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Operations

SEMI-PERMANENT WASTEWATER TREATMENT PLANTS AT CONTINGENCY LOCATIONS

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This publication supports Air Force Instruction (AFI) 10-210, *Prime Base Engineer Emergency Force (BEEF) Program*, AFI 10-209, *RED HORSE Program*, and Air Force Doctrine Publication (AFDP) 3-34, *Engineer Operations*. It provides Air Force (AF) civil engineer (CE) personnel with general information and concepts for planning and developing semi-permanent wastewater treatment facilities (WWTF) for 30 to 250 personnel at contingency locations. This publication applies to all DAF civilian employees and uniformed members of the Regular Air Force, the Air Force Reserve, and the Air National Guard civil engineer units. This publication does not apply to the United States Space Force. It presents an approach to design, construction, and operation of treatment systems that provides optimal long-term performance, limits negative effects on local resources, and promotes sustainable water management. Refer recommended changes and questions about this publication to the Office of Primary Responsibility using the Department of the Air Force (DAF) Form 847, *Recommendation for Change of Publication*; route DAF Forms 847 from the field through the appropriate functional chain of command and Major Command publications/ forms managers. Ensure all records generated as a result of processes prescribed in this publication adhere to AFI 33-322, *Records Management and Information Governance Program* and are disposed in accordance with the Air Force Records Disposition Schedule, which is located in the Air Force Records Information Management System. The use of the name or mark of any specific manufacturer, commercial product, commodity, or service in this publication does not imply endorsement by the DAF.

Chapter 1

INTRODUCTION

1.1. Overview. This publication addresses wastewater treatment facility (WWTF) alternatives for contingency locations. These alternatives provide a starting point to address risk factors related to wastewater treatment. Much of the technical information in this publication comes from requirements established by unified, multi-service, and DAF subject matter experts. While the information may reflect Department of Defense (DoD) guidance for environmentally responsible stewardship of contingency locations, DO NOT use this information as directive or authoritative guidance. The information in this publication does not supersede any legal requirements (domestic US law for operations in the US and for operations outside the US: US law with extraterritorial application, applicable international agreement requirement, or Combatant Command directive) that specifies wastewater treatment options, procedures, or associated requirements. Rather, the information addresses general techniques and procedures only. The type of systems available for use at a particular contingency location depends on what is required, authorized, and restricted by international agreements, DoD directives, and operational (e.g., Combatant Command) requirements. For additional information, consult the references listed in **paragraph 1.3** and **Attachment 1**. The Air Force Civil Engineer Center (AFCEC) has a Reachback capability to answer additional engineering, readiness, and environmental concerns. Personnel may contact the AFCEC Reachback Center by e-mailing AFCEC.RBC@us.af.mil.

1.2. General Information. Approximately 80 percent of water used during contingency operations, other than for human consumption, becomes wastewater and requires treatment or disposal. Wastewater created at contingency locations includes black water and gray water. As used here, black water is latrine or toilet wastewater containing human waste or fecal matter. Although it is sometimes treated with chemicals and reused for purposes such as irrigation of certain non-food crops and dust control, black water is generally not recycled as potable water during contingency operations. Conversely, gray water refers to wastewater from non-latrine sources such as showers, laundries, kitchens (except from food grinders/garbage disposals), vehicle wash racks, and hand-washing stations. Recycling gray water from showers, sinks, laundries, and other non-potable water sources conserves energy and water, protects the environment, and is part of joint engineer doctrine. Recycled gray water can be an option for irrigation, showering/hand washing, laundry, toilet flushing, vehicle wash racks, mechanical heating/cooling processes, and reintroduction into fresh water sources. It is important to remember the hazards of storing gray water for extended periods. If allowed to sit, gray water can turn into stagnant, sludge-filled concoctions of bacteria and pathogens—it can essentially become black water in as little as 24 hours if not filtered and treated. Civil Engineers (CE) have primary responsibility for managing wastewater collection, treatment, and disposal, particularly in an expeditionary environment. The tactics, techniques, and procedures for these functions primarily depend on location, capabilities, and the environment. Onsite, simplified conventional wastewater systems such as septic tanks, lagoons, and leach fields provide appropriate treatment for most contingency locations. These systems provide effective treatment, significantly reduce risks to public health, and likely are the lowest-cost alternative for deployed/contingency locations if international agreements, operational directives, or site conditions do not prohibit their use.

1.3. Engineer Doctrine and Standards. Air Force Civil Engineers remain cognizant of various DoD and theater-level engineering and environmental guidance affecting wastewater treatment solutions at contingency locations. Relevant guidance includes Department of Defense Instruction (DoDI) 4715.22, *Environmental Management Policy for Contingency Locations*; Air Force Doctrine Publication (AFDP) 3-34, *Engineer Operations;* Air Force Handbook (AFH) 10-222, Volume 4, *Environmental Considerations for Overseas Contingency Operations;* Joint Publication (JP) 3-34, *Joint Engineer Operations*; JP 4-03, *Joint Bulk Petroleum and Water Doctrine*, and Combatant Command (CCMD) contingency construction and environmental guidance in the Environmental Annex of the contingency operation OPLAN and/or OPORD. Find additional resources using the engineer Reachback links in **Attachment 2**.

1.3.1. The anticipated mission and duration of overseas operations determine expeditionary construction standards. CE organizes, trains, and equips its personnel to provide capabilities suitable for any environment or range of military operations—from beddown at initial contingency locations to supporting sustainment at permanent bases. The information presented in this publication supplements CE training, and when combined with other technical resources and guidance, supports delivery of engineer capability to combatant commanders. This information is not a replacement for engineering design and analysis; instead, it offers potential solutions and points the reader to documents and sources of information by authorities in the wastewater treatment field. Qualified and experienced wastewater civil engineers may find the information useful when planning/developing onsite wastewater treatment solutions at contingency locations.

1.3.2. CE personnel use conventional and expedient means for wastewater disposition, including connecting to local or municipal sewage systems, collecting and retaining wastewater for contractor removal to fixed treatment facilities, or using onsite and field expedient systems. Examples of wastewater treatment and disposal methods addressed here include septic systems, leach fields, sewage lagoons, sand filters, seepage pits, soakage pits and trenches, and evaporative beds. CE personnel have a keen awareness that expeditionary and expedient construction can differ from US conventional standards and requirements. Unlike most domestic or in-garrison situations where water usage is virtually uncontrolled and unlimited, CE guidance provides expeditionary planning factors for water usage and disposal for deployed forces. For example, the common planning factor for water usage in austere conditions is 30 gallons per capita per day (gpcd), of which approximately 20 gpcd will need to be disposed of in some manner. Early planning for expedient wastewater management is essential to protect the health of the deployed force. Portions of the wastewater treatment and disposal information presented here was adapted from Environmental Protection Agency (EPA) 625/1-80-012, *Design Manual, Onsite Wastewater Treatment and Disposal Systems*, EPA 625/R-00/008, *Onsite Wastewater Treatment Systems Manual*, and other design manuals. For more information on wastewater planning, review AFH 10-222V4.

1.4. Public Health Risks Associated with Untreated Wastewater. There are a variety of ways people could contact untreated wastewater, including recreational aquatic activities in contaminated water bodies, bathing, washing clothes or utensils, during food preparation, or ingesting vegetation exposed to contaminated water sources. Contamination can occur by direct consumption or by more subtle contact with the skin, eyes, or ears.

1.4.1. Constituents of Wastewater. Wastewater contains a combination of biological and chemical waste products. After use, this water can return to the environment and rejoin the hydrologic cycle by discharging into a surface water body (such as a lake or stream) or into groundwater. Left untreated, this wastewater can harm the health and wellbeing of deployed personnel, local populations, and ecosystems. Biological wastes can contain harmful organisms such as waterborne pathogens that can cause a myriad of illnesses including, but not limited to, cholera, typhoid, dysentery, and other infections. While some of the illnesses may pass in a few days to a week, they can also last much longer and without proper treatment can cause long-term damage or fatalities. Untreated sewage also contains high volumes of nutrients, which, when discharged to the environment can, among other impacts, fertilize algae populations and cause blooms to develop. These blooms can be toxic to humans and damage aquatic environments.

1.4.2. International Guidance for Sanitation and Health. As identified by the World Health Organization, countries are at varying levels of sanitation awareness and sensitivity to wastewater treatment and the protection of both groundwater and surface waters. Largely, these differences center on cultural, educational, and economic development factors. In industrial countries, degradation of surface and groundwater sources has been a consequence of economic development while environmental impacts have been a lesser priority. In undeveloped countries, cultural practices, and a lack of education about the relationship between water quality and disease is unfortunately still a major world health issue. The international community has acknowledged the severity of the problems caused by deteriorating water quality and, to some extent, is taking action to protect the quality of freshwater resources.

1.4.3. Goals and Considerations. A goal at every expeditionary site is to reduce health risks to personnel and provide environmental protection in support of sustainable clean water for use onsite and in the surrounding community. With this intent, the following considerations are important when determining the requirements for any onsite treatment facility:

- Type of water supply used onsite and by the surrounding community.
- Site proximity to surface waters and/or wetland areas.
- Site proximity to local farms for potential reuse of treated wastewaters.
- Awareness of local environmental concerns.

1.4.3.1. Guidance and standards vary from location to location; personnel can adjust the design methods in this publication to meet local requirements and loading. With the information provided herein and preparation of a site evaluation, units can develop an appropriate wastewater management solution for their deployment site.

1.4.3.2. Even after a WWTF, methods, and systems are in place at contingency locations, there may still be areas on the base that need expedient systems. This may be due to distance from the primary treatment system(s) or due to shortages of Basic Expeditionary Airfield Resources that have not yet arrived. Personnel can review AFTTP 3-32.33V1, *Expedient Hygiene, Water, and Waste Methods* and AFTTP 3-32.34V1, *Civil Engineer Bare Base Development*, for expedient options and alternative solutions.

Chapter 2

SYSTEMS OVERVIEW AND SITE SELECTION FACTORS

2.1. General Information. The approach to wastewater collection, treatment, and disposal at overseas contingency locations depends on several factors. These include CCMD or coalition guidance, international agreements, local site conditions, and deployment site requirements. Engineers use site screening and system selection factors to design and operate wastewater facilities and systems to ensure protection of health and safety. The advantages of adequate screening and planning for wastewater management is that it helps ensure projects meet requirements, complies with applicable standards, are programmed at the lowest life cycle costs, achieve resource efficiency, and minimize damage to the environment. This chapter identifies various onsite wastewater treatment alternatives, favorable criteria for siting facilities, and the required soil, site, and climate conditions that affect the design, operation, and performance of wastewater treatment and disposal systems. Certain information presented here was adapted from EPA 625/1-80-012 and EPA 625/R-00/008. Find these and other EPA wastewater treatment system publications at https://search.epa.gov/epasearch/epasearch.

2.2. Wastewater Treatment Alternatives. At initial, temporary, and semi-permanent contingency locations, connection to an existing wastewater collection system (while preferred) is often impractical or impossible. Therefore, engineers may need to develop or employ onsite wastewater treatment and disposal solutions to support the planned size and population density of the location. The design of the wastewater treatment system should meet the anticipated effluent or incoming waste load. Below is a list of various onsite treatment methods, followed by their description, advantages and disadvantages, and key selection factors. **Chapter 3** addresses specific design and alternatives for these wastewater treatment methods.

- Conventional septic systems
- Lagoons
- Sand filters
- Natural land treatment systems
- Commercial systems and package plants
- Disinfection units

2.2.1. Conventional Septic Systems. A standard septic system has a septic tank, distribution box and drain pipes in a leach field. Some soil conditions may require an alternate leach field location. Additional, alternative pretreatment units may be required to meet stricter effluent standards. Grease, non-biodegradable products, and industrial wastewater should not discharge into these systems. For this reason, garbage grinders are not allowed in septic tanks systems.

2.2.1.1. A conventional septic system allows filtration of the treated effluent to the groundwater below (**Figure 2.1**). Septic systems are simple and well suited to small populations located in semi-rural areas; the effluent quality is not well suited for environmentally sensitive areas, and non-sanitary debris introduced into the system can create significant performance problems. More sophisticated small treatment systems use septic tanks for pre-treatment. A main component in many onsite treatment and collection alternatives, the septic tank provides pretreatment for conventional subsurface soil absorption systems and commercial systems when applied under the conditions identified in **Table 2.1**. Listed in **Table 2.2** are key advantages and disadvantages of septic systems. Personnel can find additional technical information in the *International Private Sewage Disposal Code*.

Figure 2.1. Septic System Flow Diagram.

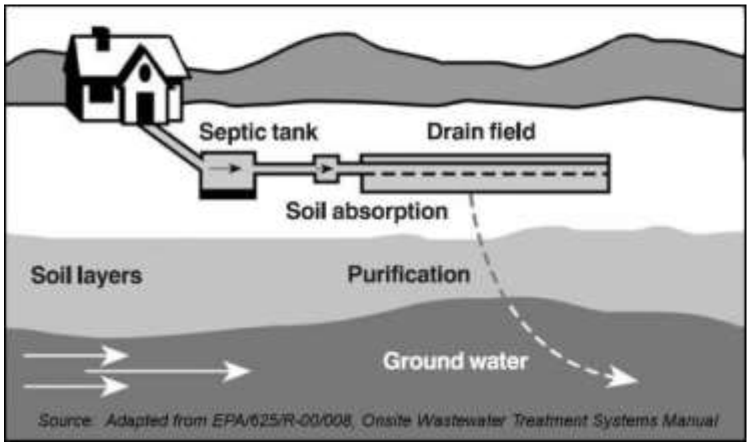


Table 2.1. Septic System Key Selection Factors.

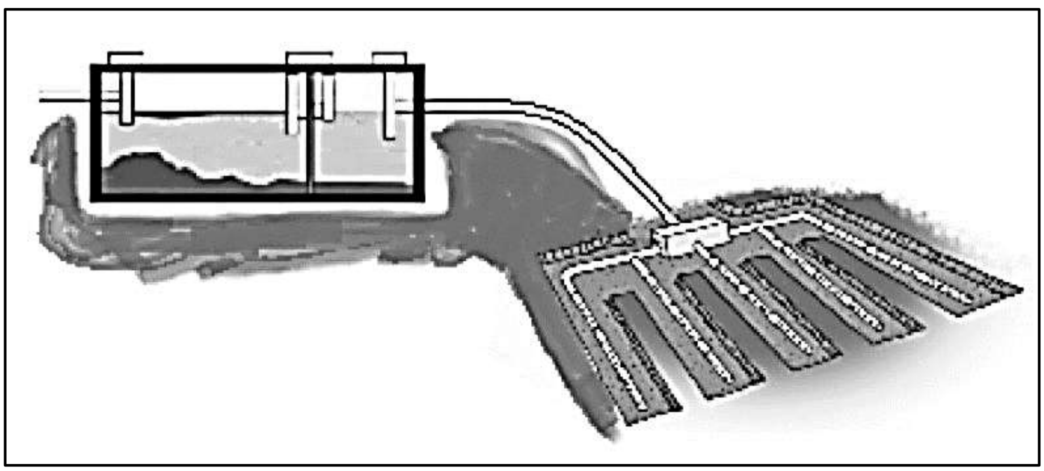
Key Selection Factors		
Flow range	< 1,000–15,000 gpd (< 3,800–56,800 Lpd).	
Treatment cost range	\$50–\$65 per gallon based on CONUS installation.	
Suitable site conditions	Well-draining soils needed to support leach field, which can be mounded, if required. Leaching area(s) can be adapted to most topographies.	
Climate	No limitations.	
Limiting factors	Grease and chemicals are prohibited from sewage flows. Leaching area not suitable for sites characterized by clay or ledge.	
O&M needs	Annual inspection of septic tank. Pump-out tank and clean effluent filter every 1 to 3 years. First-year inspection of D-box and field, then as needed every five years.	
Typical effluent quality	Biochemical oxygen demand (BOD)	50[1] mg/L–200[2] mg/L
	Total suspended solids (TSS)	40[1] mg/L–140[2] mg/L
	Total nitrogen (TN)	25[1] mg/L–50[2] mg/L
	Fecal coliform	< 24,000/100 mL
Notes: 1. Leach field effluent 2. Septic tank effluent		

Table 2.2. Septic System Advantages/Disadvantages.

Advantages	Disadvantages
Uses less energy than all other wastewater treatment methods. Simple construction and installation. Multiple tanks can be served by common leaching system. Simple to operate and maintain and generally requires minimal attention. Suitable for most climates and seasonal variations. Functions as pretreatment for all other technologies. Septic tank can serve as holding tank before subsequent drain-field or lagoon installation.	Effluent quality is mediocre at best. Additional treatment provided through leach field. Not well-suited for large populations. Poor septic tank and filter maintenance could cause leach field failure. Mounded leaching required in areas of high groundwater. Effluent requires further processing before discharge to ground or surface waters.

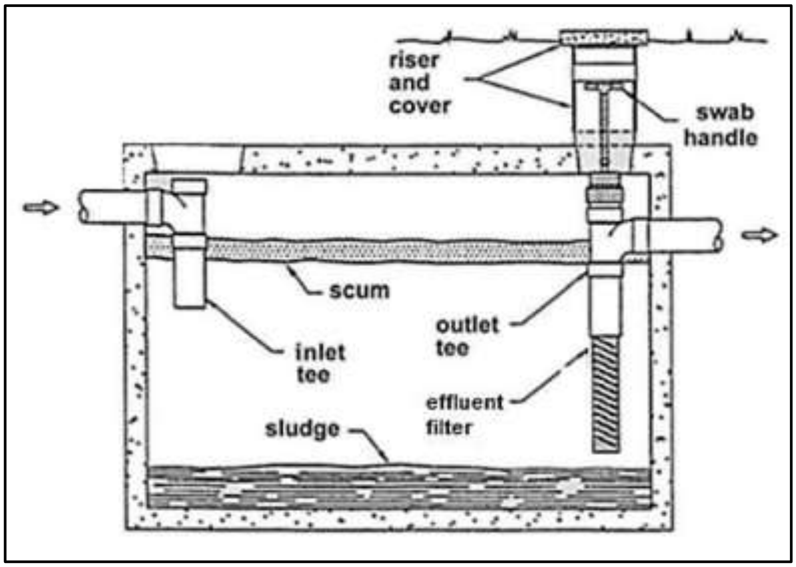
2.2.1.2. A key component of conventional septic systems is the septic tank. The septic tank is the most common form of onsite wastewater pretreatment. The effluent from the tank typically flows to a leach field (**Figure 2.2**). The septic tank collects wastewater; segregate settleable and floatable solids (sludge and scum); accumulate, consolidate, and store solids; digest organic matter; and discharge treated effluent.

Figure 2.2. Septic System with Leach Field.



2.2.1.3. As illustrated in **Figure 2.3**, wastewater flows enter the septic tank and detained there long enough for heavier solids (sludge) to settle to the bottom while oils and greases (scum) float to the top. The leach field or soil adsorption system (SAS) distributes the tank effluent to the surrounding soils through a series of perforated pipes. The treatment process completes as the effluent percolates down through the soil on its way back into the groundwater. Manhole access at the locations shown allows periodic observation and cleaning of the inlet/outlet tees. A newer feature commonly added on CONUS installations is an effluent filter in the outlet tee as shown. If used, place these filters directly in the effluent tee to protect the leach field from solids carried over from the septic tank. Maintainers can easily remove, clean, and reuse the filters. The filters are also suitable for protection of pressure-dosed systems. Effluent filters are available through industrial suppliers such as Grainger® and hardware stores and easily shipped. Effluent filters are available in various diameters for use in 4-inch to 8-inch pipes.

Figure 2.3. Single Compartment Septic Tank.



2.2.1.4. In addition to providing pretreatment for leach fields, septic tank pretreatment serves an important role in the success of other treatment alternatives, such as constructed wetlands, lagoons, sand filters, mounded systems, and packaged aerobic treatment systems. While septic tanks can achieve some separation of grease in the scum layer, place a properly designed grease trap upstream for all sewer flows generated from a kitchen or dining facility. An accumulation of grease in the septic tank could affect the quality of the effluent and clog the leach field. The configuration of the septic tank inlet tee directs sewage flow down into the clear zone without disturbing the scum layer. Likewise, the design of the effluent tee allows the liquid below the scum line to exit the tank to the distribution box (D-box) or pumping chamber. The biological process within the tank removes approximately 40 to 60 percent of the influent solids; however, personnel will have to periodically remove and dispose of the scum and sludge that remains.

2.2.2. Lagoon Systems. Lagoons (also known as ponds) usually consist of earthen basins with a liner made of natural or synthetic material. While there are many designs and terms used to categorize wastewater treatment lagoons and ponds, there are three basic types: aerobic, anaerobic, and facultative. These systems may have controlled discharge, continuous discharge, or no discharge. Some installations use lagoons alone or in combination with other treatment processes. Use of aeration equipment is sometimes an option to enhance the wastewater treatment process.

2.2.2.1. A typical residential treatment lagoon system consists of both a septic tank for primary treatment and a lagoon (or pond) for additional treatment. When not preceded by a septic tank, the lagoon influent channel is typically equipped with a manually cleaned bar screen to keep rags and other floatables out of the lagoon. Some lagoons have chlorine contact chambers as part of the effluent structure, but this is normally not required if the lagoon has a detention time in the 50- to 60-day range. Controlled discharge lagoons commonly discharge only twice a year and produce excellent results with BOD, suspended solids removals in the 85 percent to 95 percent range, and fecal coliform reductions up to 99 percent. Lagoon systems offer many advantages for small installations, especially if land is available and the location is isolated from inhabited areas. See **Table 2.3** for common advantages and disadvantages of lagoon systems.

Table 2.3. Lagoon Systems Advantages/Disadvantages.

Advantages	Disadvantages
Expensive equipment not required. Highly trained personnel not required. Economical to construct and operate. Provides adequate treatment for most applications. Is well-adapted to temporary use. Adapts to changing loads. Low or no energy requirements. Provides wildlife habitat. Few solids disposal problems. Mostly trouble-free when used correctly.	May emit odors. Requires a large area of land. Seasonal climate changes may affect the quality of treatment. Can have suspended solids carryover in the effluent. Faulty construction may contaminate groundwater. May attract nuisance insects and/or pests.

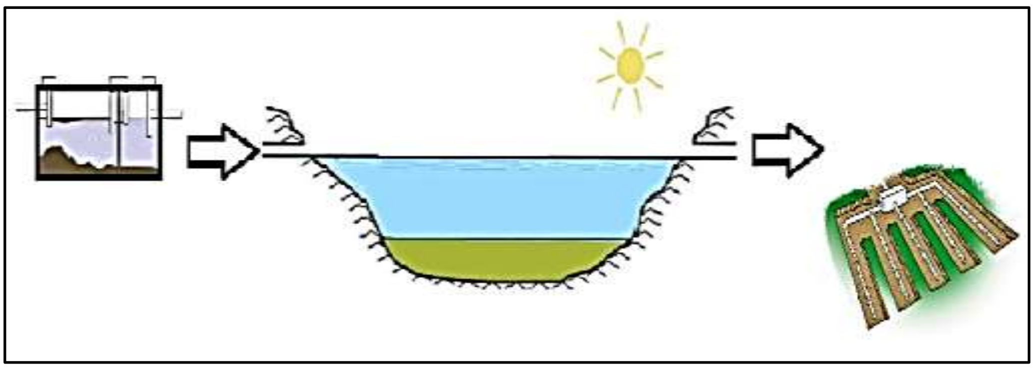
2.2.2.2. There are three types of wastewater treatment lagoons: aerobic, anaerobic, and facultative. The following paragraphs provides a brief overview of each type of lagoon system, however, more information for the commonly used facultative lagoon is provided in subsequent paragraphs.

2.2.2.2.1. The aerobic lagoon is typically shallower than other types of lagoons to facilitate permeation of oxygen from the surrounding environment. As oxygen mixes with wastewater, aerobic bacteria and algae remove biological contaminants while larger solids settle to the bottom of the lagoon. Due to the shallow nature of these lagoons, engineers commonly pave or line them to prevent the growth of weeds and vegetation. Another common feature in aerobic lagoons are mechanical aerators. To enhance oxygen distribution through the flow depth of the lagoon, mechanical aerators or mixers create a turbid environment to increase the interface between the atmosphere and wastewater. The increase in aeration provided by the aerators can decrease the required retention by providing treatment that is more effective; however, offsetting this benefit is the increased costs for operation.

2.2.2.2.2. The anaerobic lagoon creates an environment that is oxygen deficient. This type of lagoon is most often the first step in treatment for farming, industrial, or commercial wastes. The anaerobic lagoon is deeper than other types of lagoons, ranging anywhere from 8 to 20 feet (2.4 to 6 m) deep. Similar to the inside of a septic tank, the wastewater settles into various layers: oils and greases on top, heavier solids on the bottom, with the flow undergoing treatment floating between the two. The grease and scum layer serves as a barrier to oxygen attempting to enter the system. As in septic tanks, personnel should periodically remove the bottom layer of sludge to maintain adequate storage in the lagoon. Although there is some treatment of wastewater by the bacteria and organisms that thrive in anaerobic conditions, the anaerobic lagoon is typically a pretreatment process and wastewater requires further treatment prior to discharge.

2.2.2.2.3. The facultative lagoon is a common option for noncommercial sanitary wastewater treatment and has a simplified operational process. A typical system consists of a septic tank for primary treatment, a pond for secondary treatment, and either a leach field for final disinfection in groundwater discharge or other disinfection for surface water discharge (**Figure 2.4**).

Figure 2.4. System Flow Diagram.



2.2.3. Facultative Lagoons. The facultative lagoon is typically between 5 and 10 feet deep and settles into three distinct treatment layers: the aerobic zone on top, the facultative zone in the middle, and the anaerobic zone on the bottom (see **Figure 2.5** and **Figure 2.6**). Each of these zones provides a unique form of treatment, with help from bacteria, algae, and other organisms inhabiting the lagoon.

2.2.3.1. The aerobic zone provides aerobic treatment by mixing with atmospheric oxygen and helps control odors released from the waste-treatment process. An algal layer forms at the top of the aerobic zone, taking in sunlight and carbon dioxide released from the wastewater treatment process and releasing oxygen back into the aerobic zone.

2.2.3.2. The anaerobic zone breaks down settled solids with microorganisms that thrive in oxygen-depleted conditions. If correctly sized, the solids gathering in the anaerobic zone will not accumulate to where the lagoon needs cleaning out.

2.2.3.3. The facultative zone contains a spectrum of aerobic to anaerobic conditions and any of a variety of treatment processes can occur in that region. The performance of a facultative lagoon is largely dependent on its surroundings: sunlight, wind and occasional rain provides for oxygen, photosynthesis of algae, and mild mixing of the top aerobic zone. Without the right conditions, treatment performance will decline, and the retention times needed to achieve adequate effluent quality will significantly increase. The treatment process is also highly temperature-dependent; thus, lagoons installed in locations with colder winter temperatures must be sized to contain all wastewater generated through the winter. When spring/summer temperatures return, the treatment process begins, and operators can discharge the winter effluent. **Table 2.4** lists key selection factors for facultative lagoons, and **Table 2.5** identifies the main advantages and disadvantages of facultative lagoons.

Figure 2.5. Profile of Lagoon Zones.

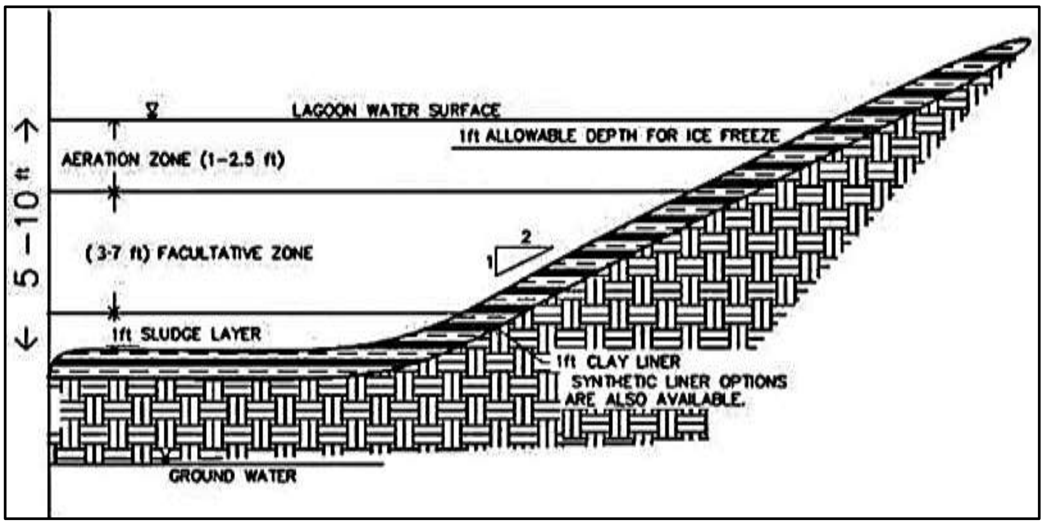


Figure 2.6. Facultative Lagoon Treatment Layers.

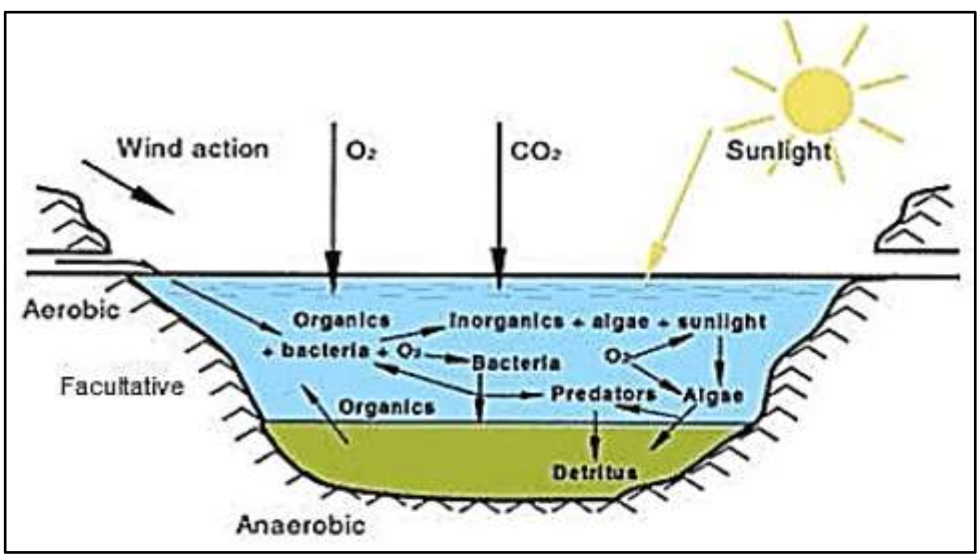


Table 2.4. Key Selection Factors for Facultative Lagoons.

Key Selection Factors		
Flow range	< 1,000–15,000 gpd (< 3,800–56,800 Lpd).	
Treatment cost range	$80–$100 per gallon based on CONUS installation.	
Suitable site conditions	Flat to moderate grade; non-forested; non-permeable soils or liner required.	
Climate	Warm to moderate climate preferred; temperatures above 30 °F recommended.	
Limiting factors	Land cost/availability.	
O&M needs	Weekly process monitoring and inspections; monthly visual inspections; weed maintenance; annual monitoring of anaerobic layer for possible solids removal.	
Typical effluent quality	BOD	20–50 mg/L
	TSS	30–80 mg/L
	TN	10–30 mg/L
	Fecal coliform	> 24,000/100 mL (unchlorinated)

Table 2.5. Facultative Lagoons Advantages/Disadvantages.

Advantages	Disadvantages
Uses less energy than most wastewater treatment methods. Cost-effective in areas where land is available and inexpensive. Effective at removing disease-causing organisms (pathogens) from wastewater. Can handle variations in flow and loadings better than many systems. Simple to operate and maintain and generally requires only part-time staff attention. Effluent can be suitable for irrigation.	Requires more land than other treatment methods. Less efficient in cold climates. If not properly maintained, lagoons can attract mosquitoes and other insects. Effluent may require algae removal or "polishing" to meet discharge quality standards. Not very effective at removing heavy metals from wastewater. Nuisance odors can occur during seasonal changes.

2.2.4. Sand Filters. Sand filters are another method of secondary treatment of septic tank effluent (**Figure 2.7**). They provide secondary treatment in three ways; filtration, chemical sorption, and assimilation (**Table 2.6**). One of the oldest methods of wastewater treatment known, sand filtration, if properly designed, operated, and constructed, produces high quality effluents. During construction, engineers often bury sand filters partially or completely in the ground but may build them above the ground to avoid bedrock or a high water table. Open or subsurface sand filters are beds of granular materials, typically 24-36 inches deep and underlain by graded gravel and collecting tile or drainpipe. Some sand filter systems recirculate filter effluent through the filter using recirculation tanks. Wastewater treatment normally follows with disinfection (as required) prior to reuse or disposal to land or surface waters.

2.2.4.1. Various types of sand filters include single-pass sand filters, bottomless sand filters, and recirculating sand filters. While single-pass and bottomless sand filters are briefly reviewed in this chapter, the primary focus is on recirculating sand filters. Key selection factors for sand filters include those listed in **Table 2.7**. **Table 2.8** lists some advantages and disadvantages of sand filters.

2.2.4.2. Bottomless sand filters provide for specific low-flow applications (less than 800 gpd [3,000 Lpd]) and where a shallow water table and/or unlimited site area is not available for a conventional leach field. Secondary pretreatment may also be required after the septic tank.

2.2.4.3. Single-pass sand filters are also suitable for lower design flows and where nitrogen removal is not required. Single–pass sand filter designs may also be in a mound arrangement for direct discharge to the soil below. **Note:** Some kind of large particle separation may be required before effluent goes into sand filters. In this application, a separate area for leaching is not required. An example of this arrangement is in Technology Fact Sheet 10, *Intermittent Sand/Media Filters*, of EPA Manual 625/R-00/008.

Figure 2.7. Sand Filter.

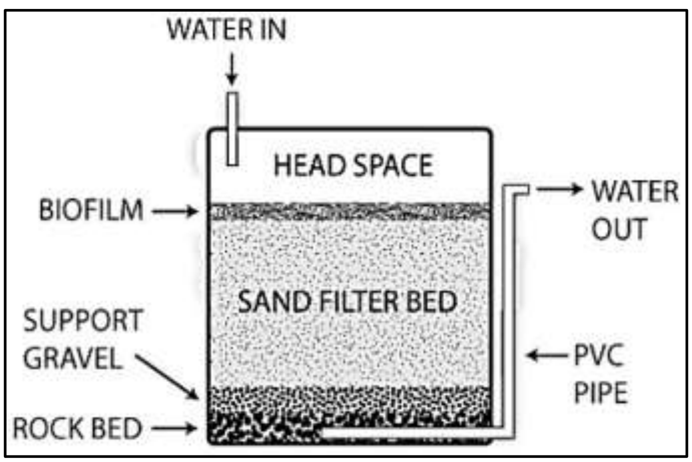


Table 2.6. Sand Filter Secondary Treatment Method.

Treatment	Process
Filtration	Particles are physically strained from the passing wastewater.
Chemical sorption	Contaminants stick to the surface of the sand and to biological growth on the sand surface.
Assimilation	Aerobic microbes consume the nutrients in the wastewater.

Table 2.7. Key Selection Factors for Sand Filters.

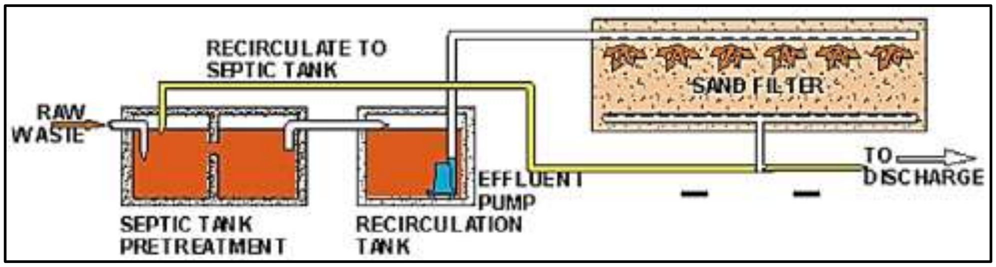
Key Selection Factors		
Flow range	< 1,000–15,000 gpd (< 3,800–56,800 Lpd).	
Treatment cost range	$65–$85 per gallon based on CONUS installation.	
Suitable site conditions	Available land supports a constructed buried system Discharge is usually to a leach field.	
Climate	Will function in most climates. Requires enclosure (covered and insulated) for extended winter conditions.	
Limiting factors	Available land area and suitability.	
O&M needs	Inspect media bed weekly, remove any weeds found. Check and adjust timer and controls quarterly. Check pump weekly and distribution system quarterly.	
Typical effluent quality (with disinfection)	BOD	< 10 mg/L
	TSS	< 15 mg/L
	TN	10–25 mg/L
	Fecal coliform	< 20 MPN/100 mL

Table 2.8. Sand Filter Advantages/Disadvantages.

Advantages	Disadvantages
High-quality effluent produced. Relatively simple to operate. Land requirements are minimal. No chemicals required. Easily accessible for O&M tasks. Flexibility in choice of media.	Recirculating sand filters are an effluent polishing method; pretreatment required. More operational interface is required than other small systems. Excavation and construction required. Power and controls are necessary to operate this process. Weekly monitoring of filter bed and pumps required. Regular maintenance necessary for good performance. If suitable media not available, local media cost can be high.

2.2.4.4. The recirculating sand filter is a high-performance process that requires a pretreated effluent and more O&M attention than other small systems. A power source is necessary for pumping. The basic components of recirculating sand filters include a recirculation/dosing tank, pump and controls, distribution piping network, filter bed with underdrain system, and a gravity return line back to the tank for mixing with septic tank effluent before reapplication to the filter (**Figure 2.8**).

Figure 2.8. Recirculating Sand Filter Process Flow Diagram.



2.2.5. Natural Land Treatment Systems. Natural land treatment refers to the application of pre-treated wastewater to the land at a controlled rate where physical, chemical, and biological processes treat the wastewater as it passes across or through the soil. Natural land treatment systems offer many advantages for small installations, especially if ample land is available and the location is isolated from inhabited areas. While there are several natural land treatment systems, principal methods include Rapid Infiltration and Overland Flow.

2.2.5.1. Normally, natural treatment systems are simple to operate, produces a high-quality effluent, but require a large amount of land. There are several types of treatment systems in the natural treatment system family. They include slow rate infiltration, overland flow systems, irrigation systems, infiltration basins, and constructed wetlands. Designers must precede these natural treatment systems with either fine screens or primary sedimentation, or both because the systems are not capable of treating raw sewage without pretreatment by these additional processes. For that reason, natural treatment systems could be a viable choice to follow a lagoon or septic system in an area that requires a high-quality effluent due to local environmental sensitivity requirements. **Table 2.9** lists the advantages and disadvantages of natural treatment systems.

Table 2.9. Advantages and Disadvantages of Natural Treatment Systems.

Advantages	Disadvantages
Expensive equipment not required. Highly trained personnel not required. Economical to construct and operate. Provides treatment superior to some conventional processes. Is well-adapted to temporary use. Adapts to changing loads. Low or no energy requirements. Provides wildlife habitat. Few solids disposal problems. Relatively trouble-free process when used correctly.	Pretreatment required. Requires a large area of land. Seasonal climate changes may affect the quality of treatment. May contaminate groundwater. May require influent storage capability when seasonal temperature variations slow or preclude treatment.

2.2.5.2. The rapid infiltration process involves collecting wastewater into a shallow infiltration basin (or spreading basin) above highly permeable soils so it can percolate and receive treatment (**Figure 2.9**). This method can treat a large amount of wastewater on a smaller plot of land, and the system is not climate-dependent, allowing the system to function year-round. Unlike facultative lagoons, continuous operation negates the need for long-term storage of untreated waste, which reduces the overall size of the system. However, units typically install multiple basins to allow resting between applications, especially during wet seasons. Key selection factors for rapid infiltration systems include those listed in **Table 2.10**. In addition, **Table 2.11** lists the main advantages and disadvantages of rapid infiltration systems.

Figure 2.9. Rapid Infiltration.

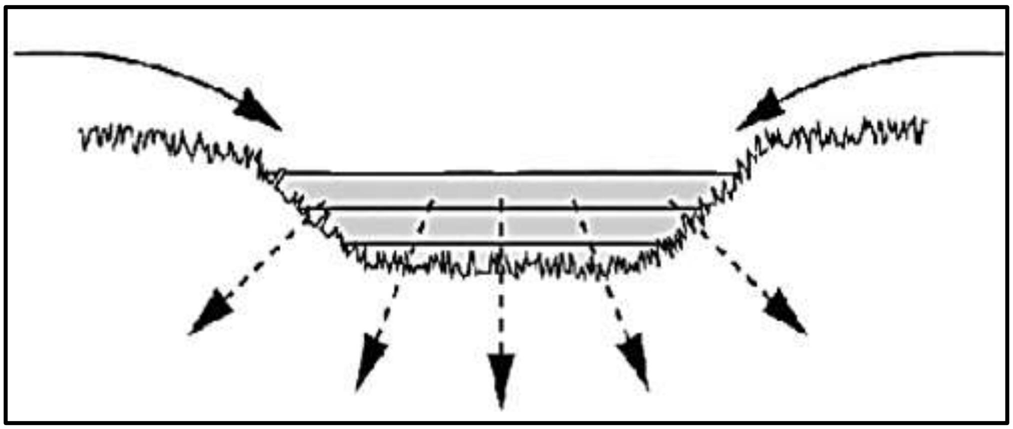


Table 2.10. Key Selection Factors for Rapid Infiltration Systems.

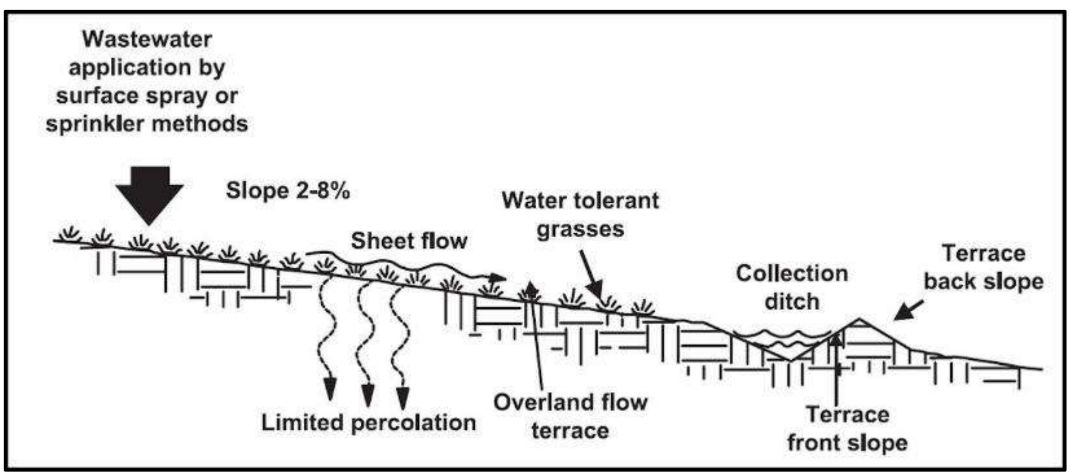
Key Selection Factors		
Flow range	< 1,000–15,000 gpd (< 3,800–56,800 Lpd).	
Treatment cost range	Not estimated.	
Suitable site conditions	Permeability of 1 inch/hour or better required. Multiple basins required. Soil depth to bedrock must be 10 feet or more.	
Climate	Can operate in freezing conditions, not adaptable to permafrost.	
Limiting factors	Available land area, coarse sand, and gravel beds not acceptable.	
O&M needs	Rotate basins every 5 to 12 days. Daily/weekly cleaning of bar screens.	
Typical effluent quality	BOD	10–30 mg/L
	TSS	10–30 mg/L
	TN	< 50 mg/L
	Fecal coliform	2 to 4 log removal

Table 2.11. Rapid Infiltration System Advantages and Disadvantages.

