systems can be designed for denitrification and phosphorous removal.

Types of industries utilizing oxidation ditches include: food processing, meat and poultry packing, breweries, pharmaceutical, milk processing, petrochemical, and numerous other types. Oxidation ditches are particularly useful for schools, small industries, housing developments, and small communities. Ultimately, this technology is most applicable for places that have a large amount of land available.

ADVANTAGES AND DISADVANTAGES

Some advantages and disadvantages of package plants are listed below.

Extended aeration plants

Advantages

- Plants are easy to operate, as many are manned for a maximum of two or three hours per day.

- Extended aeration processes are often better at handling organic loading and flow fluctuations, as there is a greater detention time for the nutrients to be assimilated by microbes.

- Systems are easy to install, as they are shipped in one or two pieces and then mounted on an onsite concrete pad, above or below grade.

- Systems are odor free, can be installed in most locations, have a relatively small footprint, and can be landscaped to match the surrounding area.

- Extended aeration systems have a relatively low sludge yield due to long sludge ages, can be designed to provide nitrification, and do not require a primary clarifier.

Disadvantages

- Extended aeration plants do not achieve denitrification or phosphorus removal without additional unit processes.

- Flexibility is limited to adapt to changing effluent requirements resulting from regulatory changes.

- A longer aeration period requires more energy.

- Systems require a larger amount of space and tankage than other "higher rate" processes, which have shorter aeration detention times.

Sequencing batch reactors

Advantages

- SBRs can consistently perform nitrification as well as denitrification and phosphorous removal.
- SBRs have large operational flexibility.
- The ability to control substrate tension within the system allows for optimization of treatment efficiency and control over nitrogen removal, filamentous organisms, and the overall stability of the process.
- Since all the unit processes are operated in a single tank, there is no need to optimize aeration and decanting to comply with power requirements and lower decant discharge rates.
- Sludge bulking is not a problem.
- Significant reductions in nitrate nitrogen can occur by incorporating an anoxic cycle in the system.
- SBRs have little operation and maintenance problems.
- Systems require less space than extended aeration plants of equal capacity.
- SBRs can be manned part time from remote locations, and operational changes can be made easily.
- The system allows for automatic and positive control of mixed liquor suspended solids (MLSS) concentration and solids retention time (SRT) through the use of sludge wasting.

Disadvantages

- It is hard to adjust the cycle times for small communities.
- Post equalization may be required where more treatment is needed.
- Sludge must be disposed frequently.
- Specific energy consumption is high.

Oxidation ditches

Advantages

- Systems are well-suited for treating typical domestic waste, have moderate energy requirements, and work effectively under most types of weather.
- Oxidation ditches provide an inexpensive wastewater treatment option with both low operation and maintenance costs and operational needs.
- Systems can be used with or without clarifiers, which affects flexibility and cost.
- Systems consistently provide high quality effluent in terms of TSS, BOD, and ammonia levels.
- Oxidation ditches have a relatively low sludge yield, require a moderate amount of operator skill, and are capable of handling shock and hydraulic loadings.

Disadvantages

- Oxidation ditches can be noisy due to mixer/aeration equipment, and tend to produce odors when not operated correctly.
- Biological treatment is unable to treat highly toxic waste streams.
- Systems have a relatively large footprint.
- Systems have less flexibility should regulations for effluent requirements change.

DESIGN CRITERIA

Table 1 lists typical design parameters for extended aeration plants, SBRS, and oxidation ditches.

TABLE 1 TYPICAL DESIGN PARAMETERS FOR PACKAGE PLANTS

	Extended Aeration	SBR	Oxidation Ditch
BOD_5 loading (F:M) (lb BOD_5/ lb MLVSS)	0.05 - 0.15	0.05 - 0.30	0.05 - 0 30
Oxygen Required Avg. at 20EC (lb/lb BOD_5 applied)	2 - 3	2 - 3	2 - 3
Oxygen Required Peak at 20EC (value x avg. flow)	1.5 - 2.0	1.25 - 2.0	1.5 - 2.0
MLSS (mg/L)	3000 -6000	1500 -5000	3000 -6000
Detention Time (hours)	18 - 36	16 - 36	18 - 36
Volumetric Loading (lb BOD_5/d/ 10^3 cu ft)	10 - 25	5 - 15	5 - 30

Source: Adapted from Metcalf and Eddy, 1991 and WEF, 1998.

Extended aeration plants

Package extended aeration plants are typically constructed from steel or concrete. If the system is small enough, the entire system will arrive as one unit that is ready to be installed. If the system is larger, the clarifier, aeration chamber, and chlorine tank are delivered as separate units, which are then assembled on-site (WEF, 1985).

Key internal components of extended aeration treatment plants consist of the following: transfer pumps to move wastewater between the equalization and aeration zones; a bar screen and/or grinder to decrease the size of large solids; an aeration system consisting of blowers and diffusers for the equalization, aeration, and sludge holding zones; an airlift pump for returning sludge; a skimmer and effluent weir for the clarifier; and UV, liquid hypochlorite, or tablet modules used in the disinfection zone. Blowers and the control panel containing switches, lights, and motor starters are typically attached to either the top or one side of the package plant (Sloan, 1999).

Biological organisms within the system need sufficient contact time with the organic material in order to produce effluent of an acceptable quality. Typical contact time for extended aeration package plants is approximately 18-24 hours. The contact time, daily flow rate, influent parameters, and effluent parameters determine the size of the aeration tank where air is used to mix wastewater and to supply oxygen to promote biological growth. A package extended aeration system is sized based on the average volume of wastewater produced within a twenty-four hour period. Although provisions are made for some peaking factor, a flow equalization system may be necessary to prevent overloading of the system from inconsistent flow rates in the morning and evening. Equalization allows the wastewater to be delivered to the treatment plant at more manageable flow rates (WEF, 1985).

Systems should be installed at sites where wastewater collection is possible by gravity flow. In addition, the site should be stable, well drained, and not prone to flooding. The facility should be installed at least 30 meters (100 feet) from all residential areas and be in accordance with all health department regulations or zoning restrictions (WEF, 1985).

In order to ensure ease of operation and maintenance, extended aeration systems should be installed so that the tank walls extend nearly 0.15 meters (6 inches) above ground. This will supply insulation in the winter, prevent surface runoff from infiltrating the system, and allow the system to be serviced readily. If a plant is installed below ground, it must have distinct diversion ditching or extension walls in order to prevent surface water infiltration into the plant. When the plant is installed completely above ground, it may be necessary to provide insulation for cold weather and walkways for easy maintenance (WEF, 1985).

Sequencing batch reactors

Important internal components include an aeration system, which typically consists of diffusers and a blower; a floating mixer; an effluent decanter; a pump for withdrawing sludge; and a sequence of liquid level floats. The PLC and the control panel are usually positioned within a nearby control building (Sloan, 1999).

When the wastewater flow rate at the site is less than 0.05 MGD, a single, prefabricated steel tank can be used. This tank is divided into one SBR basin, one aerobic sludge digester, and one influent pump well. Concrete tanks may also be used, but in North America are not as cost effective as steel for small systems. If the plant must be able to treat 0.1 to 1.5 MGD, multiple concrete SBR basins are commonly used (CASS, 1999).

The design of SBR systems can be based on carbonaceous BOD removal only or both carbonaceous and nitrogenous BOD removal. The system can be expanded to achieve optimum nitrification and carbonaceous removal by operating primarily in an oxic state with few anoxic periods such as during settle and decant.

Denitrification and biological phosphorous removal can be promoted by providing adequate anoxic periods after intense aerobic cycles. This allows DO to be dissipated and nitrate to be used by the consuming organism and released as elemental nitrogen. By introducing an anaerobic process after the anoxic process, bacteria conducive to excess phosphorous uptake will develop. Phosphorous will be released in the anaerobic phase, but additional phosphorous is incorporated into the cell mass during subsequent aerobic cycles. Since the excess phosphorous is incorporated in the cell mass, cell wastage must be practiced to achieve a net phosphorous removal. Anaerobic conditions should be avoided in treating the waste sludge since they may result in the release of the phosphorous.

A low food to microorganism (F:M) ratio SBR system designed for an average municipal flow pattern will usually have an operating cycle duration of four hours, or six cycles per day. For a two reactor system, there will be twelve cycles per day and for a four reactor system, twenty-four cycles per day. The distribution and number of cycles per day can be adjusted based on specific treatment requirements or to accommodate alternate inflow patterns.

Cycle sequences are time controlled with sufficient volume provided to handle design flow rates. If incoming flow is significantly less than the design flow, only a portion of the reactor capacity is utilized and aeration time periods can be reduced to save energy and prevent over aeration. If flow rates are greater than usual resulting from storm runoff, the control system detects the high rise in the reactor and modifies the cycle to integrate peak flow rates. This will shorten the aeration, settle, and decant sequences, minimize the anoxic sequence (if supplied), and provide more cycles per day. As a result, hydraulic surges are incorporated and the diluted wastewater is processed in less time. In order to make the above optimizations, the logic control must be provided by the PLC (Kappe, 1999).

Small SBRs can experience a variety of problems associated with operation, maintenance, and loadings. Therefore, more conservative design criteria are typically used due to the wide range of organic and hydraulic loads generated from small communities. This type of design utilizes a lower F:M ratio and longer hydraulic retention time (HRT) and SRT (CASS, 1999).

Oxidation ditches

Key components of a typical oxidation ditch include a screening device, an influent distributor (with some systems), a basin or channel, aeration devices (mechanical aerators, jet mixers, or diffusers, depending on the manufacturer), a settling tank or final clarifier (with some systems), and an RAS system (with some systems). Typically, the basin and the clarifier are individually sized to meet the specific requirements of each facility. These components are often built to share a common wall in order to reduce costs and save space (Lakeside, 1999).

Concrete tanks are typically used when installing package plant oxidation ditches. This results in lower maintenance costs as concrete tanks do not require periodic repainting or sand blasting. Fabricated steel or a combination of steel and concrete can also be used for construction, depending on site conditions (Lakeside, 1999).

The volume of the oxidation ditch is determined based on influent wastewater characteristics, effluent discharge requirements, HRT, SRT, temperature, mixed liquor suspended solids (MLSS), and pH. It may be necessary to include other site specific parameters to design the oxidation ditch as well.

Some oxidation ditches do not initially require clarifiers, but can later be upgraded and expanded by adding clarifiers, changing the type of process used, or adding additional ditches (Kruger, 1999).

PERFORMANCE

The performance of package plants in general can be affected by various operational and design issues (Metcalf and Eddy, 1991).

- Large and sudden temperature changes
- Removal efficiency of grease and scum from the primary clarifier (except with oxidation ditches that do not use primary clarifiers)
- Incredibly small flows that make designing self-cleansing conduits and channels difficult
- Fluctuations in flow, BOD_5 loading, and other influent parameters
- Hydraulic shock loads, or the large fluctuations in flow from small communities
- Sufficient control of the air supply rate

Extended aeration plants

Extended aeration plants typically perform extremely well and achieve effluent quality as seen in Table 2. If chemical precipitation is used, total phosphorous (TP) can be < 2 mg/L. In some cases, extended aeration systems result in effluent with < 15 mg/L BOD and < 10 mg/L TSS.

TABLE 2 EXTENDED AERATION PERFORMANCE

	Typical Effluent Quality	Aldie WWTP (monthly average)
BOD (mg/L)	< 30 or <10	5
TSS (mg/L)	< 30 or <10	17
TP (mg/L)	< 2*	**
NH_3-N (mg/L)	< 2	**

* May require chemicals to achieve.
** DEQ does not require monitoring of these parameters.

Source: Sloan, 1999 and Broderick, 1999.

Aldie Wastewater Treatment Plant

The Aldie Wastewater Treatment Plant, located in Aldie, Virginia, is an extended aeration facility which treats an average of 0.0031 MGD with a design flow of 0.015 MGD. This technology was chosen because it would allow the area to meet permit requirements while minimizing land use. The plant consists of an influent chamber which directs the flow to two parallel aeration basins, parallel clarifiers, and a UV disinfection system.

Sequencing batch reactors

The treatment performance of package plant SBRs is largely influenced by the plant operator. While the process requires little assistance, training programs are available to teach operators how to become skilled with small plant operations. SBRs perform well, often matching the removal efficiency of extended aeration processes. Systems can typically achieve the effluent limitations listed in Table 3.

In addition, SBR systems have demonstrated a greater removal efficiency of carbonaceous BOD than other systems due to optimization of microbial activity via anoxic stress and better utilization of applied oxygen in the cyclic system. The system can consistently provide carbonaceous BOD effluent levels of 10 mg/L.

TABLE 3 SBR PERFORMANCE

	Typical Effluent	Harrah WWTP	
		% Removal	Effluent
BOD (mg/L)	10	98	3
TSS (mg/L)	10	98	3
NH_3 (mg/L)	< 1	97	0.6

Source: Sloan, 1999 and Reynolds, 1999.

Harrah Wastewater Treatment Plant

The Harrah wastewater treatment plant in Oklahoma treats an average wastewater flow of 0.223 MGD. The SBR has achieved tertiary effluent quality without filtration from the time it was first installed. Pretreatment involves an aerated grit chamber and comminutor. Waste activated sludge is taken to a settling pond where the settled sludge is dredged annually. A nitrogen removal study performed for nine months confirmed that nitrification and denitrification occur consistently without special operator care.

Oxidation Ditches

Although the manufacturer's design may vary, most oxidation ditches typically achieve the effluent limitations listed in Table 4. With modifications, some oxidation ditches can achieve TN removal to # 5 mg/L and TP removal with biological means.

City of Ocoee Wastewater Treatment Plant

Currently, the wastewater treatment plant in Ocoee, Florida accepts an average flow of 1.1 to 1.2 MGD. The city chose to use an oxidation ditch because it was an easy technology for the plant staff to understand and implement. The facility is also designed for denitrification without the use of chemical additives. Nitrate levels consistently test at 0.8 to 1.0 mg/L with limits of 12 mg/L (Holland, 1999). Table 4 indicates how well the Ocoee oxidation ditch performs.

TABLE 4 OXIDATION DITCH PERFORMANCE

	Typical Effluent Quality		Ocoee WWTP	
	With 2° Clarifier	With Filter	% Removal	Effluent
CBOD (mg/L)	#10	5	> 97	4.8
TSS (mg/L)	#10	5	> 97	0.32
TP (mg/L)	2	1	NA	NA
$N\text{-}NO_3$ (mg/L)	NA	NA	> 95	0.25

Note: 2° = secondary. NA = not available.

Source: Kruger, 1999 and Holland, 1999.

OPERATION AND MAINTENANCE

Operation requirements will vary depending on state requirements for manning package treatment systems. Manning requirements for these systems may typically be less then eight hours a day. Each type of system has additional operational procedures that should be followed to keep the system running properly. Owners of these systems must be sure to follow all manufacturer’s recommendations for routine and preventative maintenance requirements. Each owner should check with the manufacturer to determine essential operation and maintenance (O&M) requirements.

Depending on state requirements, most systems must submit regular reports to local agencies. In addition, system operators must make safety a primary concern. Wastewater treatment manuals and federal and state regulations should be checked to ensure safe operation of these systems.

Extended aeration plants

Operational procedures for these systems consist of performing fecal coliform tests on the effluent to ensure adequate disinfection and making periodic inspections on dissolved oxygen levels (DO) and MLSS concentrations in the aeration compartment. Sludge-volume index (SVI) tests in the clarifier must also be performed to determine how well the sludge is settling. Other sampling and analyses will be required on the effluent in accordance with state regulations.

Typical maintenance steps for extended aeration systems include checking motors, gears, blowers, and pumps to ensure proper lubrication and operation. Routine inspection of equipment is also recommended to ensure proper operation. Check with the manufacturer for specific O&M requirements.

Sequencing batch reactors

To ensure proper functioning of the system, O&M must be provided for several pieces of equipment. Operational procedures include sampling and monitoring of DO, pH, and MLSS levels. Additional sampling and analyses on the effluent will be required based on state regulations.

Maintenance requirements include regular servicing of aeration blowers, which is usually performed when greasing is done, and monthly inspection of belts on the blowers to determine if they need to be adjusted or replaced. Submersible pumps require routine inspections and servicing as required by the manufacturer. The decanter will require monthly greasing. Additional O&M may be required depending on system requirements. Check with the manufacturer for specific maintenance requirements.

Oxidation ditches

Depending on the manufacturer's design, typical operational procedures for oxidation ditches include monitoring of DO, pH, MLSS, and various other types of sampling and analyses.

Maintenance steps include periodically inspecting the aerator, regularly greasing rotors, and following manufacturer recommendations for maintenance of the pumps. Operators should follow all manufacturer recommendations for operation and maintenance of the equipment.

COSTS

Costs are site specific and generally depend on flow rate, influent wastewater characteristics, effluent discharge requirements, additional required equipment, solids handling equipment, and other site specific conditions. Manufacturers should be contacted for specific cost information.

Extended aeration plants

As provided by Aeration Products, Inc., smaller extended aeration package plants designed to treat less than 0.02 MGD cost approximately $4 to $6 per gallon of water treated, based on capital costs. For larger plants, capital costs will be approximately between $2 to $2.50 per gallon of wastewater treated. Maintenance processes for these plants are labor-intensive and require semi-skilled personnel, and are usually completed through routine contract services. Maintenance cost averages $350 per year.

Table 5 provides the cost estimates for various extended aeration packages. These costs include the entire package plant, as well as a filtration unit.

TABLE 5 COST ESTIMATES FOR EXTENDED AERATION

Flow (MGD)	Estimated Budget Cost per Gallon ($)
0.015	9-11
0.04	7
1.0	1.3

Note: Larger flow rates are available from the manufacturer. Estimated cost per gallon was determined based on the mid-flow range.

Source: Parsons Engineering Science, 1999.

Sequencing batch reactors

The capital cost per capita for small SBR plants is greater than for large SBR plants. Approximate equipment costs disregarding concrete or steel tanks costs are provided in Table 6. Operation energy costs are likely to be higher for small SBR plants than for larger plants as a result of numerous loadings.

TABLE 6 COST ESTIMATES FOR SBRs

Flow (MGD)	Estimated Budget Cost per Gallon ($)
0.01	4-5
0.05	2
0.2	0.7
1.0	0.25

Note: Larger flow rates are available from the manufacturer. Estimated cost per gallon was determined based on the mid-flow range.

Source: CASS, 1999.

System costs will vary, depending on the specific job. Factors influencing cost include average and peak flow, tank type, type of aeration system used, effluent requirements, and site constraints. Operation and maintenance costs are site specific and may range from $800 to $2,000 dollars per million gallons treated. Labor and maintenance requirements may be reduced in SBRs because clarifiers and RAS pumps may not be necessary. On the other hand, maintenance requirements for the more sophisticated valves and switches associated with SBRs may be more costly than for other systems.

Oxidation ditches

Table 7 lists budget cost estimates for various sizes of oxidation ditches. Operation and maintenance costs for oxidation ditches are significantly lower than other secondary treatment processes. In comparison to other treatment technologies, energy requirements are low, operator attention is minimal, and chemical addition is not required.

TABLE 7 COST ESTIMATES FOR OXIDATION DITCHES

Flow Range (MGD)	Budget Price ($)	Estimated Budget Cost per Gallon ($)
0 - 0.03	80,000	5.33
0.03 - 0.06	91,000	2.02
0.06 - 1.1	97,500	0.17
1.1 - 1.7	106,000	0.08
1.7 - 2.5	114,700	0.05

Note: Larger flow rates are available from the manufacturer. Estimated cost per gallon was determined based on the mid-flow range.

Source: Lakeside, 1999.

REFERENCES

Other Related Fact Sheets

Sequencing Batch Reactors
EPA 932-F-99-073
September 1999

Oxidation Ditches
EPA 832-F-00-013
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Aerobic Treatment
EPA 832-F-00-031
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Other EPA Fact Sheets can be found at the following web address:
http://www.epa.gov/owmitnet/mtbfact.htm

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Agency

Wastewater Technology Fact Sheet

Sewers, Pressure

DESCRIPTION

Conventional Wastewater Collection System

Conventional wastewater collection systems transport sewage from homes or other sources by gravity flow through buried piping systems to a central treatment facility. These systems are usually reliable and consume no power. However, the slope requirements to maintain adequate flow by gravity may require deep excavations in hilly or flat terrain, as well as the addition of sewage pump stations, which can significantly increase the cost of conventional collection systems. Manholes and other sewer appurtenances also add substantial costs to conventional collection systems.

Alternative

Alternative wastewater collection systems can be cost effective for homes in areas where traditional collection systems are too expensive to install and operate. Pressure sewers are used in sparsely populated or suburban areas in which conventional collection systems would be expensive. These systems generally use smaller diameter pipes with a slight slope or follow the surface contour of the land, reducing excavation and construction costs.

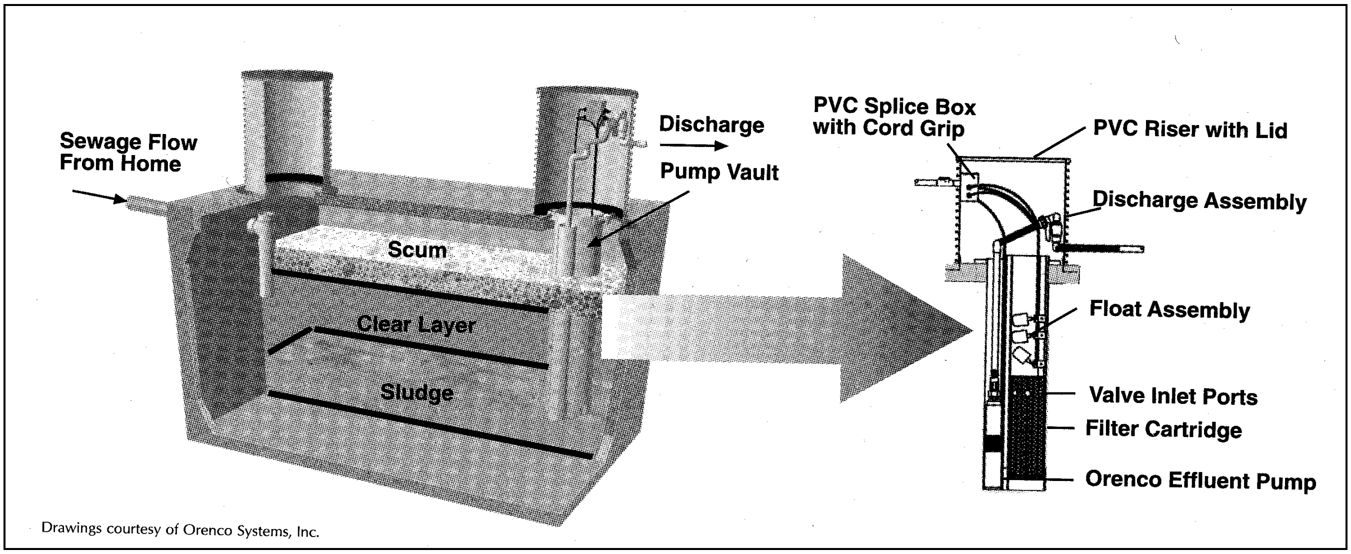
Pressure sewers differ from conventional gravity collection systems because they break down large solids in the pumping station before they are transported through the collection system. Their watertight design and the absence of manholes eliminates extraneous flows into the system. Thus, alternative sewer systems may be preferred in areas that have high groundwater that could seep into the sewer, increasing the amount of wastewater to be treated. They also protect groundwater sources by keeping wastewater in the sewer. The disadvantages of alternative sewage systems include increased energy demands, higher maintenance requirements, and greater on-lot costs. In areas with varying terrain and population density, it may prove beneficial to install a combination of sewer types.

This fact sheet discusses a sewer system that uses pressure to deliver sewage to a treatment system. Systems that use vacuum to deliver sewage to a treatment system are discussed in the *Vacuum Sewers* Fact Sheet, while gravity flow sewers are discussed in the *Small Diameter Sewers* Fact Sheet.

Pressure Sewers

Pressure sewers are particularly adaptable for rural or semi-rural communities where public contact with effluent from failing drain fields presents a substantial health concern. Since the mains for pressure sewers are, by design, watertight, the pipe connections ensure minimal leakage of sewage. This can be an important consideration in areas subject to groundwater contamination. Two major types of pressure sewer systems are the **septic tank effluent pump (STEP)** system and the **grinder pump (GP)**. Neither requires any modification to plumbing inside the house.

In STEP systems, wastewater flows into a conventional septic tank to capture solids. The liquid effluent flows to a holding tank containing a pump and control devices. The effluent is then pumped and transferred for treatment. Retrofitting existing septic tanks in areas served by septic tank/drain field systems would seem to present an opportunity for cost savings, but a large number (often a majority) must be replaced or expanded over the life of the system because of insufficient capacity, deterioration of concrete tanks, or leaks. In a GP system, sewage flows to a vault where a grinder pump grinds the solids and discharges the sewage into a pressurized pipe system. GP systems do not require a septic tank but may require more horsepower than STEP systems because of the grinding action. A GP system can result in significant capital cost



Source: C. Falvey, 2001.

FIGURE 1 TYPICAL SEPTIC TANK EFFLUENT PUMP

savings for new areas that have no septic tanks or in older areas where many tanks must be replaced or repaired. Figure 1 shows a typical septic tank effluent pump, while Figure 2 shows a typical grinder pump used in residential wastewater treatment.

The choice between GP and STEP systems depends on three main factors, as described below:

Cost: On-lot facilities, including pumps and tanks, will account for more than 75 percent of total costs, and may run as high as 90 percent. Thus, there is a strong motivation to use a system with the least expensive on-lot facilities. STEP systems may lower on-lot costs because they allow some gravity service connections due to the continued use of a septic tank. In addition, a grinder pump must be more rugged than a STEP pump to handle the added task of grinding, and, consequently, it is more expensive. If many septic tanks must be replaced, costs will be significantly higher for a STEP system than a GP system.

Downstream Treatment: GP systems produce a higher TSS that may not be acceptable at a downstream treatment facility.

Low Flow Conditions: STEP systems will better tolerate low flow conditions that occur in areas with highly fluctuating seasonal occupancy and those with slow build out from a small initial population to the ultimate design population. Thus, STEP systems may be better choices in these areas than GP systems.

APPLICABILITY

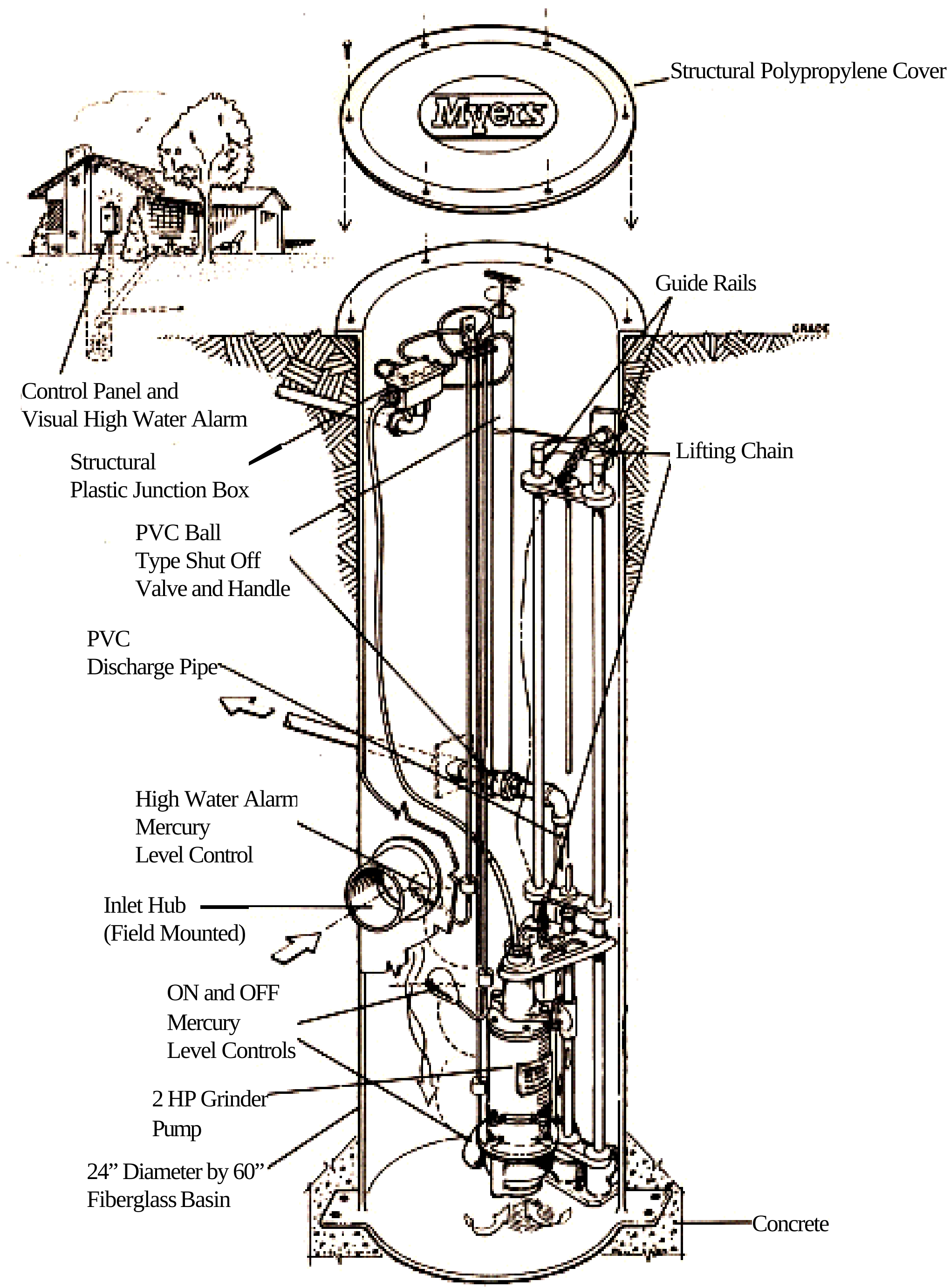
Pressure sewer systems are most cost effective where housing density is low, where the terrain has undulations with relatively high relief, and where the system outfall must be at the same or a higher elevation than most or all of the service area. They can also be effective where flat terrain is combined with high ground water or bedrock, making deep cuts and/or multiple lift stations excessively expensive. They can be cost effective even in densely populated areas where difficult construction or right of way conditions exist, or where the terrain will not accommodate gravity sewers.

Since pressure systems do not have the large excess capacity typical of conventional gravity sewers, they must be designed with a balanced approach, keeping future growth and internal hydraulic performance in mind.

ADVANTAGES AND DISADVANTAGES

Advantages

Pressure sewer systems that connect several residences to a “cluster” pump station can be less expensive than



Source: F.E. Meyers Company, 2000.

FIGURE 2 TYPICAL GRINDER PUMP

conventional gravity systems. On-property facilities represent a major portion of the capital cost of the entire system and are shared in a cluster arrangement. This can be an economic advantage since on-property components are not required until a house is constructed and are borne by the homeowner. Low front-end investment makes the present-value cost of the entire system lower than that of conventional gravity sewerage, especially in new development areas where homes are built over many years.

Because wastewater is pumped under pressure, gravity flow is not necessary and the strict alignment and slope restrictions for conventional gravity sewers can be relaxed. Network layout does not depend on ground contours: pipes can be laid in any location and extensions can be made in the street right-of-way at a relatively small cost without damage to existing structures.

Other advantages of pressure sewers include:

Material and trenching costs are significantly lower because pipe size and depth requirements are reduced.

Low-cost clean outs and valve assemblies are used rather than manholes and may be spaced further apart than manholes in a conventional system.

Infiltration is reduced, resulting in reductions in pipe size.

The user pays for the electricity to operate the pump unit. The resulting increase in electric bills is small and may replace municipality or community bills for central pumping eliminated by the pressure system.

Final treatment may be substantially reduced in hydraulic and organic loading in STEP systems. Hydraulic loadings are also reduced for GP systems.

Because sewage is transported under pressure, more flexibility is allowed in siting final treatment facilities and may help reduce the length of outfall lines or treatment plant construction costs.

Disadvantages

Requires much institutional involvement because the pressure system has many mechanical components throughout the service area.

The operation and maintenance (O&M) cost for a pressure system is often higher than a conventional gravity system due to the high number of pumps in use. However, lift stations in a conventional gravity sewer can reverse this situation.

Annual preventive maintenance calls are usually scheduled for GP components of pressure sewers. STEP systems also require pump-out of septic tanks at two to three year intervals.

Public education is necessary so the user knows how to deal with emergencies and how to avoid blockages or other maintenance problems.

The number of pumps that can share the same downstream force main is limited.

Power outages can result in overflows if standby generators are not available.

Life cycle replacement costs are expected to be higher because pressure sewers have a lower life expectancy than conventional systems.

Odors and corrosion are potential problems because the wastewater in the collection sewers is usually septic. Proper ventilation and odor control must be provided in the design and non-corrosive components should be used. Air release valves are often vented to soil beds to minimize odor problems and special discharge and treatment designs are required to avoid terminal discharge problems.

DESIGN CRITERIA

Many different design flows can be used in pressure systems. When positive displacement GP units are used, the design flow is obtained by multiplying the pump discharge by the maximum number of pumps expected to be operating simultaneously. When centrifugal pumps are used, the equation used is $Q= 20 + 0.5D$, where Q is the flow in gpm and D is the number of homes served. The operation of the system under various assumed conditions should be simulated by computer to check design adequacy. No allowances for infiltration and inflow are required. No minimum velocity is generally used in design, but GP systems must attain three to five feet per second at least once per day. A Hazen-Williams coefficient, (C) = 130 to 140, is suggested for hydraulic analysis. Pressure mains generally use 50 mm (2 inch) or larger PVC pipe (SDR 21) and rubber-ring joints or solvent welding to assemble the pipe joints. High-density polyethylene (HDPE) pipe with fused joints is widely used in Canada. Electrical requirements, especially for GP systems, may necessitate rewiring and electrical service upgrading in the service area. Pipes are generally buried to at least the winter frost penetration depth; in far northern sites insulated and heat-traced pipes are generally buried at a minimal depth. GP and STEP pumps are sized to accommodate the hydraulic grade requirements of the system. Discharge points must use drop inlets to minimize odors and corrosion. Air release valves are placed at high points in the sewer and often are vented to soil beds. Both STEP and GP systems can be assumed to be anaerobic and potentially odorous if subjected to turbulence (stripping of gases such as H_2S).

PERFORMANCE

STEP

When properly installed, septic tanks typically remove about 50 percent of BOD, 75 percent of suspended solids, virtually all grit, and about 90 percent of grease, reducing the likelihood of clogging. Also, wastewater reaching the treatment plant will be weaker than raw sewage. Typical average values of BOD and TSS are 110 mg/L and 50 mg/L, respectively. On the other hand, septic tank effluent has virtually zero dissolved oxygen.

Primary sedimentation is not required to treat septic tank effluent. The effluent responds well to aerobic treatment, but odor control at the headworks of the treatment plant should receive extra attention.

The small community of High Island, Texas, was concerned that septic tank failures were damaging a local area frequented by migratory birds. Funds and materials were secured from the EPA, several state agencies, and the Audubon Society to replace the undersized septic tanks with larger ones equipped with STEP units and low pressure sewerage ultimately discharging to a constructed wetland. This system is expected to achieve an effluent quality of less than 20 mg/L each of BOD and TSS, less than 8 mg/L ammonia, and greater than 4 mg/L dissolved oxygen (Jensen 1999).

In 1996, the village of Browns, Illinois, replaced a failing septic tank system with a STEP system discharging to low pressure sewers and ultimately to a recirculating gravel filter. Cost was a major concern to the residents of the village, who were used to average monthly sewer bills of $20. Conditions in the village were poor for conventional sewer systems, making them prohibitively expensive. An alternative low pressure-STEP system averaged only $19.38 per month per resident, and eliminated the public health hazard caused by the failed septic tanks (ICAA, 2000).

GP Treatment

The wastewater reaching the treatment plant will typically be stronger than that from conventional systems because infiltration is not possible. Typical design average concentrations of both BOD and TSS are 350 mg/L (WPCF, 1986).

GP/low pressure sewer systems have replaced failing septic tanks in Lake Worth, Texas (Head, et. al., 2000); Beach Drive in Kitsap County, Washington (Mayhew and Fitzwater, 1999); and Cuyler, New York (Earle, 1998). Each of these communities chose alternative systems over conventional systems based on lower costs and better suitability to local soil conditions.

OPERATION AND MAINTENANCE

Routine operation and maintenance requirements for both STEP and GP systems are minimal. Small systems that serve 300 or fewer homes do not usually require a full-time staff. Service can be performed by personnel from the municipal public works or highway department. Most system maintenance activities involve responding to homeowner service calls usually for electrical control problems or pump blockages. STEP systems also require pumping every two to three years.

TABLE 1 RELATIVE CHARACTERISTICS OF ALTERNATIVE SEWERS

Sewer Type	Slope Requirement	Construction Cost in Rocky, High Groundwater Sites	Operation and Maintenance Requirements	Ideal Power Requirements
Conventional	Downhill	High	Moderate	None*
Pressure				
STEP	None	Low	Moderate-high	Low
GP	None	Low	Moderate-high	Moderate

* Power may be required for lift stations
Source: Small Flows Clearinghouse, 1992.

The inherent septic nature of wastewater in pressure sewers requires that system personnel take appropriate safety precautions when performing maintenance to minimize exposure to toxic gases, such as hydrogen sulfide, which may be present in the sewer lines, pump vaults, or septic tanks. Odor problems may develop in pressure sewer systems because of improper house venting. The addition of strong oxidizing agents, such as chlorine or hydrogen peroxide, may be necessary to control odor where venting is not the cause of the problem.

Generally, it is in the best interest of the municipality and the homeowners to have the municipality or sewer utility be responsible for maintaining all system components. General easement agreements are needed to permit access to on-site components, such as septic tanks, STEP units, or GP units on private property.

COSTS

Pressure sewers are generally more cost-effective than conventional gravity sewers in rural areas because capital costs for pressure sewers are generally lower than for gravity sewers. While capital cost savings of 90 percent have been achieved, no universal statement of savings is possible because each site and system is unique. Table 1 presents a generic comparison of common characteristics of sanitary sewer systems that should be considered in the initial decision-making process on whether to use pressure sewer systems or conventional gravity sewer systems.

Table 2 presents data from recent evaluations of the costs of pressure sewer mains and appurtenances (essentially the same for GP and STEP), including items specific to each type of pressure sewer. Purchasing pumping stations in volume may reduce costs by up to 50 percent. The linear cost of mains can vary by a factor of two to three, depending on the type of trenching equipment and local costs of high-quality backfill and pipe. The local geology and utility systems will impact the installation cost of either system.

The homeowner is responsible for energy costs, which will vary from $1.00 to $2.50/month for GP systems, depending on the horsepower of the unit. STEP units generally cost less than $1.00/month.

Preventive maintenance should be performed annually for each unit, with monthly maintenance of other mechanical components. STEP systems require periodic pumping of septic tanks. Total O&M costs average $100-200 per year per unit, and include costs for troubleshooting, inspection of new installations, and responding to problems.

Mean time between service calls (MTBSC) data vary greatly, but values of 4 to 10 years for both GP and STEP units are reasonable estimates for quality installations.

TABLE 2 AVERAGE INSTALLED UNIT COSTS FOR PRESSURE SEWER MAINS & APPURTENANCES

Item	Unit Cost ($)
2 inch mains	9.40/LF
3 inch mains	10.00/LF
4 inch mains	11.30/LF
6 inch mains	15.80/LF
8 inch mains	17.60/LF
Extra for mains in asphalt concrete pavement	6.30/LF
2 inch isolation valves	315/each
3 inch isolation valves	345/each
4 inch isolation valves	440/each
6 inch isolation valves	500/each
8 inch isolation valves	720/each
Individual Grinder pump	1,505/each
Single (simplex) package pump system	5,140/each
package installation	625 - 1,880/each
Automatic air release stations	1,255/each

Source: U.S. EPA, 1991.

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Other Related Fact Sheets

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http://www.epa.gov/owm/mtb/mtbfact.htm

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United States Environmental Protection Agency
Office of Water Washington, D.C.
EPA 932-F-99-068 September 1999

Decentralized Systems Technology Fact Sheet
Septage Treatment/Disposal

DESCRIPTION

In 1990 the U.S. Department of Commerce, Census Bureau, estimated that the number of housing units with septic tanks or cesspools in the U.S. was 24.6 million and approximately 5.5 billion gallons of septage were being generated each year. "Septage" is the liquid and solid material pumped from a septic tank, cesspool, or other primary treatment source. Scum accumulates on the surface while the sludge settles at the bottom, comprising 20 to 50% of the total septic tank volume when pumped. A septic tank will usually retain 60 to 70% of the solids, oil, and grease that passes through the system.

Septage is classified according to the environment in which it is generated. This fact sheet will focus solely on domestic septage. Treatment and disposal of domestic septage is governed by the U.S. Code of Federal Regulations (40 CFR) Part 503. Municipalities can also establish local regulations for septage handling, treatment, and disposal in addition to the federal and state regulations.

There are several approaches to septage treatment and disposal which include private or public ownership. Larger municipalities are capable of managing the whole process from handling and treatment to disposal, while other municipalities opt to use privately owned facilities that alleviate some of the responsibilities of operating a facility. Land disposal of septage after adequate treatment is also a popular option.

Septage characteristics

Factors that affect the physical characteristics of septage are: climate, user habits, septic tank size, design, and pumping frequency, water supply characteristics, piping material, and the use of water-conservation fixtures, garbage disposals, household chemicals, and water softeners. Table 1 lists the characteristics and limits of domestic septage.

TABLE 1 CHARACTERISTICS OF SEPTAGE CONVENTIONAL PARAMETERS

	Concentration	
Parameter	Minimum	Maximum
Total solids	1,132	130,475
Total volatile solids	353	71,402
Total suspended solids	310	93,378
Volatile suspended	95	51,500
Biochemical oxygen demand	440	78,600
Chemical oxygen demand	1,500	703,000
Total Kjeldahl nitrogen	66	1,060
Ammonia nitrogen	3	116
Total phosphorus	20	760
Alkalinity	522	4,190
Grease	208	23,368
pH	1.5	12.6
Total coliform	10^7/100 mL	10^9/100 mL
Fecal coliform	10^6/100 mL	10^8/100 mL

Note: The measurements above are in mg/L unless otherwise indicted.

Source: U.S. EPA, 1994.

TABLE 2 SOURCES OF SEPTAGE

Description Rate	Removal Pump-out	Characteristics
Septic tank	2-6 years, but can vary with location local ordinances	Concentrated BOD, solids, nutrients, variable toxics (such as metals), inorganics (sand), odor, pathogens, oil, and grease
Cesspool	2-10 years	Concentrated BOD, solids, nutrients, variable toxics, inorganics, sometimes high grit, odor, pathogens, oil, and grease
Privies/portable toilets	1 week to months	Variable BOD, soilds, inorganics, odor, pathogens, and some chemicals
Aerobic tanks	Months to 1 year	Variable BOD, inorganics, odor, pathogens, and concentrated solids
Holding tanks (septic tank with no drain-field, typically a local requirement	Days to weeks	Variable BOD, solids, inorganics, odor, and pathogens, similar to raw wastewater solids
Dry pits (associated with septic fields)	2-6 years	Variable BOD, solids, inorganics, and odor
Miscellaneous May Exhibit Characteristics of Septage		
Private wastewater treatment plants	Variable	Septic tank
Boat pump-out station	Variable	Portable toilets
Grit traps	Variable	Oil, grease, solids, inorganics, odor, and variable BOD
Grease traps	Weeks to months	Oil, grease, BOD, viscous solids, and odor

Source: Septage Handling Task Force (1997), copyright Water Environment Federation, used with permission.

APPLICABILITY

Septage is highly variable and organic, with significant levels of grease, grit, hair, and debris. The liquids and solids pumped from a septic tank or cesspool have an offensive odor and appearance, a tendency to foam upon agitation, and a resistance to settling and dewatering. Septage is also a host for many disease-causing viruses, bacteria, and parasites. As a result, septage requires special handling and treatment. However, the polymers and chemical conditioners available today have considerably reduced these requirements.

The handling and disposal of septage are based on the characteristics and volume of septic waste. Knowldege of this information is also useful for design purposes and determining typical design values for treatment and disposal. Table 2 summarizes the sources of septage.

ADVANTAGES AND DISADVANTAGES

Advantages

The advantage of using treatment plants is that they provide regional solutions to septage management.

Disadvantages

- May need a holding facility during periods of frozen or saturated soil.
- Need a relatively large, remote land area for the setup of the septic system.
- Capital and operation and maintenance costs tend to be high.
- Skilled operators may be required.
- Some limitations to certain management options of untreated septage include lack of available sites and potential odor and pathogen problems. These problems can be reduced by pretreating and stabilizing the septage before it is applied to the land.
- Septage treated at a wastewater treatment facility has the potential to upset processes if th septage addition is not properly

controlled, and increased requirements for handling and disposing of residuals.

DESIGN CRITERIA

Surface application

Septage can be applied to the land as a fertilizer and soil conditioner. Application rates depend on the slope, soil type, depth of application, drainage class, and hydraulic loading. Septage must not be applied before or during rainfall or on frozen ground. Thus, an interim storage facility is needed. Some states require septage to be disinfected before application.

- Spray Irrigation-pretreated (e.g., screened) septage is pumped at 80 to 100 psi through nozzles and sprayed directly onto the land. Spray irrigation can be used on steep or rough land and minimizes disturbances to the soil by trucks. It is important to consider the wind patterns and the site location when using spray irrigation because of the offensive odors associated with septage.

- Ridge and Furrow Irrigation-this is used for relatively level land, with slopes no greater than 0.5 to 1.5%. In this disposal method, pretreated septage is applied directly to furrows or to row crops that will not be directly consumed by humans.

- Hauler Truck Spreading-septage is applied to the soil directly from a hauler truck that uses a splash plate to improve distribution. The same truck that pumps out the septic tank can be used for transporting and disposing the septage.

- Farm Tractor and Wagon Spreading-liquid septage or septage solids are transferred to farm equipment for spreading. This allows for application of liquid or solid septage. However, if the septage was not lime stabilized, then the septage must be incorporated into the soil within 6 hours.

Subsurface Incorporation

Subsurface incorporation places untreated septage just below the soil surface, reducing odors and health risks while fertilizing and conditioning the soil. Septage can only be applied to slopes less than 8%, and the soil depth to seasonal high water table must be at least 20 inches (or as mandated by local regulations). A holding facility is required during periods of wet or frozen ground. To prevent soil compaction and allow sufficient infiltration, equipment must not be driven over the site until 1 to 2 weeks after application.

- Plow and Furrow Cover-typically, a moldboard plow is used with furrow wheels and coulters. The coulter blade slits the ground ahead of a plow. Liquid septage is discharged from a tank into a narrow furrow about 15 to 20 cm deep and is then covered by a second plow.

- Subsurface Injection-liquid septage is injected in a narrow cavity created by a tillage tool. The opening is about 10 to 15 cm below the surface. Some equipment uses a forced closure of the injection swath.

Burial

Septage burial includes disposal in holding lagoons, trenches, and sanitary landfills. There is a high odor potential during septage application until a final cover is placed on top. It is essential to select an appropriate site for disposal not only to control odors, but to avoid groundwater pollution.

- Holding Lagoons- these disposal lagoons are a maximum of 6 feet deep, with septage placed in small incremental lifts of 15 to 30 cm and no infiltration. Multiple lagoons are loaded in sequential order for optimum drying. To decrease odors, the lagoon inlet pipe can be placed below liquid level.

- Trenches-multiple trenches are filled sequentially with septage in small lifts of 15 to 20 cm for optimum drying. Each trench is then covered with soil (2 feet), and new trenches are opened. Another option is to leave a filled trench uncovered to enable some solids to settle and liquids to evaporate and leach out. The solids, along with some bottom and sidewall material, are removed and the trench can be reused.

- Sanitary Landfills- the primary problems that need to be considered when septage is added to a sanitary landfill are the production of leachate, treatment, and odor. Therefore, septage must not be disposed of in landfills with areas that have over 90 cm of rainfall, landfills that do not have leachate prevention and control facilities, or those not having isolated underlying rock. Each area that is filled with septage should be covered with 15 cm of soil each day and 2 feet of final cover within 1 week after the placement of the final lift. In general, sanitary landfills are not cost-effective disposal options for septage.