Advantages	Disadvantages
Uses less energy than most wastewater treatment methods. Cost-effective in areas where land is available and inexpensive. Simple to operate and maintain and generally requires only part-time staff attention. Efficient in cold climates. Can support nitrification/denitrification. Most rapid infiltration systems do not discharge an effluent to surface waters.	Rapid infiltration systems must be preceded by one or more pretreatment processes, including a bar screen or septic system. Less effective in heavy rain. Must have at least two operating basins. Requires more land than some other treatment methods. Soil clogging may generate odors. Infiltration cycles must be tracked and managed, including seasonal adjustments.

2.2.5.3. The overland flow treatment dispenses wastewater down a gradual, mainly impervious, grass-covered slope where it collects at the bottom and discharges back into the hydrologic cycle (**Figure 2.10**). The process requires little pretreatment outside of primary settling; however, it is a secondary or advanced treatment process. Treatment takes place in the top layer of soil and the bacteria and algae in the grasses help break down dissolved organics. The grasses will consume some nutrients; however, overland flow provides a lower degree of treatment for phosphorous and suspended solids than rapid infiltration.

Figure 2.10. Overland Flow Treatment.



2.2.5.3.1. Siting overland flow systems can be a challenge as the ideal impervious site is not always available. Identify a functional site early in the design process to confirm availability. **Table 2.12** lists key selection factors for overland flow treatment systems. Since these systems operate on a feed/dry cycle, at least two process trains are needed so one can be in use while the other rests (dries). This system is not a good choice in areas with high rainfall or extremely cold weather. It is also not appropriate in arid regions lacking natural vegetation. The overland flow system is generally lower in cost and has the added benefit of retaining 40 percent to 80 percent of the effluent within the watershed.

2.2.5.3.2. Consider selling grasses harvested from the flow slope as mulch or hay to offset costs. Another advantage of the overland flow system is its ability to run year-round; however, nitrogen removal reduces greatly in the winter. **Table 2.13** lists other advantages and disadvantages.

Table 2.12. Key Selection Factors for Overland Flow Treatment.

Key Selection Factors		
Flow range	< 1,000–15,000 gpd (< 3,800–56,800 Lpd).	
Treatment cost range	Not estimated.	
Suitable site conditions	Sloped land ideally 2% to 8% slope, up to 10% acceptable Low or semi-permeable soils desirable.	
Climate	Warm to moderate climate preferred. Temperatures above 30 °F recommended.	
Limiting factors	Available land area, suitability, mild climate. At least two trains required as the system uses a feed/dry cycle. Not effective during periods of heavy rain.	
O&M needs	Daily/weekly bar screen cleaning. Seasonal/annual vegetation "harvesting."	
Typical effluent quality	BOD	5–25 mg/L
	TSS	10–15 mg/L
	TN	10–25 mg/L
	Fecal coliform	Up to 90% removal

Table 2.13. Overland Flow Treatment Advantages and Disadvantages.

Advantages	Disadvantages
Uses less energy than most wastewater treatment methods. Cost-effective in areas where land is available and inexpensive. Simple to operate and maintain and generally require only part-time staff attention. Effluent can be suitable for irrigation. Crops can be supported, providing a source of revenue. Few odor issues.	Require more land than other treatment methods. Less efficient in cold climates. Not effective at removing phosphorus from wastewater. Overland flow systems must be preceded by one or more pretreatment processes, including a bar screen. Not effective in heavy rain or during "harvest" cycles. Two or more operating trains required.

2.2.6. Constructed Wetlands Treatment Systems. Using natural wetlands for wastewater treatment is not normally an option. However, it may be feasible to create and use constructed wetlands to emulate the benefits provided by natural wetlands. Typically, engineers design constructed wetlands treatment systems as a contained bed or channel filled with appropriate vegetation and uses it as a polishing treatment. These systems treat wastewater by passing it through the constructed wetlands. Engineers design the wetlands to recreate and enhance the natural physical, chemical, and biological processes specifically to treat municipal and industrial wastewater, and storm water runoff. Significant water quality improvements, including nutrient reduction is possible using this system. Constructed wetlands treatment is a cost-effective, low-maintenance treatment option that can continue in all but the coldest of climates. There is no sludge processing as treated bio solids can remain within the system. Unfortunately, constructed wetlands typically require large portions of land, and they will eventually become saturated with nutrients and other treatment byproducts. The performance of constructed wetlands depends upon a steady flow of debris-free wastewater. The treatment process is dependent upon vegetation growth, so the climate can affect its efficiency. While most vegetation can survive a freeze, treatment during colder times is not very effective and an alternate source of treatment or a storage method for influent is necessary. Key selection factors for constructed wetlands include those listed in **Table 2.14**. See **Table 2.15** for the main advantages and disadvantages of constructed wetlands. There are two types of constructed wetlands used to treat wastewater: free water surface (FWS) and subsurface flow (SF) wetland treatment systems.

2.2.6.1. FWS Treatment. The more commonly implemented systems are FWS, and occur mostly as marshes, but bogs and swamps are also used (**Figure 2.11**). The treatment process orients more around interaction with the vegetation. Water flows over the vegetation/soil to an outlet point. In some FWS, the water is disposed of via evapotranspiration and seepage into the wetland. The water surface in FWS systems is exposed to the atmosphere. As such, most FWS wetlands are accessible by humans and can be breeding grounds for mosquitoes.

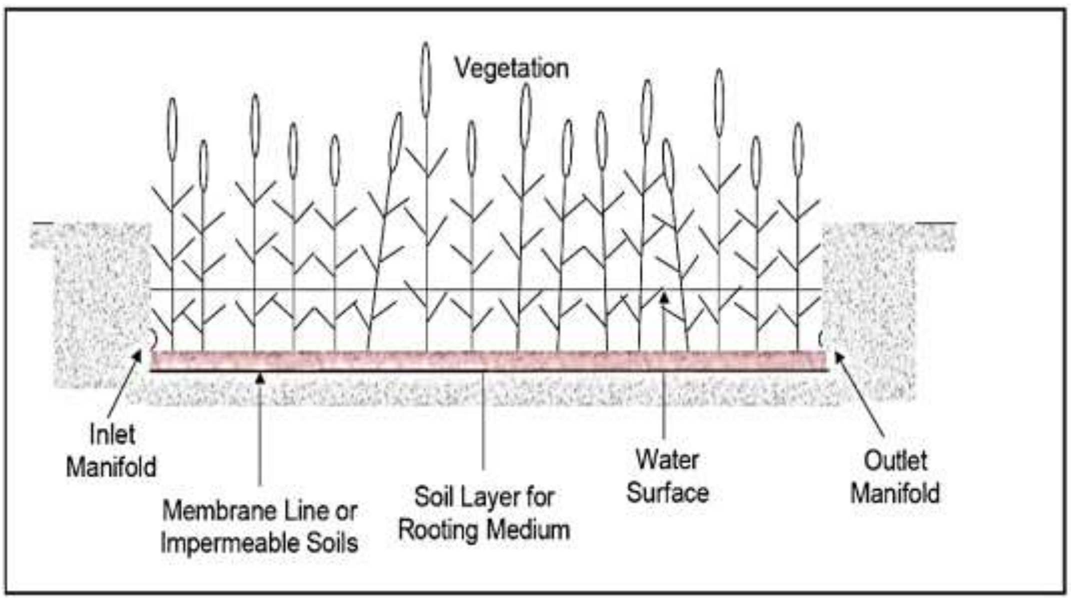
Table 2.14. Key Selection Factors for Constructed Wetlands.

Key Selection Factors		
Flow range	< 1,000–15,000 gpd (< 3,800–56,800 Lpd).	
Treatment cost range	Not estimated.	
Suitable site conditions	Flat to moderate grade, non-forested. Low permeable soils or liner desirable.	
Climate	Warm to moderate climate preferred (FWS) Temperatures above 30 °F recommended.	
Limiting factors	Land cost/availability.	
O&M needs	Periodic vegetation harvesting required.	
Typical effluent quality	BOD	< 20 mg/L
	TSS	< 20 mg/l
	TN	< 10 mg/L
	Fecal coliform	2 to 3 log reduction

Table 2.15. Constructed Wetlands Treatment Advantages/Disadvantages.

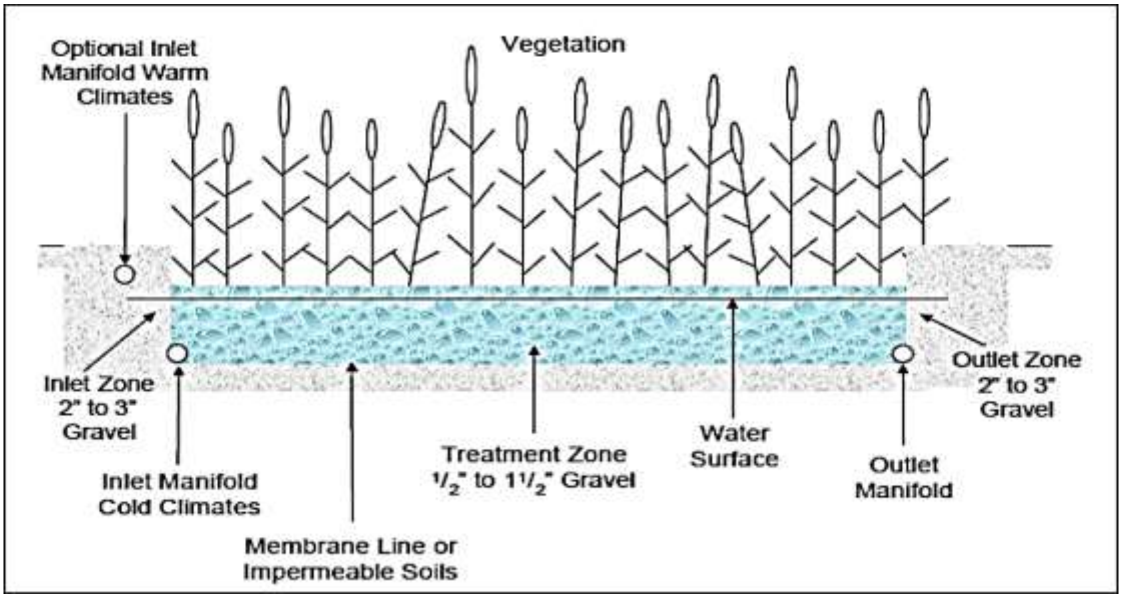
Advantages	Disadvantages
Uses less energy than most wastewater treatment methods. Cost-effective in areas where land is available and inexpensive. Effective at removing disease-causing organisms (pathogens) from wastewater. Can provide habitat for wildlife. Simple to operate and maintain and generally require only part-time staff attention. Effluent can be suitable for irrigation.	Require more land than other treatment methods. Less efficient in cold climates. If not properly maintained, FWS wetlands can attract mosquitoes and other insects. BOD loading is limited to 100–60 lbs/acre/day. Not effective at removing phosphorus from wastewater. Constructed wetlands must be preceded by one or more pretreatment processes including a bar screen; considered more of a treatment polisher or limited and small treatment.

Figure 2.11. Free Water Surface Wetlands Treatment.



2.2.6.2. SF Treatment. In a SF system, treatment takes place both on the surface of the media and in the roots of the vegetation growing in the media. Use a gravel-based media inside a lined or impervious channel. Marsh-like vegetation anchors itself in the media and operators raise the wastewater level to just below the top of the media. Keeping the water level below the top of the media is an effective method for preventing mosquitoes and provides a barrier against human contact with raw wastewater. **Figure 2.12** depicts a SF wetland treatment.

Figure 2.12. Subsurface Flow Wetlands Treatment.



2.2.7. Commercial Process Systems. For onsite wastewater management requiring advanced treatment beyond the conventional septic tank and leach field, many commercial systems offer an alternative to the recirculating sand filter design, considered the generic advanced treatment design. The popularity of these commercial systems is because for the same design flow, the process tanks typically require a smaller footprint than the recirculating sand filter design and tank installation can be below grade, which can be advantageous when space is at a premium. Legal, operational, or practical factors might limit selection of commercial system alternatives. These systems incorporate the advances made in municipal processes and apply them to a smaller-scale system. While most are simple adaptations, many include proprietary features and are trade name-protected

2.2.7.1. Systems Availability. The following are some of the available commercial systems capable of meeting a discharge effluent limit of 30 mg/L TSS, 30 mg/L BOD, and 25 mg/L total nitrogen. Some reliably provide nitrogen reduction to below 10 mg/L where necessary, but often require soda ash for alkalinity adjustment and a carbon source for the denitrification conversion necessary to reach that low value. Fecal coliform removals can also be achieved with disinfection.

2.2.7.1.1. Packed Bed Filter System. Packed bed filter systems are similar to recirculating sand filters. However, rather than sand, the system utilizes a lightweight textile media with a large surface area. The system can provide equivalent treatment to that of a sand filter loaded at rates of 25 to 50 gpd/ft^2 (1,020 to 2,040 Lpd/m2). After flowing into the processing tank, sewage separates into scum, sludge, and liquid effluent. The effluent flows into the filter media pod where microorganisms growing on the synthetic textile sheets remove impurities. After passing through the tank and the packed bed filter, the effluent discharges to the leach field for further treatment prior to groundwater integration.

2.2.7.1.2. Biological Nutrient Removal (BNR). Some BNR systems utilize a submerged attached growth bioreactor that operates in batch mode. This type of unit has a deep bed sand filter designed for the removal of soluble organic matter, nitrogen, and suspended solids within a single reactor. In addition to the deep bed sand filters, the system also contains an anoxic/equalization tank that serves as a primary clarifier ahead of the bioreactor. This bioreactor is mixed but not aerated to encourage denitrification of the recycled flows from the reactor. Within the reactor, the sand media functions as a filter and provides the surface area for maintaining the attached growth biomass. Recycle pumps and air compressors maintain the desired aerobic and anoxic process conditions at various batch stages.

2.2.7.1.3. Aerobic Nitrogen Reduction. Aerobic nitrogen reduction systems use the natural settling process that takes place before the wastewater moves into the activated sludge treatment module. Introducing oxygen facilitates mixing through the media channel. After cleansing by the microbes in the media channel, effluent typically discharges to a leach field for groundwater disposal.

2.2.7.1.4. Biofilter Systems. The biofilter system includes a synthetic, absorbent filter medium configured as a free draining, attached-growth, biological trickling filter. The engineered filter medium creates an environment that encourages microbial attachment that simultaneously provides aerobic, anaerobic, and anoxic environments for biological treatment, without air compressors and their high-energy use. Biofilters are appropriate for cold regions. This effluent typically discharges to a leach field for groundwater disposal.

2.2.7.1.5. Membrane Bioreactor (MBR) Systems. Recent technical innovation and significant membrane cost reductions have pushed MBRs to become an established process option to treat wastewater. The MBR process is also capable of enhanced wastewater treatment where effluent reuse may be a goal. The MBR process consists of a suspended growth biological reactor integrated with an ultrafiltration membrane system, using hollow fiber membranes. Essentially, the ultrafiltration system replaces the solids-separation function of secondary clarifiers and sand filters in a conventional activated sludge system, producing a high-quality effluent, simplifying operation, and greatly reducing space requirements.

2.2.7.1.6. Extended Aeration. 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 provided by aeration or mechanical means maintains the microbial organisms in contact with the dissolved organics. Basically, the extended aeration process includes the following components: bar screen, aeration chamber, clarifier chamber, and recycling. The effluent can be disinfected and capable of meeting reuse quality. The extended aeration or aerobic bioreactor system is not a proprietary process; however, many manufacturers trademark their package system.

2.2.7.2. Package Plants. Small installations have several options available for wastewater treatment. They may utilize the wastewater systems of neighboring communities, when possible. If permitted, they may install soil absorption systems. If sufficient land area is available, they may construct stabilization ponds. However, if none of these options are available, several types of commercially available wastewater treatment package plants should meet their needs. The term "package" as applied to wastewater treatment plants usually means a compact, relatively simple to operate unit designed to give complete treatment to the wastewater from a small community. **Figure 2.13** illustrates some aboveground and belowground package plants for wastewater treatment.

Figure 2.13. Various Package Plants.

2.2.7.2.1. Most package plants currently being used employ a modification of the activated sludge process. The conventional activated-sludge plant aerates settled wastewater and return activated sludge at a mixed-liquor suspended solids concentration of about 2000 milligrams per liter for about 6 hours. The activated sludge is then settled in a secondary settling tank. Return sludge amounting to about 25 percent of the influent flow is recycled ahead of the aeration tank. The remainder of the activated sludge is wasted. The modifications to the activated sludge process that are used for package plants are the extended aeration process and the contact stabilization process.

2.2.7.2.2. These systems have potential advantages over some "natural" alternatives in that they can provide a high-quality effluent, and they are generally very land-efficient. Disadvantages include the need for close skilled operator supervision, high maintenance requirements, and high- power consumption compared to natural wastewater treatment systems. The key selection factors in **Table 2.16** and additional advantages and disadvantages listed in **Table 2.17** are generic to all package plants.

Table 2.16. Key Selection Factors for Commercial Package Plants.

Key Selection Factors		
Flow range	3,000–15,000 gpd (11,350–56,800 Lpd).	
Treatment cost range	\$150–\$200 per gallon based on CONUS installation.	
Suitable site conditions	Available land supports a constructed system. Discharge can be to a leach field or surface waters.	
Climate	Will function in any climate except extreme Arctic conditions.	
Limiting factors	Cost, licensed operator availability, and suitability.	
O&M needs	Inspect process tanks and equipment weekly. Check and adjust timer and controls quarterly. Check pump weekly and distribution system quarterly. Refer to manufacturer's O&M manual regularly.	
Typical effluent quality (with disinfection)	BOD	30 mg/L or less
	TSS	30 mg/L or less
	TN	< 25 mg/L
	Fecal coliform	< 2 to 12.5 MPN/100mL

Table 2.17. Commercial Package Plants Advantages/Disadvantages.

Advantages	Disadvantages
High-quality effluent produced. Relatively simple to operate. Land requirements are minimal. Chemicals usually not required. Easily accessible for O&M tasks. Flexibility in choice of processes.	Pretreatment required to remove large floatables. More operational interface is required than other small systems. Site preparation and some construction required. Power and controls necessary to operate these processes. Daily monitoring of process/equipment is required. Regular maintenance necessary for good performance. Shipping costs to remote locations can be high. Vendor support may be limited outside CONUS.

2.2.8. Disinfection. Disinfection is the inactivation of disease-causing organisms. Disinfection occurs after primary or secondary treatment by an onsite wastewater treatment system. There are several methods of disinfection, but two of the systems—ultraviolet (UV) and chlorine disinfection—are the most likely to be used with a simple onsite wastewater disposal system. The need for disinfection will depend on applicable requirements (e.g., international agreement, DoD, operational chain of command), proximity to environmentally sensitive areas and drinking water supplies, and type of discharge (groundwater vs. surface water). Generally, surface water discharge is more likely to require disinfection. Chemical disinfection is undesirable in instances where the chemical residual would harm beneficial microbes. For example, do not use chemical disinfection in conjunction with a septic tank and leach field. The residual chemical will harm the organisms responsible for treatment in the soil biomat.

2.2.8.1. UV Disinfection. Generally, UV disinfection is more appropriate for commercial package wastewater treatment units due to its specific influent and O&M requirements. UV disinfection involves exposing wastewater to UV light. The UV light penetrates pathogenic organisms' cells and breaks up their genetic material, making it impossible for them to reproduce or sustain life. Use UV disinfection only when designed to work with the preceding wastewater treatment system, e.g., a commercial package system specifically designed for UV disinfection. **Table 2.18** list advantages and disadvantages of UV disinfection.

Table 2.18. UV Disinfection Advantages/Disadvantages.

Advantages	Disadvantages
No danger of overdosing. No smell. Short contact time. Does not require hazardous material storage. Minimal space requirements. Relatively insensitive to temperature and pH (acidity or alkalinity) fluctuations. Will not cause any byproducts or residuals to be discharged to the environment.	Higher energy requirements compared to chemical disinfection. Cannot be used when wastewater has high levels of suspended solids, turbidity, color, or soluble organics. Replacement parts may not be available in remote locations. Requires a higher level of design precision. Requires a relatively high level of operator skill.

2.2.8.2. Chlorine Disinfection. 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. Common chlorine-containing disinfection products include chlorine gas, 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. Of these, tablet (solid) chlorination is the most common option selected for small onsite wastewater disposal systems that require disinfection. Liquid bleach should also be considered as suitable for some locations. **Table 2.19** list advantages and disadvantages of chlorine disinfection.

Table 2.19. Chlorine Disinfection Advantages/Disadvantages.

Advantages	Disadvantages
Chlorine is reliable and effective against a wide spectrum of pathogenic organisms. Chlorine is more cost-effective than UV disinfection. Chlorine residual in wastewater effluent prolongs disinfection after initial treatment. Chlorine residual can be measured to evaluate effectiveness. Dosing rates are flexible and can be controlled easily.	Chlorine is highly corrosive and toxic, special storage and handling required. Chlorine residuals are toxic to aquatic life, dechlorination may be necessary before surface discharge. Chlorine reacts with certain organic matter in wastewater, creating hazardous compounds. Wastewater with high BOD concentration may require higher chlorine doses for adequate disinfection, creating hazardous disinfectant by-products such as harmful compounds and gases, and possible corrosive water. (consult with bioenvironmental engineers)

2.2.8.2.1. Calcium hypochlorite is added by immersing chlorine tablets in the wastewater using a tablet chlorinator. As illustrated in **Figure 2.14** and **Figure 2.15**, a typical calcium hypochlorite tablet chlorinator or tablet disinfection system usually include the items listed below. Wastewater flows through the contact basin and erodes the tablets at a predictable rate based on the amount of water flowing through the basin. An accurate chlorine dosage can be achieved by controlling the water flow rate through the chlorinator.

- A PVC tube to dispense tablets, generally by gravity.
- A contact chamber where the wastewater comes into contact with the tablets.
- A storage reservoir where the disinfected water is retained before discharge.

2.2.8.2.2. Disinfection with liquid bleach can range from sophisticated installations using metering pumps to simple, manual addition of the chemical. Where metering pumps are used, design the pump to withstand the corrosive effect of liquid bleach. Additionally, adjust the pump to meter the appropriate amount of the chemical based on flow; this may require flow meters with instrumentation and a control system. The system should be designed by a registered professional engineer. Manual bleach addition occurs only when no other resource is available. The operator may pour bleach into a wet well of wastewater and allow mixing and contact time. Generally, 15 minutes of contact with 0.2 mg/L of bleach is adequate for disinfection. The operator determines the concentration of liquid bleach for the volume of liquid, and meter out the appropriate amount to achieve disinfection. Take care when handling liquid bleach—it is corrosive and damaging to the skin and eyes. Additionally, its vapors are corrosive to metals; metal objects generally are not stored in the same room as liquid bleach. Recommend well ventilating liquid bleach storage areas. Since liquid bleach is more volatile and may present complex storage and handling requirements, the best option may be to use tablet chlorination/dechlorination, with very few exceptions.

Figure 2.14. Tablet Chlorinator Detail.

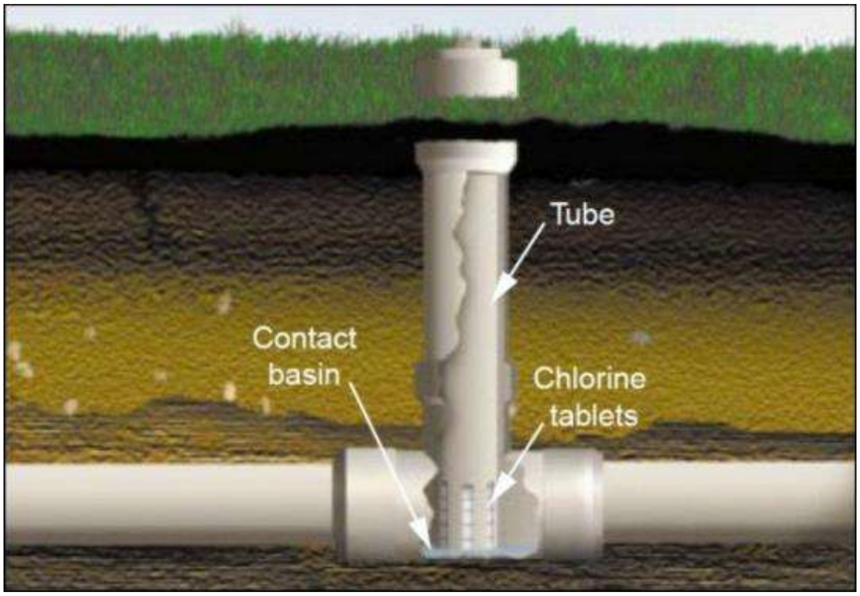
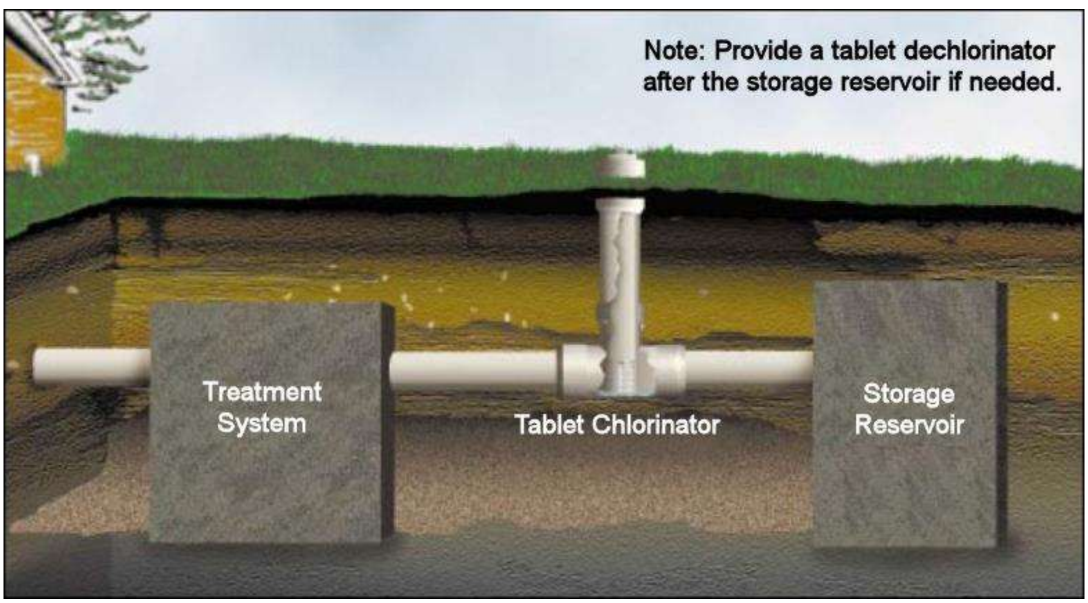


Figure 2.15. Tablet Disinfection System.



2.2.9. Commercial Systems Selection and Purchase. Unified Facilities Criteria (UFC) 3-240-01, *Wastewater Collection and Treatment*, offers basic guidelines for selection of wastewater treatment processes. Treatment system selection and design should be determined by feasibility studies, considering all engineering, economic, energy, and environmental factors. Address special considerations for tropics/semiarid and cold/arctic locations outside the U.S. All legitimate alternatives should be identified and evaluated by life cycle cost analyses. As noted, there are several alternatives available for consideration. Use specifications prepared by AFCEC or its consultant for selecting materials and equipment for construction of each system as appropriate. Many systems are deliverable as a single package for installation with limited pre-construction; however, site preparation, including a leveling pad or foundation, is a minimum requirement. The manufacturer or supplier also provides guidelines for system installation and testing. Order specialty treatment equipment with all O&M manuals, including troubleshooting guides.

2.2.9.1. Commercial treatment systems are typically proprietary systems purchased from a single supplier and delivered as a unit, which may require some assembly and site preparation prior to delivery. There is no common requirement for operating a proprietary system as each supplier has their own unique requirements. Commercial treatment systems come in several process types; some are designed to achieve advanced treatment for surface water discharge, whereas other systems are intended as an add-on to a conventional septic system intended for subsurface discharge of the final effluent.

2.2.9.2. When working with consultants or designers, consider that these professionals are most comfortable with technologies they are familiar with already. For this reason, it is useful to get more than one estimate or opinion with written justification why their recommendations are the most appropriate for the site and unit needs. Each system type has its own merits. Evaluating different methods and manufacturers can be a daunting task even for experienced system designers. Selecting a package plant for use at a semi-permanent deployment location would likely be an option when the site is not well suited for more conventional treatment methods like septic systems or lagoons or if advanced treatment is required due to local conditions or regulations. The person charged with the task of selecting a technology and its fabricator needs to consider several factors, some include:

- Discharge quality requirements
- Site-related issues
- Constructability
- Purchase cost, including shipping
- Installation and O&M costs
- O&M frequency and staffing requirements
- Power requirements and availability
- Availability of operating supplies (e.g., lubricants, chemicals)

2.2.9.3. The checklists in **Table 2.20** through **Table 2.24** outlines additional parameters to consider prior to selecting a commercial package plant and vendor. Lifecycle costs should be an important consideration. While some technologies may have a lower initial capital cost, they may also have a high O&M cost. Cost estimates also include electricity and the cost of spare parts over the lifecycle of the facility. See **Table 2.24** for a sample evaluation of a lifecycle cost analysis. Comparing the total costs for all of the technologies under consideration, assuming a 20-year period multiplier for the annual O&M costs, should yield a true picture of the total cost of each system under consideration.

Table 2.20. Process Factors to Consider.

Process Factors	✓
WWTF process is appropriate for wastewater flows and generated loads	
WWTF effluent quality will meet established standards	
Ease of installation and future repairs	
Ease of operation	
Maintenance requirements and frequency	
Component lifecycle	
Are special lubricants or chemicals required? Are they locally available?	
Constructability: Are suitable contractors locally available?	
Will the WWTF be affected by climate conditions?	
Verify additional guidance per the country's Final Governing Standards (FGS) if the country you are in has established them	

Table 2.21. Site Considerations Checklist.

Site Considerations	✓
Consider the available area and location within the deployment site	
Proximity to drinking water wells	
Proximity to surface water and wetlands	
Investigate permitting requirements	
Adequate space to facilitate installation and repairs	
Ease of access for service, delivery, and maintenance vehicles	
Existing obstacles: Boulders, structures, wildlife migration route	
Drainage pattern	
Ease of any required excavation	
Potential for flooding	
Snow-removal issues, if applicable	
Potential facility appearance issues if there are concerned site abutters	

Table 2.22. Cost Considerations Checklist.

Cost Considerations	✓
Design fees by engineering consultant, including detailed site plan and performance specifications for a complete system	
Purchase cost of the complete WWTF that meets the required permits and warranties specified	

Shipping and delivery cost of the WWTF and all required materials and equipment	
Installation costs, including equipment and personnel. Equipment supplier may provide separate contract for installation, start-up, and training of local operator	
O&M costs, including chemical and materials, labor, special personnel, and sludge disposal	
Monitoring costs, lab facilities required for testing	

Table 2.23. WWTF Experience and Reliability of Manufacturer Checklist.

WWTF Experience and Reliability of Manufacturer	✓
Manufacturer's experience with the selected process and design parameters.	
Installation list with references to contact.	
Performance data from similar established installations.	
Manufacturer's experience with military installations.	
Technical assistance; personnel proximity or Internet availability.	

Table 2.24. Lifecycle Cost Analysis.

Treatment Option	Design and Installation	Annual Operation	Total Cost
Technology A	X	Y	X + (Y x 20)
Technology B	Z	U	Z + (U x 20)

2.2.10. Cost Estimating. Planners responsible for estimating construction costs follow guidance in DAFI 32-1020, *Planning and Programming Built Infrastructure Project*, and AFI 32-1023, *Designing and Constructing Military Construction Projects*, when making cost estimates for supporting facilities, including wastewater treatment plants. Be sure to consider initial construction, overhead, and life-cycle costs for each alternative treatment system. Construction costs for onsite treatment systems at overseas contingency locations can vary widely depending on the treatment system selected. First, consider a conventional septic system for its simplicity and cost efficiencies. Consider alternatives only when site conditions or environmental factors warrant the additional expense and complexity.

2.2.10.1. Depending on the location, it is likely that additional costs could be a factor at an overseas deployment location. The most likely factor in increased cost is the availability of materials and equipment and the need to transport these process elements to the site. Materials and simple equipment used in basic treatment systems should be available at many contingency locations, and many wastewater-related equipment and supply items are available worldwide. However, costs for many equipment items and specialty devices may vary significantly based on the location of the supply source, its proximity to the deployment site, and delivery to the deployment site.

2.2.10.2. Additional costs associated with installation at a foreign deployment site are unique for each installation and must be determined on a case-by-case basis. When projecting a WWTF for an existing deployment site or a site with significant intelligence on local conditions and commercial access to equipment and supplies, it may be a good idea to do some pre-planning and cost estimating. However, it is difficult to prepare accurate cost estimates for a new deployment site until the following factors are considered.

2.2.10.2.1. Availability and purchase cost of materials and process equipment:

- Does the location have access to piping and concrete suppliers?
- Can the site provide adequate materials for back-fill and grading?

2.2.10.2.2. Delivered cost of materials and equipment to the deployment site:

- Is delivery limited to air shipment?
- Is weight and size of process equipment a limiting factor?

2.2.10.2.3. Site preparation and utility requirements:

- Is power required for pumping or process equipment?
- Is water required for O&M of process equipment?

2.2.10.2.4. Installation costs, including labor and equipment:

- Is construction equipment available at the site?
- Can a local contractor be hired for installation?

2.2.10.2.5. Expertise required for installation and start-up:

- Lower-complexity WWTF requires minimal expertise—likely by Air Force personnel.
- Commercial systems require professional assistance—additional cost for services.

2.2.10.2.6. Available personnel/operator qualified for WWTF O&M (for remote locations with commercial systems, recommend an onsite operator):

- Commercial systems will require onsite qualified licensed operator.
- On-line or web-based assistance may be available to the operator for additional troubleshooting.
- On-line monitoring connection by a supplier is not likely available to military deployment sites.

2.3. Site Screening Factors. The site-screening checklist at **Table 2.25** lists initial planning factors to establish baseline conditions for deployment sites and identify potential limiting factors. The checklist can help evaluators identify limitations that may exclude certain alternatives and thus reduce the number of alternatives left for consideration.

Table 2.25. Site-Screening Factors Checklist.

Location Information – General	✓
Geographical conditions.	
Climate, temperature range.	
Potential for extreme environmental conditions.	
Access for service, delivery and maintenance vehicles.	
Regulatory requirements regarding environmental protection.	
Deployment Site Statistics	✓
Number of personnel assigned (short-term and long-term).	
Staff expertise in WWTF design and operation and maintenance (O&M).	
Site boundaries/limitations.	
Available space for proposed WWTF.	
Capital funding available for WWTF installation.	
Long-term funding available for annual O&M costs.	
Available water supply sources.	

2.4. WWTF Selection Process. The goal of process selection for wastewater management is to gain maximum feasible compliance for the protection of health, safety, and the environment. Consider using the WWTF selection factors in **Table 2.26** to help guide the selection process for a suitable, practical, and sustainable plan at each site. The following paragraphs and the WWTF Planning and Selection Matrix at **Attachment 3**, further addresses these selection factors. The matrix is a visual aid addressing recommended steps for developing a wastewater plan for a site based on available site information and guidance documents. It is usable throughout this publication as a systematic decision tree for the process of evaluating, screening, selecting, designing, and constructing a WWTF that meets the needs of the deployment site while considering many important factors.

Table 2.26. WWTF Selection Checklists.

Establish Design Conditions for WWTF	✓
Estimate design flow based on expected water use and population.	
Estimate wastewater characteristics and loading factors.	
Identify potential peaking factors.	
Establish water quality discharge requirements based on regulations and/or local limitations.	
Identify water supply source type and location.	

Evaluate Site Characteristics	✓
Review available soil data from published sources.	
Survey site for ledge, surface waters, wetlands.	
Check site slopes for support of gravity flow transmission.	
Consider natural drainage and potential flooding issues.	
Conduct onsite testing to establish detailed soil conditions.	
Identify whether discharge will be to groundwater or surface water.	
Screen Treatment Alternatives	✓
Consider only those that can meet site needs and limitations.	
Compare alternatives based on required onsite arrangement.	
Consider package systems if no onsite alternatives are possible.	
Select Alternative and Arrangement, Considering	✓
Ease of installation.	
Level of complexity/simplicity.	
Reliability of WWTF to meet treatment needs.	
Maintenance requirements.	
Available personnel for O&M.	
Removal and management of residuals.	
Design Selected Alternative	✓
Verify sizing and performance expectations.	
Identify special circumstances to consider (e.g., does grade/slope require pumping or transport within the site?).	
Layout proposed arrangement for the site.	
Follow procedures outlined in this publication for each component.	

2.5. Wastewater Flow and Characteristics. Wastewater characteristics vary throughout the world. For wastewater treatment process design, determining the flow rate and mass loading variations are important in sizing certain unit processes. An adequate determination of waste characteristics is best made from existing sampling data (if available) or based on a similar deployment site. In lieu of available data, make estimates based on water supply and consumption records. The physical, chemical, and biological characteristics of wastewater can also vary at each site based on several factors, including established habits of community personnel that cause hourly, daily, and weekly variations, seasonal conditions, and changes in water supply sources.

2.5.1. Wastewater Estimates. Sanitary flows vary based on the source, water consumption, and site-specific conditions. As shown in **Table 2.27**, wastewater projections for deployed locations are significantly lower than typical U.S. locations where water supply is readily available, not typically restricted, and of consistently good quality.

Table 2.27. Wastewater Flow Estimates.

Site Personnel (Number of Staff)	**Estimated Wastewater Generated at Deployed Locations Using:**		**Typical Wastewater Generated for U.S. Locations**
	BEAR*	**Fixed Water Plant**	
	19.7 gpcd[1] (74.6 Lpcd)	**42.7 gpcd[1] (162 Lpcd)**	**60 gpcd (227 Lpcd)**
30	591 (2,237)	1,280 (4,850)	1,800 (6,810)
100	1,970 (7,457)	4,270 (16,163)	7,000 (26,500)
150	2,955 (11,185)	6,405 (24,245)	10,500 (39,750)
200	3,940 (14,914)	8,540 (32,327)	14,000 (53,000)
250	4,925 (18,643)	10,675 (40,410)	15,000 (56,780)
Note 1. Basis for totals:	gpcd (Lpcd)	gpcd (Lpcd)	
Latrine	7.7 (29)	7.7 (29)	
Showers	5.0 (19)	15.0 (57)	
Food preparation	4.0 (15)	5.0 (19)	
Hospital	1.0 (3.8)	1.0 (3.8)	
Laundry	2.0 (7.6)	14.0 (53)	* Basic Expeditionary Airfield Resources
Total	**19.7 (74.6)**	**42.7 (162)**	

2.5.1.1. As identified in AFPAM 10-219V5, *Bare Base Conceptual Planning*, an estimated 19.7 gallons per capita per day (gpcd) (74.6 liters per capita per day [Lpcd]) of wastewater is generated from an average potable water supply of 30 gpcd using mobile water system assets. Where non-mobile (fixed water treatment plants) water assets are available, typical water consumption is 60 gpcd (227 Lpcd), which generates an estimated 42.7 gpcd (162 Lpcd) of wastewater flow.

2.5.1.2. In contrast to mobile water system assets, the typical U.S. wastewater flow values are an estimated 60 gpcd (227 Lpcd). The water use difference may also affect the relative wastewater characteristics with respect to pollutant loading and design adjustments may be necessary.

2.5.2. Wastewater Characteristics. It is important to note that water resources are usually limited at contingency locations, and therefore units will take conservation measures to mitigate the shortages. These results in higher BOD loading rates per volume or flow compared to non-contingency locations as shown in **Table 2.28**. Designing for the appropriate BOD loading rate and ambient temperature is key to achieving desired levels of treatment.

Table 2.28. Untreated Domestic Wastewater Characteristics.

Selected Parameter	Units	Typical Range[1]	Deployed – Adjusted[2]	
			19.7 gpcd (74.6 Lpcd)	42.7 gpcd (162 Lpcd)
Solids, total (TS)	mg/L	390–1,230	-	-
Dissolved, total (TDS)	mg/L	270–860	-	-
Suspended solids, total (TSS)	mg/L	120–400	800	600
BOD 5-day (BOD_5)	mg/L	110–350	550	450
Chemical oxygen demand (COD)	mg/L	250–800	1,200	1,000
Nitrogen (total as N)	mg/L	20–70	80	70
Organic	mg/L	8–25	40	30
Ammonia as N	mg/L	12–45	80	50
Nitrites as NO-2	mg/L	0	0	0
Nitrites as NO-3	mg/L	0	0	0
Phosphorus (total as P)	mg/L	4–12	15	12
Volatile organic compounds (VOC)	ug/L	100–400+	400	400
Total coliform[3]	cfu/100 mL	10^6 - 10^{10}	10^7 - 10^{10}	10^7 - 10^{10}
Fecal coliform	cfu/100 mL	10^3 - 10^8	10^5 – 10^8	10^5 - 10^8

Notes:
1. Range indicated is based on wastewater flow rate of 60 to 200 gpcd (227 to 757 Lpcd) for CONUS collection systems.
2. Adjusted values for the Air Force based on flow rates identified in AFPAM 10-219V5.
3. cfu/100 mL = colony-forming units per 100 milliliters.

Source: Adopted in part from Metcalf & Eddy, *Wastewater Engineering, Treatment and Reuse, 3rd Edition McGraw-Hill 2003.*

2.5.2.1. Another important concern to address is chemical wastes in wastewater. In general, the treatment alternatives listed in this publication are for biological wastes (e.g., human waste, hand wash-water). Disposing of chemicals in the wastewater treatment process will inhibit treatment and damage the process. The most notable chemicals are those used in portable toilets or chemical toilets. If these types of toilets are widely used, it is advisable to use commercial package plants designed to handle that type of waste.

2.5.2.2. Unfortunately, there are no typical values for wastewater because it varies so much and depends on many factors. The summary of cited values in **Table 2.28** above is based on a review of published data. From this starting point, estimated values reflect expected concentrations for two deployment site conditions: one where the water supply is limited to mobile sources; the other where the water supply is permanent, such as an onsite well or a connection to a nearby water supply.