Septage is resistant to dewatering and as a result conditioning chemicals are used. The amount of chemical used is based on the load and its characteristics. A combination of lime and ferric chloride has been successfully used, along with certain polymers. Septage treatment plants also use other processes to dewater conditioned septage such as screw presses, plate and frame presses, belt presses, rotary vacuum filters, gravity and vacuum-assisted drying beds, and sand drying beds.

Another feasible option for septage treatment facilities is composting in locations where bulking agents are available and the humus product is needed as a soil conditioner. If the necessary bulking agents are not accessible, this method can be expensive. For this reason, it is preferable to dewater septage before composting.

OPERATION AND MAINTENANCE

The three basic alternatives for septage treatment and disposal are land application, treatment at wastewater treatment plants, and treatment at independent septage treatment plants.

Treatment at independent septage treatment plants

- Stabilization lagoon.
- Chlorine oxidation.
- Aerobic digestion.
- Anaerobic digestion.
- Biological and chemical treatment.
- Conditioning and stabilization.
- Composting

Treatment at wastewater treatment plants

- Addition to upstream sewer manhole.
- Addition to plant headworks.
- Addition to sludge handling process.
- Addition to both liquid stream and sludge handling processes.

Land application

- Surface application.
- Subsurface incorporation.
- Burial.

Selecting the appropriate septage management option depends on technical issues and regulatory requirements. Some of the factors that influence the process of selection include: land availability and site conditions, buffer zone requirements, hauling distance, fuel costs, labor costs, costs of disposal, and other legal and regulatory requirements.

Treatment at Independent Septage Treatment Plants

Independent septage treatment plants use such processes as chlorine oxidation, aerobic digestion, anaerobic digestion, and biological and chemical treatment. Many septage treatment plants also use lime to provide both conditioning and stabilization before the septage is dewatered. The liquid residual can be discharged to a privately owned treatment facility or undergo further treatment and then be discharged. Septage solids are then sent to either a landfill, composted, applied to the land, or incinerated.

When suitable land is unavailable and wastewater treatment facilities are too distant or do not have adequate capacity, independent septage treatment plants can be of use. Such treatment plants have been designed exclusively for treating septage and have many unit processes to handle both the liquid and solid portions of septage.

Stabilization is a treatment method that decreases odors, the levels of disease-causing organisms, and the potential for putrefaction of septage. Pretreatment/stabilization is achieved by physical, chemical, or biological processes. Some methods of stabilizing septage are discussed below.

Alkali (Lime) Stabilization

Lime or other alkaline material is added to liquid septage to raise the pH to 12.0 for a minimum of 30 minutes. Although there is a lot of variation in septage characteristics and lime requirements, mixing is not very difficult, and approximately 20 to 25 pounds of lime are used for every 1,000 gallons of septage. The three main stabilization approaches before land application are to add lime slurry: 1) to the pumper truck before the septage is pumped, 2) to the pumper truck while the septage is being pumped, or 3) to a tank that is storing septage that was discharged from a pumper truck. The septage and lime may sometimes be mixed by a coarse bubble diffuser system located in the tank or truck. In some states, it is prohibited to use hauler trucks for the stabilization process. A separate storage tank is necessary for lime and septage mixing. This is beneficial because a separate holding tank allows for more uniform mixing and easier sampling, monitoring, and control.

Aerobic Digestion

Septage is aerated for 15 to 20 days in an open tank to achieve biological reduction in organic solids and odor potential. The time requirements increase with lower temperatures. Normally, this is not a cost-effective option.

Anaerobic Digestion

Septage is retained for 15 to 30 days in an enclosed vessel to achieve biological reduction of organic solids. Anaerobic digestion is generally not used except for co-treatment with sewage sludge. However, one advantage is that anaerobic digestion generates methane gas, which can be used for digester heating or other purposes.

Composting

Liquid septage or septage solids are mixed with a bulking agent (e.g., wood chips, sawdust) and aerated mechanically or by turning. Biological activity generates temperatures that are sufficiently high to destroy pathogens. The composting process converts septage into a stable, humus material that can be used as a soil amendment. This process tends to create odors that can be a problem if not handled properly.

After the septage is stabilized, it is then sent for further treatment or disposal, which is described in the sections that follow.

Land application

Land application of septage is currently the most commonly used disposal method in the U.S. It is relatively simple and cost-effective, uses low energy, and recycles organic material and nutrients to the land.

With proper management, domestic septage is a resource containing nutrients that can condition the soil and decrease the reliance on chemical fertilizers for agriculture. Septage management maximizes these benefits of septage while protecting public health and the environment.

Land application includes spreading septage from septage hauler trucks, specially designed land application vehicles, or tank wagons onto sites using spray irrigation, ridge and furrow irrigation, and overland flow.

Treatment at Wastewater Treatment Plants

A convenient and attractive option for septage treatment is performing the treatment at a wastewater treatment facility. The constituents of septage are similar to domestic sewage, even though septage is stronger and more concentrated. The advantages of treating septage at wastewater treatment plants are that many plants are capable of handling some septage and that it centralizes waste treatment operations. The four main approaches to treating septage at a wastewater treatment plant are:

To Upstream Sewer Manhole

When septage is added to a sewer upstream of the wastewater treatment plant, substantial dilution of septage occurs prior to it reaching the wastewater treatment plant. This method is only feasible with large sewers and treatment plants. It is economical due to the very simple receiving station design. However, there is the potential for grit and debris to accumulate in the sewer and for odor problems near the manhole.

To Plant Headworks

Septage can be added to sewage immediately upstream of the screening and grit removal processes. This method, like the one mentioned above, is economical because of the very simple receiving station design. It also allows the wastewater treatment plant staff to have control of the septage discharge.

To Sludge Handling Process

Septage can also be handled as sludge and processed with wastewater treatment plant sludge after pretreatment in the receiving station. This method reduces the loading to liquid stream processes, and it eliminates the potential for affecting effluent quality. However, there could be an adverse effect on the sludge treatment processes, such as dewatering. Adding septage to the sludge handling process may also cause clogging of the pipes and increase wear on the pumps if the septage is not screened and degritted in the receiving station.

To Both Liquid Stream and Sludge Handling Processes

Septage can also be pretreated to separate liquid and solid fractions, which are then processed accordingly. This provides more concentrated sludge for processing and reduces the organic loading to liquid stream processes and the hydraulic loading to sludge processes. Increased operations are required for septage pretreatment at the receiving station.

COST

Cost considerations cannot be generalized because of the wide range of options available for septage management. The cost of a septage management system is dependent on the treatment and disposal method used and the regulatory requirements of a particular area.

Administrators of a septage management program should be aware of disposal options and the cost involved. The median cost of disposal (or tipping fee) typically ranges from 3 to 6 cents per gallon.

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Decentralized Systems Technology Fact Sheet

Control Panels

DESCRIPTION

In recent years, regulatory agencies have increased performance requirements for onsite wastewater treatment. This necessitates onsite alternatives that provide higher levels of treatment than standard septic tank drainfield systems are capable of achieving. Alternative systems are more complex and typically rely on uniform distribution and periodic dosing of pretreated effluent. Pumps are the primary method for dosing and distributing effluent, and dosing pump control is typically performed with a control panel using water level sensors, programmable timers, and other controls. Control panels may also be able to provide remote control and monitoring. This fact sheet discusses the use of control panels in the management of onsite wastewater treatment systems.

A control panel consists of controls and sensors that ensure the onsite system will operate efficiently as well as sound an alarm whenever malfunctions threaten efficient performance. Typical control panel functions may include high-water level alarm, pump start/stop control, low-water level alarms, programmable timers, and intrinsically safe control relays for pumping locations in a hazardous or potentially explosive environment. Telemetry, current sensing, programmable controllers, and other special options are generally considered too costly for residential applications, but have been utilized with larger commercial flows. Standard control panel features may include circuit breakers, disconnects, manual/off/automatic motor control operation, audio/visual alarms (with silencer), and automatic reset upon correction of alarm condition (Bounds 1995).

APPLICABILITY

Control panels are commonly used in municipal lift stations and pumping stations to monitor various parameters and conditions including liquid level and pressure. As costs have decreased and technology has improved, control panels are increasingly being applied to the management of decentralized or onsite wastewater treatment systems. Control panels are generally installed with new systems, but may also be retrofitted to existing systems.

Examples of onsite systems that may be equipped with control panels include the following:

- Septic tank effluent pump (STEP) and grinder pump (GP) systems associated with septic tanks and/or pressure sewers;
- Low pressure effluent dispersal systems;
- Aerobic treatment units;
- Recirculating sand filters; and
- Drip dispersal systems.

ADVANTAGES AND DISADVANTAGES

Advantages

- Reduces costs for operation and maintenance (O&M) by preventing failures and reducing the amount of service time spent gathering information about the malfunction;
- Lowers energy consumption; and
- Increases manageability and reliability of onsite systems.

Disadvantages

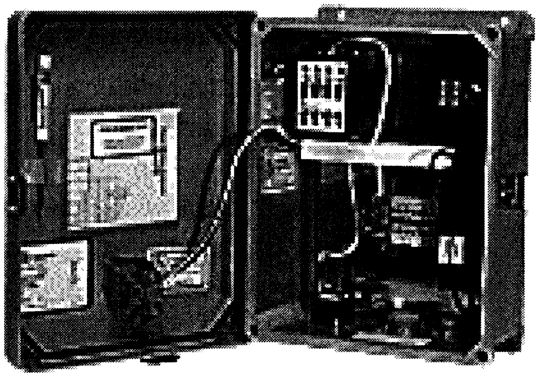
- Increases initial capital costs;

- Increased complexity requires higher level of training to install and operate (may require an electrician).

DESIGN CRITERIA

Control panels are usually conveniently located where they will be accessible for operation and maintenance. They should be within sight of the pump.

Figure 1 shows a typical control panel. The basic components and features of this control panel include the following:



Source: Orenco Systems Inc., 2001.

FIGURE 1 TYPICAL CONTROL PANEL

Programmable Timer - Precisely controls the pumping doses. The timer is programmed so that the "on" time (dosing period) is short and effluent is dosed in small volumes. The "off" setting spaces resting periods uniformly between doses throughout the day. Programmable timers are particularly beneficial in systems that require surge control, where a long period of storage is required between intermittent discharges (e.g., churches, schools, etc.). Timers are available with digital or analog features, and provide adjustable on/off duration settings. A timer can be disabled by a low level float, thereby maintaining a minimum liquid level.

Motor Contactor - Switches power to the pump on command through a signal from the programmable timer.

Toggle Switch (HOA Switch) - Allows the pumping operation to be automatically or manually controlled without interrupting the memory of the programmable timer.

Current Limiting Circuit Breaker - Provides a disconnect means and secondary overload protection for the pump circuit.

Fuse Disconnect - Provides a separate disconnect means and overload protection for the control circuitry (alarm system, motor contactor, programmable timers, relays, etc.). Power to the alarm and control circuitry is wired separately from the pump circuit, so that the alarm system remains functional if the internal overload switch or current-liming circuit breaker is tripped.

Audible Alarm - Provides an audible alarm when a high or low liquid level requires correction. The alarm should be loud enough to provide ample warning but not so loud that it causes irritation. A minimum of 80 decibels sound pressure at 24 inches is recommended. A push-to-silence feature should also be included to ensure that the alarm does not become a nuisance.

Visual Alarm - Provides visual indication when a high or low liquid level requires correction. The alarm light is usually red and varies in shape and size.

Audio-Alarm Silence Relay - Automatically resets the audio alarm after the alarm condition has been corrected.

Redundant-Off/Low Level Alarm Relay - Automatically overrides the pump control circuit to shut down the pump and energize the alarm system to signal a low liquid level condition.

Terminal Blocks - Touchsafe type terminal blocks provide greater protection against accidental shorting across terminals and touching of live connections.

Enclosure - Should be constructed of noncorroding and durable materials rated NEMA 4X to ensure adequate environmental protection for the enclosed components.

Lockable Latch - Provides lock-out capability to ensure security.

Listing - All controls should be manufactured by a company listed by an approved accrediting agency (e.g., UL, CSA, or ETL). At locations where flammable or explosive materials may be present, all controls and relays should be intrinsically safe, meaning that they operate at low energy to prevent electrical devices from creating arcs, sparks, or heat (during normal or fault conditions) that could ignite an explosive substance.

Warnings and Instructional Stickers - All control systems must contain the proper electrical warnings and instructional information to ensure user awareness and safety.

Wiring Diagram - Provides float and pump wiring instructions and information regarding the intended function of each component.

PERFORMANCE

River Rock Landing, Michigan

River Rock Landing is a newly-developed residential site consisting of 29 homes outside of Lansing, Michigan. A community cluster treatment system was constructed to treat an estimated peak flow of 37,900 L/d (10,000 gpd). Wastewater is collected through a STEP system with small diameter pressure sewers, then treated with side-by-side duplex recirculating sand filters followed by side-by-side duplex intermittent sand filters. The treated effluent is returned to groundwater through an unlined pond. An NPDES discharge permit was obtained to manually discharge excess water from the pond to the nearby Grand River if necessary (Stephens 2000).

The treatment facility is required by the Michigan Department of Environmental Quality to be operated under the supervision of a qualified and certified operator. As part of the management program for the facility, a control panel was installed at the treatment site. A dedicated telephone line is connected to this control panel, enabling a computer with a modem to access it directly from any location. The panel at this site is programmed to record and report on demand the following information:

- Current high and low water alarm conditions, and a log of past alarm events;
- Pump run events and run times;
- Water level readings in the tanks and pond; and
- Amperage being drawn by pumps (Stephens 2000).

In addition to these monitoring functions, the program allows the remote operator to make system adjustments as follows:

- Adjust programmed pump run cycles (time-off and time-on settings);
- Adjust alarm characteristics such as audible delays;
- Set and adjust high-level pump override cycles; and
- Turn pumps on and off as necessary to correct a high water condition (Stephens 2000).

These monitoring capabilities do not eliminate the need for personal visits to the site to evaluate the performance of system components that are not accessible over the phone wire. However, the ability to monitor and manage the system provides the operator with confidence that common system management problems will be identified. In addition, system information logs provide performance records to help the operator recognize trends and troubleshoot problems (Stephens 2000).

Island City Academy, Michigan

Island City Academy is a new charter school located outside of Eaton Rapids, Michigan. An estimated peak wastewater flow of 18,900 L/d (5,000 gpd) enters a septic tank, then flows to a pair of side-by-side recirculating sand filters. Final effluent is discharged to a series of pressure-dosed soil absorption trenches. The wastewater treatment facility is fitted with a control panel that monitors and reports pump run times and events, as well as alarm conditions. Programmable timing features can be adjusted and pumps can be controlled remotely through the control panel. Daily flow information is also logged for future reference. At one point an employee of the Academy reported that several of the toilets at the Academy would not flush properly. The system operator was able to check the treatment system and verify that it was operating normally. Academy staff were then able to contact a drain cleaning firm to clear a stoppage in the building plumbing which caused the toilet malfunction (Stephens 2000).

OPERATION AND MAINTENANCE

When an alarm occurs, the user should contact an accredited maintenance service. An average of 24 hours of reserve storage is provided above the alarm level (Bounds 1995), and response within this time period is adequate.

When servicing any control system, all warnings must be given strict attention. An operator must not work on any system without first disconnecting the power at the circuit breaker and/or disconnect fuse. All control panels should be provided with a lockable latch to ensure operator safety when working away from the control panel.

COSTS

Control panels range in price from approximately $1,500 to $3,000, depending on options selected (Jesperson 2000).

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September 2000

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Decentralized Systems Technology Fact Sheet

Septic Tank Polishing

DESCRIPTION

Polishing systems are used to improve the quality of septic tank system effluent. Effluent polishing may be necessary due to site constraints, regulations, or other limiting factors. One of the most common technologies used to polish septic tank effluent is the sand filter. Because sand filters can be designed in various configurations, they are highly flexible and can be adapted to many different types of sites, making them ideal for use in different community settings. The three types of sand filters typically used for septic tank polishing include buried, intermittent, and recirculating sand filters.

Treatment of effluent by sand filter systems involves physical, chemical, and biological processes. Suspended solids are removed principally by mechanical straining and sedimentation. Action by bacteria that colonize sand grains further enhances the removal of suspended solids. The removal of biological oxygen demand (BOD) and the conversion of ammonia to nitrate (nitrification) is performed under aerobic conditions by microorganisms present in the sand bed. The conversion of nitrate to nitrogen gas (denitrification) is routinely performed by anaerobic bacteria that exist in the anaerobic zones near the bottom of the filter and in anaerobic tanks, resulting in a significant (up to 45 percent) loss of nitrogen. Specific constituents are removed by sorption, both chemical and physical. Intermittent application and venting of the underdrains helps to maintain aerobic conditions in the filter, which helps achieve a high performance level.

DESIGN CRITERIA

Buried sand filters are typically installed with underdrains in 30 cm (1 ft) of coarse gravel, covered with 60-90 cm of sand. Liquid enters through a perforated pipe in another foot of gravel, and covered with at least 15 cm (6 in) of topsoil. **Intermittent** sand filters are divided into two or more units that are alternately loaded and rested. Wastewater is applied over a bed of sand 60 to 90 cm (2 to 3 ft) deep. The sand should have an effective size of 0.2 to 0.6 mm, with a uniformity coefficient less than 4.0. The filtrate is collected by underdrains contained in a bottom layer of gravel. The sand remains aerobic and serves as a biological filter, removing suspended solids (SS) and dissolved organics. Because of smaller sand size and higher loading rates, these units must be accessible for periodic servicing. The **recirculating** filter system consists of a septic tank and a recirculation tank that contains a timer-controlled sump pump for dosing onto a sand filter. The filter bed contains 90 cm (3 ft) of coarse sand and 30 cm (1 ft) or less of gravel surrounding the underdrain system. In this case, the sand should have an effective size of 0.6 to 1.5 mm with less than a 2.5 uniformity coefficient. A recirculation ratio of 4:1 (recycled filter effluent to forward flow) is recommended. If tank effluent requires disinfection, common methods used in on-site systems include tablet chlorination, iodine crystals, or ultraviolet irradiation. Designers must be careful when specifying sand - minimum dust content is essential.

Although sand is the most common media, alternative polishing media exist, including foam and geotextile fabric, which produce high quality effluents. These media are pre-fabricated, allowing performance to be unaffected by the grading of the sand. However, stringent fecal coliform effluent requirements may require sand filter polishing in addition to textile filtering.

Buried sand filters are generally constructed in two sections that are dosed separately from a tank with alternating siphons. Above ground sand filters (intermittent or recirculating) can be installed in areas where subsurface construction is impossible. Dosing tanks with pumps or siphons feed these filters. The filters may be open or covered, but must be accessible for cleaning. Covering and insulation are recommended for intermittent and recirculating filters to minimize freezing in cold weather and potential health risks and nuisances in warm weather.

Typical recommended loading rates from sand filter systems are 30 to 60 L/m^2 d (0.75 to 1.5 gal/ft^2 d) for buried sand filters; 200 L/m^2 d (5 gal/ft^2 d) for intermittent sand filters; and 120 L/m^2 d (3 gal/ft^2 d) for recirculating sand filters (based on forward flow alone).

ADVANTAGES AND DISADVANTAGES

Advantages

Sand filters are relatively inexpensive, have low energy requirements, and are highly flexible. They can be used on sites with shallow soil cover, high groundwater, and unsuitable permeability. Sand filters do not require highly skilled operators because the process is stable and no chemicals are required during operations. Filters generally produce high quality effluents.

Disadvantages

Land availability may limit the application of polishing systems. Furthermore, the amount of head required by the filters typically exceeds 90 cm (3 ft). As a consequence, pumping may be required if elevation differentials are inadequate. Odors from anaerobic portions of open, single pass filters used to treat septic tank effluent may be a problem if not installed correctly, and ongoing maintenance is necessary for the media, pumps, and controls. Power is required for pumping and some disinfection units. State or federal discharge permits are required, accompanied by periodic sampling and monitoring.

PERFORMANCE

Table 1 provides details of typical improvements in effluent quality with intermittent sand filtration of lagoon effluent.

OPERATION AND MAINTENANCE

Sand filters require relatively little operational control and maintenance. Primary servicing tasks include filter surface maintenance, dosing equipment, and monitoring of influent and effluent. With continued use, sand filter surfaces will become clogged with organic biomass and solids, and when operating infiltration rates fall below the hydraulic loading rate, permanent ponding of the filter surface will occur, indicating that the filter should be taken off-line for rest or sand removal and

TABLE 1 TREATMENT PERFORMANCE OF ON-SITE SEPTIC TANK AND SAND FILTER

Parameter	Raw Waste	Septic Tank Effluent	Intermittent Sand Filter Effluent
BOD, mg/L	210 - 530	140 - 200	< 10
SS, mg/L	237 - 600	50 - 90	< 10
Total nitrogen, mg/L	35 - 80	25 - 60	--
Ammonia-nitrogen, mg/L	7 - 40	20 - 60	< 0.5
Nitrate-nitrogen, mg/L	< 1	< 1	25
Total phosphorus, mg/L	10 - 27	10 - 30	--
Fecal coliforms (# / 100 mL)	10^6 - 10^{10}	10^3 - 10^6	10^2 - 10^4
Viruses (# / 100 mL)	Unknown	10^5 - 10^7	--

Source: Adapted from Tchobanoglous and Burton, 1991.

replacement. Inaccessible buried filters are designed to operate without maintenance for their design life. Filters exposed to sunlight may develop algae mats, which can be controlled by shading the surface. Disinfection is required prior to discharge in community systems, but disinfectant quantity requirements are low due to the high quality of the effluent from the sand filter.

Weeding should be performed at the surface of above-ground filters to prevent unwanted vegetative growth. In cold climates, the filter should be insulated and the distribution lines must be drained to prevent standing water and to prevent freezing.

Although it is a common maintenance practice, surface tilling is not recommended for slow sand filtering systems. This process moves clogged zones to the bottom of the tilled zone which may exacerbate surface ponding problems.

COSTS

Filter costs depend on many factors including soil type, cost of land, site topography, groundwater level, and cost of filter media. These site and system specific factors should be examined and incorporated when preparing a polishing filter cost estimate.

Construction Costs

Under typical, favorable soil conditions, the cost to install a polishing filter system is greater than the costs of a conventional gravel pipe drainfield. Nonetheless, while drainage pipe costs are lower, the drainfield footprint may be up to two times larger than that of a conventional gravel drainfield. Typical costs for a single pass sand recirculating filter system range between $7,000 and $15,000, including the septic tank and soil adsorption field. System design by an engineer, if required, will be an additional cost. If the existing site is inadequate for a new drainfield or if the existing field is no longer serviceable, removal and disposal costs should be considered.

Operation and Maintenance Costs

Operation and maintenance costs for sand filtration filter systems are minimal. Key costs associated with proper functioning of drainfield systems include septic tank cleaning, which ranges between $400 to $1,500 per cleaning.

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Decentralized Systems Technology Fact Sheet
Septic System Tank

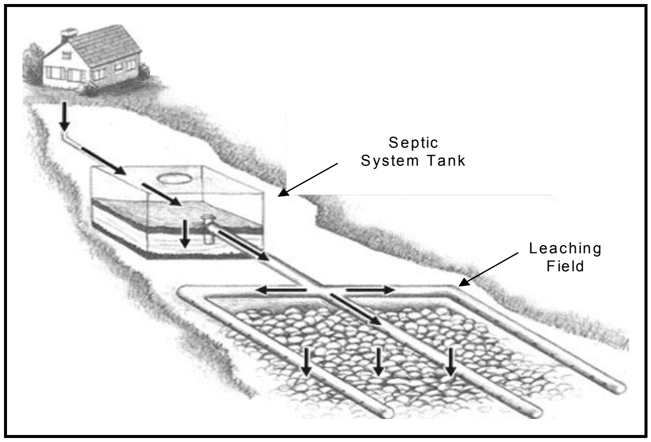
DESCRIPTION

A septic tank is an underground engineered tank consisting of single or multiple units, together with one or more connecting piping systems installed in appropriate soils to receive wastewater flow from one or more residences or public buildings. Wastewater is pretreated in the septic tank before being discharged to a final treatment system. Annually or semi-annually, liquids and solids retained in the tank are pumped into a tank vehicle which transports sewage to a final treatment site.

A septic tank is a traditional wastewater treatment technology using a tank as the primary treatment and holding device. A system to handle multiple residences may be designed as a collection of individual holding tanks with a community treatment and disposal system or a community collection and treatment system. The decision on which type to use is based on available land, existing systems, and maintenance issues. Figure 1 illustrates a septic tank with a leaching field downstream.

The primary device in treatment is the tank, an enclosed watertight container that collects and provides primary treatment of wastewater by holding wastewater in the tank and allowing settleable solids to settle to the bottom while floatable solids (oil and greases) rise to the top. The tank should retain the wastewater for at least 24 hours.

Some solids are removed from the wastewater, some are digested, and some are stored in the tank. Up to 50 percent of the solids retained in the tank decompose, while the remainder accumulate as sludge at the tank bottom and must be removed periodically by pumping the tank.



Source: U.S. EPA, 1991.

FIGURE 1 SEPTIC SYSTEM TANK

There are three main types of tanks for on-site sewage holding and pretreatment:

- Concrete tanks.
- Fiberglass tanks.
- Polyethylene/plastic tanks.

All tanks must be watertight. Water entering the system can saturate the soil absorption field, resulting in a failed system.

From the tank, the wastewater enters a sewer or is passed directly to a treatment system. The most common outlet is a pipe fitting connected to the septic tank. An effluent filter can be placed in the outlet for additional filtering of the wastewater.

Removing more solids from the wastewater helps to prevent clogging the absorption field and causing premature failure.

APPLICABILITY

A holding tank is used to pre-treat sewage and make subsequent treatment systems more effective by allowing a constant flow to enter the treatment system. The effluent from the tank is consistent, easy to convey, and easily treated by either aerobic (with free oxygen) or anaerobic (without free oxygen) processes.

ADVANTAGES AND DISADVANTAGES

Advantages

Subsurface infiltration systems are ideally suited for decentralized treatment of wastewater because they are buried. The tanks are relatively inexpensive and can be installed in multiple tank installations.

Disadvantages

The sludge may pose an odor problem if the sewage remains untreated for an extended period. Provisions for alarms and pumping are necessary if the downstream treatment units go off-line due to power loss or equipment failure.

DESIGN CRITERIA

A holding tank must be the proper size, have a watertight design, and stable structure for proper performance.

Tank size: The size of a tank for a single residence depends upon the number of bedrooms, the number of inhabitants, the home's square footage, and whether or not water-saving fixtures are used. For example, a three-bedroom house with four occupants and no water-saving fixtures would require a 1,000-gallon septic tank. The tank should be designed to hold at least one week of waste flow (U.S. EPA, 1992.) Holding tank systems for multiple units should include the above parameters for each residence. Commercial inputs should be evaluated on a case by case basis and may need pre-treatment to remove oil, grease, or solids.

Tank design: A key factor in the holding tank's design is the relationship between the liquid surface area, the quantity of sewage it can store, and the rate of wastewater discharged. Each of these factors will impact the tank efficiency and the amount of sludge it retains.

The greater the liquid's surface area, the more sewage the tank can accommodate. As solids collect in the tank, the water depth decreases, which reduces the time sewage flow is retained in the tank. Less solids will settle in the tank, resulting in increased solids in the tank effluent that may have a negative impact on the final treatment process.

Placing risers on the tank openings makes it easier to access the tank for inspection and maintenance. If a septic tank is buried more than 12 inches below the soil surface, a riser must be used on the openings to bring the lid to within 6 inches of the soil surface. Generally, the riser can be extended to the ground surface and protected with a lid.

Hydraulic Loading Rate

The design capacity of the holding tank is related to the hydraulic loading rate of the treatment system. For a ground absorption system, it is determined by soil characteristics, groundwater mounding potential, and applied wastewater quality. Prolonged wastewater loading will clog the infiltrative surface, reduce the capacity of the soil to accept the wastewater, and may back up the wastewater into the holding tank. However, if the loading is controlled, biological activity at the infiltrative surface will maintain waste accumulations in relative equilibrium so that reasonable infiltration rates and pass through in the holding tank can be sustained.

PERFORMANCE

To keep a holding tank system operating efficiently, the tank should be pumped periodically. As the system is used, sludge accumulates in the bottom of the tank. As the sludge level increases, wastewater spends less time in the tank, and solids are more likely to escape into the absorption area. Properly sized tanks can accumulate sludge for at least three years.

The frequency of pumping depends on:

- Tank capacity.
- Amount of wastewater flowing into the tank related to size of household(s).
- Amount of solids in the wastewater. For example, there will be more solids if garbage disposals are used.
- Performance of the final treatment system.

OPERATION AND MAINTENANCE

A well-designed holding tank requires limited operator attention. Management needs include tracking system status, testing for solids accumulation, evaluating pump performance, and monitoring system controls. Monitoring performance of pretreatment units, mechanical components, and wastewater ponding levels above the filtration surface is essential. If a performance or level change is noted, the operator should inspect the system to determine if additional service is required. Routine servicing of a holding tank is limited to annual or semiannual inspection and cleaning, if necessary.

COSTS

The costs for tanks greatly vary for each site. Land and earthworks are the most significant capital costs. Where a select fill must be used to bed the tank, the cost of transporting this material may be significant. The factors that affect costs include location, access, subsurface site conditions, and the type of tank installed. A general cost range for tanks is from $1.00 to $4.00 per gallon. (A 1,000 gallon tank installed in the City of Austin cost $2,000.) Other costs include installation of equipment to transport the wastewater to the holding and/or treatment site.

REFERENCES

Other Related Fact Sheets

Septic Tank Leaching Chamber
EPA 832-F-00-044
September 2000

Septic Treatment/Disposal
EPA 832-F-99-068
September 1999

Septic Tank - Soil Absorption Systems
EPA 832-F-99-075
September 1999

Other EPA Fact Sheets can be found at the following web address:
http://www.epa.gov/owmitnet/mtbfact.htm

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United States Environmental Protection Agency
Office of Water Washington, D.C.
EPA 832-F-00-079
September 2000

Decentralized Systems Technology Fact Sheet

Septic Tank Systems for Large Flow Applications

DESCRIPTION

A septic tank system is a traditional wastewater treatment technology utilizing treatment in a tank system followed by soil absorption. The system operates on gravity and has been used in residential areas for decades. A modification to the traditional system is an enlargement to accommodate many homes and/or commercial discharges. This is accomplished with individual septic tanks followed by a community collection and subsurface disposal system, or a community collection system followed by a single treatment system. Commercial establishments, such as restaurants, nursing homes, hospitals and other public use areas do not generally use septic tank systems due to oil & grease, odor, and flow issues.

The primary device in treatment is a septic tank enclosed in a watertight container that collects and provides primary treatment of wastewater by separating solids from the wastewater. The tank removes solids by holding wastewater in the tank and allowing settleable solids to settle to the bottom of the tank while floatable solids (oil and grease) rise to the top. In large commercial systems, a separate oil/grease removal system is applied to the commercial waste before introduction to the septic tank. The tank should hold the wastewater for at least 24 hours to allow enough time for the solids to settle.

Some solids are removed from the water and stored in the tank while some are digested. Up to 50 percent of solids retained in the tank decompose while the remainder accumulate as sludge at the tank bottom and must be removed periodically by pumping the tank.

Three main types of septic tanks are used for wastewater treatment:

- Concrete.
- Fiberglass.
- Polyethylene/plastic.

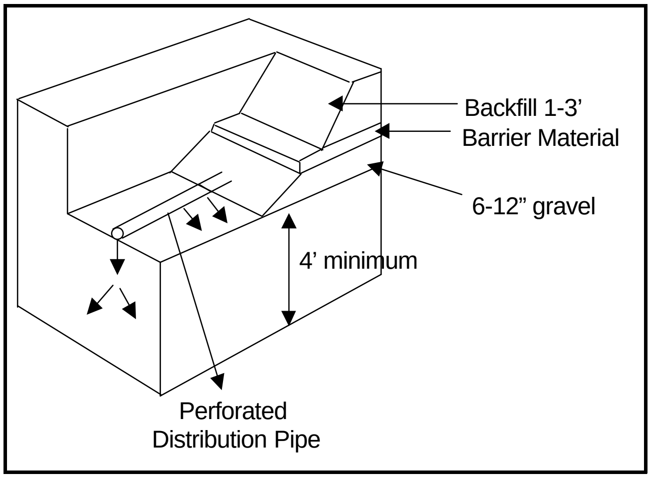
All tanks must be watertight because groundwater entering the system can saturate the soil absorption field, resulting in a failed system. Furthermore, in instances where septic tanks precede a secondary treatment process, excess groundwater may inundate the downstream process, causing it to perform poorly.

From the septic tank, the clarified wastewater passes through the tank outlet and enters the soil absorption field. The most common outlet is a tee fitting connected to the pipe leading to the soil absorption field. The top of the tee retains floatable solids (scum, oil, and grease) that might otherwise clog the absorption field. An effluent filter can be placed in the outlet tee for additional filtering of wastewater. The effluent filter removes additional solids, keeping them from clogging the absorption field and causing premature failure. Effluent filters must be cleaned regularly.

Soil Absorption Field

The soil absorption field provides final treatment and distribution of the wastewater. A conventional system consists of perforated pipes surrounded by media such as gravel, chipped tires, or other material, covered with geotextile fabric and loamy soil. This system relies heavily on the soil to treat wastewater, where microorganisms help remove organic matter, solids, and nutrients from the water.

As effluent continually flows into the soil, the microbes eating the components of the wastewater form a biological mat. The mat slows the movement of the water through the soil and helps keep the area below the mat from becoming saturated. The water must travel into unsaturated soil so microbes there and in the mat can feed on the waste and nutrients in the effluent. The grass covering the soil absorption system also uses the nutrients and water to grow.



Source: Robillard and Martin, 2000

FIGURE 1 SECTION OF TRENCH SOIL ABSORPTION SYSTEM

Treatment

Used properly, the septic tank and soil absorption system works well, reducing two parameters commonly used to measure pollution: (1) biochemical oxygen demand, which is lowered by more than 65 percent; and (2) total suspended solids, which are cut by more than 70 percent. Oil and grease are typically reduced by 70 to 80 percent (EPA 1980).

Using a septic tank to pretreat sewage from commercial sources also makes other secondary treatment systems more effective. The effluent from the septic tank is consistent, easy to convey, and easily treated by either aerobic (with free oxygen) or anaerobic (without free oxygen) processes.

Common Modifications

Septic tanks for large flow systems may be followed by traditional soil absorption systems or by one of several alternate technologies such as constructed wetlands or slow sand filtration. Pressure sewers and small diameter gravity sewers may also be used as alternate collection systems for transport of effluent to central treatment facilities. These systems are discussed in other fact sheets (see Reference section). This fact sheet focuses on the traditional septic tank system applied to commercial waste and multiple sources, using subsurface infiltration for wastewater disposal.

Subsurface Infiltration

Subsurface wastewater infiltration systems (SWISs) are subgrade land application systems most commonly applied in unsewered areas by individual residences, commercial establishments, mobile home parks, and campgrounds (EPA, 1992). The soil infiltration surfaces are exposed in buried excavations that are generally filled with porous media. The media maintain the structure of the excavation, allows the free flow of pretreated wastewater to the infiltrative surfaces, and provides storage of wastewater during times of higher flows. The wastewater enters the soil where treatment is provided by filtration, adsorption, and biologically mediated reactions which consume or transform various pollutants. Ultimately, the wastewater treated in the SWIS enters and flows with the local groundwater.

Various SWIS designs have been developed for various site and soil conditions encountered. The designs differ primarily in where the filter surface is placed. The surface may be exposed within the natural soil profile (conventional or alternative technology) or at or above the surface of the natural soil (at-grade or mound systems) (see related Fact Sheets). The elevation of the filter surface is critical to provide an adequate depth of unsaturated soil between the filter surface and a limiting condition (e.g. bedrock or groundwater) to treat wastewater applied.

The geometry of the filter surface also varies, with long, narrow filter surfaces (trenches) much preferred. Wide filter surfaces (beds) and deep filter surfaces (pits and deep trenches) do not perform as well, although they require less area.

Subsurface infiltration systems are capable of high levels of treatment for most domestic wastewater pollutants. Under suitable site conditions, they provide nearly total removal of biodegradable organics, suspended solids, phosphorus, heavy metals, and virus and fecal indicators.

The fate of toxic organics and metals is not as well documented, but limited studies suggest that many of these constituents do not travel far from the system. Nitrogen is the most significant wastewater parameter not readily removed by the soil. Nitrate concentrations above the drinking water standard of 10 mg-N/L are commonly found in groundwater immediately below SWISs (EPA 1992), but these concentrations fall with distance down-gradient of the SWIS.

APPLICABILITY

Community Establishments

Septic tanks are usually the first component of an on-site system and are the most widely used on-site wastewater treatment option in the United States. Currently, about 25 percent of new homes in the United States use septic tanks for treatment prior to disposal of home wastewater.

Septic tanks for single family homes are generally purchased as “off the shelf” items, which means that they are ready for installation and based on a standard flow. The wastewater characteristics used to design septic tanks are generally those for a typical residence.

Commercial Establishments

For many commercial establishments, the wastewater-generating sources are sufficiently similar to the wastewater-generating sources in a residential dwelling. For other establishments, however, the wastewater characteristics may be considerably different from those of typical residential wastewater.

Commercial establishments can take advantage of a centralized system if the flows and capacities are sufficient and adequate pretreatment is available. Wastewater must be pretreated prior to being discharged to a soil absorption system. Wastewater is most commonly pretreated by an on-site septic tank when a soil absorption system is used for treatment/disposal. In areas where soil and groundwater conditions are favorable for wastewater disposal and land costs are low, a community soil absorption system is usually the most cost effective wastewater treatment/disposal option for flows below 35,000 gallons per day. Careful application of the effluent to the soil absorption system ensures uniform application of effluent over the filtration surface. Distribution laterals should be provided with cleanouts for access and flushing. Ponding monitors should be installed in trench areas to allow observation of liquid level in trenches.

Subsurface Infiltration

In some instances, it is desirable to bury the absorption system. Buried systems, known as subsurface wastewater infiltration systems (SWISs), are advantageous because the land above a SWIS may be used as green space or park land, and because they provide groundwater recharge. Subsurface infiltration systems are well suited for treatment of small wastewater flows. Small SWISs, commonly called *septic tank systems*, are traditionally used in unsewered areas by individual residences, commercial establishments, mobile home parks, and campgrounds. Since the late 1970s, larger SWISs have been increasingly used by clusters of homes and small communities where wastewater flows are less than 25,000 gpd. They are a proven technology, but require specific site conditions to be successfully implemented. SWISs are often preferred over on-site mechanical treatment facilities because of their consistent performance with few operation and maintenance requirements, lower life cycle costs, and less visual impact on the community.

DESIGN CRITERIA

Pretreatment of Wastewater for Commercial Septic Tank Systems

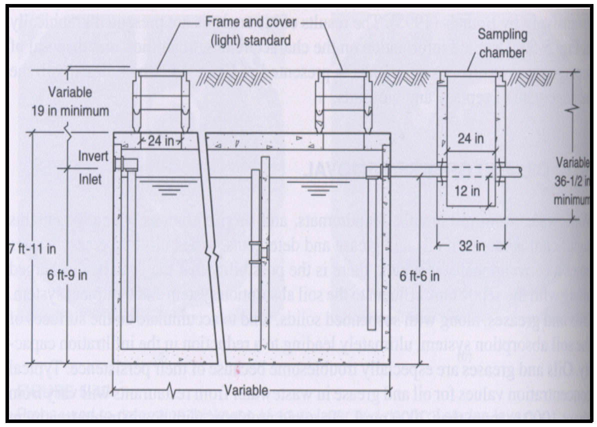
The most serious operational problem encountered with commercial septic tank systems has been the carry-over of solids, oil and grease due to poor design and lack of proper maintenance. The carryover of suspended material is most serious where a disposal field is to be used to dispose of septic tank effluent without further treatment. Recognizing that poor septic tank maintenance is common, some regulatory agencies require the addition of a large septic or other solids separation unit before collected septic tank effluent can be disposed of in subsurface disposal fields. The use of oil and grease traps reduces the discharge of TSS and oil and grease significantly. The presence of oil and grease in effluents from septic tanks servicing restaurants has led to the failure of downstream treatment processes such as intermittent and recirculating sand filters. As a consequence of these problems, pretreatment is recommended.

Pretreatment in centralized treatment systems involves coarse screening, comminution, grit removal, oil and grease removal, flow equalization, and TSS removal.

Pretreatment for Oil and Grease Removal

Wastewater from restaurants, laundromats, and other commercial establishments may contain significant amounts of oils and grease which may be discharged to the soil absorption system when they enter a septic tank. Oils and greases tend to accumulate on the surface of the soil absorption system, reducing the infiltration capacity. Oils and greases are especially troublesome because of their persistence and low rate of biodegradation. To avoid problems in decentralized wastewater treatment and disposal systems, the effluent oil and grease concentration should be reduced to less than about 30 mg/L before it is introduced to the soil absorption system (Crites and Tchobanoglous 1998).

The problems associated with the removal of oils and greases become more complex with the increase in different types of oils and greases available for cooking. The problem is further complicated because many of these oils are soluble at relatively low temperatures, making their removal more difficult. Typically, skimming or interceptor tanks (grease traps) are used to trap greases and oils. Figure 2 shows a schematic of an oil and grease trap with an external sampling chamber.



Note: 1 in = 2.54 cm

Source: Crites and Tchobanoglous, 1998

FIGURE 2 SCHEMATIC OF OIL AND GREASE TRAP WITH EXTERNAL SAMPLING CHAMBER

Several commercial oil and grease traps are available. Most commercial units are rated by average flow rather than instantaneous peak flows observed in the field from restaurants and laundries. The use of conventional septic tanks as interceptor tanks has also proven to be effective in removing oil and grease. Depending on the tank configuration, some replumbing may be necessary when septic tanks are used to trap grease. Typically, the inlet is located below the water surface while the outlet is placed closer to the tank's bottom. The larger volume provided by the septic tank helps achieve the maximum possible separation of oils and greasy wastes. For restaurants, the use of a series of three interceptor tanks is effective to separate oil and grease. High concentrations of oil and grease associated with restaurants make the use of three interceptor tanks in series necessary to reduce this concentration to acceptable levels.

Volumes for grease interceptor tanks typically vary from one to three times the average daily flowrate. For example, if a restaurant serves 100 customers/day at an average flow of 38 liters/day/customer (10 gallons/day/customer), the size of the grease interceptor tank should be between 3,800 and 11,400 liters (1,000 and 3,000 gallons). Depending on the activities at a given facility, accumulated sludge and scum should be removed every three to six months (Crites and Tchobanoglous 1998).

Septic Tanks

A septic tank must be the proper size and construction and have a watertight design and stable structure to perform successfully.

- Tank size. The required size of a septic tank for a commercial establishment depends on anticipated flows from the facility, coupled with additional flow from residences or other inputs, if on a community system.

- Tank construction. A key factor in septic tank design is the relationship between the amount of surface area, its sewage storage capacity, and the amount and speed of wastewater discharge. These factors affect the tank's efficiency and the amount of sludge retention. Tank construction must also assure a watertight structure.

A key to maintaining a septic tank is placing risers on the tank openings. If a septic tank is buried below the soil surface, a riser must be used on the openings to bring the lid to the soil surface. These risers make it easier to locate and maintain the tank.

Septic tank effluent may be applied to the soil absorption field by intermittent gravity flow or via a pump or dosing siphon. Periodic application using a dosing siphon maintains an aerobic environment in the disposal field, allowing biological treatment of the effluent to occur more rapidly. Dosing siphons are particularly desirable for fields composed of highly permeable soils because they help maintain the unsaturated flow conditions necessary to achieve effective biological treatment of effluent.

Subsurface Infiltration

Important considerations in designing subsurface infiltration systems include:

- Soil texture. There are three sizes of soil particles: sand, silt and clay. Texture reflects the relative percentage of each of these soil particles at a particular site. Soil texture affects the rate at which wastewater infiltrates into and percolates through the soil (called hydraulic conductivity). These factors determine how large an absorption field is needed. Sand transmits water faster than silt, which is faster than clay.

- Hydraulic loading. This is the amount of effluent applied per square foot of trench surface or field, an important factor in septic tank design. Because water filters through clay soils more slowly than through sand or silt, the hydraulic loading rate is lower for clay than for silt, and lower for silt than for sand. Because clay soils have a very low conductivity, they may easily smear and compact during construction, reducing their infiltration rate to half the expected rate.

Site Selection

Selection criteria for a site on which wastewater treatment and renovation is to occur must consider two fundamental design factors. These are the ability of a site to assimilate the desired hydraulic load and the ability of the site to assimilate the process load. The process load consists of the organic matter, nutrients, and other solids contained in the wastewater. The hydraulic assimilative capacity of a site is often determined by the texture of the soil material on a site. Sites with sandy textured soils generally are assigned high hydraulic loadings while sites with fine textured clay are often assigned low hydraulic assimilative capacities. This typical hydraulic loading scenario often results in excessive loadings of the process constituents on a sandy site.

Sandy textured soils generally exhibit rapid permeability. This suggests that these soils will drain rapidly and reaerate quickly. These characteristics allow moderately high organic loadings onto these soils, but limit the potential for these soils to attenuate soluble pollutants such as nitrogen and phosphorus. The fine textured soils - those that contain clays - exhibit high potential to attenuate soluble pollutants, but exhibit very limited capacity to transmit liquid; consequently the hydraulic loadings applied to these soils must be very conservative. No soil provides the optimum characteristics to assimilate all constituents applied and the challenge to the onsite wastewater professional is to balance the loadings applied with the total assimilative capacity of the designed receiver site. Treatment objectives must be utilized to optimize system design.

When large volumes of wastewater are designated for application onto a site, then a groundwater mounding analysis may be required. This analysis is required to assure that the separation distance between the bottom of the trench and the shallow groundwater is adequate to provide necessary treatment. Large systems should be designed so that the longest dimension of the trench is along site contour lines and the shortest dimension crosses field contours. This generally results in systems designed with hydraulic gradients that facilitate treatment.

Soil and site conditions on which wastewater will be treated will vary from location to location. Sites selected as receivers for wastewater must exhibit characteristics that facilitate treatment and renovation of wastewater. Sites for wastewater treatment and renovation must be selected based on criteria established by local regulatory agencies as acceptable

Trench bottom application rates range from 0.2 to 1.2 gpd/ft^2 depending on soil conditions. Table 1 contains suggested rates of wastewater applications for trench and bed bottom areas.

TABLE 1 SUGGESTED RATES OF WASTEWATER APPLICATION

Soil Texture	Percolation Rate (min/in/ min/cm)	Application Rate (gpd/ft^2/ Lpd/m^2)
Gravel, coarse sand	<1/ <0.4	not suitable
Coarse to medium sand	1 - 5/ 0.4 - 2.0	1.2/ 0.049
Fine to loamy sand	6 - 15/ 2.4 - 5.9	0.8/ 0.033
Sandy loam to loam	16 - 30/ 6.3 - 11.8	0.6/ 0.024
Loam, porous silt	31 - 60/ 12.2 - 23.6	0.45/ 0.018
Silty clay loam, clay loam	61 - 120/ 24.0 - 47.2	0.2/ 0.008
Clay, colloidal clay	>120 / >47.2	not suitable

Notes: 1) min/in x 0.4 = min/cm
2) gpd/ft^2 x 40.8 = Lpd/m^2

Source: Crites & Tchobanoglous, 1998.