2.5.3. Water Quality Standards Applicable to Stream or Surface Water Discharge. Units must review regulatory requirements mandated by international agreement, DoD policy, or combatant command (command authority) (COCOM)/operational chain of command when considering options and selecting the wastewater treatment design that best meets the needs of the site. In the U.S., individual states impose stringent limits for nitrogen and phosphorus to limit nutrient loading on local streams and harbors. The same concerns may exist at a contingency location and units may have to consider the potential use of a surface water discharge at their deployment site. Typically, units do not pursue surface water and/or stream discharges for onsite systems; instead, groundwater recharge is encouraged through leach field effluent disposal. In situations where a leach field is not possible or feasible, pretreatment before discharging to surface waters would require one of the advanced treatment methods addressed in **Chapter 3**, with an additional requirement for disinfection. Another alternative to consider would be a non-discharging lagoon system, depending on the size of the deployment site and population generating the wastewater.

2.5.4. Water Quality Standards Applicable to Subsurface/Groundwater Discharge. The focus of this publication is for WWTFs intended to serve contingency locations staffed with 30 to 250 personnel. For this size facility, the estimated flow ranges from less than 1,000 gpd (3,790 Lpd) up to 10,000 gpd (37,850 Lpd), for a site with non-mobile water supplies and much lower design flows for sites served with mobile water supplies. In this range, onsite systems with groundwater discharge are often the most simple, expedient, long-term management plan. However, always review MAJCOM or CCMD guidance for specific requirements onsite WWTF systems.

2.5.4.1. Studies have shown that conventional septic treatment and leaching systems achieve high removal rates for most pollutants of concern. Soil filtration through the biomat effectively removes biochemical oxygen demand, suspended solids, fecal coliform, and ammonia nitrogen. The aerobic subsoil and high temperatures also reduces viruses and effectively treats toxic organics. However, nitrate generated from ammonia conversion is highly soluble and passes through to the groundwater. Because of their solubility, chlorides also pass through to the groundwater.

2.5.4.2. **Table 2.29** presents the recommended effluent water quality under various site conditions, including protective zones for water supply wells or other nitrogen-sensitive areas. In general, the estimated water quality at the point where the leach field effluent meets the groundwater typically includes 50 mg/L BOD, 50 mg/L TSS, and 45 mg/L total nitrogen. As shown in **Table 2.30**, the conventional septic system meets these limits for lower flows. Where additional nitrogen reduction requires denitrification to meet sensitive groundwater conditions, consider advanced treatment such as a recirculating sand filter or a commercially available alternative treatment system described elsewhere in this publication. These systems can reliably produce an effluent quality of 30 mg/L BOD and TSS, 25 mg/L total nitrogen to the leach field and are typically required for facilities treating higher wastewater flows, as indicated.

Table 2.29. Selected Effluent Quality Requirements.

Parameter	Units	EPA Ground Water Discharge Limits[1]			Surface Water Discharge Limits[3]
		<10,000 gpd	≥ 10,000 gpd	< 200 feet to well[2]	
BOD	mg/L	50	30	30	30
TSS	mg/L	50	30	30	30
TN	mg/L	45	25	10[3]	103
Fecal coliform[4]	cfu/100 mL	--	--	10	200

Notes:
1. In CONUS, these facilities are regulated by each state. These values reflect Massachusetts Regulation 310 CMR 15.000 issued under the Department of Environmental Protection.
2. Protective zones include close proximity to public water supply well or other nitrogen-sensitive area.
3. This value is based on EPA permits issued in CONUS in nitrogen-sensitive areas. Where local environmental conditions require, consider lower limits.
4. Fecal coliform is not typically regulated for groundwater discharge unless the location is in a protective zone of a public water supply well.

Table 2.30. Effluent Quality Comparison of Treatment Alternatives.

WWTF Description[1]	Typical Effluent Quality			Meets Requirements	
	BOD	TSS	TN	GW Discharge[2]	SW Discharge
Septic system (post leach field)	50	40	25	Yes	No
Facultative lagoon	20–50	30–80	10–30	Yes	Yes
Rapid infiltration system	10–30	10–30	< 50	Yes	Yes
Overland flow	< 25	< 15	< 25	Yes	Yes
Constructed wetland	< 25	< 25	10–25	Yes	Yes
Recirculating sand filter	< 10	< 15	10–25	Yes	Yes
Commercial package system	≤ 30	≤ 30	< 25	Yes	Yes

Notes: 1. All systems noted include a septic tank for pre-treatment.
2. Septic system meets EPA requirements for flows < 10,000 gpd (37,850 Lpd).

2.5.5. Characteristics of Receiving Site. Initially assess receiving site characteristics by performing a physical survey or reports from local representatives. Consider the climate, size of the site, physical features and restrictions, and security when reviewing alternatives. In addition, the personnel population, both initially and long-term for the deployment, may be a factor. Site requirements with respect to expected term for the deployment location, funding limitations for construction, and/or long-term O&M costs will be important factors in selecting an alternative. All these factors are critical to selecting a successful wastewater plan that addresses the needs of the deployment location in the most efficient and cost-effective manner. The WWTF Planning and Selection Matrix in **Attachment 3** identifies and qualifies key factors to consider that will facilitate a decision on the most appropriate system for a specific site. Consider the treatment alternatives described in previous sections of this chapter.

2.6. Site Evaluations. When reviewing WWTF alternatives for a particular location, evaluators often proceed in three phases, a preliminary review of documented site information, a reconnaissance of potential sites (preliminary site survey), and a detailed evaluation of the priority site or sites. Using this phased approach can help focus site evaluation efforts on only the most promising sites. The scale and detail of the evaluation depends on the anticipated amount of flow and quality of wastewater to be treated, the nature of local soils, the hydrogeological setting, and number of available sites, among other factors.

2.6.1. Review Documented Site Information. Evaluators usually conduct a preliminary review before performing fieldwork or site testing. The preliminary review examines key criteria, including climate, topography, geology, soil surveys, wastewater characteristics, surface water and groundwater risk factors, and general site conditions. The information may lack accuracy but is useful in identifying problems or features to investigate. Further, the preliminary review can help identify potential receiver sites, determine the most feasible receiving environments, identify potential design boundaries, and assist in developing a relative suitability ranking. More than one receiving environment might be feasible and available for use. Focusing the effort on the most promising receiving environments and receiver sites allows the evaluator to eliminate the least suitable sites early in the site evaluation process. For example, basic knowledge of the local climate might eliminate evaporation or evapotranspiration as a potential receiving environment immediately. While certain conditions may be beyond predictability, the preliminary review phase should provide an overview of key site conditions that help evaluators compare the feasibility of one alternative over another for a specific site or location.

2.6.1.1. Climate. Climate can affect the performance of certain wastewater treatment system alternatives, and extreme climate conditions will likely prohibit or reduce the available options for a specific site. Sites with extreme cold and/or permafrost conditions limit and challenge belowground construction of wastewater management facilities. Elsewhere, seasonal variations in temperature and precipitation usually will not be prohibitive for most alternatives. Other extreme conditions such as high temperatures, continuous heavy precipitation, or desert conditions must also be considered during design, but are also likely not prohibitive. The climate of a deployment location will influence site conditions, including soil and groundwater and surface water characteristics.

2.6.1.2. Topography and Geology. Consider site topography in siting sanitary and dining facility sources of wastewater with respect to the intended sites for treatment and disposal sites for the collected wastewater. Where possible, gravity flow will minimize the need for pumping equipment and simplify design and operations. Geology will directly affect the constructability of a wastewater treatment system and preferred location. Surface water features and water supply well locations will require protection from contamination and thus impose additional siting limitations.

2.6.1.3. Soil Survey Data. Contemporary soil survey data usually consists of a collection of reports, maps, images, and geographic information system data, indicating the type, description, distribution, and interpretation of potential uses of soils in a particular area or region. Soil survey data for an existing deployment site may be available from onsite personnel or local community records. For a new deployment location, consider obtaining general soils data through the International Soil Reference and Information Centre (ISRIC). ISRIC is an independent foundation responsible for collecting, archiving, and distributing data and research information. Typically, soil surveys rely on deductive projections of soil units based on topographical or landscape position and evaluators should regard it as general in nature. The accuracy of soil survey maps decreases as assessments move from the landscape scale to the site scale. This information is useful as background and an indication of potential future problems; however, onsite testing is necessary to specifically identify the soil type and determine the suitability of a specific site. See **paragraph 2.6.2.2** for preliminary soil investigations and **paragraph 2.6.3** for detailed site evaluations.

2.6.1.4. Wastewater Characterization. Having an accurate characterization of the anticipated wastewater stream is critical when assessing the level of wastewater treatment and disposal for contingency locations. Specifically, evaluators consider the characterization of wastewater from water-using activities, including daily volumes, rates of flow, and quality (i.e., pollutant load). Where applicable, review beddown planning factors for anticipated wastewater characteristics at contingency locations. Consider the type of plumbing fixtures and appliances, their extent and frequency of use, and any other factors influencing wastewater flow and quality. Also, be sure to consider any short- or long-term variations to daily wastewater volume and flow that will affect the size of system components. Once evaluators know the characteristics of the anticipated wastewater, they should consider the potential treatment and disposal options available.

2.6.1.5. Wastewater Disposal. Since site characteristics constrain the method of disposal more than other components, evaluators should address the disposal component first. To determine the disposal method properly, a detailed site evaluation is required. Since it is not economical nor practical to evaluate a site for every conceivable system design, begin by eliminating disposal options with the least potential so the detailed site evaluation concentrates on the most promising options. Evaluate disposal options based on characterization (i.e., flow and quality) of the wastewater to be treated and disposed. For contingency locations, the method of disposal is usually via subsurface soil absorption, evaporation, or discharge into surface waters.

2.6.2. Reconnaissance Survey. Evaluators use the reconnaissance survey to obtain preliminary site data to help determine the appropriate receiving environment, screen potential receiver sites, and further focus the detailed site evaluation. The survey typically includes visual checks of each potential site, preliminary soils investigations using hand borings, and potential system layouts. Information gathered from the preliminary review, soil sampling tools, and other materials should be on hand during the reconnaissance survey. Begin the reconnaissance survey with a site walkover to observe and identify existing conditions, select areas to perform soil borings, or view potential routes for piping or outfall structures. The site evaluator should have an estimate of the total area needed for the receiver site based on wastewater characterization, including average daily flow (ADF) and anticipated soil characteristics from the preliminary review.

2.6.2.1. Visual Survey. Used to identify general features that might affect site suitability or system layout and design. General features that should be noted include the following:

2.6.2.1.1. Landscape Position. Landscape position and landform determines surface and subsurface drainage patterns that can affect treatment and infiltration system location. Landscape features that retain or concentrate subsurface flows, such as swales, depressions, or floodplains, should be avoided. Preferred landscape positions are convex slopes, flat areas with deep, permeable soils, and other sites that promote wastewater infiltration and dispersion through unsaturated soils. Use landscape positions when determining the locations for soil investigations.

- The underlying bedrock often controls landscapes, which are modified by a variety of natural forces. Ridgelines are narrow areas that typically have limited soil depth but often a good potential for surface/subsurface drainage.
- Shoulderslopes and backslopes are convex slopes where erosion is common. These areas often have good drainage, but the soil mantle is typically thin and exposed bedrock outcrops are common. Sideslopes are often steep, and erosion is active.
- Footslopes and depressions are concave areas of soil accumulation; however, depressions usually have poor drainage. The deeper, better-drained soils are found on ridgelines, lower sideslopes, and footslopes. Bottomlands might have deeper soils but might also have poor subsurface drainage.

2.6.2.1.2. Topography. Long, planar slopes or plateaus provide greater flexibility in design than ridges, knolls, or other mounded or steeply sloping sites. This is an important consideration in gravity-flow treatment systems, collection piping for cluster systems, treatment unit sites, and potential routes for point discharge outfalls.

2.6.2.1.3. Vegetation. Existing vegetation type and size provide information regarding soil depth and internal soil drainage, which are important considerations in the subsurface wastewater infiltration system layout.

2.6.2.1.4. Natural and Cultural Features. Surface waters, wetlands, areas of potential flooding, rock outcrops, wells, roads, buildings, buried utilities, underground storage tanks, property lines, and other features should be noted because they will affect the suitability of the receiver site.

2.6.2.2. Preliminary Soil Investigations. Select areas for soil investigation based on the desired location and your experience and knowledge of the landscape position, local soil formation factors, and geologic conditions. Consider using preliminary soil borings to examine potential sites unless subsurface wastewater infiltration as a treatment or dispersal option has been ruled out for other reasons. Shallow borings, typically to a depth of at least 5 feet should be made with a soil probe or hand auger to observe the texture, structure, horizon thickness, moisture content, color, bulk density, and spatial variability of the soil. Excavated test pits are not typically required during this phase, however they are often used during detailed site evaluations (**paragraph 2.6.3**) to produce comprehensive soil profiles. See **Attachment 4** for field-expedient soil testing methods that can aid in the preliminary identification and classification of soils.

2.6.2.3. Potential System Layouts. The final step of the reconnaissance survey is to make a preliminary layout of the proposed system on each remaining candidate site based on assessed site characteristics and projected wastewater flows. This step is necessary to determine whether the site has sufficient area and to identify where detailed soils investigations should be performed or concentrated. In practice, this step becomes integrated into the field reconnaissance process, so the conceptual design unfolds progressively as it is adapted to the growing body of site and soil information. Typically, placement of the WWTF depends on the site features (**Table 2.31**) and planned developments at the location. Consider using geographic and geospatial information, aerial photographs, topographic terrain maps, visual surveys, and other available data. **Note:** A detailed site evaluation is needed to confirm the selected location can work from a more comprehensive design perspective and is key to providing a successful onsite WWTF in the most suitable location.

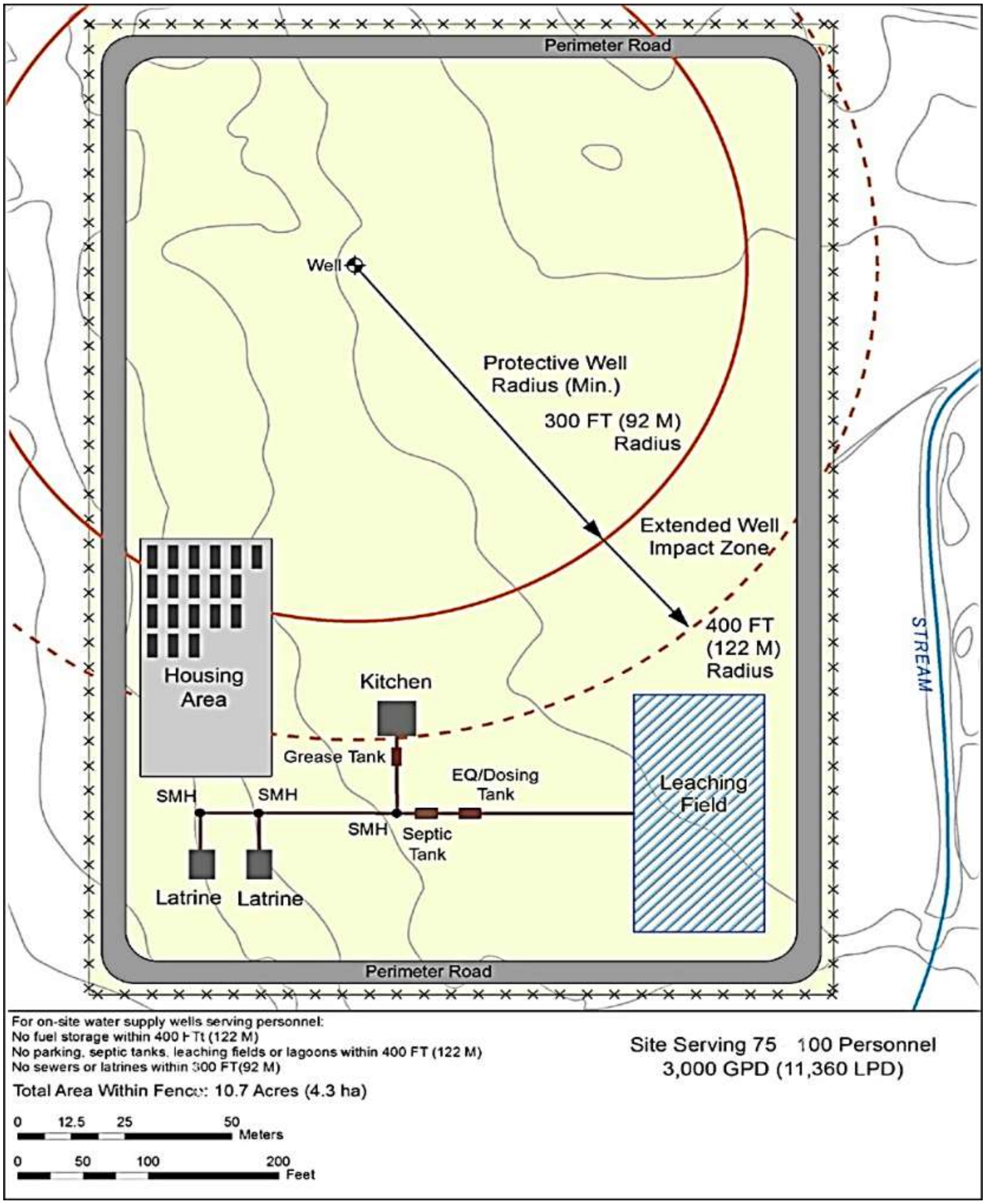
Table 2.31. WWTF Site Placement Considerations.

Site Features
Location/type of water supply source
Location of surface water features and/or wetlands
Presence of significant ledge
Potential or actual hazards, e.g., toxic chemicals, unexploded explosive ordnance (UXO), etc., (whether visible, concealed, aboveground, or buried)
Site topography
Available area in the deployment site

2.6.2.3.1. Illustrated in **Figure 2.16** is an example arrangement of a deployed site layout for a conventional septic system sized to treat up to 3,000 gallons per day (gpd) (11,360 liters per day [Lpd]) of wastewater. This arrangement assumes that the soil characteristics will support a leach field and provides the smallest footprint while considering the following:

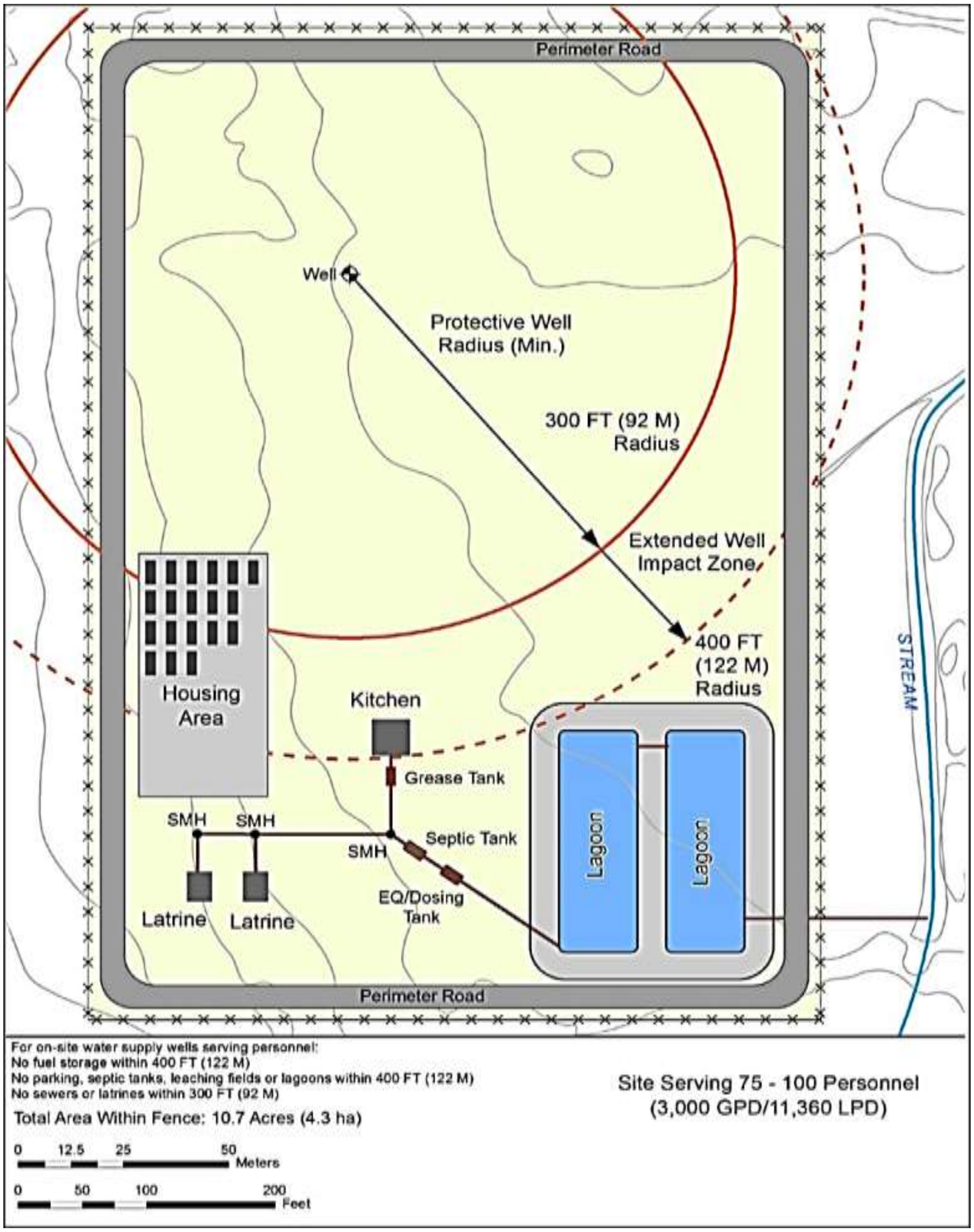
- Adequate offset between water supply well and other features.
- Gravity sewer piping to carry flows away from sources.
- Location of septic tank away from housing and kitchen facilities to reduce odors.
- Location of leach field away from vehicle traffic.
- Adequate offset between surface water and wastewater facilities (see **paragraph 2.6.4.3**).

Figure 2.16. Site Layout Conventional Septic System.



2.6.2.3.2. Shown in **Figure 2.17** is a sample arrangement for the same design flow at a similar deployment site where the soil conditions are not favorable for an onsite leach field. In this case, a lagoon system is the selected treatment method. The lagoon system includes two cells and effluent screening prior to the surface water discharge.

Figure 2.17. Site Layout Lagoon System.



2.6.2.3.3. For conventional (leaching systems) and lagoon systems, the recommended Do's and Don'ts for site management and use protects the long-term viability of the water and wastewater facilities at the site. Consider the recommendations in **Table 2.32**. If the recommended distances in the table are not available onsite, consider moving or modifying the arrangement, alternate locations, or using different wastewater treatment and disposal options, i.e., packaged treatment systems, surface water discharge, nondischarge wastewater systems, or host nation (HN) off-site WWTFs and systems. Be sure to consult with the Engineering Flight and Bioenvironmental Engineering (BE) when considering alternatives for wastewater treatment and disposal.

Table 2.32. WWTF Location Recommendations.

Recommendations
Maintain water supply offsets to potential contaminant sources:
Locate sewer pipes, latrines, and tanks at least 300 feet from the public water supply well.
Locate the leach field at least 400 feet from the well.
Locate fuel storage at least 400 feet from the well.
Protect the sewer system and leaching area from damage:
Do not park or drive vehicles over treatment system areas.
Establish vehicle access outside these areas.
Do not dig or construct within 10 feet of the leach field.
Consider only raised platforms over leach field for tent placement.
Do not plant trees in the sewer or leach field areas.
Consider grass or shallow ground cover over field to prevent erosion.
Do not drive over shallow sewer piping.
Bury sewer piping at least 3 feet deep if crossing a travelled way (**Note:** Greater depths may be needed depending upon type of backfill, pipe material, and compaction specified.
Considerations for lagoons:
Maintain 100-foot buffer between toe of berms to surface waters.
Avoid constructing lagoons in potential floodplain zones.
Locate downwind and away from lodging and kitchen areas.
Locate at least 400 feet away from water supplies.

2.6.3. Detailed Site Evaluation. The objective of the detailed evaluation is to evaluate and document site conditions and characteristics in sufficient detail to allow interpretation and use by others in designing, siting, and installing the WWTF. Address surface features such as topography, drainage, vegetation, site improvements, property boundaries, and other significant features identified during the reconnaissance survey. In addition, address subsurface features such as soil characteristics, depth to bedrock and ground water, subsurface drainage, presence of rock in the subsoil, and identification of hydraulic and treatment boundaries. Convey this information using standardized nomenclature for soil descriptions and hydrological conditions, such as American Society for Testing and Materials (ASTM) D2487, *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*, or other applicable standards. Excavation pits, soil borings, soil permeability measurements, ground water characterizations, and pilot infiltration testing may be necessary for large subsurface infiltration systems. For evapotranspiration systems, field measurements of pan evaporation rates or other parameters, as appropriate, might be necessary. Because detailed site evaluations can be extensive, they should not be performed unless the preliminary and reconnaissance evaluations indicate a high probability that the site is suitable. At a minimum, the detailed investigation should include soil profile descriptions and topographic mapping. Specific site evaluation information may include the surface and subsurface features listed in **Table 2.33**.

Table 2.33. Common Site Evaluation Information.

General Site Information	
Directions to site.	Existing use.
Projected design flow (gpd).	Intended use.
Surface Features	
Benchmark description.	Assigned elevation (ft.).
Property boundaries.	Surface water features.
Existing/proposed structures.	Existing/propose water supply wells.
Existing/proposed wastewater systems.	Utility locations.
Soil investigation points.	Location of area of suitable soils.
Contour elevations.	Slope aspect and percent.
Proposed system component locations.	Other significant features.
North arrow.	Scale.
Other comments:	
Subsurface Features	
Detailed soil descriptions (horizon depth, texture, color, structure, oxygen reduction effect, consistence, moisture, roots, and boundaries).	
Depth and thickness of strong textural contrasts.	
Depth to seasonal saturation.	Ground water flow direction.
Soil testing results.	Depth to perched water table.
Parent material.	Soil samples collected.
Depth completed.	Soil formation factors.
Depth to bedrock.	Type of bedrock.
Depth to permanent water table.	Ground water gradient.

2.6.3.1. Soil Profile Descriptions. Soil profile descriptions provide invaluable information for designing onsite systems that use soil as the final wastewater treatment. ASTM D5921, *Standard Practice for Subsurface Site Characterization of Test Pits for On-Site Septic Systems*, which is summarized in **Table 2.34**, might be useful when describing soil profiles in the field. Depending on composition, soil can treat organic materials, inorganic substances, and pathogens in wastewater by acting as a filter, exchanger, adsorber, and a surface on which many chemical and biochemical processes may occur. The combination of these processes acting on the wastewater as it passes through the soil produces a water of acceptable quality for discharge into the groundwater under the proper conditions.

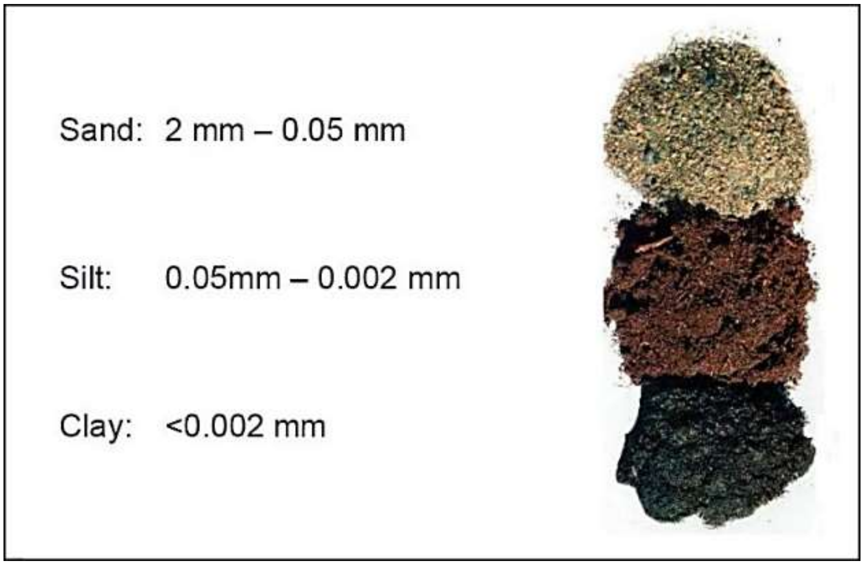
Table 2.34. Practices to Characterize Subsurface Conditions.

Activity	Process	Information Collected
Select pit site	Pick site near but not in proposed leach field; orient pit so sunlight illuminates vertical face of pit.	Location of soil absorption field.
Excavate pit	Excavate to depth required.	Required ground water table (or seasonally high water table) separation distance, soil profile depth.
Enter pit	Take safety precautions; beware of cave-ins; select area of pit wall to examine.	Safe depths for unbraced pit walls.
Expose soil structure	Use knife, blade, screwdriver, or other tool to pick at area 0.5m wide along full height of pit wall.	Soil structural type (e.g., prismatic, columnar, angular blocky, sub-angular blocky, platy, granular).
Describe soil horizons	Note master soil horizon layers; and features of each horizon.	List soil horizon features; depth of horizon, thickness; moisture content; color (hue, value, chroma); volumetric percentage of rock; size, shape, type of rock; texture of < 2 mm fraction of horizon; presence/ absence of mottles; soil structure by grade; level of cementation; presence/absence of carbonates; soil penetration resistance; and abundance, size, distribution of roots.
Determine soil changes	Look for lateral changes in soil profile; use auger and/or compare to profile of second pit.	Determine changes. If any, in soil profile across proposed site.
Interpret results	Identify limiting depths.	Check vertical separation distances; identify mottled layers, concretions; determine depth to saturation; measure depth to confining layer; and identify highly permeable layers.
Prepare site report	Log data onto applicable survey forms.	Formulate system type, size location, and installation recommendations.
Source: ASTM D5921 and EPA 625/R-00/008.		

2.6.3.1.1. Much of the treatment provided by the soil may be by the physical entrapment of particulate matter in the wastewater. This process performs best when the soil is unsaturated. If saturated soil conditions prevail, the wastewater flows through the larger pores and receives minimal treatment. However, if the soil remains unsaturated by restricting the wastewater flow into the soil, filtration improves because the wastewater then flows through the smaller pores of the soil. The soil depth needed to remove bacteria and viruses to acceptable levels and nearly all the phosphorus, depends on the permeability of the soil. Soils with rapid permeability may require greater unsaturated depths below the infiltrative surface than soils with slow permeability.

2.6.3.1.2. While a nearly infinite variety of substances may exist in soils, their basic components are minerals, organic matter, air, and water. The groups of mineral particles separated on the basis of a range in size (soil separates) are sand, silt, and clay. Air and water may exist in the pores between solid soil particles. Collectively, sand, silt, and clay refers to the fine earth fraction of soil, all of which are less than 2 millimeters (mm) (0.08 inch) in diameter and range, as noted in **Figure 2.18**.

Figure 2.18. Soil Separates and Size Ranges.



2.6.3.1.3. The percentage by weight of each mineral affects the permeability of the soil and thus the ability of the soil to absorb and drain water. **Figure 2.19** identifies soil textures based on the percentage of separates (sand, silt, and clay). Soils are divided into drainage classes related to the frequency and duration of saturation during soil formation. Soil texture can be used to estimate the percolation rate, which is used to estimate the size of the onsite treatment area. The following is a general description for each soil textural class based on the soil classification used by the U.S. Department of Agriculture (USDA). **Table 2.35** describes the feeling and appearance of the various soil textures for a general soil classification.

2.6.3.1.4. Ideal conditions for septic systems and their respective leaching areas include sandy, well-draining soils with limited silt and clay. Where clay soils are prevalent, consider a lagoon system for post-septic tank treatment in lieu of a leach field.

2.6.3.1.5. One of the identifying characteristics of wetlands is the presence of hydric, or wet, soils. The USDA Natural Resources Conservation Service (NRCS) defines hydric soils as "soils that formed under conditions of saturation, flooding or ponding long enough during the growing season to develop anaerobic conditions in the upper part." These soils do not drain well and are not appropriate for septic systems. Avoid wetland areas to reduce potential contamination of local groundwater.

Figure 2.19. Soil Textural Triangle.

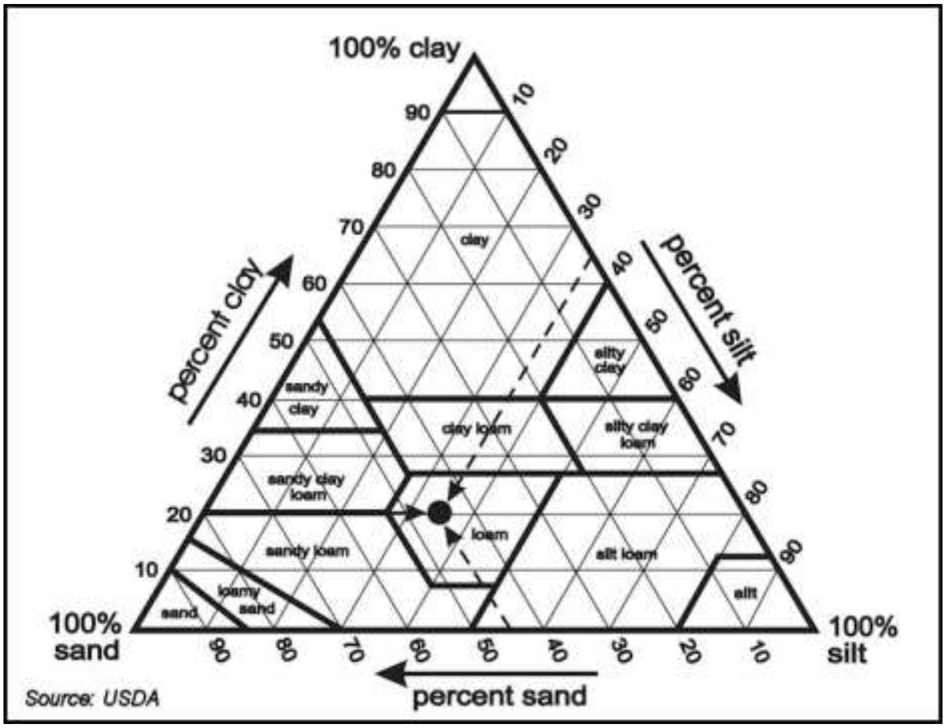


Table 2.35. Textural Properties of Mineral Soils.

Soil Class	Feeling and Appearance	
	Dry Soil	**Moist Soil**
Sand	Loose, single grains that feel gritty. Squeezed in the hand, the soil mass falls apart when the pressure is released.	Squeezed in the hand, it forms a cast that crumbles when touched. Does not form a ribbon between thumb and forefinger.
Sandy Loam	Aggregates easily crushed; very faint velvety feeling initially but with continued rubbing the gritty feeling of sand soon dominates.	Forms a cast which bears careful handling without breaking. Does not form a ribbon between thumb and forefinger.
Loam	Aggregates are crushed under moderate pressure; clods can be quite firm. When pulverized, loam has velvety feel that becomes gritty with continued rubbing. Casts bear careful handling.	Cast can be handled quite freely without breaking. Very slight tendency to ribbon between thumb and forefinger. Rubbed surface is rough.
Silt Loam	Aggregates are firm but may be crushed under moderate pressure. Clods are firm to hard. Smooth, flour-like feel dominates when soil is pulverized.	Cast can be freely handled without breaking. Slight tendency to ribbon between thumb and forefinger. Rubbed surface has a broken or rippled appearance.

Soil Class	Feeling and Appearance	
	Dry Soil	**Moist Soil**
Clay Loam	Very firm aggregates and hard clods that strongly resist crushing by hand. When pulverized, the soil takes on a somewhat gritty feeling due to the harshness of the very small aggregates that persist.	Cast can bear much handling without breaking. Pinched between the thumb and forefinger, it forms a ribbon whose surface tends to feel slightly gritty when dampened and rubbed. Soil is plastic, sticky and puddles easily.
Clay	Aggregates are hard; clods are extremely hard and strongly resist crushing by hand. When pulverized, it has a grit-like texture due to the harshness of numerous very small aggregates that persist.	Casts can bear considerable handling without breaking. Forms a flexible ribbon between thumb and forefinger and retains its plasticity when elongated. Rubbed surface has a very smooth, satin feeling. Sticky when wet and easily puddled.

2.6.3.1.6. In **Figure 2.20**, historic high groundwater elevation appears to be only 3 to 4 inches below the ground surface. This site is not advisable for a septic system. If installed, a mounded leach field would be necessary to accomplish a 2- to 4-foot offset to the high groundwater level shown.

2.6.3.1.7. Mottling above observed groundwater is an indication of a zone that was periodically saturated (sometimes seasonal) and may impede drainage under a leach field. Well-drained soil is often brown or red, while poorly drained soil is gray. The gray colors result from many cycles of soil saturation (**Figure 2.21**).

Figure 2.20. Soil Mottling.

Figure 2.21. Soil Mottling in Wetland.

Dull gray general soil background, or matrix color, and bright red-orange iron concentrations, or mottles, indicate a fluctuating water table. *Corps of Engineers*

2.6.3.2. Subsurface Soil Evaluations. As part of detailed site evaluations, soil borings, observation pits, and soil percolation tests can help determine subsurface soil features for areas proposed for a wastewater effluent leach field or lagoon. Refer to **Figure 2.22** for a soil testing plan example. This plan shows the general locations for performing soil investigations, including borings, observation pits, and percolation tests. If the conditions are previously established or found to be consistent throughout the site, consider reducing the testing protocol. For all testing, document and maintain at the site, a detailed plan with locations and notes on the conditions. The data will be useful during system design and future modifications (if necessary) for repair or expansion.

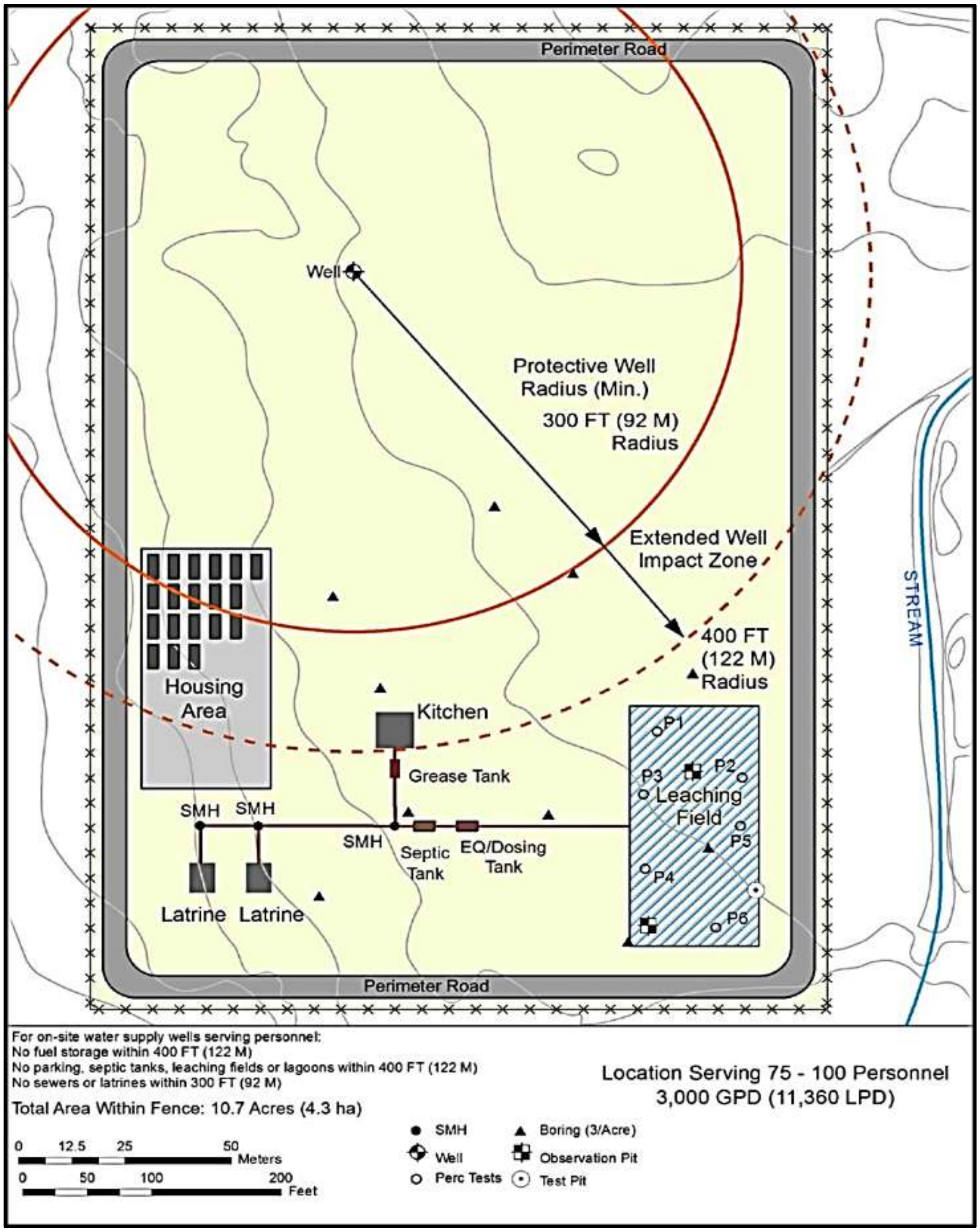
2.6.3.3. Soil Borings. Soil borings may be feasible if the equipment and expertise is readily available at the site. Soil borings can help determine the soil texture and depth to the groundwater table or ledge. Consider boring study for proposed wastewater system area to:

- Assess general soil conditions.
- Locate ledge or boulders that may hinder construction.
- Locate water table, if encountered.
- Identify other problem conditions.
- Identify the most appropriate location for the leaching area (consider preliminary soil investigation and slope of site).

2.6.3.4. Observation Pits. In contrast to soil borings, most sites will have an excavator and experienced operator readily available to dig observation pits. Also, observation pits provide access for a more detailed analysis of the soil conditions than soil borings. However, it might not be possible to identify all design boundaries, such as the permanent water table surface or bedrock if they are beyond the depth of the observation pit. In addition to providing detailed soil characterizations, observation pits can help determine:

- Presence of groundwater in the area and/or mottling point, if observed.
- Presence of rocks or boulders in the immediate area.
- Presence of clay or other hindering soil features.
- Consistency of the materials in the area.
- Soil horizon relationships.
- Approximate bottom of leach field required to maintain adequate distance to the groundwater.