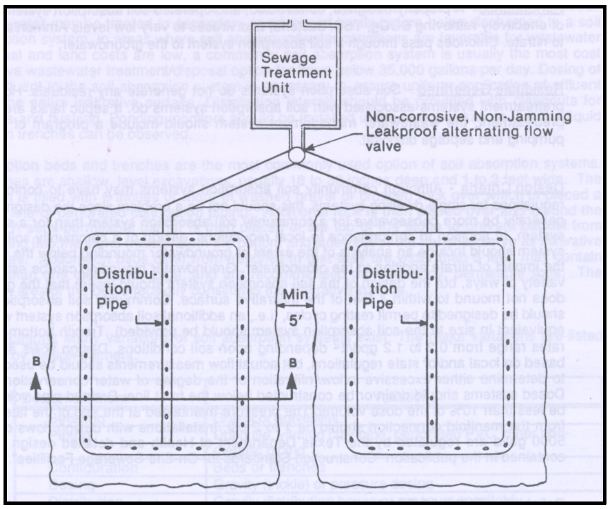
Hydraulic Loading Rate

The design hydraulic loading rate is determined by soil characteristics, groundwater mounding potential, and applied wastewater quality. Clogging of the infiltrative surface will occur in response to prolonged wastewater loading, which will reduce the capacity of the soil to accept the wastewater. However, if loading is controlled, biological activity at the infiltrative surface will maintain waste accumulations in relative equilibrium so reasonable infiltration rates can be sustained.

Selection of the design hydraulic loading rate must consider both soil and system design factors. Typically, design rates for larger SWISs are based on detailed soil analyses and experience, rather than measured hydraulic conductivities.

Wastewater Pretreatment

At a minimum, wastewater treatment in a septic tank is required before application to a SWIS. Figure 3 presents a schematic of a dual soil absorption system. Higher levels of treatment such as achieved with an aerobic treatment unit (ATU) can reduce SWIS size or prolong system life, but this must be weighed against the increased costs of pretreatment and potential damage from poor maintenance of the system.



Source: Barrett and Malina, 1991

FIGURE 3 PLAN VIEW OF DUAL SOIL ABSORPTION BED SYSTEM

ADVANTAGES AND DISADVANTAGES

Advantages

Subsurface infiltration systems are ideally suited for decentralized treatment of wastewater because they are buried. They are often the only method of wastewater treatment available for rural homes and business establishments. Some communities choose subsurface infiltration systems to avoid costly sewer construction. Where individual lots are not suited for their use, remote sites may be used to cluster homes onto a single SWIS, limiting the need for sewers. Alternatively, wastewater from entire communities may be treated by a SWIS. Because the system is buried, the land area can be used as green space or park land. In addition, SWISs provide groundwater recharge.

Disadvantages

Use of SWISs is limited by site and soil conditions. Because the infiltrative surface is buried, it can be managed only by taking it out of service every 6 to 12 months to "rest", requiring the construction of standby cells with alternating loading cycles. Therefore, larger SWISs are usually restricted to well-drained sandy soils to reduce land area requirements. Because nitrogen is not effectively removed by SWISs, pretreatment may be necessary to prevent nitrate contamination above drinking water standards in underlying groundwater.

Flows from commercial establishments greater than the design capacity of the system may overwhelm the SWIS and produce overflow conditions and objectionable odors.

PERFORMANCE

Septic tanks and other pretreatment units must be properly maintained to keep a SWIS system treating sewage efficiently. As the septic tank or ATU is used, sludge accumulates in the bottom of the treatment unit. As the sludge level increases, wastewater spends less time in the tank and solids may escape into the absorption area. Properly sized septic tanks generally have enough space to accumulate sludge for at least three years. ATUs require aggressive sludge management.

The frequency of tank pumping depends on:

- The capacity.
- The amount of wastewater flowing into the tank (related to size of household).
- The amount of solids in the wastewater (for example, more solids are generated if garbage disposals are used).

The soil absorption field will not immediately fail if the tank is not pumped, but the septic tank will no longer protect the soil absorption field from solids. If the tank or ATU is neglected for long, it may be necessary to replace the soil absorption field.

One example of septic tank/absorption field system failure is found in Missouri. Several statewide surveys have shown that 70 percent (150,000) of systems are not functioning properly, causing nearly 60 million gallons of untreated or semi-treated sewage per day to reach groundwater supplies (Schultheis and Hubble). Based on the general soils map of Missouri, 60 to 99 percent of counties in the Ozarks region show severe limitations in the use of absorption field systems.

Many studies of failing septic tank systems have been conducted. The Lower Colorado River Authority (LCRA) received a grant from the Texas Water Commission (TWC) to identify clustered sites of on-site wastewater treatment and disposal facilities in the Lavaca and Colorado coastal basins that may be failing. Information from this study will identify areas which may qualify for funding under Section 319 of the Clean Water Act.

A study was conducted by the Texas Water Commission (TWC) to gauge whether septic tanks were polluting Lake Granbury in Hood County, Texas (TWRI Spring 1993). Because so many septic tanks were in use near the lake, there was additional concern of fecal coliform contamination. Analysis of samples taken in coves along the lake showed that 10 percent of tested areas had more than 200 colony-forming units per 100 milliliters, indicating that the lake is highly contaminated with fecal coliform bacteria.

Increasingly stringent discharge regulations have led many communities to turn to more effective on-site means to treat waste. One example is Eagle Mountain Lake near Fort Worth, Texas, where the Tarrant County Water Control and Improvement District (WCID) is taking strides to improve the effluent quality of the 2,500 local on-site wastewater systems at Eagle Mountain Lake. Many homes in this area are weekend homes, with septic tanks designed for limited use. WCID is designing the on-site system to be large enough for full time use to improve effluent quality.

In the Texas Panhandle, the Texas Natural Resource Conservation Commission (TNRCC) has used innovative on-site technologies to solve wastewater problems in the region associated with failing septic tank systems due to rapid growth in the region. In the 1980s, the town of Umbarger installed a 44,000-gallon septic tank and a 30,720-square foot drainfield to serve its 325 residents. This community system replaced the collection of many smaller septic tanks distributed throughout the town, many of which had previously experienced failures.

OPERATION AND MAINTENANCE

Subsurface Infiltration

A well-designed SWIS requires limited operator attention. Management functions primarily involve tracking system status, testing for solids accumulation, evaluating pump performance, monitoring system controls, and monitoring performance of pretreatment units, mechanical components, and wastewater ponding levels above the filtration surface. Operator intervention may be required if a change is noted. Routine servicing of SWIS is generally limited to annual or semiannual alternating of infiltration cells.

Another maintenance task to prevent a system from backing up is to clean the screen on the effluent end of the septic tank. This filter must be cleaned periodically by removing the filter from the outlet and spraying it with a hose directed back into the septic tank.

Soil absorption fields must be protected from solids and rainfall. If a tank is not pumped, solids can enter the field. Rainfall running off roofs or impermeable surfaces such as concrete areas should be diverted around the soil absorption field to prevent it from becoming saturated with rainwater. Fields saturated with rainwater cannot accept wastewater. Planting cool-season grasses over the soil absorption field in winter can help remove water from the soil and keep the system working properly.

COSTS

Subsurface Infiltration

Land and earthwork are the most significant capital costs. Where fill must be used to bed the primary infiltrative surface, the cost of transporting the material also becomes significant. Other costs include pretreatment and transmission of wastewater to the treatment site.

Other factors that affect septic tank costs include subsurface site conditions, location of and access to the site, and the type of tank used. Costs of tanks, including installation, typically range from $1.00 to $4.00 per gallon of tankage. Pumping septic tanks ranges from $150 to $200 per 2,000 gallons. If a tank is pumped once every 3 ½ years, the maintenance cost will be about $50 per year, with a pump and haul cost of $175.

REFERENCES

Other Related Fact Sheets

Mound Systems
EPA 832-F-99-074
September 1999

Pressure Sewers
EPA 832-F-00-070
September 2000

Small Diameter Gravity Sewers
EPA 832-F-00-038
September 2000

Other EPA Fact Sheets can be found at the following web address:
http://www.epa.gov/owmitnet/mtbfact.htm

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Decentralized Systems Technology Fact Sheet
Septic Tank Leaching Chamber

DESCRIPTION

A leaching chamber is a wastewater treatment system consisting of trenches or beds, together with one or more distribution pipes or open-bottomed plastic chambers, installed in appropriate soils. These chambers receive wastewater flow from a septic tank or other treatment device and transmit it into soil for final treatment and disposal.

A typical septic tank system consists of a septic tank and a below-ground absorption field (also called a drainfield, leaching field, or nitrification field). Leaching chambers are drainfields used to dispose of previously treated effluent. The drainfield system typically consists of leaching chambers installed in trenches and connected to the septic tank via pipe. Effluent flows out of the septic tank and is distributed into the soil through the leaching chamber system. The soil below the drainfield provides final treatment and disposal of the septic tank effluent. After the effluent has passed into the soil, most of it percolates downward and outward, eventually entering the shallow groundwater. A small portion of the effluent is used by plants through their roots or evaporates from the soil. Figure 1 shows a typical leaching chamber.

Leaching chambers have two key functions: to dispose of effluent from the septic tanks and to distribute this effluent in a manner allowing adequate natural wastewater treatment in the soil before the effluent reaches the underlying groundwater aquifer. Although the septic tank removes some pollutants from wastewater, further treatment is required after the effluent leaves the tank. Nitrogen compounds, suspended solids, organic and inorganic materials, and bacteria and viruses must be reduced before the effluent is considered purified. These pollutants are reduced or completely removed from the wastewater by the soil into which the wastewater drains from the leaching chambers.

Source: Infiltrator Systems Inc., 2000.

FIGURE 1 LEACHING CHAMBER

Depending on the drainfield size requirements, one or more chambers are typically connected to form an underground drainfield network. The leaching chambers are usually made of sturdy plastic and do not require gravel fill. The sides of each chamber have several openings to allow wastewater to seep into the surrounding soil.

A typical leaching chamber consists of several high-density polyethylene arch-shaped, injection-molded chamber segments. A typical chamber has an average inside width of 51 to 102 centimeters (20 to 40 inches) and an overall length of 1.8 to 2.4 meters (6 to 8 feet). The chamber segments are usually one-foot high, with wide slotted sidewalls, which are usually 20 degrees toward the chamber center or away from the trench sidewall. Each chamber segment is designed to mechanically interlock with the downstream chamber segment, forming a complete drainfield trench that consists of an inlet plate with a splash plate below the inlet on the trench bottom, and a solid-end plate at the distal end of the chamber drainfield line.

Common Modifications

Typical leaching chambers are gravelless systems, with drainfield chambers with no bottoms and plastic chamber sidewalls, available in a variety of shapes and sizes. Some gravelless drainfield systems use large diameter corrugated plastic tubing covered with permeable nylon filter fabric not surrounded by gravel or rock. The area of fabric in contact with the soil provides the surface for the septic tank effluent to infiltrate the soil. The pipe is a minimum of 25.4 to 30.5 centimeters (10 to 12 inches) in diameter covered with spun bonded nylon filter fabric to distribute water around the pipe. The pipe is placed in a 30.5 to 61 centimeter (12 to 24 inches) wide trench. These systems can be installed in areas with steep slopes with small equipment and in hand dug trenches where conventional gravel systems would not be possible.

Use of these systems decreases overall drainfield costs and may reduce the number of trees that must be removed from the drainfield lot. However, fabric-wrapped pipe cannot overcome unsuitable site conditions and should not be installed where gravel systems will not function properly or in fine sandy organic rich, coastal plain soils with shallow groundwater.

APPLICABILITY

Leaching chambers are widely used as drainfield systems for septic tank effluent discharge. Many leaching chambers have been installed in 50 states, Canada, and overseas over the last 15 years. Currently, a high percentage of new construction uses lightweight plastic leaching chambers for new septic tank systems in states such as Colorado.

Leaching chambers are an alternative to the conventional septic tank drainfield, which consists of several trenches with gravel beds and perforated plastic pipes. Leaching chambers allow more of the soil profile to be used since the septic tank effluent is distributed to the ground below and the soil surrounding the chamber. Therefore, leaching chambers are more effective than traditional gravel drainfields, especially when the drainfield must be located on a steep slope. Leaching chambers are suitable for lots with tight sizing constraints or where water tables or bedrock limit the depth of the drainfield. Some states offer up to 50 percent sizing reduction allowance when using leaching chambers instead of conventional septic tank gravel drainfields. Because they can be installed without heavy equipment, leaching chamber systems are easy to install and repair. These high-capacity open-bottom drainfield systems can provide greater storage and more time for proper infiltration than conventional gravel systems and, therefore, are also suitable for stormwater management.

Current Status

Septic tank system drainfields are usually classified as two types: gravel or gravelless systems. In gravel drainfield systems, the pipelines distributing septic tank wastewater are placed over a layer of gravel. Four inches of additional rock are then typically placed around the pipe and two inches above the pipe. Gravelless systems provide the same functions as gravel drainfields while overcoming the potentially damaging impacts of gravel such as compaction of moist soil during installation and reduction of infiltration by obstructing the soil. The leaching chambers create a larger contact area for effluent to infiltrate into the soil, providing efficient treatment.

Typically, leaching chambers consist of series of large, two to four foot wide modular plastic arch segments that snap together. These arch segments replace the perforated drainpipes used in gravel drainfields. The wide chambers are manifolded with conventional plastic pipe such as high-density polyethylene (HDPE).

ADVANTAGES AND DISADVANTAGES

Limitations

Leaching chamber application is limited under certain conditions. The main limitations for installation and normal operation are small lot sizes, inappropriate soils, and shallow water tables. Leaching chamber systems can be used only in areas with soils that have percolation rates of 0.2 to 2.4 minutes per millimeter (5 to 60 minutes per inch). Neglect of septic tank and leaching chamber maintenance can lead to drainfield failure and soil and groundwater contamination.

Reliability

Leaching chambers are reliable, do not have moving parts, and need little maintenance to function properly. They are usually made of plastic materials, with a useful life of 20 years or more in contrast to the average useful life of a drainfield of 15 years, with a maximum of 20 to 25 years.

Some systems can be combined with other drainfield systems such as mounds and pressure distribution systems. Some can also be used for stormwater applications. Leaching chambers do not require more maintenance than conventional drainfield systems.

Advantages

Key advantages of leaching chamber systems compared to gravel drainfields include:

- Easier and faster to install.
- Soil in the trenches is not as likely to be compacted.
- Less expensive in areas where gravel must be transported over a long distance, such as parts of eastern North Carolina, the Rocky Mountains, eastern Oregon, and Connecticut.
- Leaching chambers allow for lower intrusion of soil and silt into the drainfield and thereby extend the useful life of the drainfields.
- Some leaching chambers have greater storage volumes than gravel trenches or beds.
- Inspection of the chambers is easier.
- Eliminates the need for gravel.
- Leaching chambers require a smaller footprint. Some states allow up to a 50 percent reduction in drainfield size compared to conventional gravel drainfield systems.

The lightweight chamber segments available on the market stack together compactly for efficient transport. Some chambers interlock with ribs without fasteners, cutting installation time by more than 50 percent over conventional gravel/pipe systems. Such systems can be relocated if the site owner decides to build on the drainfield site. Leaching chamber systems can be installed below paved areas and areas of high traffic.

Disadvantages

A key disadvantage of leaching chambers compared to gravel drainfields is that they can be expensive if a low-cost source of gravel is readily available. Also, tests to assess the effectiveness of these drainfield systems have yielded mixed results. Direct effluent infiltration is advantageous in some soils yet detrimental in others. While open chambers can break up tight, clay soils and open up more airspace for biological treatment, they are less effective than gravel drainfields in preventing groundwater pollution. Because the open bottom allows septic tank effluent to infiltrate the soil unfiltered, high percolation rates (sandy soils) and groundwater levels must be carefully considered before installing such systems.

DESIGN CRITERIA

The size of a leaching chamber system is based on the wastewater flow and soil properties. For a three bedroom home, the area needed for a leaching chamber system could range from 18.6 sq. meters (200 square feet) for a coarse-textured soil up to 185.8 sq. meters (2,000 square feet) for a fine-textured soil. When the total drainfield area is estimated, setbacks from the house and property lines must be provided. These are usually state-regulated and vary from state to state. Table 1 recommended setback distances.

TABLE 1 SETBACK DISTANCES FROM LEACHING CHAMBER DISPOSAL AREAS

Item	Minimum Distance, ft
Private Water Supply Well	100
Public Water Supply Well	300
Leak or Impoundment	50
Stream or Open Ditch	25
Property Lines	10
Water Line Under Pressure	10
Sewer Interceptor Drain	25

Source: Schultheis, 1999.

The key design parameter for leaching chambers is the maximum long-term acceptance rate (LTAR), which depends on the type of drainfield soils. Table 2 presents recommended LTARs for leaching chamber sizing.

The design LTAR should be based on the most hydraulically limiting naturally occurring soil horizon within three feet of the ground surface or to a depth of one foot below trench bottom, whichever is deeper. To determine the total trench bottom area required, the design daily wastewater flow should be divided by the applicable LTAR. The minimum linear footage of the leaching chamber system should be determined by dividing the total trench bottom area by 1.2 meters (4 feet), when used in a conventional drainfield trench. No reduction area is allowed for leaching chamber systems installed in bed or fill systems. In addition to the area needed for the leach field, space should be reserved for possible expansion (for example, a 50 percent expansion area is required in New York State; a 100 percent repair area is required in North Carolina).

Leaching chamber systems in septic tank drainfields are typically installed in three foot wide trenches, separated by at least nine feet, edge to edge. Soil backfill is placed along the chamber sidewall area to a minimum compacted (walked-in) height of eight inches above the trench bottom. Additional backfill is placed to a minimum compacted height of 30.5 centimeters (12 inches) above the chamber. The leaching chamber trench bottom is usually at least 61 centimeters (24 inches) below finished grade, and the inlet invert is approximately 20.3 centimeters (8 inches) above the trench bottom, and at least 43.2 centimeters (17 inches) below the finished grade. Most health codes limit the length of individual trenches to 18.3 meters (60 feet). A leaching chamber system should have at least two trenches. Figure 2 shows a schematic of a leaching chamber trench.

TABLE 2 LEACHING CHAMBER LONG-TERM ACCEPTANCE RATE

Soil Type	Long-Term Acceptance Rate (gpd/ft./yr)	
	Natural Soil	Saprolite
Sands	0.8 – 1.0	0.4 – 0.6
Coarse Loams	0.6 – 0.8	0.1 – 0.4
Fine Loams	0.3 – 0.6	-
Clays	0.1 – 0.4	-

Source: Infiltrator Systems Inc., 2000.

Individual chamber trenches should be leveled in all directions and follow the contour of the ground surface elevation without any dams or other water stops. Leaching systems installed on sloping sites may use distribution devices or step-downs when necessary to channel the level of the leaching chamber segments from upper to lower elevations. The manufacturer's installation instructions should be followed and systems should be installed by an authorized contractor.

PERFORMANCE

The performance of leaching chamber systems is determined by the characteristics of the soil, available slope, space, soil depth over the groundwater table, and other site-specific factors. The overall performance of leaching chambers is highly dependent on the performance of the connected septic tanks.

OPERATION AND MAINTENANCE

Septic tank/leaching chamber systems can operate independently and require little day-to-day maintenance. Proper maintenance of the septic tank includes inspection to determine the rate of sludge and scum accumulation in the tank every three to five years. Under normal conditions, the septic tank should be pumped every five to eight years.

Materials that do not readily decompose (grease and cooking oil, coffee grounds, disposable diapers, tampons, cigarette butts, condoms, plastics, etc.) should not be flushed into septic tanks because they may clog the tank inlet and/or outlet and cause the leaching chambers to fail. Harmful chemicals, such as pesticides, herbicides, gasoline, oil, paint and paint thinners should not be discharged to sanitary drains because they may harm soil microorganisms in the drainfield which provide natural wastewater treatment. Excessive use of chlorine-based cleaners can harm the normal operation of leaching chambers because they may cause soil dispersion and sealing, reducing soil treatment capabilities.

COSTS

Leaching chamber costs depend on many factors, including:

1. Soil type.
2. Cost of land.
3. Site topography.
4. Groundwater level.

These site and system specific factors must be examined and incorporated when preparing a leaching chamber cost estimate.

Construction Costs

Even with favorable soil conditions, a leaching chamber system is more expensive then a conventional gravel-pipe drainfield. The cost of a standardized, 2.13 meter (seven foot) leaching chamber segment ranges from $50 to $150. While drainage pipe is less expensive per foot, a larger drainfield footprint is needed for conventional gravel drainfields. The cost for a single-family septic tank leaching chamber drainfield typically ranges between $2,000 and $5,000 in 1993 dollars. If the site is inadequate for a new drainfield and the field must be removed and replaced with a new one, the cost of a new leaching chamber system may exceed $10,000.

Operation and Maintenance Costs

Operation and maintenance costs for these systems are minimal. Key costs associated with the proper functioning of the drainfield systems include septic tank cleaning, which typically ranges between $500 to $1,500 per cleaning.

REFERENCES

Other Related Fact Sheets

Septic System Tank
EPA 832-F-00-040
September 2000

Septage Treatment/Disposal
EPA 832-F-99-068
September 1999

Septic Tank-Soil Absorption Systems
EPA 832-F-99-075
September 1999

Other EPA Fact Sheets can be found at the following web address:
http://www.epa.gov/owmitnet/mtbfact.htm

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Septic Tank - Soil Absorption Systems

DESCRIPTION

An estimated 30 percent of all U.S. households use on-site treatment methods (Hoover *et al.*, 1994). Septic tank/soil absorption has been the most popular on-site method (U.S. EPA, 1980a.) The septic tank is an underground, watertight vessel installed to receive wastewater from the home. It is designed to allow the solids to settle out and separate from the liquid, to allow for limited digestion of organic matter, and to store the solids while the clarified liquid is passed on for further treatment and disposal. Though septic tank effluent can be treated in a variety of ways, this Fact Sheet describes the distribution of effluent wastewater into a subsurface soil absorption area or drainfield.

APPLICABILITY

Septic tank/soil absorption systems are an option to consider wherever a centralized treatment system is not available. Since subsurface soil treatment and disposal relies upon gradual seepage of wastewater into the surrounding soils, these systems can only be considered where favorable soil characteristics and geology exist for treatment and subsequent disposal of the treated wastewater into the environment.

For effective wastewater treatment, prospective soils should be relatively permeable and should remain unsaturated to several feet below the system depth. Moreover, the soil absorption system should be set well above water tables and bedrock. Further, it cannot be easily located in steeply sloped areas (U.S. EPA, 1980a.) For regions with high water tables or shallow bedrock, other systems using more advanced technology may be better options for wastewater treatment. (See *Wastewater Technology Fact Sheet: Mound Systems*.) In cases where impermeable soils exist, fill systems and sand-lined trench systems—in which fill material is brought in to replace unsuitable soils—may be a feasible alternative.

To avoid contamination of drinking water sources and other problems, soil absorption systems must be situated at prescribed distances from wells, surface waters and springs, escarpments, property boundaries and building foundations (U.S. EPA, 1980a). These regulations may restrict the feasibility of septic system installation, depending on property size, shape, and proximity to the features noted.

Conventional septic systems are designed to operate indefinitely if properly maintained. However, because most household systems are *not* well-maintained, the functioning life of septic systems is typically 20 years or less. In contemporary practice, it is commonly required that a second area of suitable soil be reserved at the site as a “repair area” in the event that the initial system fails to operate properly or to allow for the possibility of a future home addition project (Hoover, 1999.)

Since the soil absorption area must remain unsaturated for proper system functioning, it may not be feasible to install septic systems in regions prone to frequent heavy rains and flooding, or in topographical depressions where surface waters accumulate.

ADVANTAGES AND DISADVANTAGES

Advantages

- Simplicity, reliability and low cost.
- Low maintenance requirements.
- Nutrients in waste are returned to soil.
- A properly designed, well-maintained system can last for more than twenty years.

Disadvantages

- Siting limitations for septic systems include natural soil type and permeability, bedrock and groundwater elevations, and site topography.
- Regulations pertaining to set-backs from water supply, lot lines, and drainage lines must be taken into account.
- Restrictions on the character of influent wastewater must be included in project planning.
- Improperly functioning systems can introduce nitrogen, phosphorus, organic matter, and bacterial and viral pathogens into the surrounding area and groundwater.

DESIGN CRITERIA

A septic system usually includes three components: the septic tank, a drainfield and the soil beneath the drainfield. The tank must be a watertight container constructed of a sound, durable material resistant to corrosion or decay (concrete, fiber reinforced plastic, fiberglass, or polyethylene). The septic tank is connected to a piping system that distributes wastewater effluent into subsurface soil for absorption and subsequent treatment.

Wastewater generated from a household is collected and transported through the house drains to the buried septic tank, where most of the solids settle while grease and scum float to the surface. Inlet baffles or effluent screens help to force wastewater down into the tank, preventing short-circuiting across the top. Outlet baffles keep the scum layer from moving into the soil absorption system. Collected solids undergo some decay by anaerobic digestion in the tank bottom. The capacity of a septic tank typically ranges from 3,785 to 7570 liters (1,000 to 2,000 gallons).

Clarified septic tank effluent exits the septic tank and enters the soil absorption system (also called a "leachfield" or "drainfield") where a biological "clogging mat" or "biomat" forms, contributing to even distribution of the waste into the drainfield (U.S. EPA, 1980a; Hoover et. al., 1996.) State regulations usually require between two and four feet (or sometimes less) of unsaturated soil beneath the drainfield to renovate wastewater before it reaches a "limiting layer"—the point at which conditions for waste renovation become unsuitable. The limiting layer may be bedrock, an impervious soil layer or the seasonal high water table.

Absorption beds and trenches are the most common design options for soil absorption systems. Trenches are shallow, level excavations, usually from 0.305 to 1.524 meters (one to five feet) deep and 0.305 to 0.914 meters (one to three feet) wide (see U.S. EPA, 1980a.) The bottom is filled with at least 15.24 centimeters (six inches) of washed gravel or crushed rock over which a single line of 10.16 centimeters (four-inch) perforated pipe is placed. Additional rock is placed over and around the pipe. A synthetic building fabric is laid on top of the gravel to prevent backfill from migrating into the gravel trench. Beds are constructed analogously to trenches, but are more than three feet wide and may contain multiple lines of distribution piping. While beds are sometimes preferred for space savings in more permeable soils, trench designs provide more surface area for soil absorption (U.S. EPA,1980a; Hoover, 1999.)

The size of a soil absorption system is based on the size of the house and the soil characteristics. Traditionally, soil is evaluated using a "percolation rate", a measure of the water migration rate through the candidate soil. Acceptable limits of percolation for drainfield suitability range between 23 seconds and 24 minutes per centimeter (1 and 60 minutes per inch) (U.S. EPA, 1980a.) Percolation rates of

1.18 and 24 minutes per centimeter (3 and 60 minutes per inch) would correspond to absorption areas of about 70 and 340 square meters respectively per bedroom of the house to be serviced (Harlan and Dickey, 1999.) Though the number of bedrooms has typically been used as a rule-of-thumb measure for tank sizing, it should be noted that this is only an approximation; by itself, it is an unreliable way to gauge anticipated waste volume (U.S. EPA, 1980a.)

While some states continue to use the percolation rate as a criterion for site suitability, many use a more comprehensive measure, the long-term acceptance rate (LTAR), as part of a thorough site evaluation (Hoover, 1999). The LTAR accounts for the texture, structure, color, and consistency of all soil layers beneath the drainfield, as well as the local topography, to make a determination of the wastewater loads the area is able to accept on a long-term basis once the biomass has formed.

The character of wastewater flowing into the soil absorption area is a critical variable for proper functioning of septic systems. Soil absorption systems work most effectively when the influent wastewater does not contain significant levels of settleable solids, greases and fats (U.S. EPA, 1980a), which can accelerate clogging of the infiltrative soil. Accordingly, the use of household garbage disposals and pouring of grease down domestic drains can reduce the effectiveness of septic tank/soil absorption systems (Gannon *et al*., 1998). To avoid infiltrative soil clogging, septic tanks are fitted with outlet baffles to prevent floating grease, scum, and entrained particles from moving into the soil absorption system. Also, the use of two-compartment tanks is recommended over single-compartment designs. Even so, tanks must be properly sized to avoid hydraulic overload and the passing of unwanted materials into the soil absorption system.

Digestion of wastes is a temperature dependent process, and colder temperatures may hinder effective breakdown of wastes in septic tanks (Seifert, 1999.) Therefore, in cold climates tanks may need to be buried more deeply, and/or insulated.

Septic systems can act as sources of nitrogen, phosphorus, organic matter, and bacterial and viral pathogens, which can have potentially serious environmental and health impacts (Gannon *et al.*, 1994.) Failure of systems to adequately treat wastewater may be related to inadequate siting, inappropriate installation, or neglectful operation. Hydraulic overloading has been identified as a major cause of system failure (Jarrett *et al.*, 1985). Since septic wastewater contains various nitrogen compounds (e.g., ammonia, ammonium compounds, and organic forms of nitrogen) (Brown, 1998), installation of septic systems in areas that are densely developed can, in combination with other factors, result in the introduction of nitrogen contaminants into groundwater. Groundwater impacts can occur even when soil conditions are favorable because the unsaturated aerobic treatment zone located beneath the drainfield—a zone required for pathogen removal—promotes conversion of wastewater-borne nitrogen to nitrates (Hoover, 1999.) If nitrate contamination of groundwater is a concern in the region, control methods or denitrifying technologies may be required for safe operation of a septic system.

Symptoms of a failing septic system can include strong odors, ponding of improperly treated wastewater or backup of wastewater into the home (Hoover, 1999.) Less obvious symptoms arise when systems are operating less-than-optimally, including a measurable decline in water quality, leading over the long term to local environmental degradation (Brown, 1998).

Solvents, poisons, and other household chemicals should not be allowed to flow into a septic system; these substances may kill beneficial bacteria in the tank and drainfield, and lead to system failure (Montgomery, 1990.) Though some organic solvents have been marketed as septic system cleaners and substitutes for sludge pumping, there is little evidence that such cleaners perform any of their advertised functions. It is known that they can exterminate useful microbes, resulting in increased discharge of pollutants (Gannon *et al.*, 1999; Montgomery, 1999.) In addition, the chemicals in these products can contaminate receiving waters (U.S. EPA, 1993). Additive restrictions are most effective when used as part of a Best Management

Practice system involving other source reduction practices such as phosphate bans and use of low-volume plumbing fixtures.

Design of subsurface disposal beds and trenches varies greatly due to specific site conditions. In sloping areas, a serial distribution system configures the trenches so that each is used to its capacity before effluent overflows into the succeeding trench. A dosing or pressurized distribution system may be installed to ensure complete distribution of the effluent to each trench(U.S. EPA, 1980a.) Alternating valves permit switching between beds or trenches to allow drying out or resting of the system (U.S. EPA, 1980a; Gannon *et al.*, 1999). A dosing system, such as a low-pressure pipe system, is useful in areas of both high groundwater and permeable soils, where shallow gravel ditches installed from 22.86 to 30.48 centimeters (9 to 12 inches) below grade are employed. Another option is the use of drip irrigation (Hoover, 1999.)

For systems that are properly sited, sized, constructed, and maintained, septic tank/soil absorption has proven to be an efficient and cost effective method of onsite wastewater treatment and disposal. Operating without mechanical equipment, properly maintained soil absorption systems have a service life in excess of 20 years. Several important steps must be taken during construction to ensure system reliability:

- Keep heavy equipment off the soil absorption system area both before and after construction. Soil compaction can result in premature failure of the system.

- Divert rainwater from building roofs and paved areas away from the soil absorption system. This surface water can increase the amount of water the soil has to absorb and lead to premature failure.

- Ensure that the alternating device and the trench bottoms are level to provide even distribution of the septic tank effluent. If settling and frost action cause shifting, part of the soil absorption system may be overloaded.

- Avoid installing the septic tank and soil absorption system when the soil is wet. Construction in wet soil can cause puddling, smearing, and increased soil compaction, which greatly reduces soil permeability and the life of a system.

- Install water-saving devices to reduce the amount of wastewater entering the soil absorption system.

- Have the septic tank pumped at least every three to five years, and inspected regularly.

PERFORMANCE

When correctly installed and maintained, septic tank/soil absorption systems are an effective way to treat and dispose of domestic wastewaters. Nevertheless, even under the best of circumstances septic systems allow a “planned release” of contaminants into the groundwater (Tolman *et al.*, 1989) and must be designed and operated to minimize the impact of this release. While hydraulic overloading been identified as a major cause of septic system failure (Jarrett *et al.*, 1985), contamination due to system failure can be caused by a variety of factors. In one study, widespread septic failures in Illinois were primarily attributed to unsuitability of soils, age of system, lack of maintenance, and improper design and installation of systems (Smith and Ince, 1989.) Likewise, a study of septic systems in the Borough of Hopatcong, New Jersey, found poor soil conditions and shallow bedrock to be significant contributors to system failure (HSAC, 1997.) By one estimate, only 32 percent of the total United States land area has soils suitable for waste treatment by traditional septic tank/soil absorption systems (U.S. EPA, 1980a.)

Frequency of use also affects system performance. Drainfields installed on seasonally used properties have been found to develop an incomplete biological clogging mat, leading to uneven distribution and absorption of wastewater (Postma *et al.*, 1992.)

A critical factor in optimal system performance is the depth of unsaturated soil beneath the soil absorption field. A septic system performance study conducted on a coastal barrier island (characterized by variably high water tables and sandy soils—conditions unfavorable for septic system operation) found that a 60-cm soil layer provided adequate microbial treatment, even at the highest loading rate studied (Cogger *et al.*, 1988.) By contrast, the same study found that another system of the same design having a 30-cm soil layer beneath the leachfield suffered from rising water tables and ineffective treatment. For the loading rates studied, the depth of unsaturated soil beneath the system was determined to be a more decisive factor in system performance than hydraulic loading.

Despite the limitations discussed above, septic systems tend to be preferred over other on-site treatment methods for long-term domestic use. A 1980 study found septic tank/soil absorption systems to offer the lowest cost and the highest level of performance among six on-site treatment techniques tested (U.S. EPA, 1980b). In addition to septic tank/soil absorption, the other five techniques included incinerating toilets, recycling toilets, extended aeration units followed by open sand filters, septic tanks followed by open sand filters, and septic tanks followed by horizontal sand filters).

OPERATION AND MAINTENANCE

To keep the system healthy, care must be taken to avoid putting high-solids or grease containing materials down drains or toilets, including paper towels, cigarettes, cat litter, feminine hygiene products, and residual cooking fat (HSAC 1997). In the past, pump-out of accumulated solids from septic tanks every three to five years has been recommended, however solids loading has been shown to be extremely variable and for modern tanks, pump-out may not need to occur as often (U.S. EPA, 1994). Pump-out every four years should be planned, but actual practice should be determined by inspection.

Inspections should be conducted at least biannually to confirm that baffles are operating correctly, that no leaks are occurring, and to check the levels of sludge and scum in the tank (U.S. EPA, 1994). The tank should be pumped out if the sludge layer thickness exceeds 25 percent of the working liquid capacity of the tank (Hoover, 1999), or if the bottom of the scum layer is within 7.62 centimeters (three inches) of the bottom of the outlet baffle (U.S. EPA, 1994). More frequent inspections are required for systems using more advanced on-site technologies (Hoover *et al.*, 1995.)

Though many enzyme additives are marketed as septic system digestion aides, the effectiveness and usefulness of many of these products is questionable. (Seifert, 1999.) If waste products are not being properly digested before they are discharged, the most likely cause is hydraulic overloading. In cold climates, lower average tank temperatures can also inhibit digestion.

Similarly, many chemical additives are available for system cleaning and rehabilitation. However, many of these products are not effective (see Bicki and Bettler, 1988, on use of peroxide for rehabilitation of septic systems) and some may even harm the system (Gannon *et al.*, 1998.) The use of chemical additives should be avoided.

COSTS

Costs for installation and maintenance of septic systems vary according to geographical region, system size and type, and the specific soil and geological characteristics of the selected site. Installation of a new bed or trench septic system on a site meeting the criteria for such systems varies widely in cost. Figures range from as low as $1,500 to more than $8,000 (Montgomery, 1990; Anchorage HHS, 1999; Ingersoll, 1994.) An average installation cost of $4,000 is assumed for a traditional septic tank/soil absorption system in a geologically favorable area.

The cost of tank pump-out varies from as low as $60 to(Ingersoll, 1994) to as much as $260 (HSAC, 1997.) For a pumping cost of $150, assuming pump-out every four years, the total pump-out cost over a 20-year period would be $750 (subject to inflation). Biannual inspections cost between $50 and $250 (Scott County, 1999); for a $125 fee, the cumulative inspection cost over 20 years would be $1,250. Non-inflation adjusted inspection and maintenance costs for a properly functioning septic system average $100 per year for a hypothetical 20-year system life.

The total (non-inflation adjusted) cost including purchase price averaged over a 20-year period comes to $300 per year. It should be noted, however, that if a system is properly maintained, its life should exceed 20 years.

The value of proper maintenance is further underscored by the costs associated with repairing failing septic systems. These can range widely, depending on the nature of the problem and on the location of the site. A typical range would be $1,200 to $2,500 for revitalization or repair of an exhausted drainfield. Complete removal and replacement of existing systems can cost five to ten times more than this (see, for example, HSAC,1997; Ingersoll, 1994.)

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ADDITIONAL INFORMATION

Contact your local county extension office and your state department of health for information and region-specific details. Additional information is available from:

American Society of Civil Engineers
World Headquarters
1801 Alexander Bell Drive
Reston, VA 20191-4400

American Society of Home Inspectors
Contact: Rob Paterkiewicz
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University of Florida
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National Society of Consulting Soil Scientists
Mary Reed, Executive Secretary
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United States Environmental Protection Agency
Office of Water Washington, D.C.
EPA 832-F-00-038 September 2000

Decentralized Systems Technology Fact Sheet
Small Diameter Gravity Sewers

DESCRIPTION

Alternative wastewater collection systems are often implemented in situations where conventional wastewater collection systems are not feasible. Typically, it is desirable to use conventional wastewater collection systems based on a proven track record. However, in areas of hilly or flat terrain, the use of conventional wastewater collection systems may require deep excavation, significantly increasing the cost of conventional collection systems.

Conventional Wastewater Collection Systems

Conventional wastewater collection systems are the most popular method to collect and convey wastewater. Pipes are installed on a slope, allowing wastewater to flow by gravity from a house site to the treatment facility. Pipes are sized and designed with straight alignment and uniform gradients to maintain self-cleansing velocities. Manholes are installed between straight runs of pipe to ensure that stoppages can be readily accessed. Pipes are generally eight inches or larger and are typically installed at a minimum depth of three feet and a maximum depth of 25 feet. Manholes are located no more than 400 feet apart or at changes of direction or slope.

Alternative Wastewater Collection Systems

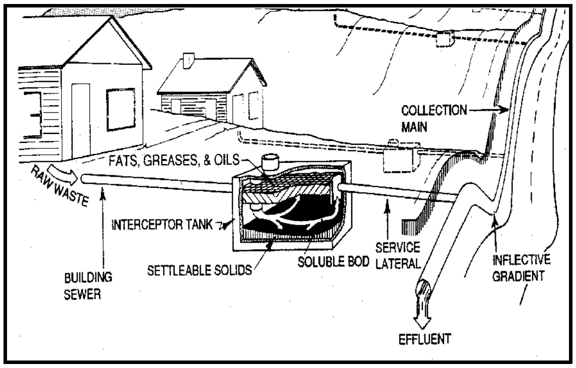
Where deep excavation is a concern, it may be beneficial to use an alternative wastewater collection system. These systems generally use smaller diameter pipes with a slight slope or follow the surface contour of the land, reducing the amount of excavation and construction costs. This is illustrated in Figure 1, which shows a pipe following an inflective gradient (the contours of the ground). As long as the head of the sewer is at a higher invert elevation than the tail of the sewer's invert elevation, flow will continue through the system in the intended direction. Alternative collection systems may be preferred in areas with high groundwater that may seep into the sewer, increasing the amount of wastewater to be treated. Areas where small lot sizes, poor soil conditions, or other site-related limitations make on-site wastewater treatment options inappropriate or expensive may benefit from alternative wastewater collection systems.

This Fact Sheet discusses small diameter gravity sewers.

Small Diameter Gravity Sewers

Small diameter gravity sewers (SDGS) convey effluent by gravity from an interceptor tank (or septic tank) to a centralized treatment location or pump station for transfer to another collection system or treatment facility. A typical SDGS system is depicted in Figure 1.

Most suspended solids are removed from the wastestream by septic tanks, reducing the potential for clogging to occur and allowing for smaller diameter piping both downstream of the septic tank in the lateral and in the sewer main. Cleanouts are used to provide access for flushing; manholes are rarely used. Air release risers are required at or slightly downstream of summits in the sewer profile. Odor control is important at all access points since the SDGS carries odorous septic tank effluent. Because of the small diameters and flexible slope and alignment of the SDGS, excavation depths and volumes are typically much smaller than with conventional sewers. Minimum pipe diameters can be three inches. Plastic pipe is typically used because it is economical in small sizes and resists corrosion.



Source: U.S. EPA, 1991.

FIGURE 1 SDGS SYSTEM

APPLICABILITY

- Approximately 250 SDGS systems have been financed in the United States by the EPA Construction Grants Program. Many more have been financed with private or local funding. These systems were introduced in the United States in the mid-1970s, but have been used in Australia since the 1960s.

- SDGS systems can be most cost-effective where housing density is low, the terrain has undulations of low relief, and the elevation of the system terminus is lower than all or nearly all of the service area. They can also be effective where the terrain is too flat for conventional gravity sewers without deep excavation, where the soil is rocky or unstable, or where the groundwater level is high.

- SDGS systems do not have the large excess capacity typical of conventional gravity sewers and should be designed with an adequate allowance for future growth.

ADVANTAGES AND DISADVANTAGES

Advantages

- Construction is fast, requiring less time to provide service.

- Unskilled personnel can operate and maintain the system.

- Elimination of manholes reduces a source of inflow, further reducing the size of pipes, lift/pumping stations, and final treatment, ultimately reducing cost.

- Reduced excavation costs: Trenches for SDGS pipelines are typically narrower and shallower than for conventional sewers.

- Reduced material costs: SDGS pipelines are smaller than conventional sewers, reducing pipe and trenching costs.

- Final treatment requirements are scaled down in terms of organic loading since partial removal is performed in the septic tank.

- Reduced depth of mains lessens construction costs due to high ground water or rocky conditions.

Disadvantages

Though not necessarily a disadvantage, limited experience with SDGS technology has yielded some situations where systems have performed inadequately. This is usually more a function of poor design and construction than the ability of a properly designed and constructed SDGS system to perform adequately.

While SDGS systems have no major disadvantages specific to temperate climates, some restrictions may limit their application:

- SDGS systems cannot handle commercial wastewater with high grit or settleable solids levels. Restaurants may be hooked up if they are equipped with effective grease traps. Laundromats may be a constraining factor for SDGS systems in small communities. No reports could be found on the use of SDGS systems as a commercial wastewater collection option.

- In addition to corrosion within the pipe from the wastewater, corrosion outside the pipe has been a problem in some SDGS systems in the United States where piping is installed in highly corrosive soil. If the piping will be exposed to a corrosive environment, non-corrosive materials must be incorporated in the design.

- Disposing of collected septage from septic tanks is probably the most complex aspect of the SDGS system and should be carried out by local authorities. However, many tanks are installed on private property requiring easement agreements for local authorities to gain access. Contracting to carry out these functions is an option, as long as the local authorities retain enforceable power for hygiene control.

- Odors are the most common problem. Many early systems used an on-lot balancing tank that promoted stripping of hydrogen sulfide from the interceptor (septic) tank effluent. Other odor problems are caused by inadequate house ventilation systems and mainline manholes or venting structures. Appropriate engineering can control odor problems.

- SDGS systems must be buried deep enough so that they will not freeze. Excavation may be substantial in areas where there is a deep frostline.

DESIGN CRITERIA

Peak flows are based on the formula Q=20 + 0.5D, where Q is flow (gallons per minute) and D is the number of dwelling units served by the system (EPA 1992). Whenever possible, it is desirable to use actual flow data for design purposes. However, if this is not available, peak flows are calculated. Each segment of the sewer is analyzed by the Hazen-Williams or Manning equations to determine if the pipe is of adequate size and slope to handle the peak design flow. No minimum velocity is required and PVC pipe (SDR 35) is commonly used for gravity segments. Stronger pipe (e.g., SDR 21) may be dictated where septic tank effluent pump (STEP) units feed the system. Check valves may also be used in flooded sections or where backup (surcharging) from the main may occur. These valves are installed downstream of mainline cleanouts.

Typical pipe diameters for SDGS are 80 millimeters (three inches) or more, but the minimum recommended pipe size is 101.6 mm (4 mm) because 80 mm (3 inch) pipes are not readily available and need to be special ordered. The slope of the pipe should be adequate to carry peak hourly flows. SDGS systems do not need to meet a minimum velocity because solids settling is not a design parameter in them. The depth of the piping should be the minimum necessary to prevent damage from anticipated earth and truck loadings and freezing. If no heavy earth or truck loadings are anticipated, a depth of 600 to 750 millimeters (24 to 30 inches) is typical.

All components must be corrosion-resistant and all discharges (e.g., to a conventional gravity interception or treatment facility) should be made through drop inlets below the liquid level to minimize odors. The system is ventilated through service-connection house vent stacks. Other atmospheric openings should be directed to soil beds for odor control, unless they are located away from the populace.

Septic tanks are generally sized based on local plumbing codes. STEP units used for below-grade services are covered in a Fact Sheet on pressure sewers. It is essential to ensure that on-lot infiltration and inflow (l/l) is eliminated through proper testing and repair, if required, of building sewers, as well as pre-installation testing of septic tanks.

Mainline cleanouts are generally spaced 120 to 300 meters (400 to 1,000 feet) apart. Treatment is normally by stabilization pond or subsurface infiltration. Effluent may also be directed to a pump station or treatment facility.

A well operated and maintained septic tank will typically remove up to 50 percent of BOD_5, 75 percent of SS, virtually all grit, and about 90 percent of grease. Clogging is not normally a problem. Also, wastewater reaching the treatment plant will typically be more dilute than raw sewage. Typical average values of BOD and TSS are 110 mg/l and 50 mg/l, respectively.

Primary sedimentation is not required to treat septic tank effluent. Sand filters are effective in treatment. Effluent responds well to aerobic treatment, but odor control at the headworks of the treatment plant should receive extra attention.

PERFORMANCE

Point Royal Estates, Texas

Point Royal Estates is an 80-home subdivision developed in the early 1970s near Lake Ray Hubbard in the northwest part of Rockwall County, Texas. For many years, septic tank and drainfield failures were a great inconvenience to the residents of Point Royal Estates, ultimately causing property values to decrease.

Originally, each home was served by two 250-gallon septic tanks, and gravity absorption field lines were placed in the back yards. The systems began to fail regularly, largely due to infiltration problems since soils in the area are mostly extremely tight clays. Many residents pumped their tanks twice a year but still reported system failures. Some residents resorted to renting “port-a-potties”.

In 1990, the City of Rowlett formed a Public Improvement District to install a conventional sewer system in Point Royal Estates. The final cost estimate for this project was nearly $10,000 per residence. These high costs prompted the city to explore other alternatives.

In 1993, the Point Royal Water and Sewage Supply Corporation (PRWSSC) was formed to evaluate alternatives for sewage collection. After a series of public meetings, it became obvious that a small diameter sewer might be the best option for the subdivision. The final cost estimate for a SDGS system was about $3,500 per residence.

The system consisted of interceptor tanks ranging in size from 1,000-1,200 gallons installed at each residence. These tanks were installed with baffles and Clemson design tubes to prevent solids buildup and reduce the amount of sludge sent through the downstream sewer piping. Homes were connected to the interceptor tanks with four-inch PVC pipes installed at a 2 percent slope. Effluent was transported from the interceptor tanks to the SDGS collection line by a two-inch PVC gravity sewer. Valves and cleanout ports that could be easily accessed and serviced were installed at most homes. Existing septic tanks were abandoned and crushed, when practical.

Oxytec, Inc. was the general contractor for the installation, which began in April 1994. Final inspections were performed in July 1995 and no operational problems have yet been reported.

OPERATION AND MAINTENANCE

O&M requirements for SDGS systems are usually low, especially if there are no STEP units or lift stations. Periodic flushing of low-velocity segments of the collector mains may be required. The septic tanks must be pumped periodically to prevent solids from entering the collector mains. It is generally recommended that pumping be performed every three to five years. However, the actual operating experience of SDGS systems indicates that once every seven to ten years is adequate. Where lift stations are used, such as in low lying areas where waste is collected from multiple sources, they should be checked on a daily or weekly basis. A daily log should be kept on all operating checks, maintenance performed, and service calls. Regular flow monitoring is useful to evaluate whether inflow and infiltration problems are developing.