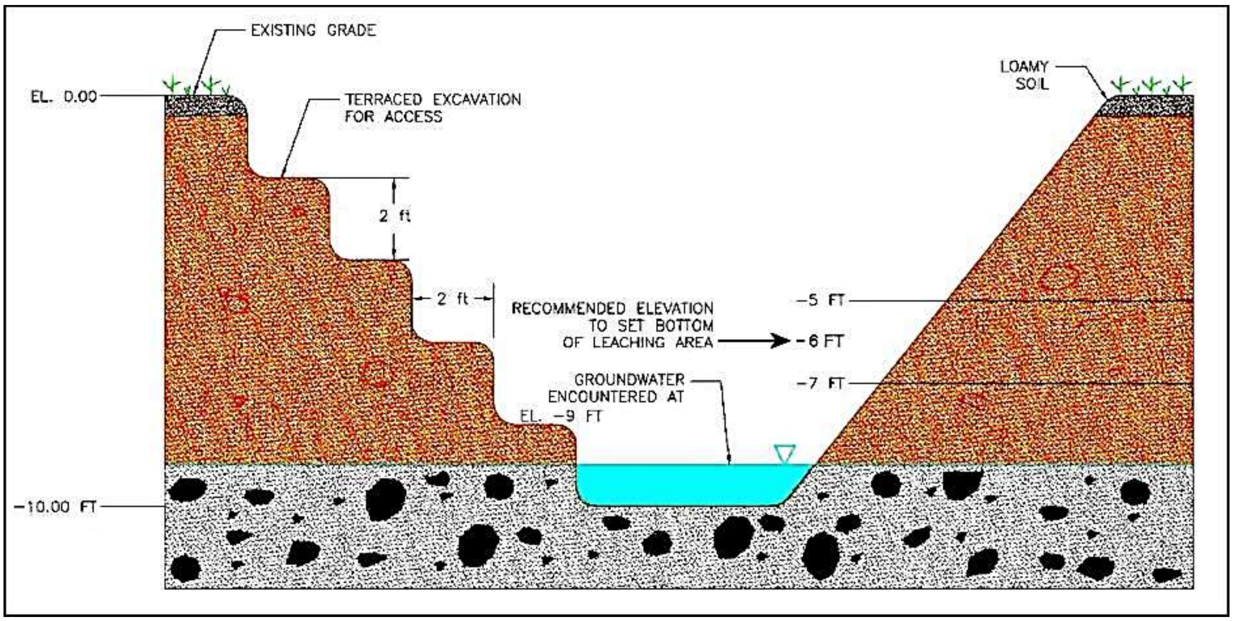
Figure 2.22. Soil Testing Plan.



2.6.3.4.1. Dig observation pits based on the system size. Excavate pit up to 10 feet deep (or to refusal) in the lowest part of the test area of the proposed leaching area to check soil texture and determine mottling or groundwater elevation. Recommended pervious material below a leaching area is 3 to 4 feet minimum.

2.6.3.4.2. In the example shown in **Figure 2.23**, the excavation ran into groundwater at 9 feet below site grade. Pending favorable percolation rates in subsequent analyses, construct the proposed leach field with a bottom elevation of 6 feet below grade or above. If the excavation encounters seasonally saturated soil or an impervious layer (rock or clay) at a depth of 3 feet or closer to the ground surface, the area may not be appropriate for a subsurface leaching system. However, consider a mounded leaching system if other factors are suitable.

Figure 2.23. Example Observation Pit for Leaching Area.



2.6.3.5. Percolation Test. The percolation test is designed to determine the suitability of a site for a subsurface discharge (to absorb liquid) and thus simulate the conditions in a septic system. The steps listed in **Table 2.36** and illustrated in **Figure 2.24**, addresses procedures for performing a percolation test. Perform the test at the bottom elevation of proposed leach fields. Dig percolation test holes and conduct tests in the intended leach field area to:

- Measure percolation rate(s) throughout the area.
- Establish percolation rate to use for design conditions.
- Verify the location and bottom elevation of the leach field.

Table 2.36. Percolation Test Procedures.

Day 1 or Early Same-Day Preparation:	
Step 1	Identify the proposed leaching area and expected depth.
Step 2	Dig four to six test holes 6 to 8 inches in diameter and 24 inches deep that are 30 to 40 feet apart in the area (and intended depth) of the proposed leach field.
Step 3	Roughen walls of test holes to remove any smears caused by the digging process and remove all loose soil from the bottom of the holes.
Step 4	Place gravel in the bottom to prevent soil erosion.
Step 5	Dig a 4-foot deep test pit in the lowest part of the test area leaching area to check soil texture. This will not be filled with water and is used to monitor groundwater during the percolation test. No percolation test holes should be within 3 feet of the pit.
Step 6	Presoak: Fill each of the test holes with water and refill to maintain a minimum depth of 12 inches for at least 4 hours. A 6-inch-diameter hole requires about 1.5 gallons per foot of depth.
Step 7	Prepare a measurement stake with nails or other markers located at specific intervals that can be easily observed. Refer to **Figure 2.24**.
Day 2 – Testing	
Step 1	Prior to testing, clear bottoms of test holes of any loose soils or debris.
Step 2	If no water remains in the hole after the overnight soak period, add 6 inches of water above the gravel.
Step 3	Fill the test holes to a specific marker elevation (typically 12 to 18 inches) above the bottom of the test hole and note the exact time.
Step 4	Measure the drop in water elevation after a set time-period or the time required to drop to the next marker.
Step 5	After each measurement, re-fill the hole to a minimum depth of 6 inches above the bottom gravel.
Step 6	Calculate the percolation rate in minutes per inch of elevation drop.
Step 7	Continue taking measurements until three consecutive percolation rates vary by no more than 10 percent.
Step 8	Refer to **Table 2.37** for the loading rates relative to percolation and soil textural class to determine the effluent loading rate on the leaching area.

2.6.3.5.1. In very sandy soils, a stopwatch may be required to measure the time in seconds for the water level to drop 1 inch (2.5 cm). Consider timing the drop over several inches to check quick- draining soils. If percolation rates exceed 60 minutes per inch (2.5 cm), the soils may not be suitable for leaching. See **Table 2.38** for soil textural class with associated descriptions and comparisons of the hydraulic loading in gpd/sf (cm/day) for two different effluent qualities:

- Biochemical oxygen demand (BOD) = 150 mg/L, which corresponds to typical septic tank effluent.

- BOD = 30 mg/L, which corresponds to more advanced treatment provided by a recirculating sand filter or commercial treatment process described in **paragraphs 2.2.4** and **2.2.7**, respectively.

Figure 2.24. Percolation Test.

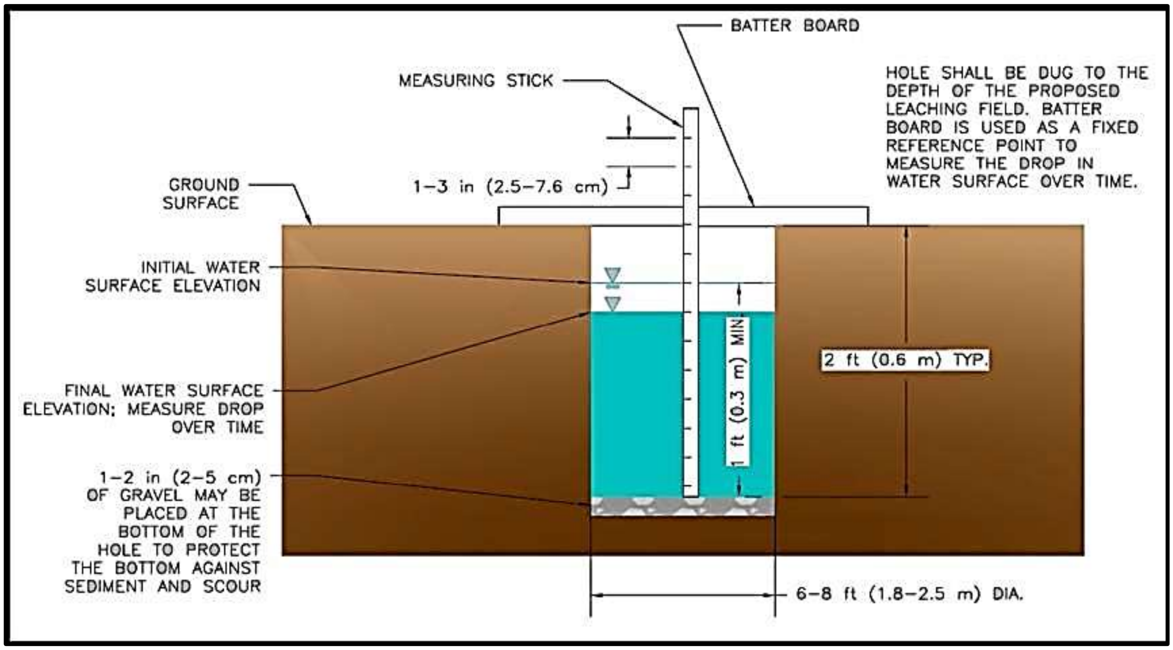


Table 2.37. Optional Design Loading Rates Based on Percolation Tests and Soil Class.

Percolation Rate (minutes/inch)	Design Loading Rates			
	Soil Class I gpd/sf (cm/day)	Soil Class II gpd/sf (cm/day)	Soil Class III gpd/sf (cm/day)	Soil Class IV gpd/sf (cm/day)
<5	0.75 (3.0)	0.60 (2.5)	-	-
6	0.70 (2.9)	0.60 (2.5)	-	-
7	0.68 (2.8)	0.60 (2.5)	-	-
8	0.66 (2.7)	0.60 (2.5)	-	-
10	-	0.60 (2.5)	-	-
15	-	0.56 (2.3)	0.37 (1.5)	-
20	-	0.53 (2.2)	0.34 (1.4)	-
25	-	0.40 (1.6)	0.33 (1.3)	-
30	-	0.33 (1.3)	0.29 (1.2)	-
40	-	-	0.25 (1.0)	-
50	-	-	0.20 (0.8)	0.20 (0.8)
60	-	-	0.15 (0.6)	0.15 (0.6)

Note: gpd/sf = gallons per day per square foot or cm/day = centimeters per day
Source: Adapted from Code of Massachusetts Regulations 310 CMR 15.000: *The State Environmental Code*

Table 2.38. Hydraulic/Organic Loading Rates for Infiltration Surfaces.

Soil Textural Class	Texture Description	Hydraulic Loading gpd/sf (cm/day)	
		BOD=150	BOD=30
I	Coarse sand, sand, loamy coarse sand, loamy sand	0.8 (3.3)	1.6 (6.5)
I	Fine sand, very fine sand, loamy fine sand, loamy very fine sand	0.4 (1.6)	1.0 (4.1)
II	Coarse sandy loam, sandy loam	0.2-0.6 (0.8-2.4)	0.5-1.0 (2.0-4.1)
II	Fine sandy loam, very fine sandy loam	0.2-0.4 (0.8-1.6)	0.6-0.8 (2.4-3.3)
III	Silty loam, silty clay loam	0.2-0.4 (0.8-1.6)	0.5-0.8 (2.0-3.3)
IV	Sandy clay, clay	0.2 (0.8)	0.3 (1.2)

2.6.4. Groundwater and Surface Water Features. The environmental conditions, including the groundwater and surface water features provide important information needed to size, select, and site the appropriate wastewater treatment system.

2.6.4.1. Water Table or Saturated Zone Elevation. Groundwater protection is critical for maintaining environmental health. The location of the water table or saturated zone is an important factor in locating onsite leaching systems. Soil characteristics under the leaching area provide additional treatment for the septic tank effluent before it reaches the water table. The treatment zones, as shown in **Figure 2.25**, generally include:

- Infiltration zone: About 1 inch (2.5 cm) thick directly under the leaching area is the most biologically active zone and is called the biomat; the biomat is the layer of biological growth and inorganic residue under a leach field that develops at the wastewater-soil interface and extends up to about 1 inch into the soil matrix.
- Vadose (unsaturated) zone: Located below the biomat where nitrification occurs if sufficient oxygen is present in the soil.
- Saturated zone: Here the treated wastewater is transported from the site with the laminar flow of groundwater.

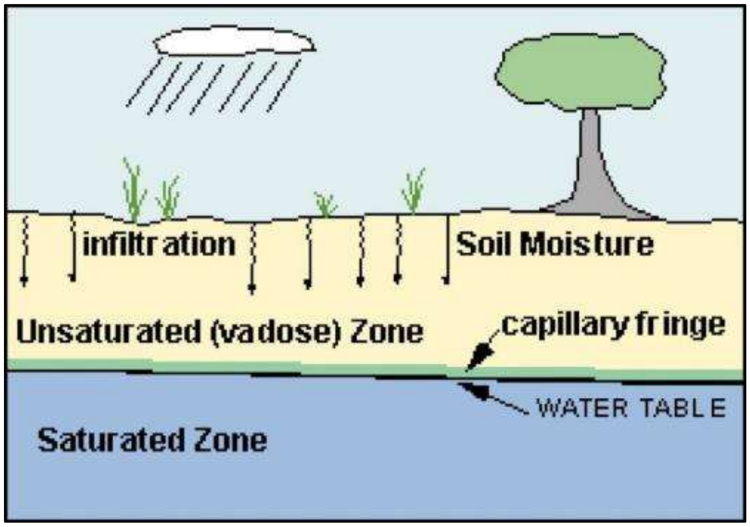
2.6.4.1.1. Most U.S. state health codes require minimum separation distances of at least 18 inches (46 cm) from the seasonally high water table or saturation zone to the bottom of the leach field, regardless of soil characteristics. In general, 2- to 4-foot separation distances have proven to be adequate to remove most fecal coliform from septic tank effluent through the soil zones.

2.6.4.1.2. Where high groundwater conditions exist and a mounded leaching system are considered, additional design factors include:

- Increasing the surface (loading area) of the leach field.

- Improving pre-treatment to the field.
- Adding dosing field cell(s) to allow cycled dosing.

Figure 2.25. Groundwater Zones.



2.6.4.2. Hydraulic Loading Limitations. Use the soil texture classification (sand, silt, and clay proportions) determined from the site excavation, and the percolation rate measured in the field, to define the conditions for long-term hydraulic loading. Where unsuitable silt and clay conditions exist, the limited hydraulic loading may eliminate onsite treatment from consideration. Where leaching systems are not usable, consider a lagoon system as an alternative if adequate land is available onsite.

2.6.4.3. Groundwater and Surface Water Protection. To minimize the potential impact from onsite treatment systems on nearby groundwater drinking water wells, wetlands, and surface water bodies such as ponds and streams, the setback distances below are recommended. These distances are intended only as a guide. Safe distance varies from site to site, based upon topography, soil permeability, groundwater gradients, geology, etc.

- 400-foot (122 m) minimum setback from drinking water supply source.
- 100-foot (30.5 m) minimum setback from leach field or lagoon to tributary stream.
- 50-foot (15 m) minimum setback from septic tank to surface water.
- 100-foot (30.5 m) minimum setback from leach field to surface water (not used for drinking water).

2.6.5. Floodplains. Construction on floodplains is not advisable due to the potential for damage to the onsite systems and related risk of pollutant contamination. Where possible, consider a mounded leach field and/or surface-located pre-treatment system beyond the floodplain area. Make sure all tanks and piping are watertight and tested to avoid contaminating the groundwater.

Chapter 3

TREATMENT SYSTEMS DESIGN AND ALTERNATIVES

3.1. General Information. Onsite wastewater treatment systems vary in design and performance, and depending upon site conditions and circumstances, each has its own unique advantages and disadvantages. In general, wastewater treatment systems should be designed to transform raw wastewater into an effluent suited to the disposal component or method. For example, in a subsurface soil absorption system, the pretreatment unit (e.g., septic tank) should remove nearly all settleable solids and floatable grease and scum so that a reasonably clear liquid is discharged into the soil absorption field. This allows the field to operate more efficiently. Likewise, for a surface discharge system, the treatment unit should produce an effluent that will meet applicable surface discharge standards. The wastewater treatment designs and alternatives addressed in this chapter may or may not be practical or otherwise allowed at a particular location because of legal, operational, or practical (e.g., natural terrain) factors. Refer to MAJCOM or Combatant Command guidance for specific requirements.

3.2. Design Review, Construction Inspection, and Monitoring. A successful project depends on proper design, construction, and operation to ensure long-term service and reliability of the wastewater treatment system installed at a deployed location. Review and documentation of these project elements is important for ongoing maintenance as well as for future reference if we need to address a problem or changed condition. The following guides and checklist provide basic design, construction, and monitoring information for WWTFs, and personnel may use and modify them as needed for a specific project.

3.2.1. Design Review Guide. At a minimum, take the steps in **Table 3.1** when conducting a design review. Completion of the review items below are critical to ensuring the design will be capable of handling the flow. Completing a proper design review will help to minimize confusion during the construction phase. After design completion, it is ready for construction.

Table 3.1. Design Review Steps.

Design Review Guide		✓
1.	**Review Soil Testing Records**	
	Soil classification	
	Ground water depth	
	High ground water level	
2.	**Review Percolation Test Results**	
	Percolation rate	
	Hydraulic loading recommendation	
3.	**Review Wastewater Characteristics**	
	BOD	
	TSS	
	Temperature	

Design Review Guide		✓
4.	**Check Calculations**	
	Verify ADF calculation	
	Verify sizing of unit processes	
	Verify loading rates	
	Verify assumptions made	
5.	**Check Site Plan Layout**	
	Check required offsets	
	Check for conflicts with existing structures	
	Check for conflicts with pending construction projects	
	Check that dimensions shown match calculations	
	Check correct scale is indicated	
6.	**Verify Record Keeping of Project**	
	Project file has been established	
	Design calculations	
	Assumptions for design	
	Copy of design	

3.2.2. Construction Inspection Guide. The primary purpose of a construction inspection is to ensure the final product is built in accordance with the design. Construction inspectors maintain a field book and daily log of construction activities. **Table 3.2** list items that are the minimum checked and/or verified by the construction inspector to ensure compliance with the design.

Table 3.2. Construction Inspection Checklist.

Design Compliance		✓
1.	**Materials**	
	Check dimensions	
	Verify materials of construction	
	Verify quantity	
	Verify items are free from defects	
2.	**Design Integrity**	
	Verify dimensions shown on drawing match field dimensions	
	Check that location shown on drawing matches field locations	
	Take swing ties for record purposes	
	Check that piping slope on drawing matches slope in field	
	Verify elevations shown on drawings match field elevations	

Design Compliance		✓
3.	**Testing**	
	Establish field testing schedule	
	Maintain record of field tests	
	Observe field tests of all equipment and processes	
	Compare field test results to design criteria	
	Ensure contractor addresses any piece of equipment or process that does not pass the field test	
4.	**Design Records**	
	Maintain field book	
	Maintain daily log book	
	Maintain redline set of drawings	
	Take photographs of construction progress	

3.3. Septic Tank Systems. Septic tanks are a key component used in most conventional onsite treatment and collection alternatives and provides pretreatment of wastewater prior to discharge to leach fields. Septic tanks work because the design allows stratification within the tank, thus separating scum and sludge from the clear zone. The baffles help direct and slow the flow through the tank, which allows the sludge to settle and scum to remain on the surface. The key factors in design are:

- Average daily flow (ADF): The flow volume processed by the plant on a typical day.
- Velocity through the tank.
- Reserve capacity.
- Solids storage capacity.
- Hydraulic retention time.
- Recommended length to width ratio is 3:1.
- Clear zone volume is 1.5 to 2 times the daily design flow.
- Reserve sludge volume requires an additional 3-foot (0.9 m) reserve in tank bottom.
- Minimum of 1-foot (0.3 m) surface is recommended for venting and scum accumulation.
- Single-compartment septic tanks are adequate for single-unit applications and lower design flows.
- For flows over 750 gpd (2,840 Lpd), a two-compartment tank is recommended for improved reliability and performance.

3.3.1. Septic Tank Design. The following is a step-by-step guide to designing a dual-chamber septic tank:

3.3.1.1. Determine the ADF for the facility. Engineers base the ADF on the number of personnel and water use. Refer to **Table 2.27** for expected flows.

3.3.1.2. Determine total storage volume required for each chamber as shown below. In a dual-chamber septic tank, the first chamber into which sewage flows has a detention time of 48 hours. The second chamber has a detention time of 24 hours. Detention time (DT) is the length of time required for one complete volume change.

V (gallons) = ADF gpd x detention time (days).

3.3.1.3. Convert storage volume from gallons to cubic feet as shown below.

V (ft^3) = V (gallons) ÷ 7.48 gallons per cubic foot.

3.3.1.4. Determine interior dimensions of both chambers as shown below. The total available volume of the tank (V_{avail}) is equal to or greater than the volume calculated for the required detention times.

- The first chamber represents two-thirds of the volume.
- The second chamber represents one-third of the volume.

$L_1 = W$
$L_2 = 2 \times L_1$
H = 6 feet to 16 feet (max)
V_{avail} (ft^3) = (L_1 x W x H) + (L_2 x W x H)

3.3.1.5. Establish maximum allowable sludge accumulation. The sludge should not accumulate to more than 3 feet (0.9 m) or 25 percent to 35 percent of the first chamber.

3.3.2.6. Determine working volume as shown below. The working volume is amount of space available for flow above the maximum allowable sludge accumulation line and below the outlet flow tee.

Vw = 1.5 x ADF

3.3.1.7. Pipe sizing and location (refer to **Figure 3.1**).

- Influent pipe should be equal to the gravity sewer pipe at least 21 inches (0.5 m) below grade.
- Connection pipe between chambers should be 6 to 8 inches (152 to 203 mm) in diameter at same elevation as effluent pipe.
- Effluent pipe should be minimum 6 inches (152 mm) in diameter and located 3 inches (76 mm) minimum below influent invert.

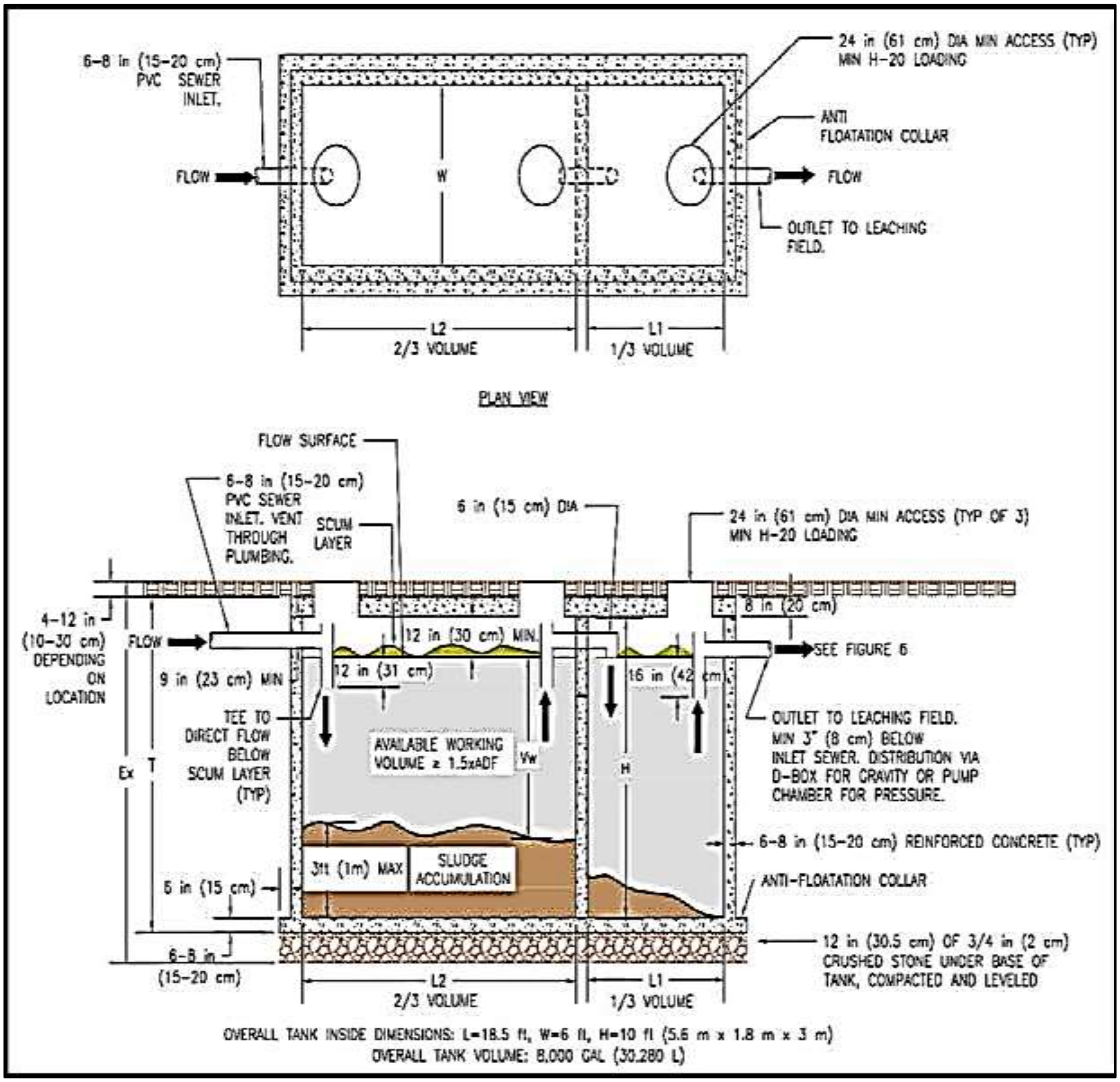
3.3.1.8. Effluent filter locations.

- Connection tee – To protect second chamber (or pump chamber).
- Effluent tee – To protect leach field (or separate pump station).

3.3.1.9. Provide tank access for inspections and regular maintenance.

- Manways shall be 24 inches (609 mm) in diameter, designed for H-20 (truck) loading if located in travel ways.
- Locate manways at each tee location.

Figure 3.1. Septic Tank Design.



3.3.1.10. Determine overall tank dimensions as shown below.

- For concrete tanks, include walls, base, and cover per **Table 3.3**.

Overall height (T) = H + Tb + Tt
Overall length = L1 + L2 + (2 x Tw) + (Tw) + (2 x Tc)
Overall width = W + (2 x Tw) + (2 x Tc)

3.3.1.11. Provide anti-flotation collar. Recommend an anti-flotation collar to counteract buoyancy when high groundwater may be an issue. Typically, a 6-inch (15 cm) collar is adequate for most situations, as shown in **Figure 3.1**. The extended base provides additional weight and bearing area for the soil pressure.

Table 3.3. Septic Tank Sizing.

Dual Chamber Septic Tank Design							
Wastewater flow (ADF)	Unit	Symbol	Flows				
	gpd (Lpd)	Q	500 (1,900)	1,000 (3,785)	3,000 (11,360)	5,000 (18,930)	10,000 (37,860)
Tank							
Total Volume	Gallons	V	1,500	3,000	9,000	15,000	30,000
Working Volume	Gallons	V_w	750	1,500	4,500	7,500	15,000
Length chamber 1	Feet	L1	3	4	6	7.5	10
Length chamber 2	Feet	L2	6	8	12	15	20
Interior width	Feet	W	3	4	6	7.5	10
Interior height	Feet	H	8	9	12	12	14
Total height	Feet	Ht	9.33	10.33	13.67	13.67	15.67
Concrete thickness							
Wall	Inches	Tw	6	6	8	8	8
Base	Inches	Tb	6	6	8	8	8
Anti-flotation collar	Inches	Tc	6	6	6	6	6
Top	Inches	Tt	8	8	8	8	8
Depth of excavation	Feet	Ex	11.00	12.00	15.00	15.00	17.00
Refer to **Figure 3.1** for dimensions key for this table							

3.3.1.12. Provided in **Table 3.4** is a detailed design calculation for a 3,000-gpd system. It lists recommended design and dimensions for septic tanks with certain design flows. **Figure 3.1** shows the recommended installation for a concrete septic tank designed to serve a flow of 3,000 gpd (11,360 Lpd). Note that the inlet and outlet tees are set with an elevation differential to draw flow through the tank.

3.3.1.13. Septic tanks must be watertight. Typically, they are made of reinforced concrete as shown in **Figure 3.1**. Steel tanks are not widely used because they require corrosive-resistant coatings and cathodic protection. Fiberglass and polyethylene-molded tanks are also available, but they must have anti-buoyancy provisions for belowground installation. If concrete tanks are not local-manufacture and shipping is required, consider polyethylene tanks for ease and cost of delivery, but availability may be limited in the larger tank sizes. If choosing polyethylene tanks, consider separating the wastewater flows into two separate treatment trains to reduce the tank sizing requirements.

Table 3.4. Septic Tank Design Example.

Septic Tank Design
Problem: Given a site with a staff of 75 and served by an onsite well:
Solution: ADF = 75 staff x 40 gpcd (from **Table 2.27**) = 3,000 gpd ADF = design flow (Q) = 3,000 gpd Total storage volume (V) = detention time (DT) x Q V = 2 days x 3,000 gpd + 1 day x 3,000 gpd **V = 9,000 gallons** **V ≈ 1,200 ft^3**
Interior height (H) = 12 ft. (refer to **Table 3.3**) Therefore required area = 100 ft^2 L_2 = 2 x L_1 L_1 = W Therefore, L_2 = 2 x W 100 ft^2 = [(2 x W) x W] + [(W x W)] 100 ft^2= 2W^2 + W^2 100 ft^2 = 3W^2 W^2 = 33.33 ft^2 W = 5.77 ft Round to 6-ft standard length from **Table 3.3** **W = 6 ft** If W = 6 ft then: L_1 = 6 ft L_2 = 12 ft

Septic Tank Design
Verify that given these dimensions there is sufficient working volume (V_W). V_W = (H – sludge depth – depth from bottom of cover to invert of effluent pipe) x L_2 x W V_W = (12 ft – 3 ft – 1.25 ft) x 12 ft x 6 ft V_W = 612 ft^3 $V_W \approx$ 4,600 gallons **4,600 gallons > 1.5 x ADF, so OK.**
Summary of Design: Tank dimensions: H = 12 ft L_1 = 6 ft L_2 = 12 ft W = 6 ft

3.3.2. Leach Field Design. There are several options for effluent disposal following the septic tank, including leach pits, trenches, beds, and chambers. There are also commercial systems that units can install after the septic tank, such as a modified trickling filter with clarifier to reduce the size of the leach field for locations with limited space. Leach pits are less favored due to their vertical orientation and limited treatment capability. Leach trenches and beds each utilize polyvinyl chloride (PVC) distribution piping in a planned design arrangement that is simple to install and allows a soil treatment layer between the bottom of the field and the groundwater. The difference between trenches and beds relates to the slope and method of installation. Consider leach chambers in lieu of former alternatives where the leach field may be located in a travelled way or reducing the leach field profile. Leach chambers made from concrete or high-density polyethylene plastic are commercially available.

3.3.2.1. Leach trenches and beds, also referred to as leach fields, are the most common methods for disposing of septic tank effluent. Sometimes called drain-fields, subsurface absorption systems (SAS), or subsurface wastewater infiltration systems, they are an integral part of the system design to achieve the following objectives of the soil treatment process:

- Stabilization of organic wastes in the effluent.
- Removal of pathogenic organisms, nutrients, and particulates.
- Recharge of the groundwater table with adequately treated effluent.
- Effluent disposal without discharge to ground surface or creation of any nuisance.

3.3.2.2. The design features that are most capable of achieving the objectives above include:

- Moderate organic loading from septic tank.

- Shallow placement of the leaching surface (< 2 feet [61 cm] below grade) to assure soil aeration.
- Narrow trenches (< 3 feet [1 m] wide).
- Trench orientation parallel to surface contours.
- Uniform distribution over the leach field for maximum performance.
- Multiple cells (fields) for alternating; provides resting between dosing and standby capacity for service periods.

3.3.2.3. Commonly, septic tank effluent distribution is by gravity to the leaching arrangement through a concrete distribution box for systems sized up to 2,000 gallons (7,570 L) per day. In **Figure 3.2**, the operator is inspecting the distribution box to check gravity flow distribution to multiple headers. Operators can adjust inlet weir inserts at each distribution pipe to maintain even distribution.

Figure 3.2. Distribution Box.

3.3.2.4. Non-pressure dosing alternatives without electricity include a siphon bell utilizing an air vent for release, float-controlled using a mechanical float for release or alternating dosing flow to multiple compartments, and tipping buckets or pan system that functions on a balance principle. In general, these alternatives are for low-flow septic systems but are an alternative where power for a pressurized pump-dosed system is not possible or practical.

3.3.2.5. In larger systems, pressure distribution of the leach field is advisable to maintain consistent loading rates throughout the field. A pressure system requires a two-compartment septic tank (or a separate pumping chamber) and the tank effluent is pumped to the leach field to maintain a minimum pressure at the furthest point of the field. The pump is activated based on set levels in the tank (or time intervals) and thus delivers periodic cycles of flow or doses. Dosing provides intervals between field loading to rest the field and is preferred in most applications because of its consistent distribution and long-term treatment reliability.

3.3.2.6. **Figure 3.3** shows a typical lateral pipe installed in a trench prior to backfilling. Note the granular pipe bedding material under the lateral. The pressure dose releases from orifice openings in the lateral located at 5-foot (1.5 m) spacing. An orifice shield (**Figure 3.4**) serves to protect the orifice, allows the discharge to spray and encourages even distribution throughout the leach field. Orifice shields are used in a pressurized distribution system to prevent surrounding media from blocking orifices. Constructed of polyvinyl chloride (PVC), orifice shields snap-fit onto laterals. Orifice shields (and orifices) can be installed facing up or down (cold weather applications), the latter being shown in **Figure 3.3**. Refer to **Figure 3.5** through **Figure 3.8** for more details on piping and field arrangements. For the leach field arrangement shown in **Figure 3.8**, a non-electric rotating cam (center) is used to alternate effluent dosing to four separate leaching areas. This allows rest between cycles for optimal performance and reliability.

Figure 3.3. Leach Trench and Lateral.

Figure 3.4. Orifice Shields.

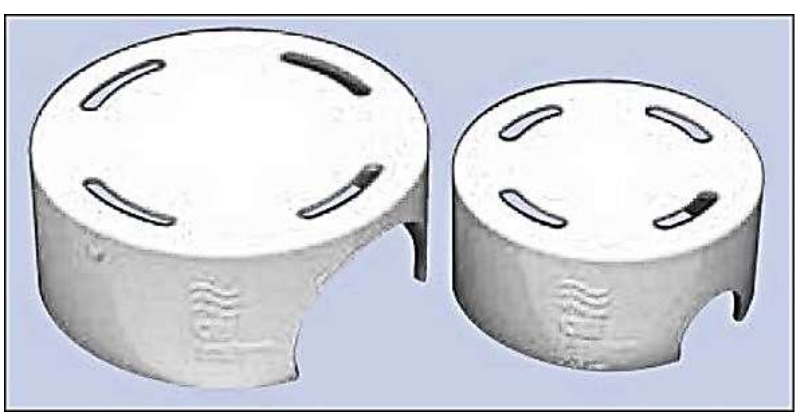


Figure 3.5. Leach Field Design.

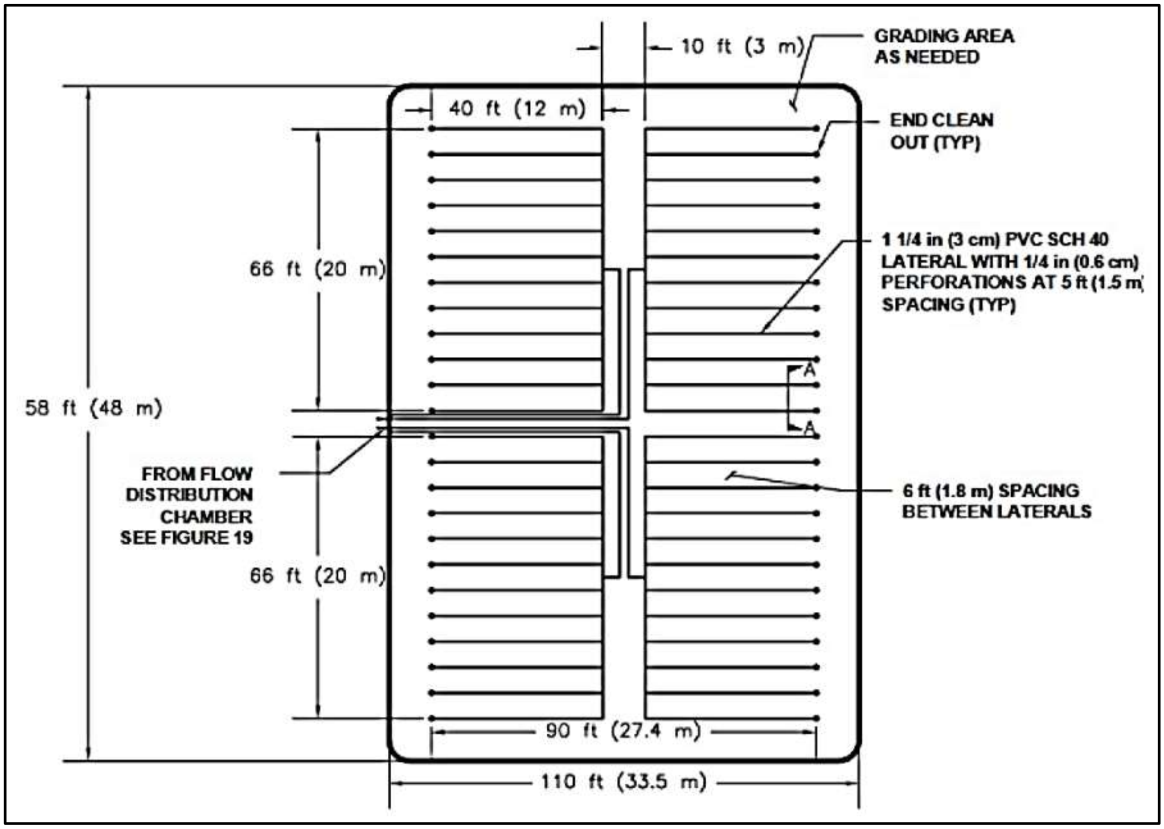


Figure 3.6. Leach Field Section A.

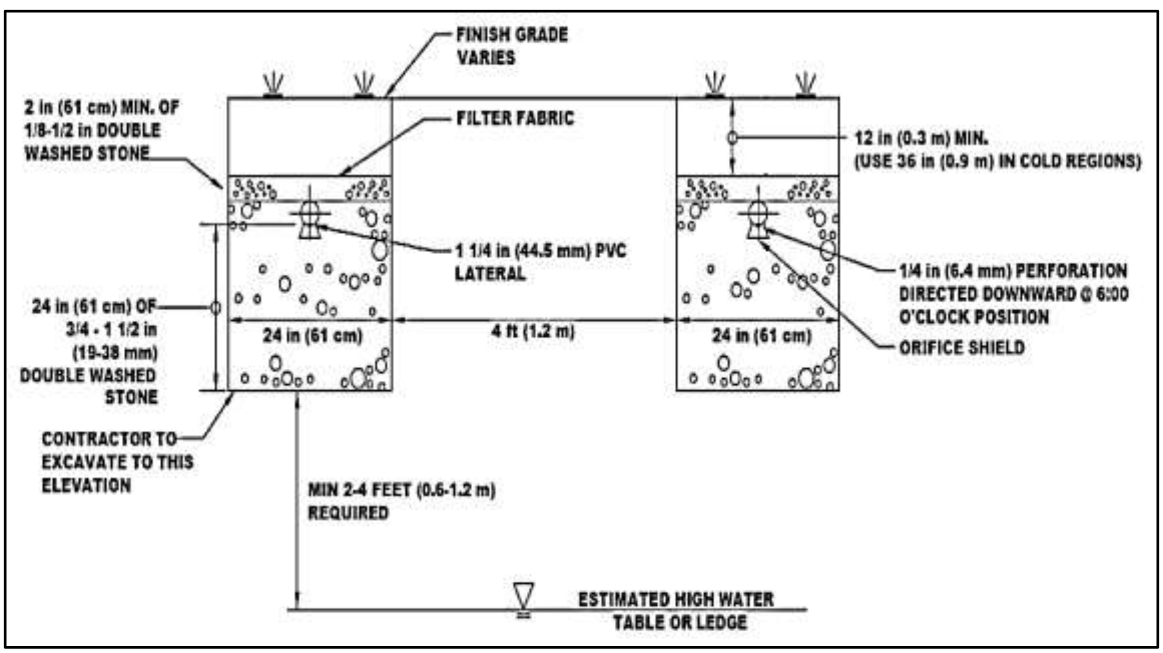


Figure 3.7. Leach Field Installation.

Figure 3.8. Distribution Arrangement.

3.3.2.7. Loading Rates – Leach Field Sizing. Generally, the design hydraulic loading rates for leaching systems are based on a typical BOD loading from a septic tank of 150 mg/L, the soil texture classification determined during the site excavation, groundwater elevation, and the percolation rate measured in the field. See **paragraph 2.6.3.5** and **Table 2.37** for information on percolation rate and soil textural class as identified in the site evaluation description. In **Table 2.37**, adjusted loading rates account for the long-term acceptance rate of the leach field. The long-term acceptance rate is limited in part by the texture of the soil layers under the field and the formation of a biomat based on the strength of effluent applied to the soil. Where engineers expect significant increased BOD strength, the loading rate may need adjustment. For this comparison, consult **Table 2.38**. The following paragraph presents an example that outlines the design process.

3.3.2.8. Leach Field Design Example. Given a site with a staff of 75 and non-mobile water assets, size a leach field to follow a septic tank. Installation shall be in a fine, sandy loam (Class II soil) with a percolation rate of 30 minutes/inch.

3.3.2.8.1. Refer to **Table 2.37** to determine the hydraulic loading rate (HLR) based on soil classification and percolation test.

$HLR_{(perc)}$ = 0.33 gpd/sf

3.3.2.8.2. If the percolation test is not available, refer to **Table 2.38** to compare HLR based on the BOD concentration expected for septic tank effluent at 150 mg/L. Make adjustments if necessary.

$HLR_{(BOD)}$ = 0.2–0.4 gpd/sf.

3.3.2.8.3. Use $HLR_{(perc)}$ = 0.33 gpd/sf because assumed BOD level = 150 mg/L and $HLR_{(perc)}$ is within the range noted above.

3.3.2.8.4. Determine average daily flow (ADF):

75 staff x 40 gpcd (from Table 2.27) = 3,000 gpd

3.3.2.8.5. Calculate required leaching area = ADF ÷ HLR

Area = 3,000 gpd ÷ 0.33 gpd/sf
Area = 9090 sf; use 10,000 sf

3.3.2.8.6. Determine minimum leaching area using a length:width ratio of 1.5:1. **Note:** Recommend dividing leaching area into four equal zones to minimize dose volume and allow for partial replacement if damage occurs to a section of the leach field. For this example, operators will dose the four zones two at a time (each pair off a dedicated force main).

Area = 1.5 W x W
10,000 sf = 1.5 W^2
6,666 sf = W2
W = 82 ft., L = 123 ft.

3.3.2.8.7. Determine leaching area piping layout using four zones to minimize each dose volume and thus reduce the size of the pump required. Minimum area for each zone = 1/4 (10,000); or each with dimensions 41 ft x 61.5 ft. To keep lateral length within 40 feet and simplify spacing:

Four zones, each: 40 ft. W x 66 ft. L

3.3.2.8.8. Calculate number and size of the laterals required for effluent distribution in each zone:

Lateral spacing = 6 ft. on center; 11 laterals required per zone
Orifice openings are 0.25 inch and spaced at 5 ft. (staggered), eight per lateral

3.3.2.8.9. Total area required for this system includes 10-foot grading buffer around perimeter, 6- foot spacing between zones along the length, and 10-foot spacing for installing two parallel distribution header lines to the zones, as shown in **Figure 3.5**.

3.3.3. Conventional Septic System Equipment List. Shown in **Table 3.5**, is a list of equipment to construct a conventional septic tank and leach field system as described above and designed for 3,000 gpd (11,360 Lpd).

Table 3.5. Septic System Materials and Equipment List.

Items	Details	Approximate Quantity
PVC pipe (2 Inches diameter)	4 x 66 ft + 2 x 200 ft to leach field 20-ft lengths.	900 LF*
Perforated PVC pipe (1.25 inches diameter, 0.125-inch perforations)	48 x 40 ft laterals, 20-ft lengths.	1,900 LF
PVC sewer pipe (6 to 8 inches diameter)	Sold in 20 LF lengths.	1,000 LF
Washed stone	Used for laterals 2 ft^2 centered on lateral.	150 CY**
Gravel base mix	Used for trenches and tanks.	50 CY
Leach field sand	110 ft x 158 ft x 2 ft trench stone.	1,160 CY
8,000-gallon dual chamber concrete septic tank	18 ft x 6 ft x 12 ft	1
4,500-gallon effluent dosing chamber	10 ft x 6 ft x 8 ft	1
Duplex dosing pumps and controls	Submersible pumps with control panel.	1
4-foot-diameter manholes	One manhole every 300 LF of sewer pipe.	3
24-inch-diameter manhole frame and cover	Three for manholes; Two for septic tank; One for dosing chamber.	6
*LF=linear feet **CY=cubic yard		

3.4. Lagoon Systems. Generally, the design and sizing of facultative lagoons is based on the retention time required for adequate BOD removal. Adequate surface area is also required so wastewater can interface with atmospheric oxygen. Lagoons can be almost any shape; however, in the rectangular formation the length usually does not exceed three times the width. **Table 3.6** summarizes the surface areas and dimensions of ponds for various flow conditions.

3.4.1. **Sizing.** Specific steps for sizing facultative lagoons are addressed below:

3.4.1.1. Determine the average air temperature in the region where unit is installing the lagoon.

3.4.1.2. Based on the average air temperature, select an areal loading rate and the total treatment time from **Table 3.6**.

3.4.1.3. Based on **Table 2.27**; determine the flow rate into the lagoon.

Table 3.6. Areal Loading Rates.

Average Air Temperature	Areal Loading Rate*	Total Treatment Time
< 0 °C (< 32 °F)	11–22 kg/ha/d (9.8-19.6 lb/ac/d)	150–180 days
0-15 °C (32–59 °F)	22–45 kg/ha/d (19.6–40 lb/ac/d)	40–150 days
> 15 °C (> 59 °F)	45–90 kg/ha/d (40–80 lb/ac/d)	10–40 days
* - kilogram (kg) / hectare (ha) / pounds (lb) / acre (ac) / day (d)		

3.4.1.4. Calculate the BOD loading into the lagoon by multiplying the flow rate by the BOD concentration. If the BOD concentration is unknown, use 200 mg/L as a standard value.

3.4.1.5. Based on the BOD loading and the areal loading rate, determine the required surface area of the lagoon using the following equation:

$$\text{Surface area} = \frac{\text{BOD loading}}{\text{Areal loading rate}}$$

3.4.1.6. Determine the dimensions for the surface area of the lagoon. Lagoons can range from square to rectangular; however, the length usually does not exceed three times the width for a rectangular lagoon.

3.4.1.7. Based on the flow rate and total treatment time; calculate the total volume required for the lagoon.

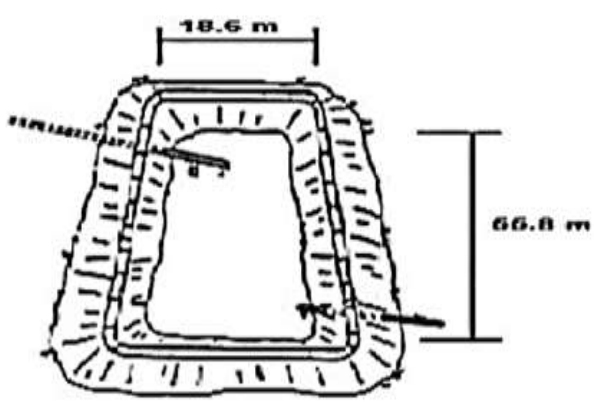
$$\text{Total volume} = \text{flow rate} \times \text{total treatment time}$$

3.4.1.8. Based on the required total volume and the surface area, calculate the depth of the lagoon.

Depth = total volume ÷ surface area

3.4.1.9. Calculate the total area required for the lagoon by adding additional area for berms, fences, etc. **Table 3.7** shows an example calculation.

Table 3.7. Example Total Area Calculation.

Known: Average air temperature = 0–15 °C (59 °F) Flow rate = 3,000 gpd = 11,356.24 Lpd	
Example Calculation: Areal loading rate = 22 kg/ha/d Total required retention time = 150 days BOD loading = 11,356.24 Lpd x 200 mg/L x (1 kg ÷ 1,000,000 mg) = 2.27 kg/day Surface area = (2.27 kg/day ÷ 22 kg/[ha/day]) x (10,000 m^2 ÷ 1 ha) = 1,032 m^2 Length = 3 x width Surface area = length x width = 3 x $width^2$ Width = $(\text{surface area})^{1/2} \div (3)^{1/2} = (1{,}032\ m^2)^{1/2} \div (3)^{1/2}$ = 18.6 m Length = 3 x 18.6 m = 55.8 m Total volume = (1 m^3 ÷ 1,000 L) x 11,356.24 Lpd x 150 days = 1,703 m^3 Depth = 1,703 m^3 ÷ 1,032 m^2 = 1.65 m	
Final Lagoon Dimensions: Length = 55.8 m Width = 18.6 m Depth = 1.65 m	

3.4.2. Selecting Type and Discharge Arrangement. There are various discharge types for facultative lagoons. A continuously discharging lagoon maintains the level of wastewater in the lagoon by discharging at the same rate it is receiving influent flow. In this situation, the most direct flow path must be adequate in length for treatment to occur. A complete retention lagoon (or evaporation lagoon) never releases flow from the containment area, but instead relies on evaporation and percolation to discharge at a rate higher than the influent rate to maintain a constant volume. Engineers usually size the controlled discharge lagoon to only discharge once or twice a year. In colder temperatures, a facultative lagoon's treatment process slows or ceases completely. In a controlled discharging lagoon, the untreated winter flows remain in the lagoon until warmer temperatures return and treatment occurs.

3.4.3. Lining Requirements. Lagoon liner alternatives include compacted clay in locations where low permeable soil conditions are compatible. Where soils are too permeable, consider installing synthetic liners such as laminated rubber, polyethylene, or PVC with a minimum thickness of 30 mils (0.03 inch) over a cushioning layer. Concrete liners are another alternative to consider if anticipating O&M issues. Sites suitable for unlined lagoons must have soils with percolation rates of 120 minutes/inch (47 min/cm) or less. Where soils are too permeable, a synthetic liner may be used. The liner needs to be at least 30-mil (0.03 inch) -thick and is typically made of laminated rubber compounds. Installation may require the services of a professional liner contractor, although homeowner-installable liners are available. To install such a liner, complete the soil-shaping portion of the lagoon then lay down a layer of sand or geotextile fabric to protect the liner from rock punctures when applying it over the cushioning layer. Depending on the manufacturer, seams in the liner may be hot-fused or overlapped; and consider anchoring the ends of the liner material in a trench dug in the top of the berms around the perimeter of the lagoon. Not all lagoons require seams; manufacturers sell sheets in sizes as large as 40,000 ft^2 (3,700 m2). If PVC is used, cover the liner with 12 inches (30.5 cm) of soil to prevent photodegradation. The inside dikes should not exceed a 3:1 slope to prevent slumping of the soil.

3.4.4. Construction Guidelines. When locating a site for the treatment lagoon, it is important to maintain certain setback distances from clean water sources. See **Chapter 2** for specific siting, location, and separation guidance.

3.4.4.1. Build the berms in 4- to 6-inch (10 to 15 cm) lifts of moist soil, taking time to compact each layer of soil before adding the next. To ensure an adequate seal in the clay liner on the lagoon bottom, it is important to destroy the original soil structure by repeated compaction and/or disking with rubber-tired equipment, such as a wheel tractor or a sheepsfoot roller. A 12-inch (30.5 cm) total thickness of compacted clayey soil on the bottom and up the inside slopes of the lagoon will generally provide an adequate seal.

3.4.4.2. Liners must be leak-tested at the time of installation. Ensure the bottom of liner is at least 3 feet (1 m) above the highest seasonal ground water level. In wet areas, this may preclude excavation and require the construction of elevated berms to contain the lagoons. For lagoons bermed above the surrounding ground level, build with an overflow culvert or spillway at the top of the berm to ensure against washout. In addition, keep water from surface drainage or storm runoff out of lagoons. Sometimes it is necessary to install diversion terraces or drains at the site. See **Figure 3.9** and **Figure 3.10** for a component overview and profile for facultative lagoons.

Figure 3.9. Component Overview Facultative Lagoon.

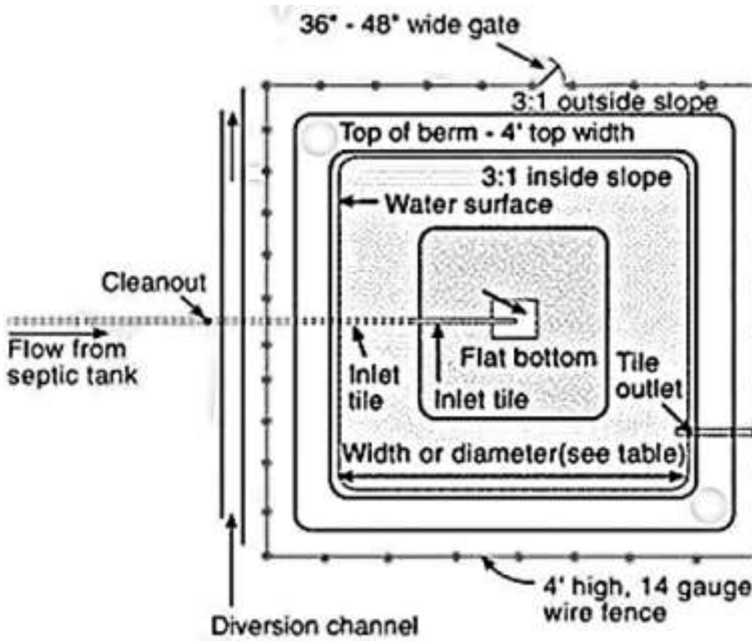
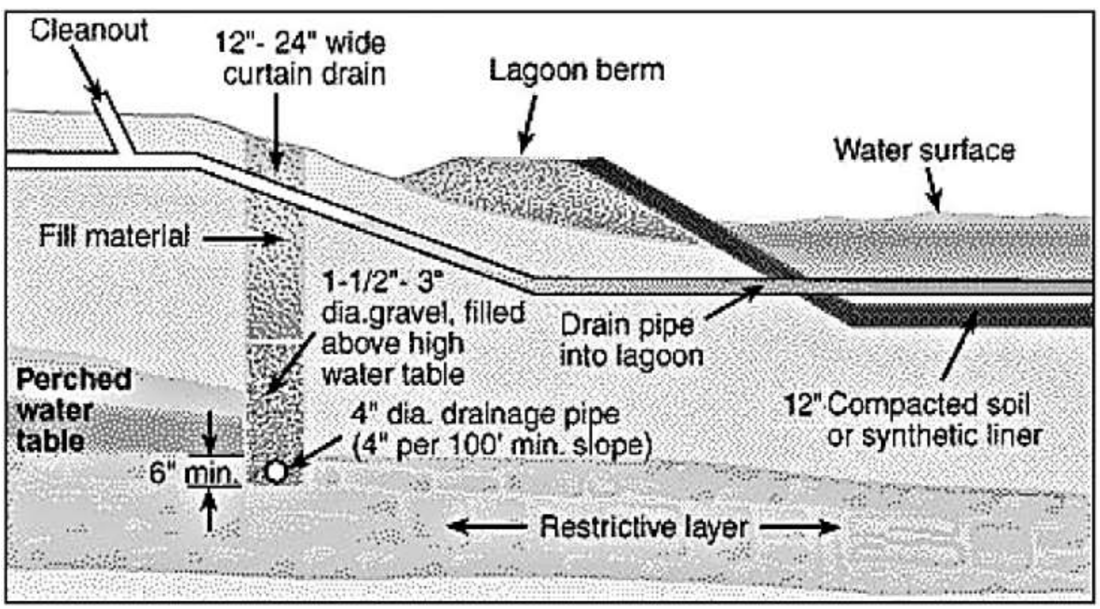


Figure 3.10. Lagoon Profile.



3.4.4.3. No starter bacteria or other additives are necessary to put a new lagoon into use. However, it is desirable to have the excavated area fully saturated and the lagoon prefilled with enough water for solids to stay in suspension. During wet weather, consider prefilling the lagoon by temporarily diverting runoff from a roof or footing drain into the lagoon. During drier weather, consider prefilling the lagoon by pumping water from a facility water well or nearby pond. Do not allow the lagoon's compacted earthen liner to dry out. After this initial prefill, the lagoon will gradually fill by the incoming effluent. For additional information on basic and advanced lagoon/pond design and construction, see EPA 600/R-11/088, *Principles of Design and Operations of Wastewater Treatment Pond Systems for Plant Operators, Engineers, and Managers*. Find this and other EPA manuals at https://search.epa.gov/epasearch/epasearch.

3.4.5. Equipment List. **Table 3.8** provides a list of equipment necessary to install a lagoon system sized for 3,000 gpd (11,360 Lpd), as designed in this example.

Table 3.8. Lagoon System Materials and Equipment List.

Items	Details	Approximate Quantity
PVC pipe (2 inches diameter)	4 x 66 ft. + 2 x 200 ft PS to leach field 20-ft lengths	900 LF
PVC sewer pipe – collection (6–8 inches diameter)	20-ft lengths	1,000 LF
PVC sewer pipe – lagoon piping (6–8 inches diameter)	20-ft lengths	1,000 LF
Gravel base mix	For pipe trenches and tanks	50 CY
Lagoon berm fill	Uniform material	900 CY
Sand bedding/ ballast	110 ft. x 158 ft. x 2 ft. trench stone	700 CY
Poly-liner	30 mils	4,000 SY
8,000-gallon dual chamber concrete septic tank	18 ft. x 6 ft. x 12 ft.	1
4,500-gallon lagoon dosing chamber	10 ft. x 6 ft. x 8 ft.	1
Duplex pumps and controls	Submersible pumps w/control panel	1
4-foot-diameter manhole	Three MHs for sewer and one MH for disinfection	4
24-inch-diameter manhole frame and cover	Three for manholes, two for septic tank, one for disinfection	6

3.5. Recirculating Sand Filters. Engineers employ these filters as secondary treatment methods to polish effluents from septic tanks or aerobic treatment processes. Operators intermittently apply wastewater to the surface of the bed through distribution pipes or troughs. Recirculating sand filters require only one-fifth of the land area as single-pass or intermittent sand filters and therefore have a wider application where nitrogen-removal treatment is a requirement. The increased hydraulic recycle rate improves process control and reduces odors. Recirculating sand filters are aerobic, fixed-film bioreactors and considered the generic equivalent of proprietary treatment systems now available on the commercial market. BOD and TSS removals are generally 70 to 80 percent and effluent values of less than 30 mg/L are common. Ammonia removal is by nitrification, and the recirculating allows nitrate removal for an overall reduction of total nitrogen by over 50 percent.

3.5.1. Design Characteristics and Specifications. Filter media characteristics determine the required filter area, dose volumes, and dosing frequency. Consider the available media before completing the detailed design of the system. There are detailed specifications in EPA-625/R-00/008, but, in general, select sand or gravel that is washed, durable, and rounded, with fine particles passing U.S. No. 200 sieve and limited to 3 percent by weight (**Figure 3.11**). Other alternative types of media may be an option, including crushed glass, anthracite, garnet, plastic, open-cell foam, expanded shale, or expanded clay.

Figure 3.11. Sand Filter Media.

3.5.1.1. Consider recirculating sand filters when a deployment site has an onsite water supply well and recommended distances between the well and leach field is not maintainable. Another reason for considering recirculating sand filters is to improve effluent quality to allow a reduced leach field area or to accommodate shallow groundwater conditions. In these cases, effluent disinfection prior to discharge may also be considered. **Table 3.9** provides a summary of typical design specifications for recirculating sand filters.

Table 3.9. Typical Design Specifications for Recirculating Sand Filters.

Design Parameter	Typical Design Value
Media	Durable, washed sand/gravel with rounded grains
Specifications Effective size (Sand) Effective size (Gravel) Uniformity Percent fines passing 200 sieve or < 0.074 mm)	 1.0 – 5.0 mm 3.0 – 20.0 mm < 2,5 < 3
Depth	24 inches (18 to 36 inches or 0.5 to 1 m)

Design Parameter	Typical Design Value
Mass loadings Hydraulic loading Sand Gravel Organic loading Sand Gravel	 3-5 gpd/ft^2 (122-204 Lpd/m^3) 10-15 gpd/ft^2 (407-611 Lpd/m^3) < 5 lb BOD_5/1000ft^2-d (<118 g BOD_5/m^2-d) < 15 lb BOD_5/1000ft^2-d (< 355 g BOD_5/m^2-d)
Underdrains Types Slope Transition bedding Size	 Slotted or perforated pipe 0—0.1% 0.6—1.0 cm washed pea gravel 0.6—4.0 cm washed gravel or crushed stone
Dosing Frequency Per dose	 48 times/day (every 30 minutes) or more 1 to 2 gallons/orifice (4 to 8 L/orifice)
Recirculation tank Volume Recirculation rate	 1.5 times design daily flow 3 to 5 times daily flow
Note: 5-day Biochemical Oxygen Demand (BOD_5) Source: EPA Onsite Treatment Systems Technology Fact Sheet 11, *Recirculating Sand/Media Filters*.	

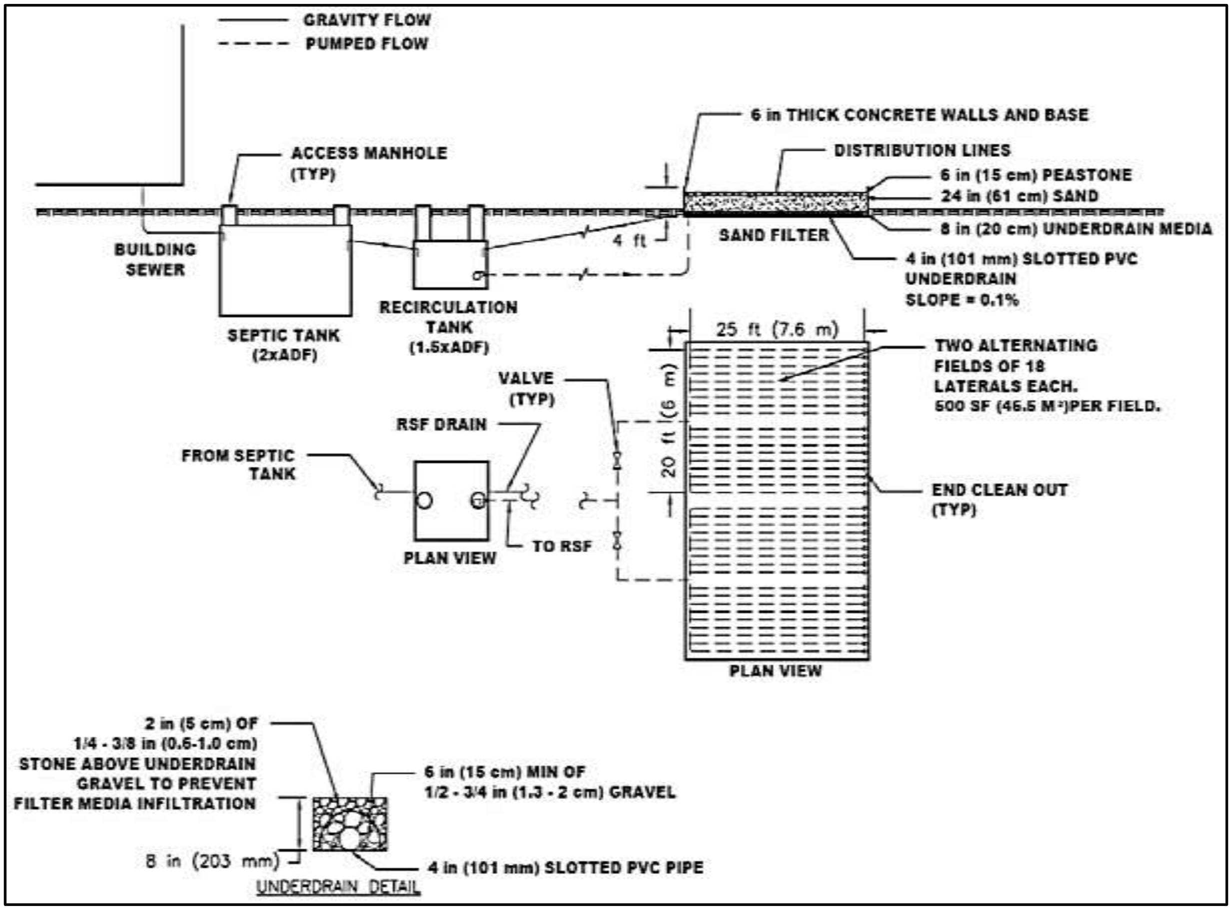
3.5.1.2. As shown in **Figure 3.12**, the basic components of recirculating filters include a recirculation/dosing tank, pump and controls, distribution piping network, filter bed with underdrain system, and a gravity return line back to the tank where mixing with the septic tank effluent occurs before being reapplied to the filter.

3.5.1.3. Filter dosing is on low volume cycles (typically two to three times per hour). Recirculation ratios are typically between 3:1 and 5:1. Time-cycled doses, typically 48 times per day, allow the media to rest between loadings for more effective treatment. Calculate the dose volume as follows:

Dose volume (gal) = design flow (gpd) x (recirculation ratio +1)/number of doses per day

3.5.1.4. The proposed arrangement includes a recirculation/dosing tank and dual train sand filters with underdrain return. Following this system would be a leach field for final discharge as shown in **Figure 3.5** and **Figure 3.6**. Refer to **paragraph 3.5.2** for recirculating sand filter system design explanation and procedures, and **Table 3.10** for an example of design calculations for a recirculating sand filter.

Figure 3.12. Recirculating Sand Filter Design Example.



3.5.2. Design Procedures.

3.5.2.1. Determine the average daily flow (ADF) and the design flow (Q) for the facility. The ADF is the amount of wastewater to be treated daily and may be estimated using **Table 2.27**.

(Q = ADF)

3.5.2.2. Determine hydraulic loading rate (HLR). The HLR ranges from 3 to 5 gallons per day per square foot (gpd/ft^2), dependent on the media type. For coarse sand like that found in recirculating sand filters, use 3 gpd/ft^2.

HLR = 3 gpd/ft^2 for coarse sand

3.5.2.3. Determine the area required (A).

A (ft^2) = ADF/HLR

3.5.2.4. Determine tank dimensions (L x W). Two parallel basins are recommended to allow alternating dosing. Each basin provides one-half the required area. For each, the length (L) is 1.5 times the width (W), but not greater than 50 feet.

L = 1.5 x W (ft) or 50 ft, whichever is less A (ft^2) = L (ft) x W (ft) x number of basins

3.5.2.5. Determine the recirculation ratio (RR) required. RR is the total flow through the recirculating sand filter compared to the design flow. In general, the RR is between 3:1 and 5:1. The higher RR is recommended for a conservative design since higher loading concentrations are expected.

RR = 5:1

3.5.2.6. Determine the influent flow (Q_i).

Q_i = ADF x (RR +1)

3.5.2.7. Determine doses per day. For a typical design, the number of pump cycles would be four to eight cycles per hour or every 7.5 to 15 minutes. Use 15-minute intervals to preserve the life of the pump.

Doses per day = 15 minutes x (1 hour ÷ 60 minutes) x (1 day ÷ 24 hours)
Doses per day = 96

3.5.2.8. Determine dose volume.

Dose volume (gallons) = Q_i ÷ (doses per day)

3.5.2.9. Determine the number of laterals required. A lateral is a perforated pipe used for the even distribution of flow over an area. The number of laterals required is based on the dimensions of the recirculating sand filter being installed. Laterals shall be spaced 2 feet on center (o.c.) along the width (W) of the recirculating sand filter.

Number of laterals per basin = (width – 2 feet) ÷ 2 feet

3.5.2.10. Lateral size. Laterals shall be made using a 0.75-inch-diameter pipe. Laterals shall extend from the influent to 1 foot from the opposite wall.

Lateral diameter = 0.75 inch Lateral length = L - 1 foot

3.5.2.11. Orifice size. The laterals shall be perforated with 0.25-inch-diameter orifices.

Orifice diameter = 0.25 inch

3.5.2.12. Orifice spacing.

Orifice spacing = 2 feet o.c.
Orifice spacing = 1 foot o.c. at lateral ends

3.5.2.13. Flow through orifice.

Orifice flow ≤ 2 gallons per dose (recommended maximum)

3.5.2.14. Determine number of orifices required.

Number of orifices = dose volume ÷ orifice flow

3.5.2.15. Determine number of orifices per lateral. The orifices are spaced 2 feet o.c.; therefore, the number of orifices is equal to the length of the lateral minus 2 feet divided by 2 feet.

Orifice per lateral = (length of lateral – 2 feet) ÷ 2 feet.

3.5.2.16. Determine total number of orifices.

Orifice total = orifice per lateral x number of laterals per basin x the number of basins

3.5.2.17. Recirculation pump runtime (T_p). Each recirculation pump shall be designed to operate for five minutes per pump cycle. See **paragraph 3.9.4.1** for information on sizing the recirculation pump.

T_p = 5 minutes x doses per day ÷ number of pumps

3.5.2.18. Determine flow rate per dose. To determine the flow per dose, divide the influent flow (Q_i) by the total pump runtime (T_p).

Flow per dose (gpm) = $Q_{\mathbf{i}} \div T_{\mathbf{p}}$

3.5.2.19. Determine flow rate per orifice. The flow per 0.25-inch orifice does not exceed 0.43 gpm. If the flow per orifice is less than or equal to 0.43 gpm, then the design is complete. If the flow per orifice is greater than 0.43 gpm, additional orifices are required, and the surface area of the recirculating sand filter basin will need to be increased.

Flow per orifice = flow per dose ÷ orifice total

Table 3.10. Recirculating Sand Filter Design Calculations Example.

Recirculating Sand Filter Design Calculations
Problem: Given a site with a staff of 75 and non-mobile water assets, design a two-basin recirculating sand filter. Recirculation pumps will cycle on and off four times per hour and will run for five minutes upon startup. Given the site conditions and the guidelines provided here on locating septic systems, the maximum width for the recirculating sand filter that the site can accommodate is 20 feet. Assume a recirculation ratio of 5:1 based on location.
Solution: ADF = 75 staff x 40 gpcd (from **Table 2.27**) = 3,000 gallons per day (gpd) Design flow (Q) = ADF = 3,000 gpd Q= 3,000 gpd HLR (coarse sand) = 3 gpd/ft^2 A = Q/HLR A= 3,000 gpd ÷ 3 gpd/ft^2 = 1,000 ft^2 A = 1,000 ft^2 Two basins; therefore, the area of each basin is: 1/2 A = 500 ft^2 A = L x W 500 = L x W Where: W = 20 feet Solve for L L = 25 feet **<u>Dimensions of basin: 20 feet x 25 feet</u>** Total amount of flow (Q_i): Q_i(gpd) = Q(gpd) x (RR + 1) Q_i = 3,000 gpd x 6 Q_i = 18,000 gpd Number of doses per day: (24 hours/day) x (4 doses/hour) = 96 doses/day Dose volume (VD): VD = (18,000 gpd) ÷ (96 doses/day) VD = 188 gallons/dose Number of laterals per basis = (W – 2) ÷ 2 (20 feet – 2 feet) ÷ 2 **<u>Required laterals per basin</u> = 9**

Recirculating Sand Filter Design Calculations
Number of orifices = VD ÷ 2 gallons per orifice Number of orifices = 188 gallons ÷ (2 gallons/orifice) Number of orifices = 94 Number of orifices per lateral = (L - 1) ÷ 2 Orifices = (25 feet – 1 foot) ÷ 2 feet Orifices per lateral = 12 Total number of orifices per basin = 12 orifices/lateral x 9 laterals Total number of orifices per basin = 108 Two basins ∴ = 216 orifices **216 orifices are > 94, so this is satisfactory** Total runtime per day per recirculation pump (T_P) = 5 minutes x (96 doses/day ÷ 2 pumps) T_P = 240 minutes/day Flow per dose provide by the pumps = Q_i ÷ (2 x T_P) Flow per dose = (18,000 gpd) ÷ (480 minutes/day) Flow per dose = 75 gpm Flow per orifice = flow per dose ÷ total number of orifices 75 gpm ÷ 216 orifices Flow per orifice = 0.35 gpm **0.35 gpm ≤ 0.43 gpm (acceptable)**
Summary of Design: Provide two basins that are each 20 feet x 25 feet. Each basin shall be equipped with nine 0.75-inch laterals located 2 feet o.c. Each lateral shall have 106 0.25-inch orifice openings located 2 feet o.c.

3.5.3. Equipment List. Presented in **Table 3.11** is a list of materials and equipment for installing a recirculating sand filter for 3,000 gpd (11,360 Lpd), as designed above. **Note:** This list is only for the recirculating sand filter, so combine it with the conventional septic system list in **Table 3.5**. For some installations, the addition of the recirculating sand filter will allow a reduction of leach field area by 50 percent.

Table 3.11. Recirculating Sand Filter System Material and Equipment List.

Items	Details	Approx. Quantity
0.75-inch PVC pipe with 0.25-inch perforations	Used for laterals 18 x 25 feet	450 LF
2-inch PVC force main	2 x 200 feet	400 LF
3-inch PVC piping	Return to PS	200 LF
4-inch PVC piping	Used for gravity recycling	400 LF
4-inch slotted PVC piping	Used for underdrain, 2x 25 feet	50 LF
Pea stone	2 x 20 feet x 25 feet, 6 inches deep	20 CY
0.25- to 0.75-inch stone	2 inches deep for underdrain	8 CY
0.5- to 0.75-inch stone	6 inches deep for gravel underdrain bed	20 CY
Gravel base mix	Used under structures, tanks, and trenches	80 CY
Sand	2 x 20 feet x 25 feet 24 inches deep for the recirculating sand filter bed	75 CY
Concrete tank w/ 8-inch-thick walls Cast-in-place	20 feet x 25 feet x 4 feet	1
4500-gallon effluent dosing chamber	10 feet x 6 feet x 8 feet	1
Duplex recycle pumps and controls	Submersible pumps w/control panel	1
24-inch-diameter manhole frame and cover	Two for concrete tank, one for dosing chamber	3
Valves, cleanouts, fittings	As necessary	1

3.6. Natural Land Treatment Systems. Natural land treatment systems are not designed to treat raw sewage; therefore, they must be preceded by either fine screens or primary sedimentation, or both. Designs include infiltration basins, spray irrigation systems, overland flow systems, and constructed wetlands. Sometimes referred to as nondischarge wastewater systems, their design should consider local conditions of water quality, climate, soil, hydrogeology, and environmental constraints.

3.6.1. Rapid Infiltration Systems. Similar to the processes taking place in a sand filtration system, rapid infiltration systems use sand and soil at the surface to facilitate physical filtering while ion exchange, chemical precipitation, and adsorption occur as the water filters downward (**Figure 3.13**). Biological treatment also occurs as wastewater mixes with air in the top 2 to 3 feet (0.6 to 1 m) of soil. Rapid infiltration's highest removal rates are in suspended solids, fecal coliform, and BOD, with limited success in nutrient and heavy metals removal. Various methods for increasing the nutrient removal rate can be implemented, including varying the wetting and drying periods, adding a pre-treatment process, adding vegetation to the topsoil, or lengthening the soil depth through which treatment occurs.

3.6.1.1. Since rapid infiltration systems operate on a feed/dry cycle, multiple process trains are required as a minimum so that one can be in use while the other(s) rest or dry (**Figure 3.14**). Influent needs to be low in TSS to prevent soil clogging. This system is not a good choice in areas with high rainfall or extremely cold weather.

3.6.1.2. While having one of the smaller aboveground footprints and typically being the most cost-effective to construct, rapid infiltration basins do have one of the shorter lifespans of most treatment processes as the land eventually become saturated with nutrients and heavy metals, reducing the systems' treatment efficiency. Major factors in locating a rapid infiltration system include soil type, depth, and percolation rates. Sands and gravel are the most desirable soil types because they are the best at facilitating percolation.

Figure 3.13. Rapid Infiltration Process.

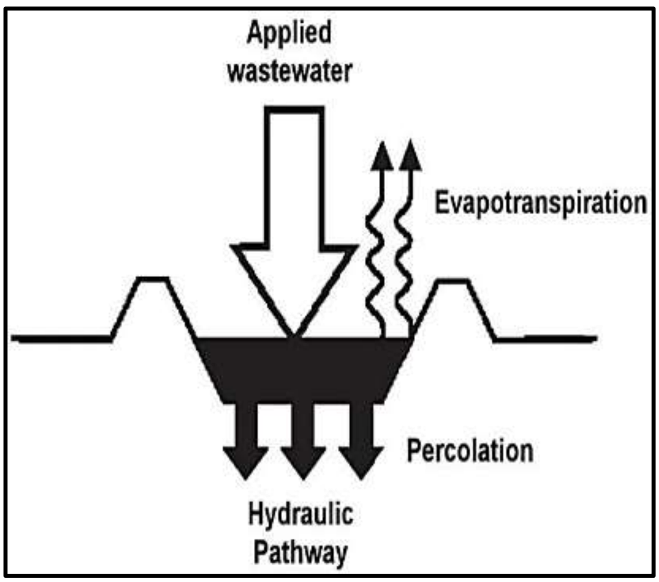
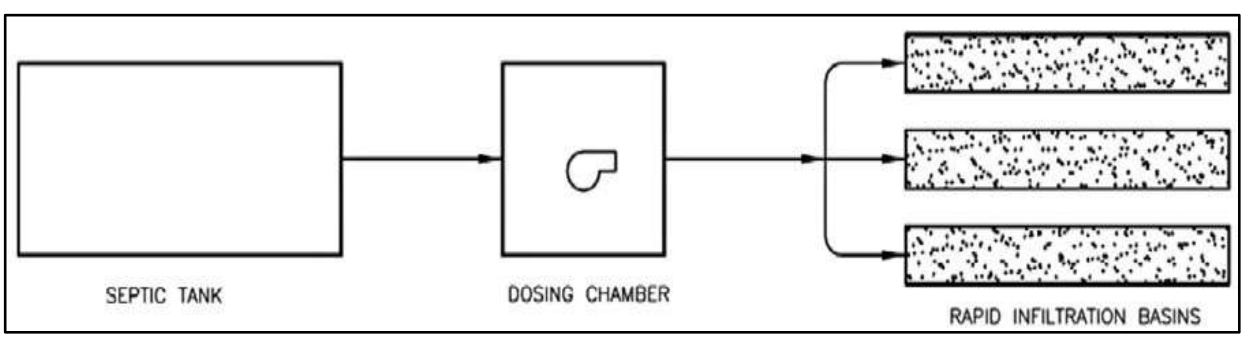


Figure 3.14. Process Flow Diagram.



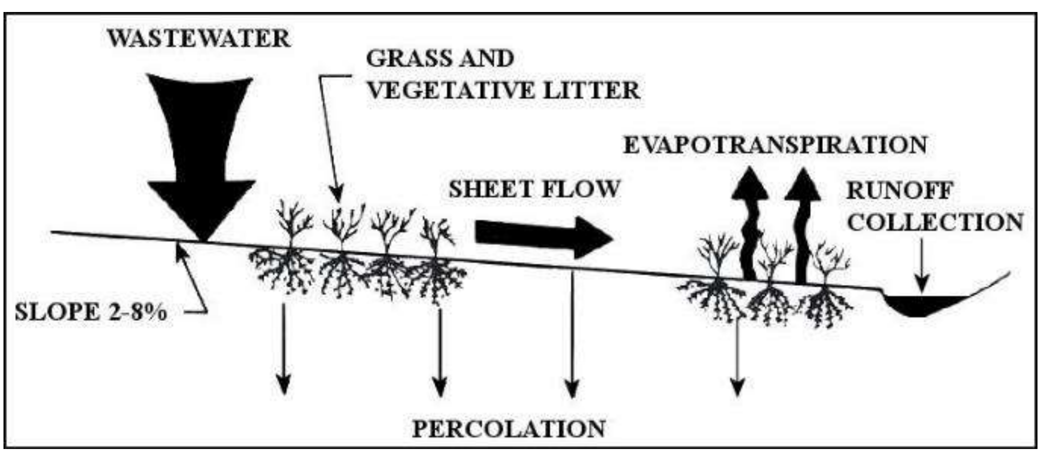
3.6.2. Irrigation Systems. Spray irrigation systems distribute wastewater evenly on a vegetated plot for final treatment and discharge. Spray irrigation can be useful in areas where conventional onsite wastewater systems are unsuitable due to low soil permeability, shallow water depth table or impermeable layer, or complex site topography. The spray irrigation system may not be ideal for certain locations because of its large areal demands, the need to discontinue spraying during extended periods of cold weather, and the high potential for human contact with the wastewater during spraying.

3.6.2.1. Spray irrigation systems are among the most land-intensive disposal systems. Drifting aerosols from spray heads can be a nuisance and should be monitored for impact on nearby land use and potential human contact. Consider using buffers, such as, vegetation, trees, or setback distances to mitigate exposure to sprayed wastewater. When using setback distances as a buffer, consider the predominant or prevailing wind direction during your deliberations. **Note:** Buffer zones for populated areas must often be as large as, or even larger than, the spray field itself to minimize problems.

3.6.2.2. When designing a spray irrigation system, pretreatment of the wastewater may be provided by a septic tank (primary clarifier), aerobic unit, sand (media) filter, disinfection unit, or other pretreatment methods. The pretreated wastewater in spray irrigation systems is applied at low rates to grassy or wooded areas. Vegetation and soil microorganisms metabolize most nutrients and organic compounds in the wastewater during percolation through the first several inches of soil. The cleaned water is then absorbed by deep-rooted vegetation, or it passes through the soil to the ground water.

3.6.3. Overland Flow. In overland flow treatment (**Figure 3.15**), pretreated wastewater is spread along a contour at the top of a gently sloping site that has minimum permeability. The wastewater then flows down the slope and is treated by microorganisms attached to vegetation as it travels by sheet flow over very impermeable soils until it is collected at the bottom of the slope for discharge. **Note:** The overland flow information and illustrations addressed in this section was adapted from EPA 625/R-06/016, *Land Treatment of Municipal Wastewater Effluents*.

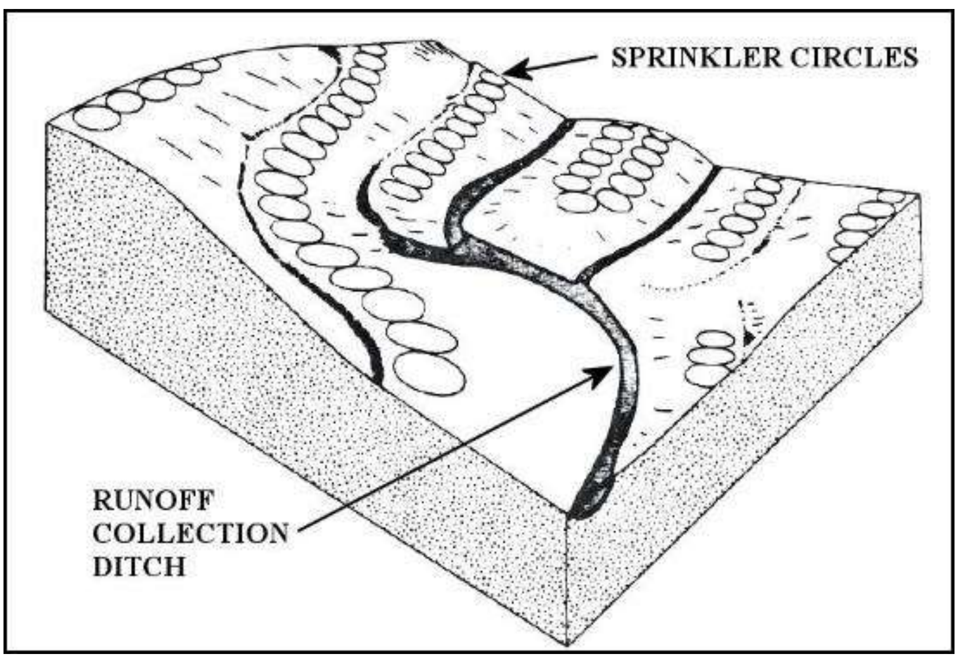
Figure 3.15. Overland Flow Hydraulic Pathway (Notional Layout).



3.6.3.1. The overland flow treatment process requires large land areas similar to the spray irrigation system. However, any necessary surface water discharge requirements (e.g., disinfection) from the overland flow system should still be met. Overland flow systems require sufficient soil depth to form slopes that are uniform and to maintain a vegetative cover. A finished slope should have a minimum of 0.15 to 0.3 m (6 to 12 in) of soil depth. The slope should be graded so that it is smooth and of nearly constant grade. This is especially true near the upper reaches of the slope to prevent channeling of wastewater and poor treatment.

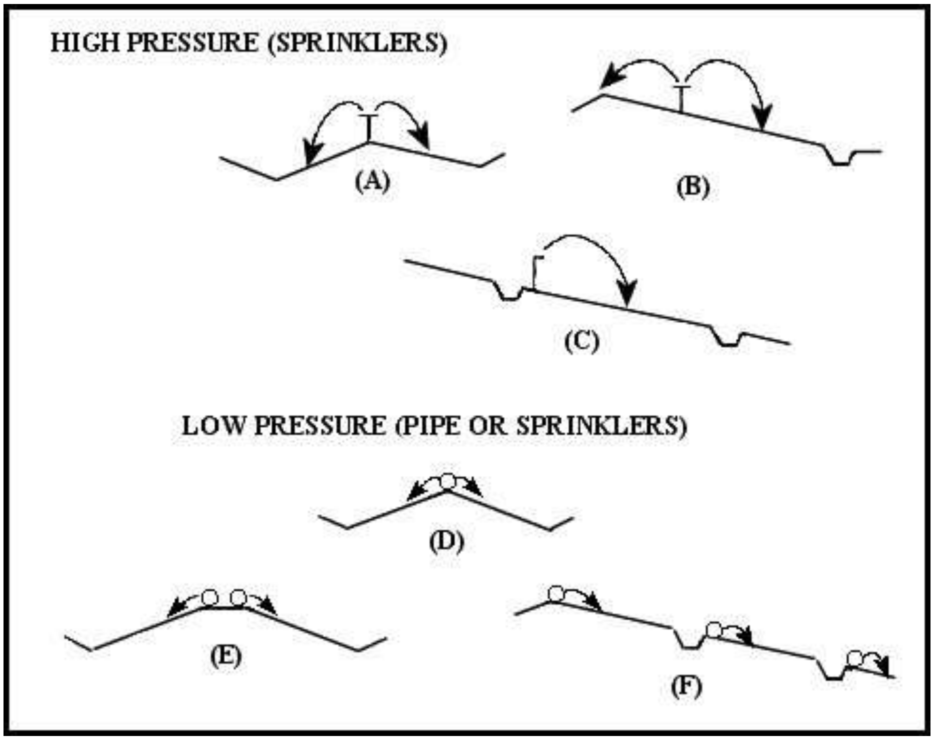
3.6.3.2. When designing overland flow treatment systems, the general layout should match as closely as possible the natural topography at the site to minimize extensive earthwork. If anticipating multiple slopes, consider laying out individual treatment slopes on a topographic map of the site until the field area requirements are satisfied. Individual slopes should be connected with a network of ditches for collection of treated runoff and stormwater runoff for conveyance to the final system discharge point (**Figure 3.16**). The choice of the system layout is also influenced by the type of wastewater distribution. If wastewater contains coarse solids that can impair and clog orifices and valves in surface and sprinkler distribution systems, fine screening or primary sedimentation with surface skimming may be necessary to prevent operating difficulties. For small systems, consider using Imhoff tanks or 1- to 2-day aerated detention ponds. For sprinkler distribution systems, screen sizes should be less than one-third the diameter of the sprinkler nozzle. Consider using grit removal for wastewaters containing high grit loads. Grit reduces pump life and can deposit in low-velocity distribution pipelines.