The municipality or sewer utility should be responsible for O&M of all of the SDGS system components to ensure a high degree of system reliability. General easement agreements are needed to permit access to components such as septic tanks or STEP units on private property.

COSTS

The installed costs of the collector mains and laterals and the interceptor tanks constitute more than 50 percent of total construction cost (see Table 1 for more detailed listing of component costs). Average unit costs for twelve projects (adjusted to January 1991) were: 10 cm (4 in.) mainline, $3.71/m ($12.19/ft); cleanouts, $290 each; and service connections, $2.76/m ($9.08/ft). A more detailed listing of this information may be found in Table 1. Average unit costs for 440 L (1,000 gal) septic tanks were $1,315, but are not included in Table 1. The average cost per connection was $5,353 (adjusted to January 1991) and the major O&M requirement for SDGS systems is the pumping of the tanks. Other O&M activities include gravity line repairs from excavation damage, supervision of new connections, and inspection and repair of mechanical components and lift stations. Most SDGS system users pay $10 to 20/month for management, including O&M and administrative costs.

TABLE 1 SMALL DIAMETER GRAVITY SEWER COMPONENT COSTS

Community (Cost Index)	In-Place Pipe	Man-holes	Clean outs	Lift Stations	Force Main	Bldg. Sewer	Service Conn.	Site Restoration	Total
Westboro, WI	5.27	0.60	-	1.65	0.55	0.76	a	0.75	13.03
Badger, SD	2.67	1.93	-	3.23	0.39	0.03	2.59	b	15.61
Avery, ID	8.57	0.60	0.25	5.11	1.64	-	0.69	b	43.39
Maplewood, WI	17.30	0.44	0.62	10.72	2.92	-	2.79	1.29	45.85
S. Corning, NY #1	13.36	0.44	0.48	-	-	1.62	7.72	3.08	43.63
S. Corning, NY #2	15.11	0.72	0.32	-	-	2.51	11.87	2.11	50.87
New Castle, VA	9.89	2.40	0.78	2.88	2.60	-	b	b	30.58
Miranda, CA	24.36	1.61	1.60	-	0.17	4.94	7.44	0.53	69.33
Gardiner, NY	15.07	1.47	0.37	0.78	0.50	0.72	2.50	0.77	30.84
Lafayette, TN	6.90	0.64	0.14	1.26	0.37	0.11	4.19	b	16.29
West Point, CA	7.26	-	0.35	2.22	1.56	-	6.00	-	38.64
Zanesville, OH	8.09	0.18	1.05	-	-	9.46	8.71	1.12	46.65
Adjusted Average	15.10	1.42	0.79	4.95	1.66	3.22	7.13	2.12	57.89

a Included in septic tank costs.
b Included in pipe costs. Costs are in $/ft pipe installed.

Source: U.S.EPA, 1991.

REFERENCES

Other Related Fact Sheets

Sewers, Pressure
EPA 832-F-00-070
September 2000

Sewers, Lift Stations
EPA 832-F-00-073
September 2000

Other EPA Fact Sheets can be found at the following web address:
http://www.epa.gov/owmitnet/mtbfact.htm

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11. Small Community Wastewater Collection Systems, Publication Number 448-405, July 1996, Virginia Cooperative Extension.

ADDITIONAL INFORMATION

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United States Environmental Protection Agency
Office of Water Washington, D.C.
EPA 832-F-00-034 September 2000

Decentralized Systems Technology Fact Sheet
Types of Filters

DESCRIPTION

The primary purpose of improving the quality of the effluent from a septic tank system is to provide a cleaner effluent and in some cases, to improve treatment to address local environmental conditions. This may be necessary due to site constraints, regulations, or other limiting factors. Sand filters in various configurations are one of many traditional technologies applied to decentralized systems. These filters are located at the effluent side of the septic tank in order to remove solids.

Research on alternate filtration media, particularly recycled materials, has expanded the options available for improving effluent quality. This Fact Sheet summarizes the research on several alternate media materials, including crushed glass, recycled textiles, synthetic foam, and peat.

In a traditional sand filter application, physical, chemical, and biological transformations facilitate the enhanced treatment of effluent. Suspended solids are removed by mechanical straining, through chance contact, and by sedimentation. Aerobic conditions must be maintained to maintain a high performance level,. Intermittent application and venting of underdrains helps maintain aerobic conditions within the filter.

The alternate media discussed in this Fact Sheet generally operate in the same way as sand filters. They provide the same treatment of wastewater and, in some cases, enhance the treatment efficiency of the filter. The loading rate achieved in some alternate media filters is twice that of traditional sand filters. The filters discussed in this Fact Sheet are single pass filters, where wastewater passes through the filter only once before being discharged.

APPLICATION

Applications for alternate media filters are emerging, with the technology still largely in the research phase. Filtration is widely used in conjunction with drainfield systems for septic tanks which require enhanced effluent quality. Alternate filter media provide an option beyond a conventional septic tank drainfield, which consists of several trenches with gravel beds and perforated plastic pipes. Alternate media filters may allow a higher soil loading rate, use less space, and use material that is easy to obtain. For example, the Waterloo biofilter (developed at the University of Waterloo, Ontario, Canada) uses absorbent plastic foam cubes as its medium. Loading rates with this porous synthetic medium are four times higher than which use a recirculating sand filter. These biofilters may be followed by disinfection.

These higher loading rate filters may perform more effectively than traditional gravel drainfields and sand filters, especially when the drainfield must be located on a steep slope. Alternate media filters are suitable for lots with sizing constraints or where water tables or bedrock limit the depth of the drainfield. States may offer a sizing reduction allowance for alternate media filters because of their high loading. They are also easy to install and repair.

DESIGN CRITERIA

Peat

Peat is a permeable, absorbent medium used as a filter medium for onsite wastewater treatment. Much research has been conducted in the Northeast where peat is widely available. Peat filters used for onsite wastewater treatment remove 60 to 90 percent of BOD_5, but no long term data yet exist. Because peat is a natural material, significant variations in composition have been noted. Several manufacturers enclose the peat in fiberglass housing.

Foam

The foam cube filter is similar in performance to an intermittent sand filter, but has been tested at 10 times the loading rate. The filter is housed in a 1.8 meter by 1.8 meter by 1.5 meter (six foot by six foot by five foot) container, with 1.2 meters (four feet) of media. Wastewater is sprayed on top of the media and withdrawn from the base of the unit. Alternatively, filter cubes installed in pre-assembled cylinders can be placed in a tank.

Crushed Glass

A pilot project was conducted for the City of Roslyn, Washington, to evaluate the feasibility of using crushed, recycled glass as a filtration medium in slow sand filters. The study used a 38 centimeter (15 inch) PVC pipe as the media container and three types of sand and crushed glass. The media were washed so that less than 0.10 percent by weight passed a #200 mesh sieve. Wastewater was added to the filter at a loading rate of 0.002 cubic meters/minute/square meter (0.06 gallon/minute/square foot). The removal of bacteriological contaminants demonstrated that the glass filter media obtained an activity level typical of slow rate sand filtration. The results suggest that slow rate filtration may be an effective treatment process for Roslyn's raw water source with the addition of a roughing filter. All three filters had similar removal efficiencies, although it was hard to draw conclusions for other geographical areas.

Textile

This medium consists of textile chips known as "coupons". The medium is placed in a filter housing similar to a sand filter, with wastewater applied by spraying it at the top of the filter. The loading rate was reported at 400 liters/square meter/day (10 gallons/square foot/day). A modification of this design uses layers of textile material with a break between layers, allowing greater loading rates, up to 600 liters/square meter/day (15 gallons/square foot/day), producing an effluent quality that meets or exceeds advanced treatment standards.

ADVANTAGES AND DISADVANTAGES

Advantages

Alternate media filters are moderately inexpensive, have low energy requirements and do not require highly skilled personnel. They generally produce high quality effluent. The process is stable and requires limited intervention by operating personnel. The media may be able to withstand higher loading rates than traditional sand filters due to increased surface area. These filters may provide a suitable treatment option for degraded or failed septic systems if it is shown that they can operate over an extended period of time at the demonstrated efficiencies.

Disadvantages

Alternate media filters are not proven technologies and no long term operating data for the crushed glass and textile media are available. The cost to operate and maintain the systems has not been standardized. Odors from open, single pass filters treating septic tank effluent may be a problem. The filter medium is unique, and may not be readily available when it must be replaced. The media may not be consistent from supplier to supplier or batch to batch and may require additional monitoring costs to confirm performance across batches.

The recent arrival and continuing research into alternate filter media do not provide a potential user with the same performance track record as conventional sand filters. Filter surfaces and disinfection equipment require periodic maintenance, pumping and some disinfection units require power and facilities must have state or federal discharge permits, along with sampling and monitoring.

Filters using alternate media have performed well in the laboratory but have seen limited use in the field. Frequent inspection and monitoring are required to obtain proper functioning of filtration units and to determine cleaning cycles.

PERFORMANCE

Effluent quality data from long term use of peat, crushed glass, and textile media as on-site filtration systems are not available, yet experimental filter systems show greater treatment efficiencies at higher loading rates than standard sand filters.

OPERATION AND MAINTENANCE

Alternate media filters require more initial operational control and maintenance due to the lack of long term operational data. Primary Operation and Maintenance (O&M) tasks include filter surface maintenance, dosing equipment servicing, and influent and effluent monitoring. With continued use, filter surfaces become clogged with organic biomass and solids. Once operating, infiltration rates may fall below the hydraulic loading rate and permanent ponding of the filter surface may occur. If this occurs, the filter should be taken off-line for rest or media removal and replacement. Buried filters are designed to operate without maintenance for their design life. Filters exposed to sunlight may develop algae mats controlled by surface shading. For community systems, disinfection is required prior to discharge, but disinfectant quantity requirements are low due to the high quality of the effluent.

COSTS

Detailed cost information is not available because most systems are still under study. Alternate media materials are not common to wastewater treatment applications, and long term costs are difficult to estimate. In areas where the filter materials are commonly found (peat is easily obtained in Maine, Minnesota, and Wisconsin) the cost of filter media is expected to be nominal. The cost of peat in other areas is significantly higher. One manufacturer reports that 30 bags of peat, each weighing 30 pounds, are needed for one filter. A research paper on crushed glass filters estimates that 10 to 20 cubic yards per installation would be necessary. Foam, crushed glass, and textile material are all subject to availability and transportation cost sensitivity.

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Other Related Fact Sheets

Intermittent Sand Filters
EPA 832-F-99-067
September 1999

Recirculating Sand Filters
EPA 832-F-99-079
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EPA

Wastewater Technology Fact Sheet
Ultraviolet Disinfection

DESCRIPTION

Disinfection is considered to be the primary mechanism for the inactivation/destruction of pathogenic organisms to prevent the spread of waterborne diseases to downstream users and the environment. It is important that wastewater be adequately treated prior to disinfection in order for any disinfectant to be effective. Some common microorganisms found in domestic wastewater and the diseases associated with them are presented in Table 1.

An Ultraviolet (UV) disinfection system transfers electromagnetic energy from a mercury arc lamp to an organism's genetic material (DNA and RNA). When UV radiation penetrates the cell wall of an organism, it destroys the cell's ability to reproduce. UV radiation, generated by an electrical discharge through mercury vapor, penetrates the genetic material of microorganisms and retards their ability to reproduce.

The effectiveness of a UV disinfection system depends on the characteristics of the wastewater, the intensity of UV radiation, the amount of time the microorganisms are exposed to the radiation, and the reactor configuration. For any one treatment plant, disinfection success is directly related to the concentration of colloidal and particulate constituents in the wastewater.

The main components of a UV disinfection system are mercury arc lamps, a reactor, and ballasts. The source of UV radiation is either the low-pressure or medium-pressure mercury arc lamp with low or high intensities.

TABLE 1 INFECTIOUS AGENTS POTENTIALLY PRESENT IN UNTREATED DOMESTIC WASTEWATER

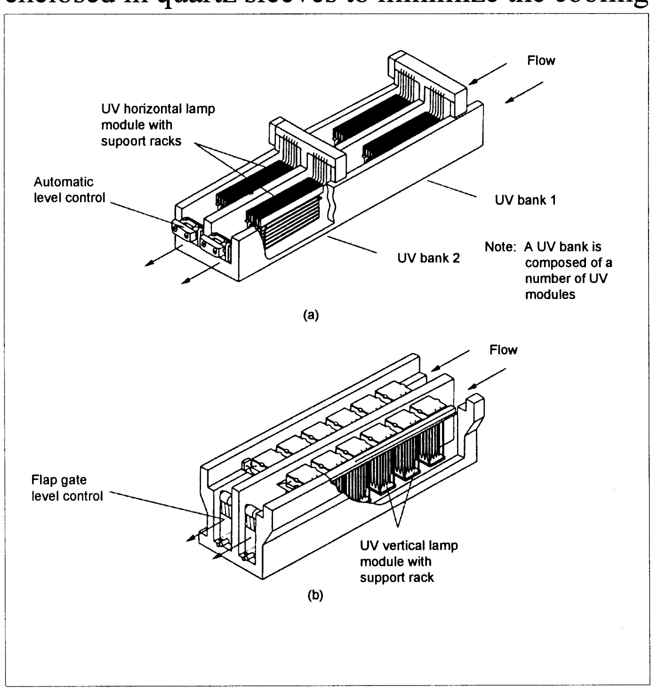
Organism	Disease Caused
Bacteria	
Escherichia coli (enterotoxigenic)	Gastroenteritis
Leptospira (spp.)	Leptospirosis
Salmonella typhi	Typhoid fever
Salmonella (=2,100 serotypes)	Salmonellosis
Shigella (4 spp.)	Shigellosis (bacillary dysentery)
Vibrio cholerae	Cholera
Protozoa	
Balantidium coli	Balantidiasis
Cryptosporidium parvum	Cryptosporidiosis
Entamoeba histolytica	Amebiasis (amoebic dysentery)
Giardia lamblia	Giardiasis
Helminths	
Ascaris lumbricoides	Ascariasis
T. solium	Taeniasis
Trichuris trichiura	Trichuriasis
Viruses	
Enteroviruses (72 types, e.g., polio, echo, and coxsackie viruses)	Gastroenteritis, heart anomalies, meningitis
Hepatitis A virus	Infectious hepatitis
Norwalk agent	Gastroenteritis
Rotavirus	Gastroenteritis

Source: Adapted from Crites and Tchobanoglous, 1998.

The optimum wavelength to effectively inactivate microorganisms is in the range of 250 to 270 nm. The intensity of the radiation emitted by the lamp dissipates as the distance from the lamp increases. Low-pressure lamps emit essentially monochromatic light at a wavelength of 253.7 nm. Standard lengths of the low-pressure lamps are 0.75 and 1.5 meters with diameters of 1.5 - 2.0 cm. The ideal lamp wall temperature is between 95 and 122°F.

Medium-pressure lamps are generally used for large facilities. They have approximately 15 to 20 times the germicidal UV intensity of low-pressure lamps. The medium-pressure lamp disinfects faster and has greater penetration capability because of its higher intensity. However, these lamps operate at higher temperatures with a higher energy consumption.

There are two types of UV disinfection reactor configurations that exist: contact types and noncontact types. In both the contact and the noncontact types, wastewater can flow either perpendicular or parallel to the lamps. In the contact reactor, a series of mercury lamps are enclosed in quartz sleeves to minimize the cooling



Source: Crites and Tchobanoglous, 1998.
(a) adapted from Trojan Technologies, Inc.
(b) adapted from Infilco Degremont, Inc.

FIGURE 1 ISOMETRIC CUT-AWAY VIEWS OF TYPICAL UV DISINFECTION SYSTEMS

effects of the wastewater. Figure 1 shows two UV contact reactors with submerged lamps placed parallel and perpendicular to the direction of the wastewater flow. Flap gates or weirs are used to control the level of the wastewater. In the noncontact reactor, the UV lamps are suspended outside a transparent conduit, which carries the wastewater to be disinfected. This configuration is not as common as the contact reactor. In both types of reactors, a ballast—or control box—provides a starting voltage for the lamps and maintains a continuous current.

ADVANTAGES AND DISADVANTAGES

Advantages

- UV disinfection is effective at inactivating most viruses, spores, and cysts.
- UV disinfection is a physical process rather than a chemical disinfectant, which eliminates the need to generate, handle, transport, or store toxic/hazardous or corrosive chemicals.
- There is no residual effect that can be harmful to humans or aquatic life.
- UV disinfection is user-friendly for operators.
- UV disinfection has a shorter contact time when compared with other disinfectants (approximately 20 to 30 seconds with low-pressure lamps).
- UV disinfection equipment requires less space than other methods.

Disadvantages

- Low dosage may not effectively inactivate some viruses, spores, and cysts.
- Organisms can sometimes repair and reverse the destructive effects of UV through a "repair mechanism," known as photoreactivation, or in the absence of light known as "dark repair."

- A preventive maintenance program is necessary to control fouling of tubes.

- Turbidity and total suspended solids (TSS) in the wastewater can render UV disinfection ineffective. UV disinfection with low-pressure lamps is not as effective for secondary effluent with TSS levels above 30 mg/L.

- UV disinfection is not as cost-effective as chlorination, but costs are competitive when chlorination dechlorination is used and fire codes are met.

APPLICABILITY

When choosing a UV disinfection system, there are three critical areas to be considered. The first is primarily determined by the manufacturer; the second, by design and Operation and Maintenance (O&M); and the third has to be controlled at the treatment facility.

Choosing a UV disinfection system depends on three critical factors listed below.

- Hydraulic properties of the reactor: Ideally, a UV disinfection system should have a uniform flow with enough axial motion (radial mixing) to maximize exposure to UV radiation. The path that an organism takes in the reactor determines the amount of UV radiation it will be exposed to before inactivation. A reactor must be designed to eliminate short-circuiting and/or dead zones, which can result in inefficient use of power and reduced contact time.

- Intensity of the UV radiation: Factors affecting the intensity are the age of the lamps, lamp fouling, and the configuration and placement of lamps in the reactor.

- Wastewater characteristics: These include the flow rate, suspended and colloidal solids, initial bacterial density, and other physical and chemical parameters. Both the concentration of TSS and the concentration of particle-associated microorganisms determine how much UV radiation ultimately reaches the target organism. The higher these concentrations, the lower the UV radiation absorbed by the organisms. Various wastewater characteristics and their effects on UV disinfection are given in Table 2.

TABLE 2 WASTEWATER CHARACTERISTICS AFFECTING UV DISINFECTION PERFORMANCE

Wastewater Characteristic	Effects on UV Disinfection
Ammonia	Minor effect, if any
Nitrite	Minor effect, if any
Nitrate	Minor effect, if any
Biochemical oxygen demand (BOD)	Minor effect, if any. Although, if a large portion of the BOD is humic and/or unsaturated (or conjugated) compounds, then UV transmittance may be diminished.
Hardness	Affects solubility of metals that can absorb UV light. Can lead to the precipitation of carbonates on quartz tubes.
Humic materials, Iron	High absorbency of UV radiation.
pH	Affects solubility of metals and carbonates.
TSS	Absorbs UV radiation and shields embedded bacteria.

Source: Adapted from: Darby et al. (1995) with permission

UV disinfection can be used in plants of various sizes that provide secondary or advanced levels of treatment.

PERFORMANCE

Gold Bar Wastewater Treatment Plant in Edmonton, Alberta, Canada

The Gold Bar Wastewater Treatment Plant (GBWTP) in Edmonton, Alberta, was required to use disinfection to meet water quality standards for contact recreation in Alberta. During that period, the average and peak design flow rates for this treatment facility were 82 and 110 million gallons per day (mgd), respectively. A pilot study was conducted to review current UV disinfection systems, effectiveness of lamp intensities, and costs. UV disinfection was determined to be the most efficient disinfection system to achieve the required treatment levels.

Lamp fouling is a potential problem among UV systems, but with proper cleaning and O&M, it should not interrupt the system's disinfection capability. Lamp cleaning at the GBWTP was achieved by a mechanical wiping mechanism accompanying each cluster of lamps. Lamps were cleaned on a regular basis using an in-channel cleaning system. The safety concerns for both low-pressure and high-intensity UV systems regarding exposure to UV radiation and electrical hazards are low under normal operating conditions. However, precautionary measures should be taken when operating high-intensity lamps to avoid overexposure. The risk was not considered major by the GBWTP and was outweighed by the potential savings of using high-intensity UV systems. At the GBWTP, a medium-pressure, high-intensity system was found to be more economical than the conventional low-pressure systems in both capital and life-cycle costs.

Northwest Bergen County Utility Authority Wastewater Treatment Plant in Waldwick, New Jersey

The use of UV disinfection for wastewater treatment has increased dramatically in the last few years due to the impact of chlorinated organics from sewage effluent on receiving waters. Such was the case with the Northwest Bergen County Utility Authority (NBCUA) Wastewater Treatment Plant located in Waldwick, New Jersey. In 1989, the treatment plant had to convert from chlorination to an alternative disinfection technology with zero residual after treatment. This change was brought about when the "zero residual" regulation was imposed by the New Jersey Department of Environmental Protection with the passage of the Toxic Catastrophic Prevention Act.

Several factors, such as public safety and recent findings and concerns over the environmental impact of chemical releases and spills, have led to more stringent permit requirements for chlorine. Also, there were other conditions that the treatment plant had to meet if chlorine use was to continue. To avoid the escalated costs that could be incurred and to be in compliance with the new regulations, the wastewater treatment plant switched to UV disinfection. The UV system was installed within the existing chlorine contact tanks, along with an extension to the existing building for easy maintenance during bad weather. The UV system at NBCUA was able to meet fecal coliform levels (200 count per 100 mL) better than chlorination since its installation in August 1989.

OPERATION AND MAINTENANCE

The proper O&M of a UV disinfection system ensures that sufficient UV radiation is transmitted to the organisms to render them sterile. All surfaces between the UV radiation and the target organisms must be clean, and the ballasts, lamps, and reactor must be functioning at peak efficiency. Inadequate cleaning is one of the most common causes of a UV system's ineffectiveness. The quartz sleeves or Teflon tubes need to be cleaned regularly by mechanical wipers, ultrasonics, or chemicals. The cleaning frequency is very site-specific, some systems need to be cleaned more often than others.

Chemical cleaning is most commonly done with citric acid. Other cleaning agents include mild vinegar solutions and sodium hydrosulfite. A combination of cleaning agents should be tested to find the agent most suitable for the wastewater characteristics without producing harmful or toxic by-products. Noncontact reactor systems are most effectively cleaned by using sodium hydrosulfite.

Any UV disinfection system should be pilot tested prior to full-scale operation to ensure that it will meet discharge permit requirements for a particular site.

The average lamp life ranges from 8,760 to 14,000 working hours, and the lamps are usually replaced after 12,000 hours of use. Operating procedures should be set to reduce the on/off cycles of the lamps, since their efficacy is reduced with repeated cycles.

The ballast must be compatible with the lamps and should be ventilated to protect it from excessive heating, which may shorten its life or even result in fires. Although the life cycle of ballasts is approximately 10 to 15 years, they are usually replaced every 10 years. Quartz sleeves will last about 5 to 8 years but are generally replaced every 5 years.

COSTS

The cost of UV disinfection systems depends on the manufacturer, the site, the capacity of the plant, and the characteristics of the wastewater to be disinfected. Total costs of UV disinfection can be competitive with chlorination when the dechlorination step is included.

The annual operating costs for UV disinfection include power consumption; cleaning chemicals and supplies; miscellaneous equipment repairs (2.5% of total equipment cost); replacement of lamps, ballasts and sleeves; and staffing requirements.

Costs have decreased in recent years due to improvements in lamp and system designs, increased competition, and improvements in the systems' reliability.

Medium-pressure lamps cost four to five times as much as low-pressure lamps. However, the reduced number of lamps necessary for adequate disinfection could make medium-pressure lamps cost-effective. Table 3A summarizes the costs of some of the lamps used in UV disinfection. This information was collected in a study conducted by the Water Environment Research Federation in 1995 for secondary effluents from disinfection facilities at average dry weather flow rates of 1, 10, and 100 mgd (2.25, 20, and 175 mgd peak wet weather flow, respectively). Table 3B describes the typical capital and O&M costs that are associated with a UV disinfection.