Figure 3.16. Overland Flow Multiple Slope Treatment and Runoff (Notional Layout).



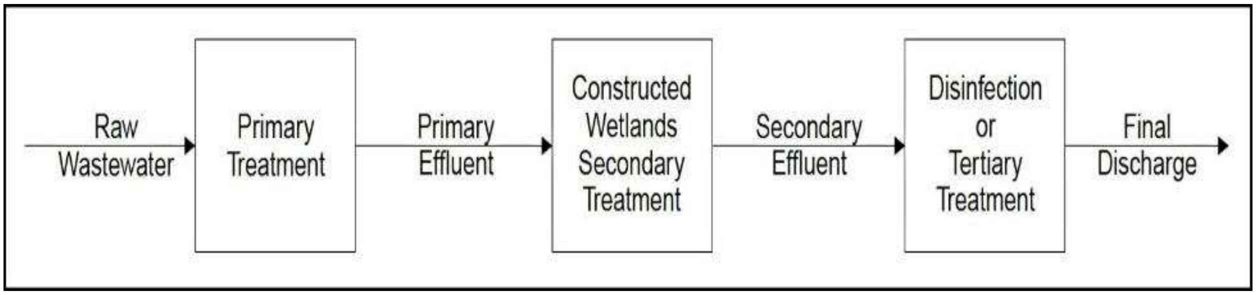
3.6.3.3. High-solids-content wastewaters are typically applied using high-pressure sprinklers to ensure uniform distribution of the solids on the treatment slope. Low-pressure systems involving gated pipe or sprinklers have been used successfully for screened, primary, secondary or pond effluents. The various possibilities for both high- and low-pressure types are illustrated in **Figure 3.17**.

Figure 3.17. Wastewater Distribution Alternatives for Overland Flow.



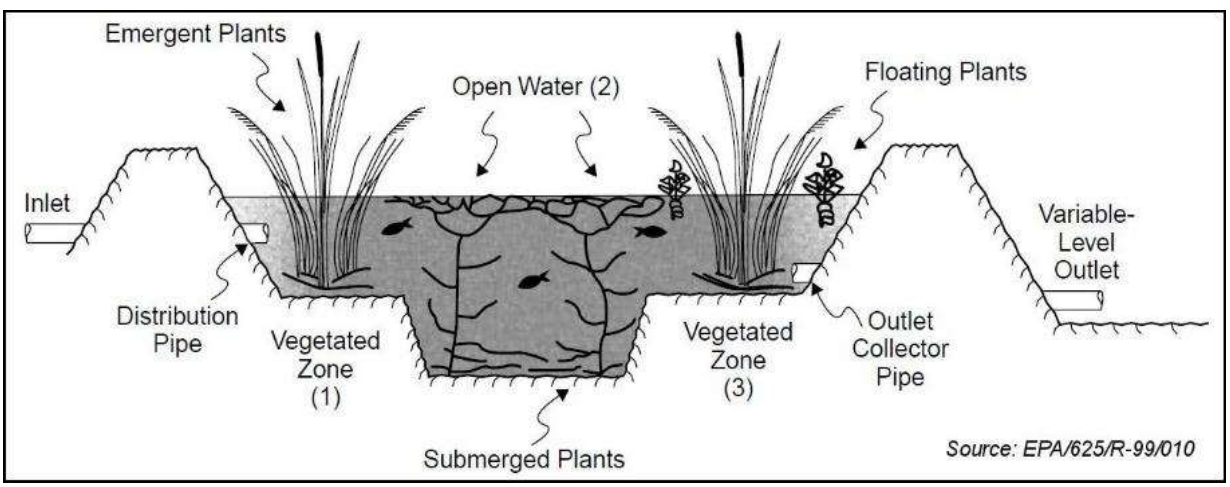
3.6.4. Constructed Wetlands. Both the FWS (surface flow) and SF (subsurface flow) constructed wetlands can be designed to provide secondary treatment of primary effluent or polishing treatment for secondary effluent. They are not for treatment of raw wastewater. These systems can also be used in combination with other secondary treatment technologies. For example, a constructed wetland could be placed upstream in the treatment train from an infiltration system to optimize the cost of secondary treatment. In other uses, constructed wetlands could discharge secondary effluent to enhancement wetlands for polishing. **Figure 3.18** portrays a hypothetical wastewater treatment train utilizing constructed wetlands in series. A brief overview of their design and function follows. The constructed wetlands design information and illustrations addressed in this section was adapted from EPA 625/R-99/010, *Constructed Wetlands Treatment of Municipal Wastewaters.*

Figure 3.18. Constructed Wetlands in Wastewater Treatment Train.



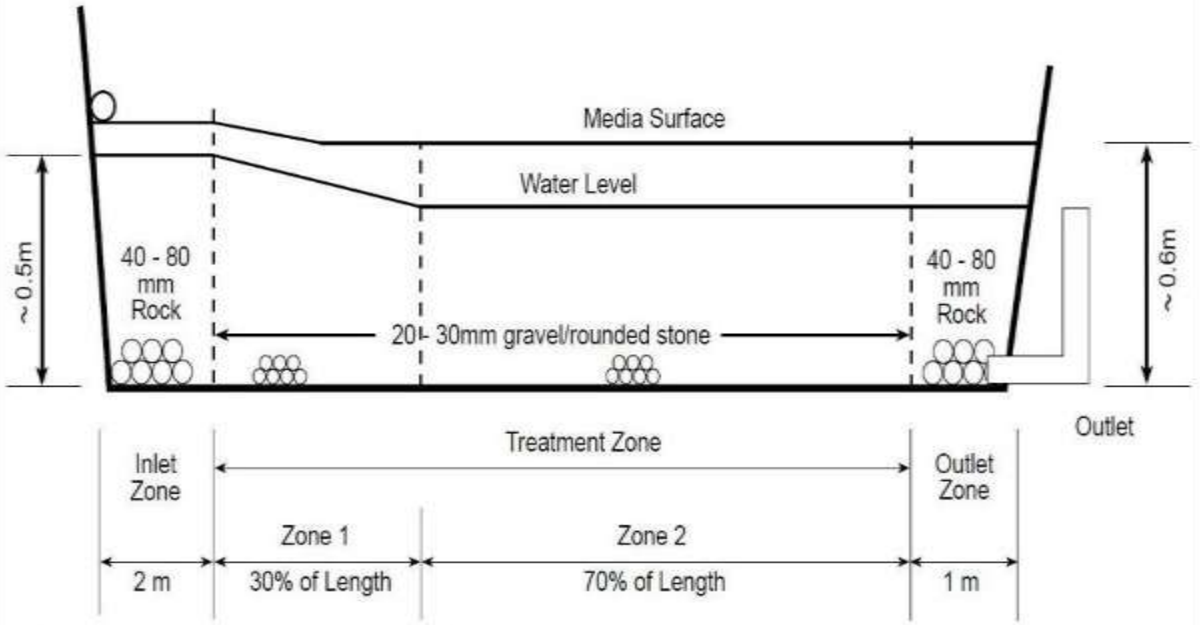
3.6.4.1. FWS systems closely resemble natural wetlands in appearance and function, with a combination of open-water areas, emergent vegetation, varying water depths, and other typical wetland features. **Figure 3.19** illustrates the main components of a FWS constructed wetland. A typical FWS constructed wetland consists of several components that may be modified among various applications but retain essentially the same features. These components include berms to enclose the treatment cells, inlet structures that regulate and distribute influent wastewater evenly for optimum treatment, various combinations of open-water areas and fully vegetated surface areas, and outlet structures that complement the even distribution provided by inlet structures and allow adjustment of water levels within the treatment cell. Shape, size, and complexity of design often are functions of site characteristics rather than preconceived design criteria.

Figure 3.19. Profile of Three-Zone FWS Cell.



3.6.4.2. SF systems, sometimes referred to as vegetated submerged bed (VSB) systems, consist of gravel beds that may be planted with wetland vegetation. **Figure 3.20** provides a schematic drawing of a SF system. Similar to the FWS system described above, a typical SF system contains berms and inlet and outlet structures for regulation and distribution of wastewater flow. In addition to shape and size, other variable factors are the choice of treatment media (gravel shape and size, for example) as an economic factor, and selection of vegetation as an optional feature that affects wetland aesthetics more than performance.

Figure 3.20. Inlet, Outlet and Treatment Zones of SF System (Side View).



Source: Adapted from EPA/625/R-99/010, Constructed Wetlands Treatment of Municipal Wastewaters

3.7. Package Wastewater Treatment Plants. Package wastewater treatment plants can be obtained from various manufacturers. Some prefabricated plants may be capable of being relocated, depending on size and original construction. Most of these units are factory fabricated and shipped as complete units, ready for connection to piping and power. When choosing the type and design of the wastewater treatment plant for the location, consider the wastewater characterization and average daily flow rates. The size of the system selected should be conservative to account for peak flow conditions. Also consider the effluent quality standards stated in guidance for the contingency location. Package treatment plants have been used for small, medium, and large installations, both temporary and permanent. Typically, wastewater treatment plants are designed to treat flows as low as 0.002 million gallon/day (mgd) or as high as 0.5 mgd, although they more commonly treat flows between 0.01 and 0.25 mgd. Effluent from these systems can be discharged to surface water or applied to the land. Chapter 2 provided an overview of the types of commercial systems and package plants. This section addresses design considerations for two common types of package plants, extended aeration, and sequencing batch reactors.

3.7.1. Extended Aeration Package Plant. Extended aeration package plants are largely preassembled, allowing rapid installation with a minimum of site preparation. For this reason, they are sometimes used for temporary or emergency applications. Generally, extended aeration package plants utilize steel tankage, but precast concrete is also used. If the system is small enough, the entire system should arrive as one unit that is ready to be installed. Tanks may be compartmentalized into flow equalization, aeration, clarification, disinfection, and aerated sludge holding/digestion segments. For larger systems, segments such as the clarifier, aeration chamber, disinfection tank, and digestion tank (if included) may be delivered as separate units, which are then assembled on-site.

3.7.1.1. The design of package plants and components such as aeration basins and clarifiers are pre-engineered, therefore, system selection is mostly based on wastewater flow. Furthermore, biological organisms within the system need sufficient contact time with the organic material 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.

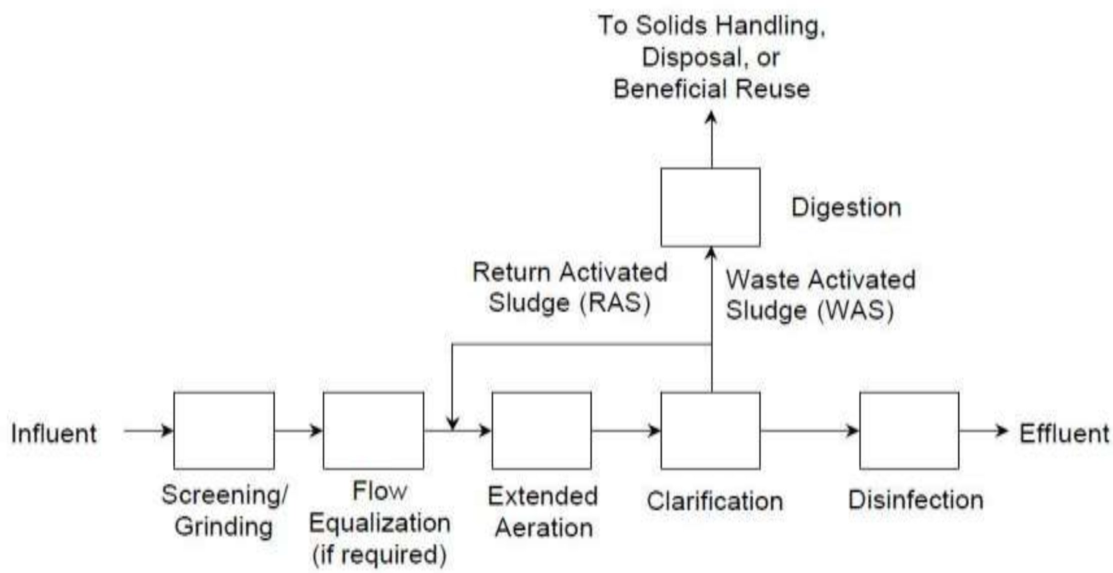
3.7.1.2. An extended aeration package plant is sized based on the average volume of wastewater produced within a twenty-four hour period. Although provisions are made for some peaking factor, a flow equalization system may be necessary to prevent overloading of the system from inconsistent flow rates in the morning and evening. Equalization allows the wastewater to be delivered to the treatment plant at more manageable flow rates. **Table 3.12** provides typical sizing of unit processes at average design flows of 0.01 to 0.1 mgd.

Table 3.12. Typical Component Sizing for Extended Aeration Plants.

	At Average Design Flow (mgd)		
Unit Process	**0.01**	**0.05**	**0.10**
Raw sewage pumping (mgd)	0.04	0.20	0.40
Aeration basin volume (cu ft)	1,330	6,690	13,400
Secondary clarifier area (sq ft)	40	200	400
Chlorinator capacity (lb/d)	10	25	50
Chlorine contact chamber volume (cu ft)	120	560	1,200
Drying bed area (sq ft)	400	1,000	2,000
Site area (ac)	0.5	0.7	1.0
Source: EPA 625/R-91/005, *Wastewater Treatment/Disposal for Small Communities*			

3.7.1.3. The following process description was adapted from EPA 832-F-00-016, *Wastewater Technology Fact Sheet: Package Plants*. An extended-aeration process typically consists of coarse screening or comminution, activated-sludge aeration using course air diffusers or mechanical aerators, secondary clarification using surface skimming and return sludge pumping, disinfection often with chlorine storage and feed facilities, and transport to a contact basin. Sludge is typically wasted to an aerobic holding or aerobic stabilization compartment. Sludge disposal varies widely. Primary clarification is rarely used. As illustrated in **Figure 3.21**, the process starts when wastewater enters the extended aeration 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. The material that is not returned, the waste activated sludge, 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. Most package plants discharge to surface waters, although they have been used to treat wastewater prior to land application or even subsurface disposal. However, the mechanical complexity of such plants is generally not compatible with low-maintenance, land-based disposal options.

Figure 3.21. Typical Extended Aeration Plant Treatment Process.

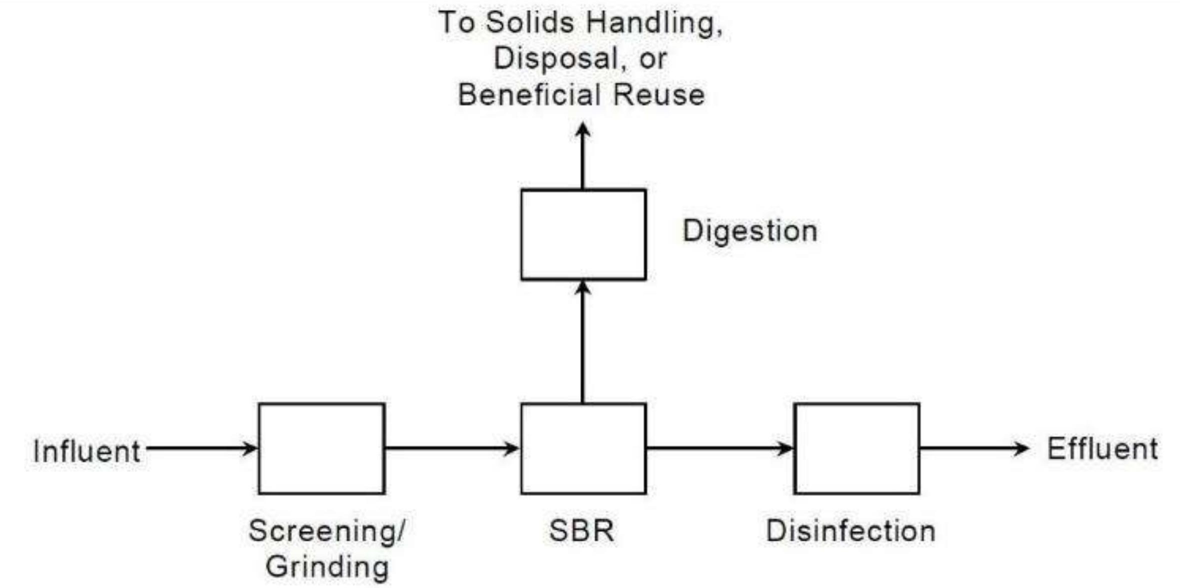


Source: Adapted from EPA 832-F-00-016, Wastewater Technology Fact Sheet: Package Plants

3.7.2. Sequencing Batch Reactor. The sequencing batch reactor (SBR) design utilizes a suspended-growth (activated sludge) process in which all major steps occur in the same reactor tank in sequential order. There are many types of SBR systems and 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 base or site installing the unit. Package SBRs are often manufactured to treat wastewater flow rates between 0.01 and 0.2 MGD, although flow rates can vary based on the system and manufacturer. When the wastewater flow rate at the site is less than 0.05 MGD, a single, prefabricated steel tank can be used. If the plant must be able to treat 0.1 to 1.5 MGD, multiple concrete SBR basins are commonly used. Single tank designs are usually divided into one SBR basin, one aerobic sludge digester, and one influent pump well. Typically, SBR systems contain two or more reactor tanks that are operated in parallel, or one equalization tank and one reactor tank. The type of tank configuration used depends on the wastewater flow characteristics (e.g., high or low volume). While the parallel setup allows the system to accommodate continuous influent flow, it does not provide for disinfection or holding for aerated sludge.

3.7.2.1. Shown in **Figure 3.22** is a diagram of the SBR treatment process. 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 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.

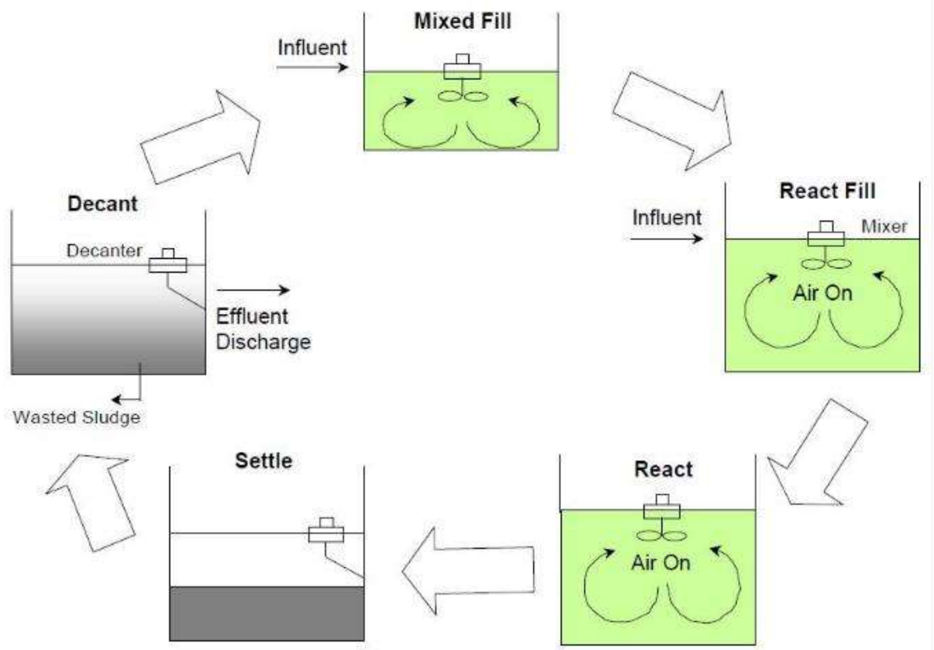
Figure 3.22. Typical Sequencing Batch Reactor Treatment Process.



Source: Adapted from EPA 832-F-00-016, Wastewater Technology Fact Sheet: Package Plants

3.7.2.2. The SBR treatment cycle treats batches of wastewater in five major steps or phases (Fill, React, Settle, Decant, and Idle). **Figure 3.23** illustrates the SBR sequence of operation. 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 is removed from the basin and disposed of as waste sludge. 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 a return activated sludge 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.

Figure 3.23. SBR Sequence of Operation.



Source: Adapted from EPA 832-F-00-016, Wastewater Technology Fact Sheet: Package Plants

3.8. Disinfection Design Considerations. Untreated domestic wastewater contains micro-organisms or pathogens that produce human diseases. The disinfection process kills these harmful organisms during wastewater treatment to meet effluent standards. Disinfection is generally required in three onsite-system circumstances. The first is after any process that is to be surface discharged. The second is before a subsurface wastewater infiltration system where there is inadequate soil (depth to ground water or structure too porous) to meet ground water quality standards. The third is prior to some other immediate reuse (onsite recycling) of effluent that stipulates some specific pathogen requirement (e.g., toilet flushing or vegetation watering). While there are several disinfection methods, ultraviolet and chlorine disinfection are likely options for small wastewater treatment systems. **Table 3.13** lists a number of factors to consider when selecting one of these disinfection systems. Certain information presented here was adapted from the EPA Wastewater Technology Fact Sheet, *Disinfection for Small Systems*. Find these and other EPA wastewater treatment system publications at https://search.epa.gov/epasearch/epasearch.

Table 3.13. Considerations for Chlorination and UV Radiation Disinfection.

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

Consideration	Chlorination	UV Radiation
Relative complexity of technology	Simple to moderate	Simple to moderate
Transportation on site	Substantial	Minimum
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
Notes: 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.		
Source: Adapted from EPA Wastewater Technology Fact Sheet, *Disinfection for Small Systems*		

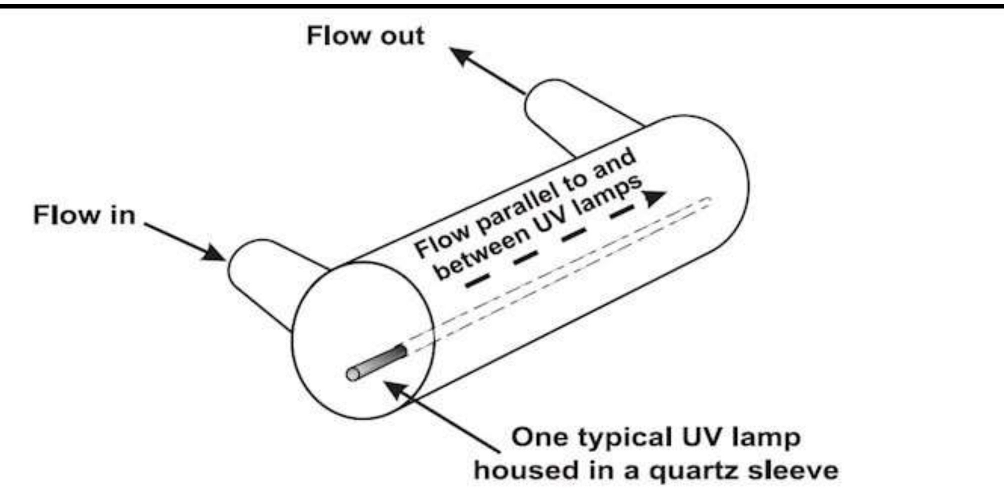
3.8.1. Ultraviolet Disinfection. The effectiveness of a UV disinfection system depends on the characteristics of the wastewater, the intensity of UV radiation, the amount of time the microorganisms are exposed to the radiation, and the reactor configuration. Various commercial UV disinfection systems are available for onsite applications. Most are self-contained and provide low-pressure mercury arc lamps encased by quartz glass tubes (**Figure 3.24**). The unit should be installed downstream of the final treatment process and protected from the elements. UV units must be located near a power source and should be readily accessible for maintenance and inspection. Appropriate controls for the unit must be corrosion-resistant and enclosed in accordance with electrical codes. Other design considerations include:

- A stable source of high-voltage electricity will be required.
- The lamps may not run without wastewater flow; this will cause overheating.
- A set of spare parts recommended by the manufacturer cab be stored on site so the system will not be inoperable due to shipping delays.
- The UV lamps can be equipped with an automatic cleaning system, such as wipers, to

remove buildup on the lamp; generally, the UV disinfection system manufacturer will provide such an automatic cleaning system.

- A monitoring and alarm (instrumentation and control) system are usually provided by the manufacturer.
- Unless instantaneous backup power is available, the effluent is stored during power outages.
- Providing two units assures continuous disinfection even when one unit is inoperable.
- In all cases consult the manufacturer for project-specific site requirements and equipment selection.

Figure 3.24. Parallel Wastewater Flow in Quartz UV Unit.



Source: Adapted from EPA 625/R-00/008, Onsite Wastewater Treatment System Manual

3.8.1.1. 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.

3.8.1.2. 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.

3.8.2. Chlorine Disinfection. Use only chlorine tablets intended for wastewater in a tablet chlorinator. Wastewater chlorine tablets are made of calcium hypochlorite. <u>Do not use swimming pool chlorine tablets for wastewater applications</u>. Swimming pool chlorine tablets consist of trichloroisocyanuric acid, which works too slowly to be effective in wastewater. Additionally, swimming pool chlorine tablets can sometimes interact with wastewater in such a way as to produce explosive gas. Never mix swimming pool chlorine contact tablets with wastewater chlorine contact tablets; an explosive compound may form. Check the ingredient label on the tablets to ensure personnel use the proper tablets.

3.8.2.1. A chlorine tablet gradually dissolves in the contact chamber of the tablet chlorinator and the tablet in the tube above it eventually falls into the wastewater stream. It is important that the proper amount of contact between the chlorine tablet and the wastewater occur. Too little contact time results in insufficiently disinfected wastewater; too much contact time dissolves the tablets very quickly and results in an excess of chorine, which can be damaging to the environment. With most tablet chlorinators, the amount of the tablet(s) in contact with the wastewater is adjustable to add or reduce contact.

3.8.2.2. Sufficient chlorination generally occurs if the water in the storage reservoir contains 0.2 mg of chlorine per liter of wastewater. This can be determined by using a chlorine test kit. The test kit requires the operator to mix a small amount of chlorinated wastewater in a solution and compare the resulting color with the colors shown in the kit to determine the chlorine concentration. The operator can adjust the chlorine contact as necessary. Test kits using paper strips are much less accurate and not recommended for use.

3.8.2.3. Approximately 15 minutes of contact time with the 0.2 mg/L chlorine solution is required in the storage reservoir prior to discharge for proper disinfection. **Table 3.14** is an example calculation to size the storage reservoir.

Table 3.14. Calculation for Storage Reservoir (Notional).

Storage Reservoir Calculations
Known: Average daily flow: 3,000 gpd Peak flow (peaking factor): 2.5 x average flow rate Detention time: 15 minutes
Determine: Volume of storage reservoir
Calculation: Average flow rate: 3,000 gpd ÷ 1,440 minutes per day = 2.1 gpm Peak flow: 2.5 x 2 gpm = 5.2 gpm Volume = flow x detention time = 5.2 gpm x 15 minutes = 78 gallons

3.8.2.4. Because chlorine is toxic to aquatic life, dechlorination after the storage reservoir may be required, particularly if the discharge is to surface waters. Many chlorine tablet manufacturers also sell sodium sulfite (Na2SO3) tablets to dechlorinate. The sodium sulfite tablets are positioned in a contact chamber similar to the chlorine contact chamber but downstream of the storage reservoir. The reaction between the chlorine and the sodium sulfite is instantaneous so another storage reservoir is not required. About 2 mg/L of sodium sulfite is required per 1 mg/L of chlorine.

3.9. Wastewater Collection System and Pumping. The type of collection system will depend mainly on site topography, process selection, and siting of the treatment system and outlet/discharge relative to the source location. Where possible, gravity piping is encouraged since pumping requires electrical power for operation and controls. Legal (e.g., international agreements) and operational (e.g., COCOM/operational chain of command) requirements may also affect the type of collection system that can be used at a specific location.

3.9.1. **Gravity Sewers.** PVC sewer pipe, couplings, and fittings conform to ASTM D3034, *Standard Specification for Type PSM Poly (Vinyl Chloride) (PVC) Sewer Pipe and Fittings*, with standard dimension ratio (SDR) 35. Joints are typically push-on, using permanently bonded elastomeric ring gaskets per the pipe manufacturer's written instructions. Where surface or very shallow installation is necessary, consider Schedule 40 ductile iron pipe instead of PVC. **Table 3.15** lists minimum slopes for various sewer diameters and associated capacities. Where possible, greater slopes are desirable; however, avoid velocities greater than 10 feet per second (1 m/s).

Table 3.15. Recommended Minimum Slope for Sewers.

Sewer Size	Minimum Slope ft. per 100 ft. (m/100 m)	Capacity (cfs)	Capacity (m^3 /s)
6 inches (152 mm)	0.7	2.6	0.074
8 inches (203 mm)	0.40	4	0.113
10 inches (254 mm)	0.28	7	0.198
12 inches (305 mm)	0.22	12	0.40
14 inches (356 mm)	0.17	17	0.48
15 inches (381 mm)	0.15	21	0.595
16 inches (406 mm)	0.14	25	0.708
18 inches (457 mm)	0.12	34	0.962

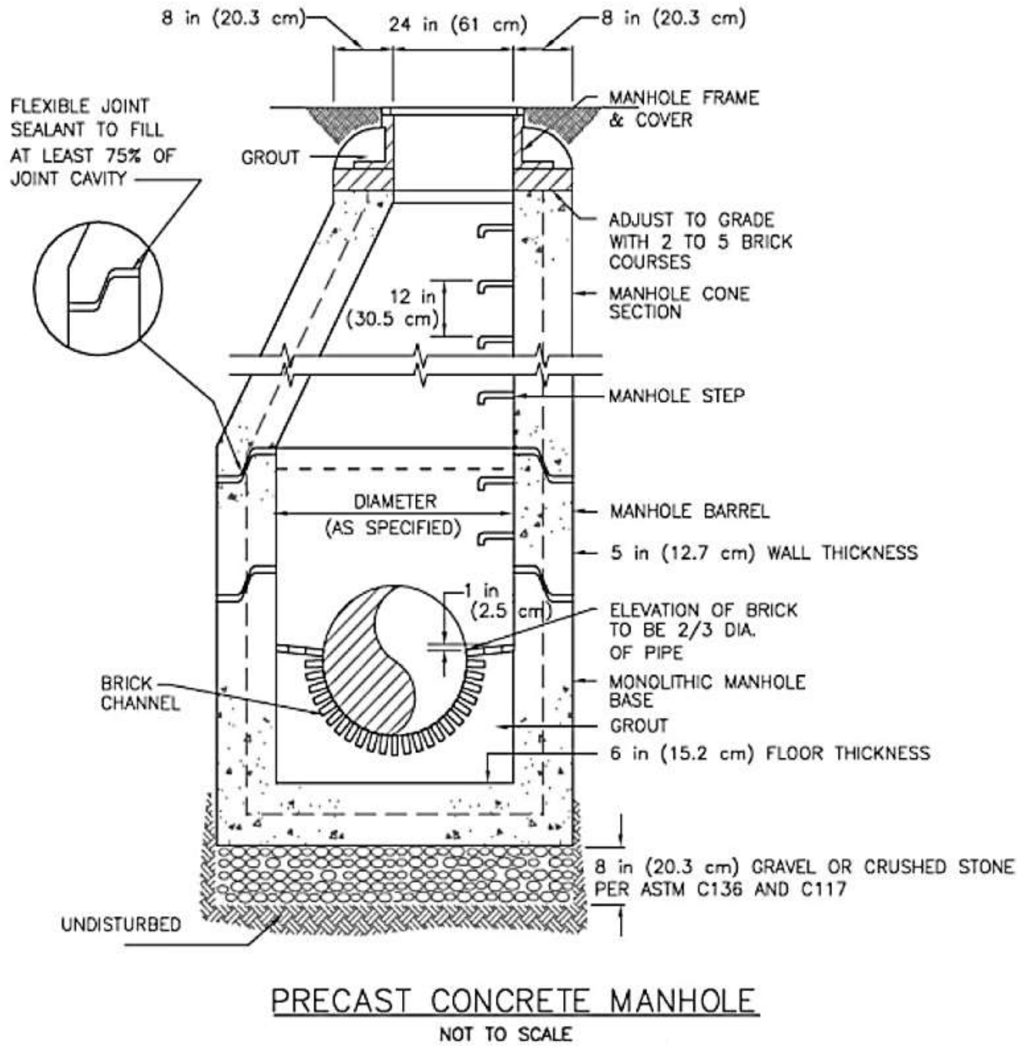
cfs (cubic feet per second)
6 inches (152 mm) added for use at typical velocity service connections
14-inch values estimated
Source: Adapted from New England Interstate Water Pollution Control Commission, TR-16, *Guides for the Design of Wastewater Treatment Works*

3.9.2. Sewer Manholes. Most sewer manholes are made of pre-cast concrete sections with a hand-troweled invert formed in the base after installation of structure and sewer piping. **Figure 3.25** shows a section of a typical sewer manhole (not to scale). Applicable codes for manhole fabrication include those listed below. **Note:** See **Attachment 2** for hyperlink to ASTM standards.

- ASTM C478, Standard Specification for Circular Precast Reinforced Concrete Manhole Sections.
- ASTM A184, Standard Specification for Welded Deformed Steel Bar Mats for Concrete Reinforcement.
- ASTM A615, Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement.

Figure 3.25. Precast Concrete Sewer Manhole.

DIAMETER	WALL THICKNESS	FLOOR THICKNESS
4 ft (1.2 m)	5 in (12.7 cm)	6 in (15.2 cm)
5 ft (1.5 m)	6 in (15.2 cm)	7 in (17.8 cm)
6 ft (1.8 m)	7 in (17.8 cm)	8 in (20.3 cm)



3.9.3. Bar Screens. Designers of WWTFs often use bar screens when processing raw sewage from a collection system. However, the wastewater alternatives provided in this publication focus on smaller treatment facilities served by a limited collection system. These smaller systems operate very well using a septic tank for pre-treatment where large solids and debris are not a concern. When used, bar screens require consistent maintenance. If using a bar screen at a deployment site, especially for a natural system, follow the O&M recommendations in **Chapter 4**. Bar screens are typically fabricated of galvanized steel with bar dimensions between 0.375 inch (10 mm) to 2 inches (50 mm) thick, by about 2 inches (50 mm) deep (**Figure 3.26**). Commonly, the position of the bars are at a 35 degree to 45-degree angle from the horizontal.

Figure 3.26. Bar Screen.

3.9.4. Pumping Systems and Force Main Sizing. Pumping stations may be necessary to deliver septic tank effluent to a mounded or dosed leach field or alternative system for additional treatment. In some cases, pumping may be necessary to feed raw sewage from certain sources to the wastewater collection system. The discharge from the pump is through a pressurized pipe (e.g., force main). Minimum force main diameter varies with the quality of the wastewater conveyed and minimum velocities required to avoid solids settlement in the pipe. In general, force mains for raw sewage applications need to be a minimum of 4 inches (101 mm) in diameter. Where anticipating low flows, use grinder pumps to reduce the risk of clogged force main piping. Effluent dosing arrangements utilize PVC or high-density polyethylene pipe unless conditions warrant the use of ductile iron pipe. Where pumps are installed, the following should be provided:

- Duplex submersible pumps with alternating controls for redundancy (or spare back-up pump available for immediate replacement).
- Alarm for failure notification, wired on separate circuit.
- Emergency storage volume in tank equal to design flow.
- Watertight tank constructed of concrete or fiberglass (steel not recommended).
- Raw sewage flows pumped using non-clog or grinder pumps capable of handling 3-inch (76 mm) solids.
- Install pumps with a quick-disconnect coupling to facilitate O&M.

3.9.4.1. Pump Selection Procedure and Example. There are several types of pumps available for conveying wastewater. However, the type of pump used in septic tanks and as recirculation pumps for recirculating sand filters are submersible. Submersible pumps have a pump and motor designed for installation in the wet well or even fully submerged. These pumps do not require an influent pipe but must be submerged for adequate cooling and safe operation. To determine the size of the pump for each application, the required flow, force main size, and total dynamic head (TDH) need to be determined. Once established, provide this information to pump manufacturers for pump selection.

3.9.4.1.1. Step 1: Determine the Peak Flow. Pumps are sized based on the peak hour flow (peak flow), not the ADF used to size the septic tank, leach basin, and recirculating sand filter. Peak flow determined by multiplying the ADF by a peaking factor (PF). The maximum anticipated flow rate for an installation based on the data below is 15,000 gpd, which is a very low flow. A PF of 5 is recommended for most applications in this flow range. **Note:** The PF is expressed as a ratio of the maximum daily flow divided by the average daily flow. The ratio generally ranges from 1.2 for very large water systems to 3.0 or even higher for specific small systems. In this example, maximum daily flow (15,000 gpd) divided by the average daily flow (3,000 gpd) equals a PF of 5.

Peak flow = ADF x PF
ADF = 3,000 gpd; PF = 5
Peak flow = 3,000 gpd x 5
Peak flow = 15,000 gpd or 10.5 gpm

3.9.4.1.2. Step 2: Determine Required Wet Well Size. Based on the peak flow and dimensions of the wet well, determine the pump run time per cycle. Use the following criteria when determining if a wet well is adequately sized:

- Pumps cycle on/off no more than four times per hour.
- Pumps run for several minutes at a time without dewatering the wet well.

3.9.4.1.2.1. Determine volume of wet well per inch. The following uses data from **Table 3.4**, "Septic Tank Design Example."

L_1 = 6 feet
W = 6 feet
H = 12 feet
Volume = 3,000 gallons
Gallons per inch (gpi) = 3,000 gallons ÷ 144 inches
gpi = 20.8

3.9.4.1.2.2. Set level control for pumps to turn on 6 inches above low-level set point.

Volume to be pumped = 6 inches x 20.8 gpi
Volume to be pumped = 125 gallons
Determine pump run time (TP)
T_P = 125 gallons ÷ 10.5 gpm
T_P = 12 minutes
Pump will run one to two times per hour (acceptable)

3.9.4.1.3. Step 3: Determine Force Main Size.

3.9.4.1.3.1. Once the peak flow has been determined, size the force main. The diameter of the force main will impact pump selection as the friction losses through the pipe are directly related to the flow rate through the pipe. As a rule of thumb, maintain the velocity of the flow in the force main between 3 feet per second (fps) and 5 fps to keep solids suspended and avoid deposition in the line.

Q (cfs) = A $(ft)^2$ x V (ft/s)

3.9.4.1.3.2. Rearrange the equation to solve for area (A).

A = Q ÷ V

3.9.4.1.3.3. Convert Q from gpd to cfs:

Q = 15,000 gpd ÷ 7.48 gallons/ft3 ÷ 86,400 seconds/day
Q = 0.0232 cfs

3.9.4.1.3.4. Assume velocity = 4 fps

3.9.4.1.3.5. Solve for A:

A = 0.0232 CFS ÷ 4 fps
A = 0.0058 ft.
A = π x r^2

3.9.4.1.3.6. Solve for r:

r = $(A \div \pi)^{1/2}$
r = 0.043 feet
r = 0.515 inch
d = 1.03 inches

3.9.4.1.3.7. Use a force main diameter of 1 inch.

3.9.4.1.4. Step 4: Determine the TDH. The TDH is the total height that a fluid is to be pumped, taking into account friction losses in the pipe. Find the TDH by adding the difference in water surface elevation (static head) to the losses in the pipe due to friction (f_L). Following is an example for determining the TDH of a septic system pump that pumps to a gravity-leach field.

3.9.4.1.4.1. Step 4a: Calculate Static Head.

Pump on elevation:
Evaluation of influent pipe at leach field:

Static head (ft.) = elevation at leach field (ft.) – pump on elevation (ft.)
Static head = 17.43 ft. – 7.41 ft.
Static head = 10.02 ft.

3.9.4.1.4.2. Step 4b: Calculate Friction Losses. In addition to the elevation difference between the starting and ending points, the pump also has to overcome the friction of the fluid moving through the pipe. The longer the pipe length between the pump and the final discharge point, the greater the friction loss.

3.9.4.1.4.2.1. Calculate the losses in the straight pipe using the Hazen-Williams Equation.

$f_L = ([4.52 \text{ x } L \text{ X } Q^{\mathbf{1.85}}) \div (C^{\mathbf{1.85}} \text{ x } d^{\mathbf{4.87}}]) \text{ x } 2.31$

Where:

f_L = friction loss in feet
L = length of pipe (ft.)
Q = flow
C = Hazen-Williams roughness coefficient
d = hydraulic diameter (interior diameter of pipe in inches

3.9.4.1.4.2.2. If the septic tank effluent to the leach field includes 400 feet of 1-inch PVC pipe, then the friction loss in the straight pipe can be determined.

Total pipe length = distance from septic tank to leach field + vertical distance from pump discharge

Total pipe length (ft.) = 400 ft. + 7.86 ft.
Total pipe length (ft.) = 407.86 ft.

3.9.4.1.4.2.3. Calculate the friction loss in the straight pipe:

$f_L \text{ (ft.)} = (4.73 \text{ x } L \text{ x } Q^{\mathbf{1.85}}) \div (C^{\mathbf{1.85}} \text{ x } d^{\mathbf{4.87}})$
$f_L = ([4.73 \text{ x } 407.86 \text{ x } (15{,}000 \text{ gpd} \div 1440 \text{ mins/day})^{\mathbf{1.85}}] \div [120^{\mathbf{1.85}} \text{ x } 1^{\mathbf{4.87}}]) \text{ x } 2.31$
$f_L = 48.48 \text{ ft.}$

3.9.4.1.4.2.4. Additional losses, such as those through fittings, may be insignificant and ignored if there are a small number of fittings (less than five). If there are a large number of fittings, account for the losses by adding another 2 to 3 feet of head loss to the final calculation. If the designer prefers to calculate the actual head loss through these fittings, then the designer consults one of the numerous hydraulic handbooks on the market. These handbooks provide tables, charts, and equations for determining the head loss through fittings. **Note:** As with minor loss tables, numerous Hazen-Williams coefficient tables are available. The designer should select the appropriate coefficient based on the pipe material and age. A sample Hazen-Williams coefficient table is provided in **Table 3.16**.

3.9.4.1.4.3. Step 4c: Determine TDH.

TDH = static head + friction losses
TDH = 10.02 ft. + 48.48 ft. = 58.50 ft.

3.9.4.1.4.4. Step 4d: Pump Selection. Once the flow rate, force main diameter, and TDH have been determined, contact the pump manufacturer to determine the appropriate pump. Information to provide to pump manufacturer:

- Location of job.
- Job name.
- Purchase order number (if applicable).
- Pump type (submersible.
- Peak flow rate (10.5 gpm).
- TDH (59 ft.).
- Force main diameter (1 inch).

Table 3.16. Sample Roughness Coefficient Chart.

Hazen-Williams Coefficient (C_{hw})	
Pipe Material and Age	**Coefficient**
Pipe extremely straight and smooth	140
Pipes very smooth	130
Smooth wood, smooth masonry	120
New (interior) riveted steel, vitrified clay	110
Old cast iron, ordinary brick	100
Old riveted steel	95
Old iron in poor condition	60-80
Corrugated steel	60
Source: Adapted from US Army Corps of Engineers (USACE), *AED Design Requirements: Booster Pumps*	

Chapter 4

TREATMENT SYSTEM OPERATION AND MAINTENANCE (O&M)

4.1. General Information. For effective utilization of the design capabilities of WWTFs, personnel must provide the required attention and maintenance. Treatment system operators are responsible for the system's O&M. However, if more than one person operates the facility, every operator working together as a team will ensure that the equipment and processes operate properly. This chapter provides general information for operation and maintenance of wastewater treatment systems. It should help personnel handle routine O&M and recognize problems that require help from suppliers, manufacturers, contractors, and engineers. Although most of these systems include operations that require little attention by an operator, nothing can replace the experience, judgment, and observations of trained personnel. As with any manufacturing process, efficient and economical operation of a wastewater treatment system depends on the personnel observing and operating the equipment. Good operating techniques provide, as a minimum, the following benefits to the installation:

- The treatment system functions as designed and constructed.
- Operating costs are held to a minimum.
- Repairs and damage to equipment are minimized.
- Good public relations results from preventing water pollution.

4.2. Basic Guide to Operations Monitoring. Once construction is complete, the facility will go into operation. Daily monitoring of the various processes is essential to ensuring their proper long-term function. If maintaining proper records, monitoring will alert the operators to potential or existing problems. **Table 4.1** is a guide to developing a comprehensive monitoring program. See individual system information in subsequent paragraphs for specific O&M methods.

Table 4.1. Guide to Operations Monitoring.

	Operations Monitoring	✓
1.	**Conduct Daily Inspections**	
	Take a site walk	
	Take site photographs periodically	
	Note any changes in conditions	
	Odors	
	Color	
	Changes in soil characteristics	
	Puddling or ponding	
	Photograph changes	
	Review maintenance log	
	Report any changes to your supervisor	

Operations Monitoring		✓
2.	**Record Keeping**	
	Establish a maintenance log	
	Repairs	
	Cleanings	
	Other problems	
	Establish a sampling log	
	Record known flow rates	
	Record pump run time	
	Record known exterior changes (such as significant increase in site population or unusual amounts of precipitation) as they may have an impact on proper functionality	
3.	**Sampling**	
	Set up a sampling schedule per guidelines	
	Record sample results in log book	
	Take samples per established sampling schedule	
	Measure flow	
	Note any deviations from previous samples	
	Report deviations to supervisor	
4.	**Maintenance**	
	Establish a routine maintenance schedule	
	Cleaning	
	Lubrication	
	Replaceable parts	
	Record routine maintenance in maintenance log	

4.3. Septic Systems O&M. A properly designed and maintained septic system requires very little O&M intervention except for the periodic removal of accumulated settled solids and scum. Preventive care and smart use measures have more impact on the successful operation of a septic system than anything that is done after the fact. Typically, septic systems operate on gravity, but some systems are equipped with influent or effluent pumps, or both. Maintenance intervals on pumps in this type of service are likely to be more frequent than on other pump installations due to the nature of the product conveyed. The following Do’s and Don’ts will support long-term use:

- Don’t plant trees or shrubs within 50 feet (15 m) of a septic tank or leach field; if any trees or shrubs exist within that perimeter, remove them.
- Don’t operate wheeled or tracked vehicles over the tank or leach field; the weight may damage the pipes and structures and could compact the soil, making the leach field less efficient.

- Don't build or dig within the leach field area—it could damage the distribution piping.
- Don't place pavement or landscaping plastic over the leach field; if pavement is necessary, the field piping must be vented to the atmosphere.
- Don't allow surface waters to flow or pool in the leach field area, channel the water elsewhere.
- Do allow grass or shallow-rooted plants to grow over the leach field to cut down on erosion and help absorb treated water discharged into the field.
- Don't dispose of grease or oils into the septic tank influent; wipe greasy cooking utensils clean before washing.
- Don't dispose of bleach and harsh cleaners down drains; these chemicals can disrupt the bacteria in the septic tank, negatively affecting the treatment process.
- Do install grease separator tanks on the discharge piping from all kitchen facilities; regularly maintain the tanks to prevent grease carry-over to the sanitary sewer.
- Don't use in-sink garbage disposals; if a garbage disposal is installed, the accumulated solids in the tank will need to be removed more often.
- Avoid introducing a large amount of water over a short period of time; wash dishes and clothes in small increments rather than saving them for big loads.
- Don't introduce anything into the sewage system except bodily wastes, wash water, and toilet paper; avoid flushing cigarette butts, paper towels, female sanitary products, plastics, and rubber products down the toilet.

4.3.1. Septic Tank Inspection and Pumpout Intervals. The primary O&M task when operating a septic system is periodic inspection of the septic tank and removal of the accumulated settled solids and the scum layer by pumping out the entire contents of the tank. A minimal effort to perform periodic maintenance will significantly reduce the risk of septic tank overload and carry- over into the leach field. Keep a log to record inspections, sludge and scum measurements, and pump-out dates. This log will be useful for long-term monitoring by changing maintenance personnel and will be a helpful reference when conditions change and require more frequent pumping. Inspection recommendations include:

- Inspect the tank and all tee locations at least annually.
- Remove sludge before it exceeds 25 to 35 percent of the tank's working volume.
- Always remove scum when pumping sludge and when it accumulates near the outlet tees.
- Remove, clean, and reinstall the effluent filters during all tank inspections.
- If any accumulation is apparent in the outlet tee, also check the leach field distribution box or dosing pump chamber for carryover.

4.3.1.1. There are simple means to measure sludge and scum in a septic tank and determine the remaining working volume. The following paragraphs address two of those methods:

4.3.1.1.1. Method 1 – Core Sampler or "Sludge Judge." This device is available for purchase and simple to make using clear plastic 1-inch (25 mm) pipe fitted with a ball valve at the end (see **Figure 4.1**). Inspection is a fundamental part of maintenance. This device measures scum and sludge depth in the septic tank by taking a column sample. A ball valve at the bottom of the tube seals fluid in when raising the tube out of the tank.

- Step 1. Lower the device vertically to the bottom of the tank (ball valve on bottom).
- Step 2. Lift the device straight up; the ball valve will retain the column of liquid/solids in the pipe.
- Step 3. Measure the layers of scum, sludge, and clear (working volume).

4.3.1.1.2. Method 2 – Stick and Foot/Sock Device. This device includes a long stick with a 3- inch (7.6 cm) piece of wood attached across one end, forming a “foot.” The device is simple to assemble.

- Step 1. Use the foot to push through the scum layer until resistance is felt from the liquid layer.
- Step 2. Pull out the device and measure the scum layer on the stick.
- Step 3. Remove the foot from the stick.
- Step 4. Wrap a cloth around the stick and secure with rubber bands or other method.
- Step 5. Lower stick through the hole made previously in the scum layer.
- Step 6. Push the stick down through the liquid in the tank until it hits the bottom of the tank.
- Step 7. Lift the stick out of the tank and measure the depth that the solids are sticking to the cloth.

Figure 4.1. Use of Sludge Judge.

4.3.1.2. Septic tank pump-out recommended if any of the following conditions exist:

- The solids layer is at or above one-third of the tank volume (depth).
- The bottom of the scum layer is within 3 inches (7.6 cm) of the bottom of inlet baffle.
- The bottom of the scum layer is within 8 inches (20.3 cm) of the bottom of outlet

device.
- Less than two-thirds of working depth remains (pump out the tank in its entirety).

4.3.1.3. Typically, personnel use vacuum tank trucks to pump out septic tanks. The pumper will use a 4- to 6-inch (101 to 152 mm) -diameter hose and vacuum everything out of the tank (both solids and liquids). Take the septage removed to a host nation government-licensed or authorized disposal site because of potential health problems from contamination. Such sites may include evaporation ponds, sewage plants, or wastewater treatment plants that accept septage for further treatment and processing. Procedure for tank pump-outs:

- Remove the entire contents of the tank through an access port located on top of the tank.
- Do not pump out the tank through the distribution box.
- Dispose of the contents of the tank in an environmentally neutral way; if hauling offsite to a nearby WWTF is not possible, consider passive land disposal based on terrain and climate conditions.

4.3.2. Leach Field Inspection and Checks. After several years of use, a build-up of bottom sludge and floating scum will reduce the effective capacity of the tank. This means waste passes through the tank too quickly and solids eventually plug the pipes in the leach field. The microorganisms in the leach field no longer have an aerobic (with oxygen) environment in which to perform their cleansing action; they are now struggling to survive in an anaerobic (without oxygen) environment. Either untreated effluent begins surfacing on the ground or sewage backs up into the connected building drains. At this point, the system has failed, and a new leach field is required. The only remedy for a non-functional leach field is replacement. There is no evidence that commercially available enzymes or chemical treatments can revitalize a leach field. There may be some short-term relief, but the problem will return quickly upon reuse of the system. To construct a new leach field on top of an existing field, dig trenches parallel to the existing pipes or widen the existing trenches.

4.3.3. Troubleshooting System Problems. There are warning signs that indicate a septic system may be failing rather than just requiring a pumpout. The indicators shown below and the information in **Table 4.2** may be helpful to troubleshoot and pinpoint system problems and identify potential remedies.

- Obnoxious odors in the system area or connected structures.
- Soft ground or newly occurring low spots in the system area.
- Grass growing faster or greener in the system area.
- Gurgling sounds in the plumbing or plumbing backups.
- Sluggishness in a toilet when flushed.
- Appearance of bacteria in nearby well water.

4.3.3.1. The distribution box (D-box) connects a single effluent line from the septic tank to a network of absorption lines. Adjustable weir outlets with eccentric openings permit balancing flow among drainfield lines.

4.3.3.2. An examination of the septic system distribution box interior may show flood lines in the box if a clogged or saturated drainfield occurred in the past, even if the box is not flooded at the time of inspection. If the septic drainfields have been flooded, continued use of the drainfield may be in jeopardy. Check whether site drainage patterns have changed or experienced flooding and make corrections, if possible.

Table 4.2. Septic System Failures Troubleshooting Matrix.

Possible Causes of Failure	Potential Remedial Procedures
Inadequate design Tank size insufficient for wastewater flow quantity or characteristics Leach field too small	 Replace septic tank with a larger one or add additional tank(s) in parallel Install additional trench area
Faulty leach field installation Plugged pipes Insufficient stone in trenches Uneven grades	 For plugged pipes, insufficient stone, and uneven grades, install a new leach field on top of the existing field
Poor soil conditions High groundwater Insufficient distance below leach field to bedrock Impervious soils	 Improve surface drainage, install curtain drains, elevate field, and/or reduce water consumption Elevate leach field and/or reduce water consumption Elevate leach field and/or reduce water consumption
Overload Excessive wastewater loading Poor storm water drainage in the area Leaking plumbing fixtures Wastewater flow quantity and/or characteristics greater than anticipated due to changes in use	 Increase tank size/reduce water consumption Improve surface drainage Repair plumbing fixtures Remove garbage grinders, increase size of leach field
Lack of tank maintenance Tank not pumped out at sufficient intervals, causing solids to be discharged to the leach field	 Pump out tank; construct new leach field on top of existing field, or relieve leach field by draining into a pit and pumping out; let the field rest for a month and resume use
Gravity D-box settlement and uneven distribution to the leach trenches	Install or reset the adjustable weir outlets to improve flow balancing
Carry-over of solids from septic tank to D-box and/or leach field	Install, clean, or replace effluent filters in the septic tank outlet tee and/or dosing pump discharge piping to the field

4.3.3.3. **Figure 4.2** shows a distribution box uncovered for inspection. All drainfield inlet lines are visible and the box is not flooded. Adjustable weir outlets are useful in making limited adjustments for a distribution box that has settled out of level after installation. As shown in **Figure 4.2**, adjust the outlet weirs by rotating the device to place the eccentric hole higher or lower with respect to the water level, thus compensating for a slightly tipped box, differences in leach line length, or differences in leach line condition. Two types of round plugs or outlets (**Figure 4.3**), typically 4 inches (10 cm) in diameter are available through on-line distributors.

Figure 4.2. Distribution Box Inspection.

Figure 4.3. Adjustable Weir Outlets.

4.4. Lagoon Systems O&M. Lagoons are simple to operate and therefore often neglected. Most problems with lagoon systems are due to poor housekeeping or process overloading. If the lagoon design and size is appropriate and the population it serves does not increase significantly, loading problems are usually not an issue. The following paragraphs concern best practices and housekeeping issues that can affect lagoon operation. For additional information, refer to UFC 3-240-01.

4.4.1. Best Practices. There are best practices for lagoon maintenance. External sources of water can be diverted away to avoid filling the lagoon beyond capacity with flow that does not need to be treated. Excess turbulence from run-off can also disturb the facultative layers. Lagoons are not for treating hazardous chemicals. All excess hazardous chemicals should be disposed of in accordance with product labels. Provide regular maintenance for grass, weeds, and general vegetation around and in the lagoons. Remove any growths or obstacles within the lagoon to avoid disturbing the flow pattern and create short-circuiting or "dead spots." Remove blue-green algae to maintain the health of the lagoon. Algal blooms can occur when the desirable green algae reproduce rapidly in response to changes in weather and then dies off, creating odors and clouding. Foul odors may release during the changing seasons, as changing temperatures within the facultative layers causes the anaerobic layer to rise as the aerobic layer sinks. Monitor the anaerobic layer yearly for thickness and removal as necessary.

4.4.2. Bar Screens. Provide lagoons with bar screens in their inlet structure. Inspect these screens at least twice a day, more often during storms, and clean as necessary. Dispose of screenings immediately in a sanitary manner. One method is burial in a nearby trench, another is to place the screenings into containers with lids (e.g., garbage cans) and arrange to empty containers on a regular basis. Consider burying in a landfill or incinerating the collected screenings.

4.4.3. Mixing and Aeration. Lagoons can be operated efficiently without mechanical mixing or aeration if they are not overloaded and the naturally occurring circulation and the oxygen supplied by suspended plant growth is sufficient to support stabilization of the organic wastes in the influent. For more heavily loaded lagoons, or for lagoons located in difficult climates (extremely low or high temperatures, or extremely heavy precipitation), mechanical mixing and/or aeration may be required. Most systems or devices that mix or move water around require a source of electrical power. If this is not available or would be difficult to obtain, solar-powered mixer/aerators are available. These devices are floating mixers anchored in the lagoon and powered by solar panels. (One source for this type of mixer is Solar Bee®).

4.4.3.1. Floating mixers/aerators, however powered, are the best choice for lagoons, but other methods include:

- Pumped recirculation of the lagoon contents (for mixing only).
- Diffused low-pressure air (aeration only; energy-intensive; not very efficient in lagoon environments).
- Use of an air-cooled outboard motor mounted on a small boat.

4.4.3.2. Regardless of the system in use, the operator matches the mixer/aerator operating time with the dissolved oxygen requirements of the lagoon. Too much dissolved oxygen is not better than just enough and, since it wastes energy and incurs needless wear on the equipment, it is not a good practice to over-mix or over-aerate the lagoon contents.

4.4.4. Scum Control. Scum accumulation is common in lagoons—more so in the spring in temperate climates when biological activity resumes as water temperature rises. Wind often dissipates scum accumulations, but, in the absence of wind, or in sheltered areas, mechanical means may be an option to break up the scum. Address scum accumulations in a timely manner because if they are allowed to remain, over time the scum can cause objectionable odors and may dry out and become crusted, making it more difficult to break up. Scum may be broken up with rakes or jets of water from the shore or with rakes from boats. Personnel can also use outboard motors as a means of breaking up scum layers. Use air-cooled motors because algae and scum can easily plug water-cooled motors.

4.4.5. Odor Control. Most incidents of odor generation in a lagoon result from either overloading or poor maintenance. Process upsets caused by unexpected shutdowns can also trigger an odor event. If operators suspect overloading, divert the influent to another treatment source (e.g., a second lagoon) to allow time for the odor to resolve itself. Gradually resume loading after the odor subsides. Other effective measures to reduce odor include the following:

- Adding chlorine.
- Providing mechanical aeration.
- Odor-masking agents are another possibility, but, in the long run they are less effective than the remedies noted above.
- Sodium nitrate can also be used to reduce odors, but it must be dispersed throughout the pond to be effective.

4.4.5.1. There are a few items to note regarding the effectiveness of the above-listed remedies. Unless chlorination equipment or floating aerators are already on hand, it could be difficult to acquire and install the necessary equipment to aerate and/or chlorinate in a timely manner. In addition, sodium nitrate provides a source of oxygen for the facultative organisms in the lagoon and does not interfere with biological activity like chlorine or sodium hypochlorite.

4.4.5.2. Regardless of the method chosen to address odor issues, it is not wise to wait until an odor situation arises before deciding what to do about it. Prior planning related to addressing an odor incident allows the operator to react quickly without having to decide what to do and then try to locate the necessary equipment and/or chemicals.

4.4.6. Weed and Insect Control. Weed control is an essential part of lagoon maintenance. There are three areas of concern:

- The lagoon levee.
- The shallow areas on the edge of the lagoon.
- Suspended vegetation growing on the water's surface.

4.4.6.1. Basic control of weeds (undesirable vegetation in unwanted areas) on the levee consists of a program of regular mowing combined with planting grasses that choke out weeds. Consider use of herbicides only as a last resort. Another option may be to place riprap or install a lagoon liner to reduce or eliminate unwanted growth on the sloped portion of the levee.

4.3.6.2. Shallow water vegetation (e.g., tules) can be reduced or eliminated by maintaining the lagoon depth at 3 feet (1 m) or greater. For vegetation control in edge areas where this may not be possible, consider the following options:

- Prompt removal of emergent vegetation, including roots, is the best means of control

- Manipulate the level in lagoon to either expose vegetation for removal or drown it
- Burning them out with a gas burner is also an option.

4.4.6.3. Without lagoon edge vegetation, the likelihood of insect propagation greatly reduces. When removing emergent growth be sure to wear the appropriate gear, including approved flotation devices and work safely. **Caution:** Do not work alone on the edge of a lagoon or in a boat. Drowning after a slip or fall is a continuing risk.

4.4.6.4. Suspended vegetation (e.g., duckweed) will not flourish in a lagoon exposed to wind. Remove any established suspended vegetation, typically by collecting it with rakes or other implements while in a boat if it is not reachable from the shore.

4.4.6.5. Mosquitoes commonly breed in sheltered water areas with vegetation or scum where the female mosquito can attach her egg rafts. If the scum is broken up or removed and vegetation removed, the fragile mosquito egg rafts will not survive. Also, consider introducing small mosquito fish for mosquito control. Insecticides best control midges, when present. If it becomes necessary to use an insecticide, check with local authorities to find out which insecticides are acceptable. Always follow safe application procedures, including ambient conditions necessary for safe and effective application of the insecticide.

4.4.7. Levee Maintenance. Levees may erode by (1) wave action or surface runoff during rainstorms or (2) animal burrows, which can compromise the integrity of a levee bank. Inspect the levee regularly, looking for signs of erosion or animal burrows. If erosion is a continuous problem, consider installing bank protection such as those listed below. Plantings are also a part of good levee control. Do not plant vegetation with long roots like willows or alfalfa. Low-growing, spreading native grasses are the best option. If using the top of a levee as a wet weather road, consider paving or laying stones to prevent ruts caused by vehicles on wet ground. If leaks appear on the outside of the levee, consult with an engineer to resolve this problem before damage occurs.

- Riprap or stone/broken concrete rubble.
- Semi-porous plastic sheeting can be useful if properly installed in conjunction with riprap.
- Evict any burrowing animals found and fill in their burrows.

4.4.8. Sampling and Analysis. Sample analysis is one of the best ways for an operator to monitor the condition and efficiency of the lagoon. Not only will the data tell the operator what is going on in the lagoon, but when analysis results are recorded it allows the operator to predict the trend direction that the lagoon is going in, i.e., whether the lagoon is in a steady state or if the process parameters are headed in the wrong direction. This information allows the operator to troubleshoot the lagoon and make process adjustments before a serious problem occurs. For recommended sample types, frequencies, and sample locations, see **Table 4.3**.

Table 4.3. Lagoon Sampling Location and Frequency Matrix.

Test	Frequency	Location	Common Range
pH	Weekly	Lagoon	7.5+
Dissolved oxygen (DO)	Weekly	Lagoon Effluent	4-12 mg/L 4-12 mg/L
Temperature	Weekly	Lagoon	N/A
BOD	Weekly	Influent Effluent	100-300 mg/L 20-50 mg/l
Coliforms	Biweekly/monthly*	Effluent	MPN>24,000/100 mL (Unchlorinated)
CI2 residual	Daily/weekly*	Effluent	0.5-2.0 mg/L
Suspended Solids	Weekly/biweekly*	Influent Effluent	100-350 mg/L 40-80 mg/L
Dissolved Solids	Biweekly	Influent	250-800 mg/L

*During the first month following startup, sample these parameters more frequently until the system stabilizes.

4.4.8.1. Always, take samples at the same location. Take influent and effluent samples at a point where the flow is well mixed. Take lagoon samples at least 8 feet (2.5 m) from the edge and at a depth of at least 1 foot (0.3 m). Do not collect lagoon samples immediately after a high wind or storm because the lagoon will be temporarily agitated, and the sample will not be representative. Good sampling technique is important to ensure a representative sample every time. There are two types of samples normally collected for a lagoon system:

4.4.8.1.1. Grab samples are used to measure temperature, pH, dissolved oxygen, and chlorine residual. Perform these measurements immediately after collecting the sample to ensure accurate results.

4.4.8.1.2. Composite samples are stored in a refrigerator or ice chest until analyzed. Typically, personnel use composite samples to measure BOD and suspended solids. Sampling records also provide a measure of the treatment efficiency in the lagoon. **Table 4.4** lists some common treatment efficiency ranges. Dissolved oxygen, pH, and temperature are important indicators to determine lagoon conditions. BOD, coliform, and solids testing measure the lagoon treatment efficiency.

Table 4.4. Lagoon Expected Ranges of Removal.

Parameter	Detention Time	Expected Removal
BOD (total range)	50 to 100 days	50% to 90%
BOD (facultative lagoon)	50 to 60 days	70% to 80%
Coliform bacteria (facultative lagoon)	50 to 60 days	90% to 95%
Suspended solids Dissolved organic solids	After 3 days After 10 days	90% 80%

4.4.9. Troubleshooting System Problems. There are warning signs that indicate when a lagoon system may be overloaded. Use the indicators listed below and the information in **Table 4.5** to troubleshoot and pinpoint system problems and identify potential remedies.

- Obnoxious odors in the area of the lagoon.
- Sudden changes in pH or dissolved oxygen.
- Rapid change in pond surface appearance (color).
- Large amount of black or brown scum.

Table 4.5. Lagoon System Failures Troubleshooting Matrix.

Possible Causes of Failure	Potential Remedial Procedures
Poor-quality effluent. Mixing equipment failure. Organic overload. Excessive scum mat accumulation. Loss of volume due to sludge accumulation. Excessive plant growth. Effluent sample out of range; high coliforms.	Increase operating time of other mixers. Provide temporary mixing (outboard motor). Increase recirculation or mixing, pre-chlorinate, or add sodium nitrate or hydrogen peroxide. Break up scum mats with tools or water spray. Remove sludge. Remove plant growth; use herbicide as last resort. Test more frequently. Increase dose/frequency of chlorine addition.
Low dissolved oxygen in the lagoon. Low algae growth. Excessive scum accumulation.	Increase mixing or aeration equipment run time. Recirculate effluent to influent. Break up scum mats and/or skim off scum and dispose of in landfill or burn.
Odor conditions. Anaerobic conditions. Presence of hydrogen sulfide (rotten egg smell).	 Limit organic loading and/or increase mixing or aerator run time. Increase aeration or pre-chlorinate.

Possible Causes of Failure	Potential Remedial Procedures
Unexplained loss of water. Seepage through the levee. Excessive evaporation or percolation.	 Add bentonite clay to lagoon water to seal the leak. Detention time too long; divert storm flow or local surface water (streams) into lagoon.
Insect infestation. Scum layers and/or plant growth in sheltered areas provide breeding grounds.	 Remove weeds and scum; apply approved insecticide, if necessary.
Levee erosion. Wind-generated wave action. Excessive aerator operation.	 Apply riprap to banks or construct wind barrier. Reduce aerator time if dissolved oxygen levels permit.
Excessive weed and tule growth. Lagoon too shallow. Inadequate weed-removal program.	 Deepen lagoon to at least 3 feet (1 m). Institute regular weed-removal program or line lagoon.
Animal burrows in levee. Gophers, crayfish, ground squirrels, etc.	 Alter lagoon level rapidly to flood out the burrowers; remove survivors. Install riprap over filter fabric or weed barrier sheeting.
Groundwater contamination. Leakage through bottom or levees of lagoon.	 Add bentonite to lagoon water to seal the leak.

4.5. Natural Treatment Systems O&M. Natural systems are uncomplicated, so they are often neglected. Most problems with natural systems are due to poor maintenance or process overloading. If the design and size of the system is appropriate, and the population it serves does not increase significantly, loading problems usually will not be an issue. The following paragraphs concern maintenance issues that affect the operation of various natural systems.

4.5.1. Overland Flow Systems. Overland flow is the controlled application of wastewater to relatively impermeable soils on gentle grass covered slopes. The hydraulic loading is typically several inches of liquid per week and is usually higher than for most slow rate infiltration systems. Vegetation in the overland flow system contributes to slope stability, erosion protection, and treatment. The flow is normally directed through highly vegetated lands, populated with non-root crops, trees, or grasses. The vegetation assists in the treatment process by absorbing a portion of the water and the nutrients (e.g., nitrates and phosphorus), and provides a substrate for the growth of bacteria and other microorganisms that stabilize organic wastes in the wastewater. These systems require an established pre-treatment system and a large amount of land to be successful. It is unlikely that they would be a good fit for semi-permanent deployments.

4.5.1.1. If using an overland flow system:

- The operator needs to be diligent in maintaining the bar screen and any other pre-treatment systems.
- There must be a solution in place to store or divert the flow to the overland flow system during times of cold weather, heavy rain or, in the case of crop grasses, during harvest.
- Low-permeability soils are acceptable for siting overland flow systems.

4.5.1.2. The application rate is defined as the flowrate applied to the slope per unit width of slope. The application rate used for the design of overland flow systems depend on the limiting design factor (usually BOD), the pre-application treatment, and the climate. BOD loading is limited to 85 pounds/acre/day (95.4 kg/hectare/day). Application periods usually range from 6 to 12 hours/day for 5 to 7 days/week; an 8 hour/day application period is typical. Occasionally, the system may be able to operate 24 hours/day for relatively short periods.

4.5.1.3. Slope lengths in overland flow systems typically range from 100 to 200 feet. The longer the slope the greater the removal of BOD, TSS, and nitrogen. The recommended slope length depends on the method of application. For gated pipe or spray heads where the wastewater is applied at the top of the slope, a slope length of 120 to 150 feet is recommended. For high-pressure sprinkler application, the slope should be between 150 and 200 feet.

4.5.1.4. Once the vegetative cover has been established, the overland flow slopes will need little, if any, maintenance work. It will, however, be necessary to mow the grass periodically. A few systems have been operated without cutting, but the tall grass tends to interfere with maintenance operations. Normal practice has been to cut the grass two or three times a year. The first cutting may be left on the slopes. After that, however, it is desirable to remove the cut grass. The advantages of doing so are that additional nutrient removal is achieved and channeling problems may be more readily observed. Additionally, depending on local market conditions, cut grasses may be sole as hay to offset the cost of harvesting.

4.5.1.5. Slopes should be allowed to dry sufficiently such that mowing equipment can be operated without leaving ruts or tracks that will later result in channeling of the flow. The drying time required before mowing varies with the soil and climatic conditions and can range from a few days to a few weeks. The downtime required for harvesting can be reduced by a week or more, if green chop harvesting is practiced instead of mowing, raking, and baling. Take care to minimize pathogens (disease-causing micro-organisms) effects on personnel. Local markets for green-chop should exist for this method to be considered or feasible.

4.5.1.6. It is common for certain native grasses and weeds to begin growing on the slopes, but usually they have little impact on treatment efficiency, and it is generally not necessary to eliminate them. However, there are exceptions, consider consulting local agricultural or farming community for advice. Proper management of the slopes and the application schedule will prevent conditions conducive to mosquito breeding. Other insects are usually no cause for concern, although an invasion of certain pests such as army worms may be harmful to the vegetation and may require periodic insecticide application.

4.5.2. Constructed Wetlands. Wetlands are nature's sewage treatment plants. This pamphlet does not recommend nor is it usually permitted to discharge wastewater into a naturally occurring wetland. Primarily, this is due to the potential for environmental damage to the natural ecosystem; however, it is permissible and even desirable to discharge pre-treated wastewater into constructed wetlands designed and built specifically to treat wastewater. Constructed wetlands may be of either the surface flow type or subsurface flow type. The surface flow type has exposed water that can support mosquito breeding while the subsurface flow type does not. Each type of constructed wetland requires different types of vegetation, with reeds and bulrushes typically planted in the subsurface flow type due to their deep penetrating roots and stems. Cattails, sedges, rushes, reeds, and bulrushes all grow well in exposed water wetlands. All these plants tolerate freezing conditions and do not normally require harvesting; however, maintenance personnel may occasionally burn off dried grasses in surface water systems.

4.5.2.1. Vegetation assists in the treatment process by:

- Providing oxygen though the root systems.
- Providing a substrate for the growth of bacteria and other microorganisms that stabilize organic wastes in the wastewater.

4.5.2.2. These systems require an established pre-treatment system and a large amount of land to be successful. If a constructed wetlands system is in use, the operator needs to be diligent in maintaining the bar screen and any other pre-treatment systems. There needs to be a solution in place to store or divert the flow to the constructed wetlands system during cold weather. Low-permeability soils are acceptable for siting constructed wetlands. BOD loading is limited to 100 pounds/acre/day (112 kg/hectare/day) for subsurface flow systems and 60 pounds/acre/day (67 kg/hectare/day) for surface flow types. Phosphorus removal in constructed wetlands is not significant.

4.5.3. Irrigation-Based Systems. Irrigation-based systems are similar to overland flow systems (see **paragraph 4.5.1**) in that they must be preceded by pre-treatment processes and are dependent upon vegetation for a significant portion of treatment and nutrient uptake. Influent distribution occurs by sprinklers, surface application, or a drip system. These systems require an established pre-treatment system and a large amount of land to be successful. It is unlikely that they would be a good fit for semi-permanent deployments. If an irrigation-based system is in use, the operator needs to be diligent in maintaining the bar screen and any other pre-treatment systems, as a high-quality influent is required to avoid plugging sprinklers or drip systems. A solution needs to be in place to store or divert the flow to the irrigation system during cold weather, heavy rain or, in the case of crops, during the harvest. Underdrains are often required based on soil permeability and average annual precipitation. Irrigation-based systems typically operate intermittently, with a feed cycle followed by a drying cycle. If established for use, at least two fields or some form of storage are required so that one is always available.

4.5.4. Rapid-Infiltration Basins. Rapid-infiltration basins require soil permeability rates of 1 inch/hour (2.5 cm/hour) or better to be successful. Very coarse sand and gravel are not acceptable as they allow the wastewater to pass too rapidly through the upper few feet of the bed where the biological reactions and stabilization take place. Soil depths to bedrock or 10 feet (3m) or better are also a preferred condition for siting rapid-infiltration basins. These systems require an established pre-treatment system to be successful. If an infiltration basin is in use, the operator needs to be diligent in maintaining the bar screen and any other pre-treatment systems, as a high-quality influent is required to reduce soil clogging and prevent nuisance odors. A solution needs to be in place to store or divert the flow to allow for soil reaeration between applications. Multiple basins are normally necessary to support this requirement. Typically, operators feed primary effluent to an infiltration basin for one to two days, with a five- to seven-day rest or drying period (in the summer) between applications. Recommend a seven- to twelve-day range for winter drying periods. Underdrains are often required when controlling comingling of the percolate and groundwater. Personnel can successfully operate rapid-infiltration basins in freezing conditions. See **Table 4.6** for performance data for rapid-infiltration basins.

Table 4.6. Infiltration Basin Performance Data Range.

Parameter	Average Loading Rate lb/acre/day (kg/ha/day)	Average Removal
BOD	40–160 (45–180)	86% to 98%
Nitrogen	3–37 (3.4–41.5)	10% to 93%
Phosphorus	1–12 (1–13.5)	29% to 99%
Coliform bacteria	N/A	2 to 6 logs

4.5.5. Sampling and Analysis. Sample analysis is one of the best ways for an operator to monitor the condition and efficiency of natural land treatment systems. Not only will the data indicate what is going on in the process but if the results are recorded it allows the operator to predict the trend direction that the process is going in, i.e., whether the process is in a steady state or if the process parameters are headed in the wrong direction. This information allows the operator to troubleshoot the process and make process adjustments before a serious upset occurs. Always take samples at the same location. Take influent and effluent samples at a point where the flow is well mixed. Take aquatic pool samples at least 8 feet (2.5 m) from the edge and at a depth of at least 1 foot (0.3 m). Do not collect pool samples immediately after a high wind or storm as the pool may be temporarily agitated and the sample will not be representative. Good sampling technique is important to ensure a representative sample every time. Sampling records also provide a measure of the treatment's efficiency. Dissolved oxygen, pH, and temperature testing are important indicators to determine process conditions. BOD, coliform, and solids testing measure the process treatment efficiency.

4.5.6. Troubleshooting System Problems. There are warning signs that indicate when a natural-based system is overloaded. Consider using the indicators listed below and the information in **Table 4.7**, as a troubleshooting tool to pinpoint system problems and identify potential remedies.

- Obnoxious odors in the area of the treatment system.
- Sudden changes in pH or dissolved oxygen.
- Rapid change in exposed water surface appearance (color).
- Surface ponding or increase in infiltration time.

Table 4.7. Natural System Failure Troubleshooting.

Possible Causes of Failure	Potential Remedial Procedures
Poor-quality effluent.	
Organic overload.	Divert a portion of the flow to a second or backup process train.
Loss of treatment volume due to sludge accumulation.	Remove sludge.
Excessive plant growth.	Remove plant growth; use herbicide as last resort.
Effluent sample out of range; high coliforms.	Test more frequently. Increase dose/frequency of chlorine addition.
Low dissolved oxygen in aquatic systems.	
Nutrient overload.	Divert some of the flow to a second process train.
Insufficient vegetation growth.	Check influent for toxic substances or insufficient nutrients (low BOD); add nutrient, if required.
Odor conditions.	
Anaerobic conditions.	Limit organic loading.
Presence of hydrogen sulfide (rotten egg smell).	Remove anaerobic sludge or pre-chlorinate.
Irrigation distribution system clogging.	
Foreign objects entering process.	Check headworks to ensure efficient removal of entrained matter.
Hydraulic overloading.	Divert a portion of the flow to a second process train.
Failure of vegetation to thrive.	
Introduced toxic substances.	Analyze influent for toxics; eliminate source, if present.
Low influent nutrients.	Check influent BOD; add nutrients if BOD low.
Excessive evaporation or percolation.	Insufficient water to support vegetation; divert storm water or local stream into process.
Soil erosion.	
Hydraulic overloading.	Divert some of the flow to second process train.
Short circuiting of flow path.	Inspect flow path for leaks, broken pipes, or compromised berms and levees.
Invasive weed growth.	
Aquatic pool too shallow.	Deepen pool to at least 3 feet (1 m).

Possible Causes of Failure	Potential Remedial Procedures
Inadequate weed-removal program.	Institute regular weed-removal program.
Ponding or increased infiltration time. Hydraulic overloading. Infiltration area blinding.	 Divert some of the flow to second process train. Rest the infiltration area for 30 days then return to service.

4.5.7. Routine Maintenance Checks. Thorough daily inspections to identify treatment system problems and gather data to make operating decisions are recommended as part of routine monitoring. Because land application treatment is a biological process, it is somewhat unpredictable, and observations used to adjust management according to actual field conditions are important. **Table 4.8** lists examples of routine inspection and maintenance checks that may help guide daily inspections of land application sites.

Table 4.8. Example of Routine Inspection Checks for Land Application Sites.

Feature	Condition
Facility Discharge	Check amount of flow, evidence of unusual conditions.
Lagoon or Pond	Pond level, odor, scum on surface, presence of excessive solids.
Main Pump Station	Current operations, flow, pressure, odor, leaks, mechanical concerns.
Transmission Piping	Leaks, odor, pressure at intermediate locations.
Booster Pumps	Current operations, flow pressure, odor, leaks, mechanical concerns.
Fields Irrigated	For each field: list irrigation run times, effluent or supplemental water supply, odor.
Fields Condition	For each field: assess irrigation uniformity, runoff, erosion, irrigation system condition, odor, solids on surface.
Crop Condition	For each field: general crop health, need for farming activities.
Samples Collected	List samples taken.
Source: Adapted from EPA 625/R-06/016, *Land Treatment of Municipal Wastewater Effluents.*	

4.6. Recirculating Sand Filter O&M. Recirculating sand filters can produce a high-quality effluent with 85 to 95 percent BOD and TSS removal. Operators develop the dosing rates based upon performance and may adjust them for significant flow variations. Recirculating sand filters require routine service inspections, but the complexity of the maintenance tasks is usually minimal. The primary tasks are monitoring the quality of the influent and effluent, inspecting the dosing system, maintaining the filter surface, checking the discharge orifices, and flushing the discharge manifold. Keep the surface of the sand bed weed-free. In addition, inspect the recirculation tank and perform routine maintenance on the pre-treatment system(s) (i.e., the septic tank). Consider installing a quick-disconnect coupling on the submersible pump in the recirculation tank for easy removal. Also, keep a spare pump available in case the installed pump fails. See **Table 4.9** for a summary of recirculating sand filter maintenance tasks.

Table 4.9. Recommended O&M Tasks for Recirculating Sand Filters.

Item	O&M Recommended Procedures
Pre-treatment septic tank and/or equalization tank.	Inspect inlet effluent tees at each service call. Remove solids from septic tank or other pre-treatment unit.
Dosing chamber. Pumps and controls. Floats, timers, alarms. All components.	 Check every three months. Check and adjust every three months. Check every three months.
Filter media.	If the media bed is consistently overloaded hydraulically and/or biologically, the top portion of the media may clog and need to be replaced.
Other.	Weed as needed; monitor/calibrate distribution device as needed; prevent ice sheet formation.

4.7. Commercial Treatment Systems O&M. Commercial treatment systems are often called “package plants.” While the activated sludge process is not a proprietary product, many manufacturers of package plants develop unique process features and/or equipment that may be trademark- protected. For this reason, suppliers have their own unique operating requirements. Suppliers will provide the owner/operator of a proprietary system with printed copies of the O&M instructions for that unit. In addition, suppliers often provide operator training as part of the purchased package. Keep O&M instructions where users can consult them as needed and file for future use. Consult the proprietary system instructions for O&M information relating to the installed system.

4.7.1. Biological Process Startup. Of the various biological treatment processes, they all have one common element: they utilize microorganisms to remove organic constituents (contaminants) from wastewater. These microorganisms occur naturally in wastewater but in insufficient numbers to provide treatment. Certain conditions are necessary to encourage growth of these microorganisms and thus support treatment in a process tank. Accomplish this in one of two ways: by seeding or by developing a population of microorganisms from scratch. In either case, the following conditions are required for the success of biological treatment:

- Adequate supply of oxygen for the microorganisms.
- Adequate nutrients (food) to support growth of the microorganism population.
- Mixing in the reactor to bring the oxygen and food in contact with the microorganisms.

4.7.2. Seeded Startup. Seeding is the fastest and easiest method for bringing a new biological process online or for rejuvenating an existing process that has undergone a process upset that killed all or most of the microorganisms. A nearby source of mixed liquor or activated sludge is an essential part of a seeded startup. A seeded startup is impossible without the ability to import existing mixed liquor into the facility. Assuming the seed is available, a basic procedure for a seeded start is as follows:

4.7.2.1. Fill (or nearly fill) the reactor with water (if not already filled).

4.7.2.2. Aerate the contents of the reactor until the dissolved oxygen is at least 2.0 mg/L. Aerating over 4.0 mg/L is a waste of energy and will not help the process (more is not better). If there is a separate method of mixing the reactor, other than introducing air, start it now.

4.7.2.3. Introduce raw wastewater or pretreatment (septic tank) effluent concurrently with the seed sludge. How much seed to use? Any amount is better than nothing is, but as most seed will be around 10,000 mg/L in concentration, the volume of seed added does not exceed 2,000 mg/L suspended solids concentration in the reactor(s). An easy calculation is to multiply the ADF by 8.34 x 0.02 ÷ 8.34. For a 3,000-gpd plant, this would equal 60 gallons of seed.

4.7.2.4. Note that the existing dissolved oxygen will be consumed when adding organic wastes and microorganisms to the reactor. Monitor the dissolved oxygen closely at this time and adjust the aeration rate as required to maintain 2.0 mg/L dissolved oxygen concentration.

4.7.2.5. It is not necessary to fill the clarifier (if present) completely prior to startup, one-quarter to one-third of the volume is fine. Once the reactor effluent begins to enter the clarifier, start the collector mechanism.

4.7.2.6. Whatever means of recirculating the reactor effluent mixed liquor, begin doing so at a rate of 1.5 times the influent flow as soon as it is possible to do so.

4.7.2.7. Measure dissolved oxygen and MLSS at least twice a day—twice per shift, if possible. Maintain the dissolved oxygen at 2.0 mg/L and monitor the MLSS.

4.7.2.8. When the MLSS nears 2,000 mg/L, reduce the recirculation rate back to whatever the design rate is for your process.

4.7.2.9. Increasing the mixed liquor concentration to 2,000 mg/L MLSS (typically, the minimum required for an extended-aeration WWTF) will take anywhere from two to five days, depending on the following factors:

- Amount and concentration of seed used.
- Strength of the reactor influent.
- Temperature of the reactor contents.
- Maintaining dissolved oxygen and adequate mixing in the reactor.

4.7.3. Unseeded Startup. The steps for an unseeded startup, or restart, are the same except there is no seed. Because there is no seed, it will take from one to three weeks to develop a population of microorganisms at the design concentration, dependent upon the strength of the reactor influent and the temperature of the process. The task of the operator is to oversee the process to ensure they keep the variables they can control within normal limits and to monitor the progress of biological growth within the reactor.

4.8. Pumping Systems O&M. Most of the processes used to treat wastewater at semi-permanent contingency locations rely upon gravity flow and do not involve pumps. Where pumps are required a source of electricity is required, which is not always present in sufficient quantities in remotely located deployments. There are many types of pumps, but the most prevalent type used in small wastewater treatment systems is the centrifugal pump.