TABLE 3A LAMP COSTS FOR UV DISINFECTION SYSTEMS

Item	Range*	Typical*
UV lamps	($/lamp)	($/lamp)
1-5 mgd	397-1,365	575
5-10 mgd	343-594	475
19-100 mgd	274-588	400
Construction cost for physical facilities	(% of UV lamp cost) 75-200	(% of UV lamp cost) 150

* Costs are based on a 1993 Engineering News Record Construction Cost Index of 5,210.
Source: Adapted from: Darby et al. (1995) with permission from the Water Environment Research Foundation.

TABLE 3B CAPITAL AND O&M COSTS FOR UV DISINFECTION SYSTEMS

Cost Item	UV System Cost ($)
Capital Costs	
Equipment	120,000
Structural modifications	64,000
Electrical	20,000
Miscellaneous	40,000
Total:	**244,000**
Annual operating and maintenance costs	
Energy	3300
Lamps and chemicals	2840
Cleaning	1180
Maintenance	1440
Process control	6240
Testing	4160
Total	**19,190**

Source: Hanzon and Vigilia, 1999.

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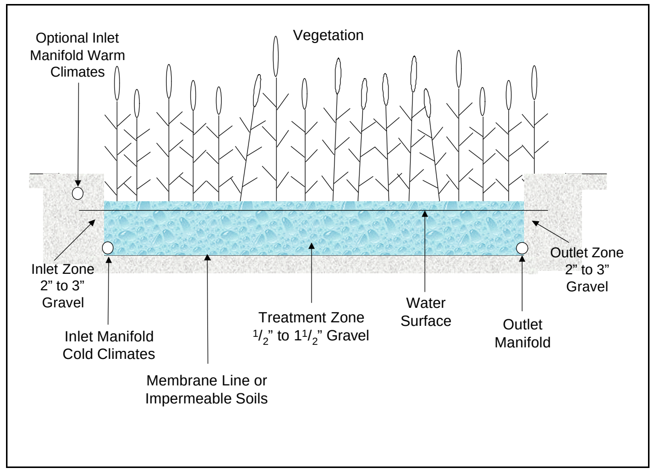
Wastewater Technology Fact Sheet
Wetlands: Subsurface Flow

DESCRIPTION

Wetland systems are typically described in terms of the position of the water surface and/or the type of vegetation grown. Most natural wetlands are free water surface systems where the water surface is exposed to the atmosphere; these include bogs (primary vegetation mosses), swamps (primary vegetation trees), and marshes (primary vegetation grasses and emergent macrophytes). A subsurface flow (SF) wetland is specifically designed for the treatment or polishing of some type of wastewater and are typically constructed as a bed or channel containing appropriate media. An example of a SF wetland is shown in Figure 1. Coarse rock, gravel, sand and other soils have all been used, but a gravel medium is most common in the U.S. and Europe. The medium is typically planted with the same types of emergent vegetation present in marshes, and the water surface is designed to remain below the top surface of the medium. The main advantages of this subsurface water level are prevention of mosquitoes and odors, and elimination of the risk of public contact with the partially treated wastewater. In contrast, the water surface in natural marshes and free water surface (FWS) constructed wetlands is exposed to the atmosphere with the attendant risk of mosquitoes and public access.



Source: Adapted from drawing by S.C. Reed, 2000.

FIGURE 1 SUBSURFACE FLOW WETLAND

The water quality improvements in natural wetlands had been observed by scientists and engineers for many years and this led to the development of constructed wetlands as an attempt to replicate the water quality and the habitat benefits of the natural wetland in a constructed ecosystem. Physical, chemical, and biochemical reactions all contribute to water quality improvement in these wetland systems. The biological reactions are believed due to the activity of microorganisms attached to the available submerged substrate surfaces. In the case of FWS wetlands these substrates are the submerged portion of the living plants, the plant litter, and the benthic soil layer. In SF wetlands the available submerged substrate includes the plant roots growing in the media, and the surfaces of the media themselves. Since the media surface area in a SF wetland can far exceed the available substrate in a FWS wetland, the microbial reaction rates in a SF wetland can be higher than a FWS wetland for most contaminants. As a result, a SF wetland can be smaller than the FWS type for the same flow rate and most effluent water quality goals.

The design goals for SF constructed wetlands are typically an exclusive commitment to treatment functions because wildlife habitat and public recreational opportunities are more limited than FWS wetlands. The size of these systems ranges from small on-site units designed to treat septic tank effluents to a $1.5x10^7$ liters per day (4 MGD) system in Louisiana treating municipal wastewater. There are approximately 100 systems in the U.S. treating municipal wastewater, with the majority of these treating less than $3.8x10^3$ m^3/day (1 MGD). Most of the municipal systems are preceded by facultative or aerated treatment ponds. There are approximately 1,000 small scale on-site type systems in the U.S. treating waste waters from individual homes, schools, apartment complexes, commercial establishments, parks, and other recreational facilities. The flow from these smaller systems ranges from a few hundred gallons per day to 151,400 liters per day (40,000 gallons per day), with septic tanks being the dominant preliminary treatment provided. SF wetlands are not now typically selected for larger flow municipal systems. The higher cost of the rock or gravel media makes a large SF wetland uneconomical compared to a FWS wetland in spite of the smaller SF wetland area required. Cost comparisons have shown that at flow rates above 227,100 liters per day (60,000 gallons per day) it will usually be cheaper to construct a FWS wetland system. However, there are exceptions where public access, mosquito, or wildlife issues justify selection of a SF wetland. One recent example is a SF wetland designed to treat the runoff from the Edmonton Airport in Alberta, Canada. The snow melt runoff is contaminated with glycol de-icing fluid and a SF wetland treating 1,264,190 liters per day (334,000 gallons per day) was selected to minimize habitat values and bird problems adjacent to the airport runways.

SF wetlands typically include one or more shallow basins or channels with a barrier to prevent seepage to sensitive groundwaters. The type of barrier will depend on local conditions. In some cases compaction of the local soils will serve adequately, in other cases clay has been imported or plastic membrane (PVC or HDPE) liners used. Appropriate inlet and outlet structures are employed to insure uniform distribution and collection of the applied wastewater. A perforated manifold pipe is most commonly used in the smaller systems. The depth of the media in these SF wetlands has ranged from 0.3 to 0.9 meters (1 to 3 feet) with 0.6 meters (2 feet) being most common. The size of the media in use in the U.S. ranges from fine gravel (≥0.6 centimeters or ≥ 0.25 in.) to large crushed rock (≥15.2 centimeters or ≥6 in.); A combination of sizes from 1.3 centimeters to 3.8 centimeters (0.5 to 1.5 inches) are most typically used. This gravel medium should be clean, hard, durable stone capable of retaining it's shape and the permeability of the wetland bed over the long term.

The most commonly used emergent vegetation in SF wetlands include cattail (*Typha* spp.), bulrush (*Scirpus* spp.), and reeds (*Phragmites* spp.). In Europe, *Phragmites* are the preferred plants for these systems. *Phragmites* have several advantages since it is a fast growing hardy plant and is not a food source for animals or birds. However, in some parts of the U.S. the use of *Phragmites* is not permitted because it is an aggressive plant and there are concerns that it might infest natural wetlands. In these cases cattails or bulrush can be used. In areas where muskrat or nutria are found, experience has shown that these animals, using the plants for food and nesting material, can completely destroy a stand of cattails or bulrush planted in a constructed wetland. Many of the smaller on-site systems serving individual homes use water tolerant decorative plants. The vegetation on a SF wetland bed is not a major factor in nutrient removal by the system and does not require harvesting. In cold climates, the accumulating plant litter on top of the gravel bed provides useful thermal insulation during the winter months. The submerged plant roots do provide substrate for microbial processes and since most emergent macrophytes can transmit oxygen from the leaves to their roots there are aerobic microsites on the rhizome and root surfaces. The remainder of the submerged environment in the SF wetland tends to be devoid of oxygen. This general lack of available oxygen limits the biological removal of ammonia nitrogen (NH_3/NH_4 - N) via nitrification in these SF wetlands, but the system is still very effective for removal of BOD, TSS, metals, and some priority pollutant organics since their treatment can occur under either aerobic or anoxic conditions. Nitrate removal via biological denitrification can also be very effective since the necessary anoxic conditions are always present and sufficient carbon sources are usually available.

The limited availability of oxygen in these SF systems reduces the capability for ammonia removal via biological nitrification. As a result, a long detention time in a very large wetland area is required to produce low levels of effluent nitrogen with typical municipal wastewater influents unless some system modification is adopted. These modifications have included installation of aeration tubing at the bottom of the bed for mechanical aeration, the use of an integrated gravel trickling filter for nitrification of the wastewater ammonia, and vertical flow wetland beds. These vertical flow beds usually contain gravel or coarse sand and are loaded intermittently at the top surface. The intermittent application and vertical drainage restores aerobic conditions in the bed permitting aerobic reactions to proceed rapidly. Cyclic filling and draining of a horizontal flow system has been successfully demonstrated at the 130,000 gallons per day SF wetland system in Minoa, NY. The reaction rates for BOD_5 and ammonia removal during these cyclic operations were double the rates observed during normal continuously saturated flow.

The phosphorus removal mechanisms available in all types of constructed wetlands also require long detention times to produce low effluent levels of phosphorus with typical municipal wastewater. If significant phosphorus removal is a project requirement then a FWS wetland will probably be the most cost effective type of constructed wetland. Phosphorus removal is also possible with final chemical addition and mixing prior to a final deep settling pond.

The minimal acceptable level of preliminary treatment prior to a SF wetland system is the equivalent of primary treatment. This can be accomplished with septic tanks or Imhoff tanks for smaller systems or deep ponds with a short detention time for larger systems. The majority of existing SF wetland systems treating municipal waste waters are preceded by either facultative or aerated ponds. Such ponds are not necessarily the preferred type of preliminary treatment. At most of these existing systems the SF wetland was selected to improve the water quality of the pond effluent. Since the SF wetland can provide very effective removal for both BOD_5 and TSS, there is no need to provide for high levels of removal of these constituents in preliminary treatments.

The SF wetland does not provide the same level of habitat value as the FWS wetland because the water in the system is not exposed and accessible to birds and animals. However, wildlife will still be present, primarily in the form of nesting animals, birds, and reptiles. If provision of more significant habitat values is a project goal it can be accomplished with deep ponds interspersed between the SF wetland cells. The first pond in such a system would be located after the point where water quality is approaching at least the secondary level

APPLICABILITY

SF wetland systems are best suited for small to moderate sized applications (≤ 227,100 liters/day or ≤60,000 gallons per day) and at larger systems where the risk of public contact, mosquitoes, or potential odors are major concerns. Their use for on-site systems provides a high quality effluent for in-ground disposal, and in some States a significant reduction in the final disposal field area is allowed. SF wetlands will reliably remove BOD, COD, and TSS, and with sufficiently long detention times can also produce low levels of nitrogen and phosphorus. Metals are removed effectively and about a one log reduction in fecal coliforms can be expected in systems designed to produce secondary or advanced secondary effluents.

ADVANTAGES AND DISADVANTAGES

Some advantages and disadvantages of subsurface flow wetlands are listed below.

Advantages

- SF wetlands provide effective treatment in a passive manner and minimize mechanical equipment, energy, and skilled operator attention.

- SF wetlands can be less expensive to construct and are usually less expensive to operate and maintain as compared to mechanical treatment processes designed to produce the same effluent quality.

- Year-round operation for secondary treatment is possible in all but the coldest climates.

- Year-round operation for advanced or tertiary treatment is possible in warm to moderately temperate climates. The SF wetland configuration provides more thermal protection than the FWS wetland type.

- SF wetland systems produce no residual biosolids or sludges requiring subsequent treatment and disposal.

- The SF wetland is very effective and reliable for removal of BOD, COD, TSS, metals, and some persistant organics in municipal wastewaters. The removal of nitrogen and phosphorus to low levels is also possible but requires a much longer detention time.

- Mosquitoes and similar insect vectors are not a problem with SF wetlands as long as the system is properly operated and a subsurface water level maintained. The risk of contact by children and pets with partially treated wastewater is also eliminated.

Disadvantages

- A SF wetland will require a large land area compared to conventional mechanical treatment processes.

- The removal of BOD, COD, and nitrogen in SF wetlands are continuously renewable processes. The phosphorus, metals, and some persistent organics removed in the system are bound in the wetland sediments and accumulate over time.

- In cold climates the low winter water temperatures reduce the rate of removal for BOD, NH_3, and NO_3. An increased detention time can compensate for these reduced rates but the increased wetland size in extremely cold climates may not be cost effective or technically possible.

- Most of the water contained in the SF wetland is anoxic and this limits the potential for nitrification of wastewater ammonia. Increasing the wetland size and detention time will compensate, but this may not be cost effective. Alternative methods for nitrification in combination with a SF wetland have been successful. SF wetlands cannot be designed for complete removal of organic compounds, TSS, nitrogen, and coliforms. The natural ecological cycles in these wetlands produce "background" concentrations of these substances in the system effluent.

- SF wetland systems can typically remove fecal coliforms by at least one log. This is not always sufficient to meet discharge limits in all locations and post disinfection may be required. UV disinfection has been successfully used in a number of applications.

- Although SF wetlands can be smaller than FWS wetlands for the removal of most constituents, the high cost of the gravel media in the SF wetland can result in higher construction costs for SF systems larger than about 227,100 liters per day (60,000 gallons per day).

DESIGN CRITERIA

Published models for the design of SF wetland systems have been available since the late 1980's. More recent efforts in the mid to late 1990's have produced three text books containing design models for SF wetlands (Reed, et al 1995, Kadlec & Knight 1996, Crites & Tchobanoglous, 1998). In all three cases, the models are based on first order plug flow kinetics, but results do not always agree due to the author's developmental choices and because the same databases were not used for derivation of the models. The Water Environment Federation (WEF) presents a comparison of the three approaches in their Manual of Practice on Natural Systems (WEF, 2000) as does the US EPA design manual on wetland systems (EPA, 2000). The designer of a SF wetland system should consult these references and select the method best suited for the project under consideration. A preliminary estimate of the land area required for a SF wetland can be obtained from Table 1 of typical areal loading rates. These values can also be used to check the results from the previously cited references.

The SF wetland size is determined by the pollutant which requires the largest land area for it's removal. This is the bottom surface area of the wetland cells and, for that area to be 100 percent effective, the wastewater flow must be uniformly distributed over the entire surface. This is possible with constructed wetlands by careful grading of the bottom surface and use of appropriate inlet and outlet structures. The total treatment area should be divided into at least two cells for all but the smallest systems. Larger systems should have at least two parallel trains of cells to provide flexibility for management and maintenance.

These wetland systems are living ecosystems and the life and death cycles of the biota produce residuals which can be measured as BOD, TSS, nitrogen, phosphorus and fecal coliforms. As a result, regardless of the size of the wetland or the characteristics of the influent, in these systems there will always be a residual background concentration of these materials. Table 2 summarizes these background concentrations.

It is necessary for the designer to determine the water temperature in the wetland because the removal of BOD, and the various nitrogen forms are temperature dependent. The water temperature in large systems with a long HRT (>10 days) will approach the average air temperature except during subfreezing weather in the winter. Methods for estimating the water temperature for wetlands with a shorter HRT (<10 days) can be found in the published references mentioned previously.

It is also necessary to consider the hydraulic aspects of system design because there is significant frictional resistance to flow through the wetland caused by the presence of the gravel media and the plant roots and other detritus. The major impact of this flow resistance is on the configuration selected for the wetland cell. The longer the flow path the higher the resistance will be. To avoid these hydraulic problems an aspect ratio (L:W) of 4:1 or less is recommended. Darcy's law is generally accepted as the model for the flow of water through SF wetlands and descriptive information can again be found in the published references mentioned previously. The flow of water through the wetland cell depends on the hydraulic gradient in the cell and on the hydraulic conductivity (k_s), size, and porosity (n) of the media used. Table 3 presents typical characteristics for potential SF wetland media. These values can be used for a preliminary estimate and for design of very small systems. For large scale systems the proposed media should be tested to determine these values.

TABLE 1 TYPICAL AREAL LOADING RATES FOR SF CONSTRUCTED WETLANDS

Constituent	Typical Influent Concentration mg/L	Target Effluent Concentration mg/L	Mass Loading Rate lb/ac/d*
Hydraulic Load (in./d)	3 to 12**		
BOD	30 to175	10 to 30	60 to 140
TSS	30 to150	10 to 30	40 to 150
NH_3/NH_4 as N	2 to 35	1 to 10	1 to 10
NO_3 as N	2 to 10	1 to 10	3 to 12
TN	2 to 40	1 to 10	3 to 11
TP	1 to 10	0.5 to 3	1 to 4

Note: Wetland water temperature » 20°C.

TABLE 2 "BACKGROUND" SF WETLAND CONCENTRATIONS

Constituent	Units	Concentration Range
BOD_5	mg/L	1 to 10
TSS	mg/L	1 to 6
TN	mg/L	1 to 3
NH_3/NH_4 as N	mg/L	less than 0.1
NO_3 as N	mg/L	less than 0.1
TP	mg/L	less than 0.2
Fecal Coliforms	MPN/100ml	50 to 500

Source: Reed et al., 1995 and U.S. EPA, 1993.

PERFORMANCE

A lightly loaded SF wetland can achieve the "background" effluent levels given in Table 2. In the general case, the SF constructed wetland is typically designed to produce a specified effluent quality and Table 1 can be used for a preliminary estimate of the size of the wetland necessary to produce the desired effluent quality. The design models in the referenced publications will provide a more precise estimate of treatment area required. Table 4 summarizes actual performance data for 14 SF wetland systems included in a US EPA Technology Assessment (EPA, 1993).

In theory, the performance of a SF wetland system can be influenced by hydrological factors. High evapotranspiration (ET) rates may increase effluent concentrations, but this also increases the HRT in the wetland. High precipitation rates dilute the pollutant concentrations but also shorten the HRT in the wetland. In most temperate areas with a moderate climate these influences are not critical for performance. These hydrological aspects need only be considered for extreme values of ET and precipitation.

OPERATION AND MAINTENANCE

The routine operation and maintenance (O&M) requirements for SF wetlands are similar to those for facultative lagoons, and include hydraulic and water depth control, inlet/outlet structure cleaning, grass mowing on berms, inspection of berm integrity, wetland vegetation management, and routine monitoring.

The water depth in the wetland may need periodic adjustment on a seasonal basis or in response to increased resistance over a very long term from the accumulating detritus in the media pore spaces. Mosquito control should not be required for a SF wetland system as long as the water level is maintained below the top of the media surface. Vegetation management in these SF wetlands does not include a routine harvest and removal of the

TABLE 3 TYPICAL MEDIA CHARACTERISTICS FOR SF WETLANDS

Media Type	Effective Size D_{10} (mm)*	Porosity, n (%)	Hydraulic Conductivity k_s ($ft^3/ft^2/d$)*
Coarse Sand	2	28 to 32	300 to 3,000
Gravelly Sand	8	30 to 35	1,600 to 16,000
Fine Gravel	16	35 to 38	3,000 to 32,000
Medium Gravel	32	36 to 40	32,000 to 160,000
Coarse Rock	128	38 to 45	16×10^4 to 82×10^4

* mm x 0.03937 = inches
** $ft^3/ft^2/d \times 0.3047 = m^3/m^2/d$, or x 7.48 = $gal/ft^2/d$

Source: Reed et al., 1995.

TABLE 4 SUMMARY OF PERFORMANCE FOR 14 SF WETLAND SYSTEMS*

Constituent	Mean Influent mg/L	Mean Effluent mg/L
BOD_5	28** (5-51)***	8** (1-15)***
TSS	60 (23-118)	10 (3-23)
TKN as N	15 (5-22)	9 (2-18)
NH_3/NH_4 as N	5 (1-10)	5 (2-10)
NO_3 as N	9 (1-18)	3 (0.1-13)
TN	20 (9-48)	9 (7-12)
TP	4 (2-6)	2 (0.2-3)
Fecal Coliforms (#/100ml)	270,000 (1,200-1,380,000)	57,000 (10-330,000)

* Mean detention time 3 d (range 1 to 5 d).
** Mean value.
*** Range of values.

Source: U.S. EPA, 1993.

harvested material. Plant uptake of pollutants represents a relatively minor pathway so harvest and removal on a routine basis does not provide a significant treatment benefit. Removal of accumulated litter is unnecessary, and in cold climates it serves as thermal insulation to prevent freezing in the wetland bed. Vegetation management may also require wildlife management, depending on the type of vegetation selected for the system, and the position of the water. Animals such as nutria and muskrats have been known to consume all of the emergent vegetation in constructed wetlands. These animals should not be attracted to a SF wetland as long as the water level is properly maintained. Routine water quality monitoring will be required for all SF systems with an NPDES permit, and the permit will specify the pollutants and frequency. Sampling for NPDES monitoring is usually limited to the untreated wastewater and the final system effluent. Since the wetland component is usually preceded by some form of preliminary treatment, the NPDES monitoring program does not document wetland influent characteristics. It is recommended, in all but the smallest systems that periodic samples of the wetland influent be obtained and tested for operational purposes in addition to the NPDES requirements. This will allow the operator a better understanding of wetland performance and provide a basis for adjustments if necessary.

COSTS

The major items included in the capital costs for SF wetlands are similar to many of those required for lagoon systems. These include land costs, site investigation, site clearing, earthwork, liner, gravel media, plants, inlet and outlet structures, fencing, miscellaneous piping, etc., engineering, legal, contingencies , and contractor's overhead and profit. The gravel media and the liner can be the most expensive items from this list. In the Gulf States where clay soils often eliminate the need for a liner the cost of imported gravel can often represent 50 percent of the construction costs. In other locations where local gravel is available but a membrane liner is required the liner costs can approach 40 percent of the construction costs. In many cases compaction of the in-situ native soils provides a sufficient barrier for groundwater contamination. Table 5 provides a summary of capital and O & M costs for a hypothetical 378,500 liters/day (100,000 gallons per day) SF constructed wetland, required to achieve a 2 mg/L ammonia concentration in the effluent. Other calculation assumptions are as follows: influent NH_3= 25 mg/L, water temperature 20°C (68°F), media depth = 0.6 meters (2 ft), porosity = 0.4, treatment area = 1.3 hectares (3.2 ac), land cost =$12,355/hectare ($5,000/ac).

TABLE 5 CAPITAL AND O&M COSTS FOR 100,000 GALLONS PER DAY SF WETLAND

Item	Cost $*	
	Native Soil Liner	Plastic Membrane Liner
Land Cost	$16,000	16,000
Site Investigation	3,600	3,600
Site Clearing	6,600	6,600
Earthwork	33,000	33,000
Liner	0	66,000
Gravel Media**	142,100	142,100
Plants	5,000	5,000
Planting	6,600	6,600
Inlets/Outlets	16,600	16,600
Subtotal	$229,500	$295,500
Engineering, legal, etc.	$133,000	$171,200
Total Capital Cost	**$362,500**	**$466,700**
O & M Costs, $/yr	$6,000/yr	$6,000/yr

* June 1999 costs, ENR CCI = 6039
**12,000 cy of 0.75 in. gravel

TABLE 6 COST COMPARISON SF WETLAND AND CONVENTIONAL WASTEWATER TREATMENT

Cost Item	Process	
	Wetland	SBR
Capital Cost	$466,700	$1,104,500
O &M Cost	$6,000/yr	$106,600/yr
Total Present Worth Costs*	$530,300	$2,233,400
Cost per 1000 gallons treated**	$0.73	$3.06

*Present worth factor 10.594 based on 20 years at 7 percent interest (June 1999 costs, ENR CCI = 6039).
**Daily flow rate for 365 d/yr, for 20 yr, divided by 1000 gallons

Source: WEF, 2000.

Table 6 compares the life cycle costs for this wetland to the cost for a conventional treatment system designed for the same flow and effluent water quality. The conventional process is a sequencing batch reactor (SBR).

REFERENCES

Other Related Fact Sheets

Free Water Surface Wetlands
EPA 832-F-00-024
September, 2000

Other EPA Fact Sheets can be found at the following web address:
http://www.epa.gov/owmitnet/mtbfact.htm

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5. U.S. EPA (2000) *Design Manual Constructed Wetlands for Municipal Wastewater Treatment*, US EPA CERI, Cincinnati, Ohio (in press.)

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