4.8.1. Centrifugal pumps convert the energy of a rotating electric motor or engine into kinetic energy (velocity) and pressure. The pump consists of a rotating impeller and a stationary volute or casing. The pump moves liquid by the impeller spinning at high speed (usually from 1,200 to 3,350 revolutions per minute [rpm]), accelerating the liquid to a high velocity. The rapidly moving liquid leaves the pump volute through the discharge nozzle under pressure. As it leaves, an area of low-pressure forms at the inlet nozzle, thus drawing in more fluid to continue the cycle. Most centrifugal pumps will not "lift" fluid but must be primed. Operators typically accomplish this by locating the pump so that the suction is flooded.

4.8.2. Centrifugal pumps are relatively simple to operate and maintain. It is important not to operate a dry pump for more than a few minutes and never run the pump for more than a few minutes against a closed discharge valve—this can heat the water in the volute to the point where steam is created, which can cause the volute to explode. Personnel should consult the manufacturer's O&M manual for maintenance requirements for a specific pump. For general pump troubleshooting, see **Table 4.10**.

Table 4.10. Centrifugal Pump Troubleshooting Matrix.

Possible Causes of Failure	Potential Remedial Procedures
Little or no discharge.	
Volute not filled with water.	Prime pump.
Impeller plugged.	Open volute and clean impeller.
Impeller damaged.	Replace impeller.
Motor wired incorrectly.	Check wiring and wiring diagram.
Leaking seal, packing, or O-ring.	Repack pump or change out seal as appropriate.
Discharge valve closed or partially closed.	Ensure discharge valve is fully open.
Suction line leaking or clogged.	Repair/replace or clean suction line.
Loss of suction.	
Leak in suction line	Repair or replace suction line.
Clogged/defective check or foot valve.	Clean or replace the affected valve.
Loss of prime.	Verify then prime the pump.
Motor overheat/overload.	
Impeller is rubbing the volute.	Dismantle pump, unclog, or replace the impeller.
Improper voltage.	Verify source voltage, verify wire size, tighten connections.

Possible Causes of Failure	Potential Remedial Procedures
Pump vibrates or is noisy. Mounting plate not rigid. Worn motor bearings. Foreign object in pump. Damaged impeller.	 Reinforce or re-grout pump foundation plate. Replace defective bearings. Dismantle pump and clean out. Inspect and replace impeller as needed.
Pump will not prime. Worn mechanical seal or packing. Plugged impeller, check valve, or suction. Leaks in the system.	 Replace defective seal or adjust packing. Remove clogs in the pump and piping. Find and repair leaks in the suction piping and/or pump.
Pump will not run. Improper wiring. Blown fuse or open circuit. Impeller jammed. Motor shorted out.	 Check wiring for integrity and proper connections. Replace fuse and reset circuit breaker. Dismantle pump and remove foreign object. Replace motor.
Pump leaks at shaft. Worn mechanical seal. Loose or worn packing.	 Replace mechanical seal. Adjust packing or replace if worn entirely.

4.9. Disinfection O&M. A routine operation and maintenance schedule should be developed and implemented for any disinfection system. The following paragraphs address O&M for UV radiation and chlorine tablet disinfection systems. Certain information was adapted from the EPA Wastewater Technology Fact Sheet, *Disinfection for Small Systems*. Find this and other EPA wastewater treatment system publications at https://search.epa.gov/epasearch/epasearch.

4.9.1. UV Radiation. A proper O&M program for a UV disinfection system should ensure that sufficient UV radiation is transmitted to the organisms to inactivate them. The following are typical O&M considerations for UV disinfection systems:

- Regular inspection and maintenance as recommended by the manufacturer.
- Replacing the lamps as recommended by the manufacturer, generally annually or when output has decreased to 70 percent efficiency.
- A regular program of water monitoring for turbidity and color.

4.9.1.1. Cleaning. Cleaning frequency is site-specific. 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. Chemical cleaning is 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.

4.9.1.2. Lamp Replacement. 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 always kept on hand 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.

4.9.1.2.1. The quartz sleeves that fit over the lamps will last about 5 to 8 years but are generally replaced every 5 years.

4.9.1.2.2. 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.

4.9.2. Tablet Chlorination. Follow manufacturer's recommendations and test/calibrate equipment according to the maintenance instructions. The following are common O&M considerations and activities for a tablet chlorinator:

- Use only wastewater-approved chlorine contact tablets.
- Inspect at least two times per week to ensure the chlorinator contains tablets at all times.
- Tablets can become blocked in the tube; check for and remove blockages during inspection.
- To reduce the risk of blockages, do not add more than five tablets at a time.
- Use a chlorine test kit to determine the chlorine concentration in the storage reservoir; insufficient chlorine or septic odors indicate a blockage or insufficient chlorine contact.

4.9.2.1. Cleaning. Disassemble and clean system components, including meters and floats, every six months. Inspect and clean valves and springs annually. Remove iron and manganese deposits with muriatic acid or other removal agents.

4.9.2.2. Chemical Storage. It is essential to store all chemical disinfectants properly and safely 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 Safety Data Sheets (SDS) for the specific chemicals of interest. SDSs are readily available from the internet by doing a search on the chemical name.

4.10. Residuals Management. Regardless of the type of system, no wastewater treatment process is capable of continuous operation without experiencing some type of residuals buildup. Removal and disposal of these residuals is a very important and sometimes neglected part of system O&M. Disposing of residuals collected or precipitated during the operation of wastewater treatment facilities is one of the most problematic and important factors in the operation of a wastewater treatment facility. The residuals personnel will most likely encounter when operating the types of systems described in this publication fall into two groups: screenings and sludge. Screenings off bar racks (typically collected manually in systems of the size and type described herein) need to be disposed of as soon as possible after collection or briefly stored in a secure, covered container until disposal. Units normally dispose of screenings by burial, either in a nearby trench or at a designated landfill. Regardless, carry out collection and disposal of screenings in such a way as to preclude providing a source of obnoxious odors or a food or breeding source for rats and noxious insects. Sludge consists of settled solids that vary in consistency from a free-flowing liquid (e.g., settled solids and scum removed from a septic tank) to a semi-solid, mud-like substance dredged from lagoons or drying beds. Transport liquid sludge to nearby wastewater treatment plants for disposal or dewater and dispose of in landfills. For remote contingency locations, a local WWTF may not be available. In this case, dewatering the septage in an onsite sludge-drying bed may be necessary prior to disposal. In addition to the landfill disposal option, consider using dewatered or semi-solid sludge as a fertilizer or soil supplement, depending upon its content and local conditions. Plow in sludge applied to agricultural land as soon as possible following application.

4.10.1. Sludge Drying Beds. Dewatering in a sludge drying bed occurs by evaporation from the surface of the sludge and draining from the lower layers of the sludge. Leachate is the name given to liquid draining from the sludge. Since most of the water removed from the sludge is by evaporation, sludge-drying beds work best in warm, arid, and semi-arid climates. Under favorable conditions, sludge can achieve a moisture content of 60 percent in 10 to 15 days. Sludge in drying beds exposed to precipitation will take longer to reach the desired solids content. Covering the drying bed with a roof, plastic, or glass will improve performance, while still allowing air to circulate. Transparent covers, such as plastic or glass, allows more sunlight and may shorten drying time. **Table 4.11** lists typical advantages and disadvantages of drying beds.

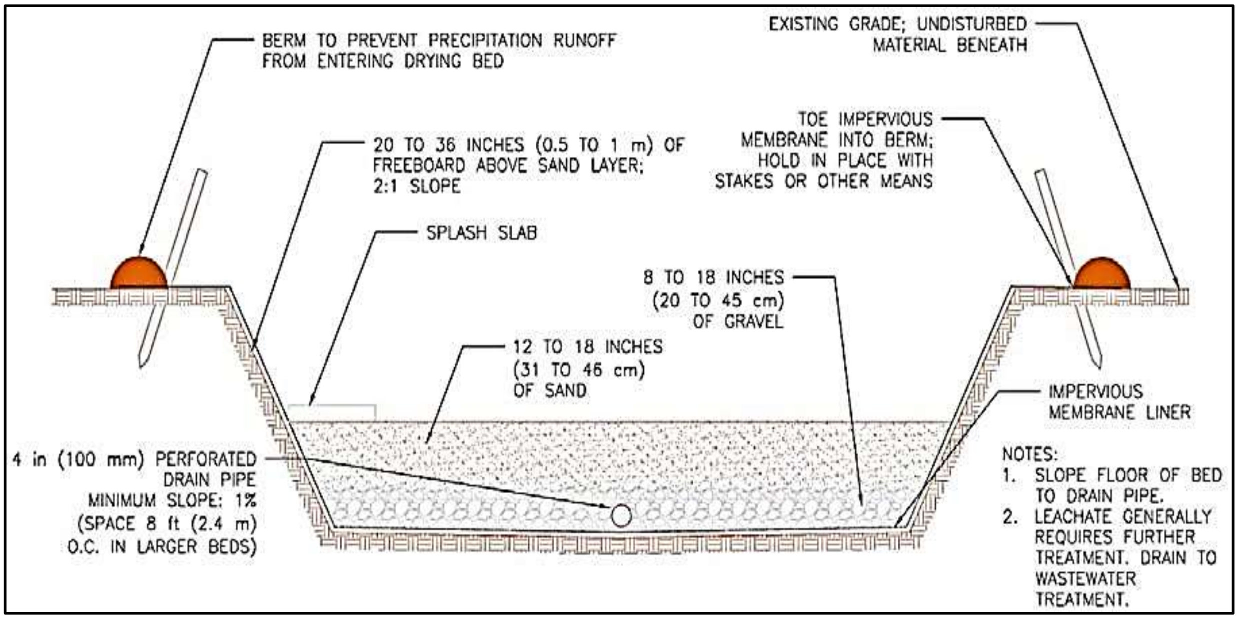
Table 4.11. Sludge Drying Beds Advantages and Disadvantages.

Advantages	Disadvantages
Low cost	Relatively high space requirements
Low maintenance requirements	Potential odors
A high dried solids-content product	Attraction of pests
The dried product may be landfilled or buried	Manual removal of dried sludge

4.10.2. Sludge Drying Bed Construction. The illustration in **Figure 4.4** is a diagram of an excavated sludge drying bed. Construct the bottom of the drying bed above the groundwater table. In cases where leachate contamination of groundwater is dangerous to public health or otherwise undesirable (for example, near a water supply well), consider providing a concrete or impervious membrane floor as the base of the sludge drying bed. If using impervious floors, position underdrains above the floor. The following are the design requirements for underdrains:

- Plastic, ductile iron, or cast-iron pipe.
- Perforated pipe.
- No less than 4 inches (100 mm) in diameter.
- Minimum slope of 1 percent.
- Spaced 8 to 20 feet (2.5 to 6 m) apart.

Figure 4.4. Excavated Sludge Drying Bed.



4.10.2.1. Since the leachate collected by the underdrain may be pathogenic and have biochemical and chemical oxygen demands, the underdrain should flow back to the wastewater treatment system or septic tank. In climates with significant precipitation, it may be advantageous to cover the bed to prevent rainwater from infiltrating back to the treatment mechanism.

4.10.2.2. Backfill underdrains with gravel. This layer ranges from 8 to 18 inches (200 to 450 mm) deep. Gravel particles range from 0.1 to 1 inch (3 to 25 mm) in diameter. The coarser materials are at the bottom of this layer. Above the gravel layer, there is a sand layer. The following are the design requirements for the sand layer:

- 12 to 18 inches (305 to 460 mm) deep.
- Sand needs to be clean, free from clay, dust, loam, or other foreign matter.
- Sand grains need to be between 0.01 and 0.03 inch (0.3 to 0.75 mm) in diameter.

4.10.2.3. Consider that some sand will be lost during dried sludge removal operations and will require replacement. Provide a splash slab of durable material about 3 to 5 inches (7.5 to 13 cm) thick and 3 ft^2 (0.3 m^2) to receive sludge being decanted and prevent erosion of the sand surface.

4.10.2.4. Construct sidewalls of concrete or wood (use treated wood to prevent rotting). **Figure 4.5** shows a field of concrete-walled sludge drying beds. The sidewalls can extend 20 to 36 inches (0.5 to 0.9 m) above the surface of the sand layer and extend to the bottom of the sludge drying bed. Alternatively, where simple, nonpermanent construction is used, the sludge drying bed may be an excavation with sloped sides. If leachate contamination of the groundwater is a concern, the impervious membrane liner can be continuous and cover the sloped excavation sides.

Figure 4.5. Concrete Walled Sludge Drying Beds.

4.10.2.5. In the case of larger sludge drying beds, consider providing partitions to isolate sections of the bed and allow alternating use. Partitions can be constructed of similar material to the sidewalls and extend 3 to 4 inches (75 to 100 mm) below the top of the sand layer. If using posts to support wooden partitions, extend the posts 2 to 3 feet (0.6 to 0.9 m) below the bottom of the gravel layer. Locate open sludge drying beds about 300 feet (100 m) from inhabited areas to avoid odor complaints.

4.10.3. Sludge Drying Bed Operation and Maintenance. Typically, fresh sludge can cause disease (pathogenic), so personnel should handle it with care. Transport sludge directly to drying beds using pumps or via a pump truck. Apply sludge in 3- to 12-inch (7 to 30 cm) layers. If the sludge tends to separate from the liquid, consider drawing off the clear liquid at the top. Allow the sludge to dry until it achieves the desired solids concentration. This will vary by climate and location; sludge can achieve a moisture content of 60 percent in 10 to 15 days, under favorable conditions. Accelerate the drying process by breaking up the dry, crusty layer at the top with a shovel or auger. Sludge will continue to dry during periods of freeze-thaw cycling. Sludge should be dry to moist and crumbly (not wet) when removed. Remove dried sludge with mechanical equipment or shovels and wheelbarrows. If transporting removed sludge with trucks, make provisions to allow trucks to drive alongside the beds. Do not drive trucks on the beds. Replace any sand removed during dried sludge removal and apply sludge.

4.10.4. Sludge Drying Bed Design Calculation. Size sludge drying beds based on the number of individuals they will serve. Generally, it is assumed that 1 to 1.5 ft^2 of drying area is required per person (see Metcalf & Eddy, *Wastewater Engineering, Treatment and Reuse*). See **Table 4.12** for an example calculation.

Table 4.12. Example Sludge Drying Bed Design Calculation.

Example: Size a sludge drying bed for a facility with a wastewater treatment system sized for 3000 gal/day.
Solution: Using a 40 gpd/person from **Table 2.27**, 3000 gal/day ÷ 40 gal/person/day = 75 people 75 people x 1.5 ft^2/person = 113 ft^2 The sludge drying bed is sized as follows: Use 120 ft^2 or 10 feet x 12 feet for ease of construction or two 6-foot x 10-foot beds for ease of access

4.11. Closing Wastewater Treatment Facilities. Once leaders make the decision to transition to permanent facilities, or cease expeditionary operations, units can usually close temporary sanitation facilities, including wastewater treatment units and systems. Eliminating and properly decommissioning such facilities will reduce the risk of exposure to personnel and the environment.

4.11.1. Usually, the lead Service is responsible for closing onsite wastewater treatment facilities and other environmental systems. When host nation entities express interest in keeping these facilities, CE assists with transfer of the sites and infrastructure in accordance with theater and CCMD requirements. This is particularly crucial in areas such as the US Central Command (CENTCOM) area of operations where we frequently downsize, close, or return non-enduring contingency locations to host nations. During site closures, mitigation of adverse environmental impacts may be required by international agreement or combatant commander policy. Commanders can use environmental surveys and condition reports conducted prior to and throughout site occupation to mitigate environmental hazards that present danger to human health and safety. Contact the CCDR's environmental staff for guidance on site closure and environmental mitigation policies. The Environmental Officer and staff also assists with site closure and transfer.

4.11.2. Typically, closure plans for WWTFs are based on site-specific information. The closure plans may address concerns relating to potential migration of residual waste constituents to environmental media, including groundwater, surface water, and the atmosphere. Further, closure plans for certain land treatment components may address the extent of degradation, transformation, and immobilization of constituents within a defined treatment zone, or the pathways of migration of hazardous waste constituents into the environmental media. The following sections provide general considerations for closure of wastewater treatment units and systems. Be sure to follow theater, CCMD, and AF requirements and procedures for your contingency location.

4.11.3. Site Closure Considerations. Environmental considerations and standards addressed in site closure plans generally attempt to control, minimize, or eliminate post-closure escape of hazardous waste, hazardous constituents, leachate, contaminated run-off, or hazardous waste decomposition products. If sampling and analysis is done during the initial Environmental Baseline Survey, the same is usually accomplished for the environmental closure report. Consider the following potential actions when performing sit closure for certain wastewater treatment systems and units:

4.11.3.1. Septic Tanks and Leach Fields. When removing septic tank contents and tanks, take care to avoid spillage and movement of fluids containing contaminants into underground sources of drinking water. If closing several septic systems at the contingency location, consider phasing out and closing individual systems as the population decreases. In addition, consider using contractor-supported portable toilets, burnout latrines, or other expedient latrines for the last few days or weeks at the location. Septic system closure may include the following procedures:

- Locate drain lines, distribution boxes, septic tank(s), and dosing tank(s).
- Remove contents from drains and drain lines.
- Cap or plug influent sewer line.
- Pump and remove septage (sewage sludge, grease, and sediment) from septic tank(s).
- Dispose of septage appropriately (local WWTF, landfill, sludge drying bed, etc.).
- Remove septic tank(s) and visually check the tank for indications of cracks or leaks, and any visibly or potentially contaminated soil in the vicinity.
- Complete sampling and analysis regiment as required by environmental guidance.
- Remove and dispose of contaminated soil, if required.
- Remove and/or fill dosing tanks and distribution boxes.
- Cap or plug effluent outlets to leach fields.
- Remove all pumps, piping, and valves of treatment system.
- Backfill all holes with compacted earth, sand, gravel, or other approved material.

4.11.3.2. Lagoons and Ponds. Depending on the specific closure plan, requirements may involve removing everything from the lagoon and restoring the original site topography, or removing all standing wastewater from the lagoon, stabilizing the bio-solids (remaining wastes, waste residues and contaminated materials), and backfilling the basin. These two closure options and their associated actions are included in the list below.

- Cap or plug influent sewer line.
- Remove or drain wastewater from the lagoon.
- Pump wastewater to local treatment facility or receiving system or,
- Allow lagoon to stabilize with no additional inflow for a period not less than the design detention time of the lagoon and drain into the receiving stream according to requirements and conditions (at a rate not exceeding the maximum design flow of the lagoon).
- Allow solid accumulation (sludge) on the bottom of lagoon to dry.
- Apply disinfectant, mix dried sludge with soil, and leave on the bottom of lagoon or

remove for disposal in a landfill or other approved method or,
- Stabilize the sludge on the bottom of lagoon through lime treatment or in-place composting (this is desirable to reduce odors and the presence of pathogenic organisms).
- Remove all mechanical equipment, piping, and valves, and liner materials (e.g., plastic and clay liners) from the lagoon(s) and disposed of in an approved manner.
- Backfill lagoon, compact soil, and cap above the existing grade.
- Consider seeding to prevent ponding and erosion.

4.11.3.3. Wastewater Treatment Package Plants. Package plants typically include prefabricated factory assembled units and other modular type units designed for the treatment of wastewater through activated sludge processes and modifications. The main closure consideration is usually the disposal of generated sludge. Consider the following procedures when closing package plants.

- Sever and cap the influent line entering the wastewater treatment plant.
- Remove all wastewater and septage (sewage sludge, grease, and sediment) from the plant.
- Dispose of wastewater and septage at a permitted treatment plant or land applied under the proper conditions and requirements.
- Dismantle and remove all piping, mechanical, and electrical equipment from the site (some of these items can be recycled, salvaged, or reused).
- Dispose of items that cannot be recycled, salvaged, or reused at a permitted landfill.
- Demolish plant basins and treat concrete as clean fill or leave onsite.
- Crack the floor of basins left onsite so they cannot hold water and fill with clean-fill material.

4.11.3.4. Sewage Sludge. Sewage sludge from wastewater treatment plants can be managed as a liquid (2 percent solids) or a cake (15 to 20 percent solids) depending on the dewatering equipment available. Common sewage sludge disposal options for contingency locations include municipal sewage systems, municipal landfills, land application of non-stabilized sludge, and composting. Refer to **paragraph 4.10** for information on managing residuals.

4.11.3.5. Chemicals. Chemicals used and stored at WWTFs should be disposed of according to the Safety Data Sheet or relocated for use elsewhere. Safety Data Sheets can be found online but should be stored with the chemicals.

4.11.3.6. Recycling Media Filters. This wastewater treatment system includes recirculating sand filters, gravel filters, and other types of media. Consider the following actions when closing recycling media filters.

- Sever and cap the influent line entering the wastewater treatment plant.
- Remove all wastewater and septage (sewage sludge, grease, and sediment) from the plant.
- Dispose of wastewater and septage at a permitted treatment plant or land applied under the proper conditions and requirements.

- Dismantle and remove all piping, mechanical, and electrical equipment from the site (some of these items can be recycled, salvaged, or reused).
- Dispose of items that cannot be recycled, salvaged, or reused at a permitted landfill.
- Demolish plant basins and treat concrete as clean fill or leave onsite.
- Crack the floor of basins left onsite so they cannot hold water and fill with clean-fill material.
- Dispose of filter media at a permitted landfill (unless the options below permitted).
- Dispose of fine sand and gravel via land application under proper conditions and requirements.
- Dispose of larger sand and gravel at a permitted landfill.
- Leave larger rocks in basin, wash using pressure washer, and dispose of as clean fill.
- Allow wash water to drain into recirculation tank and dispose of at permitted treatment plant.
- Crack the floor of basins left onsite so they cannot hold water and fill with clean-fill material.

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Attachment 1

GLOSSARY OF REFERENCES AND SUPPORTING INFORMATION

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Prescribed Forms

No prescribed forms are implemented in this publication.

Adopted Forms

DAF Form 847, *Recommendation for Change of Publication*.

Abbreviations and Acronyms

ADF—average daily flow

AFCEC—Air Force Civil Engineer Center

AFI—Air Force instruction

AFPAM—Air Force pamphlet

ASTM—American Society for Testing and Materials

BE—Bioenvironmental Engineering

BNR—Biological Nutrient Removal

BOD—biochemical oxygen demand

CCMD—Combatant Command

cfs—cubic feet per second

cfu—colony-forming unit

cm/day—centimeters per day

cm—centimeter

COCOM—combatant command (command authority)

COD—chemical oxygen demand

CONUS—continental United States

CY—cubic yard

D-box—distribution box

DoD—Department of Defense

ENR—Engineering News-Record

EPA—Environmental Protection Agency

F—Fahrenheit

fps—feet per second

ft^2—square foot

ft^3—cubic foot

ft—foot

FWS—free water surface

gal—gallons

gpcd—gallons per capita per day

gpd/sf—gallons per day per square foot

gpd—gallons per day

gpi—gallons per inch

gpm—gallons per minute

GW—groundwater

ha/day—hectare per day

ha—hectare

HLR—hydraulic loading rate

HN—host nation

in—inch

ISRIC—International Soil Reference and Information Center

kg/cm—kilogram per centimeter

kg/ha/d—kilograms per hectare per day

kg—kilogram

lb/ac/d—pounds per acre per day

lb—pound

LF—linear feet

L—liter

log—logarithmic

Lpcd—liters per capita per day

Lpd—liters per day

m/s—meters per second

m^2—square meter

m^3/s—cubic meters per second

MBR—membrane bioreactor

mgd—million gallon/day

mg/L—milligrams per liter

mL—milliliter

MLSS—mixed liquor suspended solids

m—meter

mm—millimeter

MPN—most probable number

N/A—not applicable

N—nitrogen

NRCS— Natural Resources Conservation Service, US Department of Agriculture

O&M—operation and maintenance

o.c.—on center

OPORD—operation order

perc—percolation

PF—peaking factor

pH—measure of the activity of the (solvated) hydrogen ion

PO—purchase order

P—phosphorus

PVC—polyvinyl chloride

rpm—revolutions per minute

RR—recirculation ratio

s/d—seconds per day

SAS—subsurface adsorption system

SDR—standard dimension ratio

SF—subsurface flow

SW—surface water

SY—square yard

TDH—total dynamic head

TDS—total dissolved solids

TN—total nitrogen

TSS—total suspended solids

TS—total solids

U.S.—United States

UFC—Unified Facilities Criteria

USDA—United States Department of Agriculture

UV—ultraviolet light

WHO—World Health Organization

WWTF—wastewater treatment facility

Office Symbols

AF/A4C— Air Force Directorate of Civil Engineers
AF/A4CX—Air Force Directorate of Civil Engineers, Readiness Division

Terms

Absorption—The process by which one substance is taken into and included within another substance, such as the absorption of water by soil or nutrients by plants.

Activated Sludge Process—A biological wastewater treatment process in which active sludge is agitated and aerated with incoming wastewater to promote treatment. The activated sludge is subsequently separated from the treated wastewater (mixed liquor) by settling, and most is recycled to the process.

Adsorption—The increased concentration of molecules or ions at a surface, including exchangeable cations and anions on soil particles. The adherence of a dissolved solid to the surface of a solid.

Advanced Wastewater Treatment—Treatment beyond the secondary or biological stage of treatment. It includes removing nutrients such as phosphorus and nitrogen and a high percentage of suspended solids. It is also often called tertiary treatment.

Aeration—The process of exposing wastewater to circulating air to assist biological treatment.

Aerobic—Refers to life or processes that require the presence of free elemental oxygen. Typically the dissolved oxygen is greater than 1.0 mg/L.

Aerobic Treatment Unit (ATU)—A mechanical treatment unit that provides secondary wastewater treatment by mixing air (oxygen) and aerobic and facultative bacteria with the wastewater. ATUs typically use a suspended growth treatment process (similar to activated sludge extended aeration) or a fixed film treatment process (similar to trickling filter).

Ammonia Nitrogen—Ammonia or ammonium form of nitrogen in raw sewage that is converted in the nitrification process. The majority of the organic nitrogen contained in raw sewage is converted to ammonia and/or ammonium while travelling through the sewer pipe.

Anaerobic—Refers to life or processes that require the absence of free elemental oxygen.

Anoxic—Refers to processes that require low oxygen concentrations (less than 0.5 mg/L) such as the denitrification process where the bacteria utilize the oxygen in the nitrate molecule (NO_3) to complete the reaction and thus release nitrogen gas.

Areal— Adjective, of or relating to or involving an area.

Assimilation—Aerobic microbes consume the nutrients in the wastewater.

Bacteria—Bacteria are single-cell microscopic organisms that grow in nearly every environment. In wastewater treatment, they can perform a variety of biological treatment processes.

Basal—Adjective, of, at, or forming the base.

Biochemical Oxygen Demand (BOD)—A commonly used gross measurement of the concentration of biodegradable organic impurities in wastewater. The amount of oxygen, expressed in milligrams per liter (mg/L), required by bacteria while stabilizing, digesting, or treating organic matter under aerobic conditions is determined by the availability of material in the wastewater to be used as biological food and the amount of oxygen used by the microorganisms during oxidation.

Biomat—The layer of biological growth and inorganic residue under a leach field that develops at the wastewater-soil interface and extends up to about 1 inch into the soil matrix. The biomat controls the rate at which wastewater moves through the infiltrative zones in soils or leach field.

Chemical Oxygen Demand (COD)—A measure of oxygen use equivalent to the portion of organic matter that is susceptible to oxidation by a strong chemical oxidizing agent.

Chemical Sorption—Contaminants stick to the surface of the sand and to the biological growth on the sand surface.

Chlorine Residual—The total amount of chlorine (combined and free available chlorine) remaining in water, sewage, or industrial wastes at the end of a specified contact period following disinfection.

Clay—A textural class of soils consisting of particles less than 0.002 mm in diameter.

Coliform Bacteria—A group of bacteria predominantly inhabiting the intestines of humans or other warm-blooded animals, but also occasionally found elsewhere. Used as an indicator of human fecal contamination.

Composite Sample—Consists of a collection of numerous individual discrete samples taken at regular intervals over a period of time, typically 24 hours. The combined sample represents an average of the measured characteristics over that period. Composite samples are used to measure influent and effluent characteristics for a wastewater treatment facility and compared to determine effectiveness.

Constructed Wetland—An aquatic treatment system consisting of one or more lined or unlined basins, some or all of which may be filled with a treatment medium and wastewater undergoing some combination of physical, chemical, and/or biological treatment and evaporation and evapotranspiration by means of macrophytes planted in the treatment medium.

Contingency Location—A non-enduring location outside the United States that supports and sustains operations during named and unnamed contingencies or other operations as directed by appropriate authority and is categorized by mission life-cycle requirements as initial, temporary, or semi-permanent (see DoDD 3000.10).

Denitrification—The conversion of nitrate nitrogen molecules to nitrogen gas in an anoxic reactor.

Deployment/Deployed Location—A non-enduring location that supports and sustains operations during named and unnamed contingencies or other operations as directed by appropriate authority.

Disinfection—The process of destroying pathogenic and other microorganisms in wastewater, typically through application of chlorine compounds, UV light, iodine, ozone, and the like.

Dissolved Oxygen (DO)—The oxygen dissolved in water, wastewater, or other liquid, usually expressed in milligrams per liter (mg/L), parts per million (ppm), or percent of saturation.

Dissolved Solids—The fraction of solids dissolved in water.

Distribution Box (D-box)—A watertight box where flow is equalized and distributed into multiple pipes. Often, septic tank effluent is piped to a distribution box for flow splitting into multiple areas of the leach field.

Dose—Application of wastewater volume over a period of time.

Leach field (also drain field, absorption field)—Shallow, covered excavation made in unsaturated soil into which pretreated wastewater is discharged through distribution piping for application onto soil infiltration surfaces. The soil accepts, treats, and disperses wastewater as it percolates through the soil, ultimately discharging to groundwater.

Effluent—Sewage, water, or other liquid, partially or completely treated or in its natural state, flowing out of a septic tank, subsurface wastewater infiltration system, aerobic treatment unit, or other treatment system or system component.

Effluent Filter—A removable, cleanable device inserted into the outlet tee of the septic tank or dosing pump designed to trap solids that may clog the leaching system or other downstream treatment components.

Effluent Screen—See Effluent Filter.

Environmental sensitivity—The relative susceptibility to adverse impacts of a water resource or other environments that may receive wastewater discharges.

Evapotranspiration—The combined loss of water from a given area and during a specified period of time by evaporation from the soil or water surface and by transpiration from plants.

Facultative Bacteria—A type of bacteria that consumes oxygen dissolved in water (like aerobic bacteria) or by taking if off molecules in the water that are combined with oxygen such as a nitrate molecule (NO_3).

Filter Media—Material such as sand, stone, pellets, or other product used in a bed or tank that serves as a host for biological treatment as wastewater passes through.

Filtration—Particles are physically strained from the wastewater passing through a medium such as a sand bed, soil, or other fixed material.

Fixed-Film Wastewater Treatment System—A biological wastewater treatment process that employs a medium such as rock, plastic, wood, or other natural or synthetic solid material that supports biomass on its surface.

Grab Sample—A sample volume of water taken to measure characteristics such as pH, BOD, and/or TSS at a specific point in time at the source taken. A grab sample is typically used as a check and is not as representative as a composite sample to determine process performance.

Hydraulic Loading Rate—Flow volume unit for application to a surface area, such as gallons per day per square foot.

Influent—Water, wastewater, or other liquid flowing into a reservoir, basin, treatment plant, or treatment process.

Infrastructure—The network of pipes, tanks and equipment above and below ground that transmit, process, treat, and discharge treated wastewater.

Initial Contingency Location—A contingency location occupied by a force in immediate response to a named or unnamed contingency operation and characterized by austere infrastructure and limited services with little or no external support except through Service organic capabilities. (DoDD 3000.10)

Lagoon—Wastewater treatment method that uses ponds to grow algae and sunlight to produce oxygen. The oxygen is used by microorganisms in the lagoon to break down organic material in the wastewater. Also known as oxidation pond or stabilization pond.

Laminar—Used to describe flat, sheet-like ground water flows that migrate laterally along the upper surface of a confining layer of soil or rock.

Land Application—The treatment or disposal of wastewater or wastewater solids by spreading it on land under controlled conditions.

Loading Factors—Concentration of specific wastewater pollutant characteristics such as BOD, TSS, and ammonia.

Loam—A general agricultural term, applied most frequently to sandy-silty topsoil which contain a trace of clay, are easily worked, and support plant life. (TM 3-34.64)

Mass Loading Variation—Variations in the concentration of loading factors in the influent wastewater.

Membranes—Soft, pliable sheets or layers used in filtration processes.

Membrane Bioreactors—Combined activated sludge treatment processes and membrane filtration equipment to separate liquids and solids.

Microorganisms—Microscopic organisms, either plant or animal, invisible or barely visible to the naked eye; for example, bacteria, fungi, protozoa, and viruses.

Mineralization—The conversion of an element from an organic form to an inorganic state as a result of microbial decomposition.

Most Probable Number (MPN)—Typically used in reference to a fecal colony count for 100 mL effluent sample.

Mottling—Spots or blotches of different colors or shades of color interspersed with the dominant soil color caused in part by exposure to alternating unsaturated and saturated conditions.

Nitrification—The biochemical oxidation of ammonia/ammonium to nitrate, typically achieved in an aerobic reactor. It is a two-step process whereby one type of bacteria converts ammonia and ammonium to nitrite then another bacteria converts nitrite to nitrate.

Nutrients—Elements or compounds, such as nitrogen, phosphorus, and potassium, that are necessary for plant growth.

Onsite WWTF—Refers to wastewater managed and treated at the site generated vs. being discharged to a collection system and conveyed to a remote WWTF.

Operation and Maintenance (O&M)—The organized procedure for keeping the equipment or plant in such a condition that it is able to continually and reliably perform its intended function.

Organic Nitrogen—Nitrogen combined in organic molecules such as proteins and amino acids.

Pathogenic—Causing disease; commonly applied to microorganisms that cause infectious diseases.

Peaking Factor—Adjustments to flow or loading that consider periods of higher concentration.

Percolation—The flow or trickling of a liquid downward through a contact or filtering medium.

Percolation Test—The procedure for measuring the soil percolation rate at a site.

Performance Requirement—Any requirement established by the regulatory authority to ensure future compliance with public health and environmental goals.

Permeability—The ability of a porous medium such as soil to transmit fluids or gases.

pH—A term used to describe the concentration of hydrogen ion in an aqueous solution on a logarithmic scale with numbers less than 7 being acidic, numbers greater than 7 being basic, and 7 being neutral; relative to acidity.

Pretreatment System—Any technology or combination of technologies that precedes discharge to a subsurface wastewater infiltration system or other final treatment unit or process before final dissemination into the receiving environment.

Receiving Site—A river, lake, ocean, or groundwater aquifer into which wastewater or treated effluent is discharged.

Regulatory Authority (RA)—The level of government that establishes and enforces codes related to the permitting, design, placement, installation, operation, maintenance, monitoring, and performance of wastewater treatment systems.

Residuals (Sludge)—The solids generated and retained during the treatment of wastewater, including sludge, scum, and residuals from grease traps, septic tanks, aerobic treatment units, and other components of a treatment system.

Sand Filter—A packed-bed filter of sand or other granular materials used to provide advanced secondary treatment of settled wastewater or septic tank effluent. Sand/media filters consist of a lined (e.g., impervious PVC liner on sand bedding) excavation or structure filled with uniform washed sand that is placed over an underdrain system. The wastewater is dosed onto the surface of the sand through a distribution network and allowed to percolate through the sand to the underdrain system, which collects the filter effluent for further processing or discharge.

Scum—Grease, fats, and material that floats to the top of the septic tank.

Septage—The mixture of solid wastes, scum, sludge, and liquids pumped from within septic tanks, grease traps, pump chambers, holding tanks, and other process components.

Septic Tank—A tank that receives and partially treats raw wastewater. Settleable solids settle to the bottom to form a sludge layer. Grease and other light materials float to the top to form a scum layer. The removed solids are stored in the tank, where they undergo liquefaction in which organic solids are partially broken down into dissolved fatty acids and gases. Gases generated during liquefaction of the solids are normally vented through the building's plumbing stack vent.

Settleable Solids—Matter in wastewater that will settle out of suspension by gravity.

Sewage—Any urine, feces, and the water carrying human wastes, including kitchen, bath, and laundry wastes from residences, buildings, industrial establishments, or other places. Sewage is generally synonymous with wastewater.

Sewer—Pipe system that carries sewage or wastewater.

Silt—A textural class of soils consisting of particles between 0.05 and 0.002 millimeter in diameter.

Sludge—Any heavy solid, semisolid, or liquid waste such as grit and sand that fall to the bottom of a septic tank or wastewater process tank.

Soil Map—A map showing the distribution of soil types or other soil mapping units in relation to prominent physical features.

Soil Structure—The arrangement of individual soil particles that are characterized and classified on the basis of size, shape, and degree of distinctness.

Soil Survey—The systematic examination, description, classification, and mapping of soils in an area.

Soil Texture—The relative proportions of the various soil separates (e.g., silt, clay, sand) in a soil.

Stratification—The separation of liquid into layers; heavier solids settle to the bottom and lighter material (scum) float at the surface, such as in a septic tank, resulting in a clear mid-layer.

Subsoil—In general, that part of the soil below the depth of plowing.

Subsurface Absorption System (SAS)—Also known as leach field: An underground system for dispersing and further treating pretreated wastewater. The SAS includes the distribution piping/units, any media installed around or below the distribution components, the biomat at the wastewater-soil interface, and the unsaturated soil below.

Suspended Solids—Solid pollutants that either float on the surface of or are suspended in wastewater primarily due to their small size. They can also be called total suspended solids (TSS).

Topsoil—The layer of soil containing organic material.

Treatment System—Any technology or combination of technologies (treatment trains or unit processes) that process and discharge treated wastewater to surface waters, ground water, or the atmosphere.

Turbidity—The cloudy or muddy appearance of a naturally clear liquid caused by suspension of particulate matter that usually is invisible to the naked eye. The measurement of turbidity is a key test of water quality.

United States—The several states, the District of Columbia, the Commonwealths of Puerto Rico and the Northern Mariana Islands, American Samoa, Guam, Midway and Wake Islands, the United States Virgin Islands, any other territory or possession of the United States, and associated navigable waters, contiguous zones, and ocean waters of which the natural resources are under the exclusive management authority of the United States (see DoDD 3000.10).

UV Disinfection—Disinfection achieved by passing water through a UV reactor that emits radiation with a specific wavelength to destroy bacteria in the water.

Wastewater—Water that has been used by a community or facility for domestic or industrial purposes, and which contains dissolved or suspended matter. Also known as sewage.

Wastewater Treatment Facilities—Refers to collection, transmission and treatment facilities that handle wastewater.

Water Quality Criteria—A set of enforceable requirements under the Clean Water Act that establish measurable limits for specific pollutants based on the designated use(s) of the receiving water body. Water quality criteria can be expressed as numeric limits (e.g., pollutant concentrations or mass loads) or narrative descriptions of desired conditions (e.g., no visible scum, sludge, sheens, or odors).

Water Quality Standards—A set of enforceable requirements under the Clean Water Act that include classification of receiving waters in accordance with their federal or state designated use(s), use-based water quality criteria that establish measurable limits for specific pollutants, and anti-degradation provisions to ensure that water quality is maintained or improved.

Water Table—The level in saturated soil at which the hydraulic pressure is zero, i.e., top of saturated soil.

Attachment 2

ENGINEER REACHBACK AND OTHER USEFUL LINKS

Table A2.1. Engineer References and Resources Links.

Engineer Reachback
Air Force Civil Engineer Center (AFCEC): https://www.afcec.af.mil/
CE DASH (AFCEC Technical Support Portal): https://usaf.dps.mil/teams/CEDASH/scripts/homepage/home.aspx
CE Playbooks: https://www.ceplaybooks.com.
AF Publications and Forms: https://www.e-publishing.af.mil/
AFCEC Reachback Center: email at AFCEC.RBC@us.af.mil
My Learning (Learning Management System): https://lms-jets.cce.af.mil/moodle/login/index.php
AF Design Guides (AFDG): https://www.wbdg.org/ffc/af-afcec
Whole Building Design Guide (WBDG): https://www.wbdg.org/
US Army Corp of Engineers Official Publications, http://www.publications.usace.army.mil/Home.aspx
Unified Facilities Criteria (UFC): https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc
Unified Facilities Guide Specifications (UFGS): https://www.wbdg.org/ffc/dod/unified-facilities-guide-specifications-ufgs
USACE Reachback Operations Center (UROC): https://uroc.usace.army.mil
USACE Protective Design Center: https://intelshare.intelink.gov/sites/pdc/SitePages/Home.aspx
Army Publications and Forms: https://armypubs.army.mil/
Navy Doctrine Library System: https://doctrine.navy.mil/default.aspx
DOD Issuances: https://www.esd.whs.mil/DD/DoD-Issuances/
Joint Publications: https://jdeis.js.mil/my.policy
Armed Forces Pest Management Board: https://www.acq.osd.mil/eie/afpmb/

Table A2.2. U.S. Federal and Institutions Links.

U.S. Federal and Institutions
Code of Federal Regulations (CFR): www.ecfr.gov/cgi-bin/ECFR?page=browse
EPA Publications Search: https://search.epa.gov/epasearch/epasearch
Massachusetts Department of Environmental Protection, 310 CMR 15.000, Standard Requirements for the Siting, Construction, Inspection, Upgrade and Expansion of On-Site Sewage Treatment And Disposal Systems and for the Transport and Disposal of Septage: https://www.mass.gov/doc/310-cmr-15000-title-5-of-the-state-environmental-code/download
University of Rhode Island (URI) Cooperative Extension, Water Quality Program: https://web.uri.edu/cels/water-quality-programs/

Table A2.3. Standard Specifications and Trade Organizations Links.

Standard Specifications/Trade Organizations
ASTM A184, *Standard Specification for Welded Deformed Steel Bar Mats for Concrete Reinforcement*, http://www.astm.org
ASTM A615, *Standard Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement*, http://www.astm.org
ASTM C478, *Standard Specification for Circular Precast Reinforced Concrete Manhole Sections*, http://www.astm.org
ASTM D2487, *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)* http://www.astm.org
ASTM D3034, *Standard Specification for Type PSM Poly(Vinyl Chloride) (PVC) Sewer Pipe and Fittings*, http://www.astm.org
ASTM D5879, *Standard Practice for Surface Site Characterization for Onsite Septic Systems*, http://www.astm.org
ASTM D5921, *Standard Practice for Subsurface Site Characterization of Test Pits for Onsite Septic Systems*, http://www.astm.org
Engineering News-Record (ENR) Construction Cost Index (May 2012), http://enr.construction.com/economics
International Code Council, International Private Sewage Disposal Code, https://codes.iccsafe.org/content/IPSDC2018
WVU National Environmental Services Center, Onsite Wastewater Systems https://www.nesc.wvu.edu/wastewater/onsite-wastewater-systems

Attachment 3

WWTF PLANNING AND SELECTION MATRIX

Figure A3.1. WWTF Planning and Selection Matrix. (Part 1)

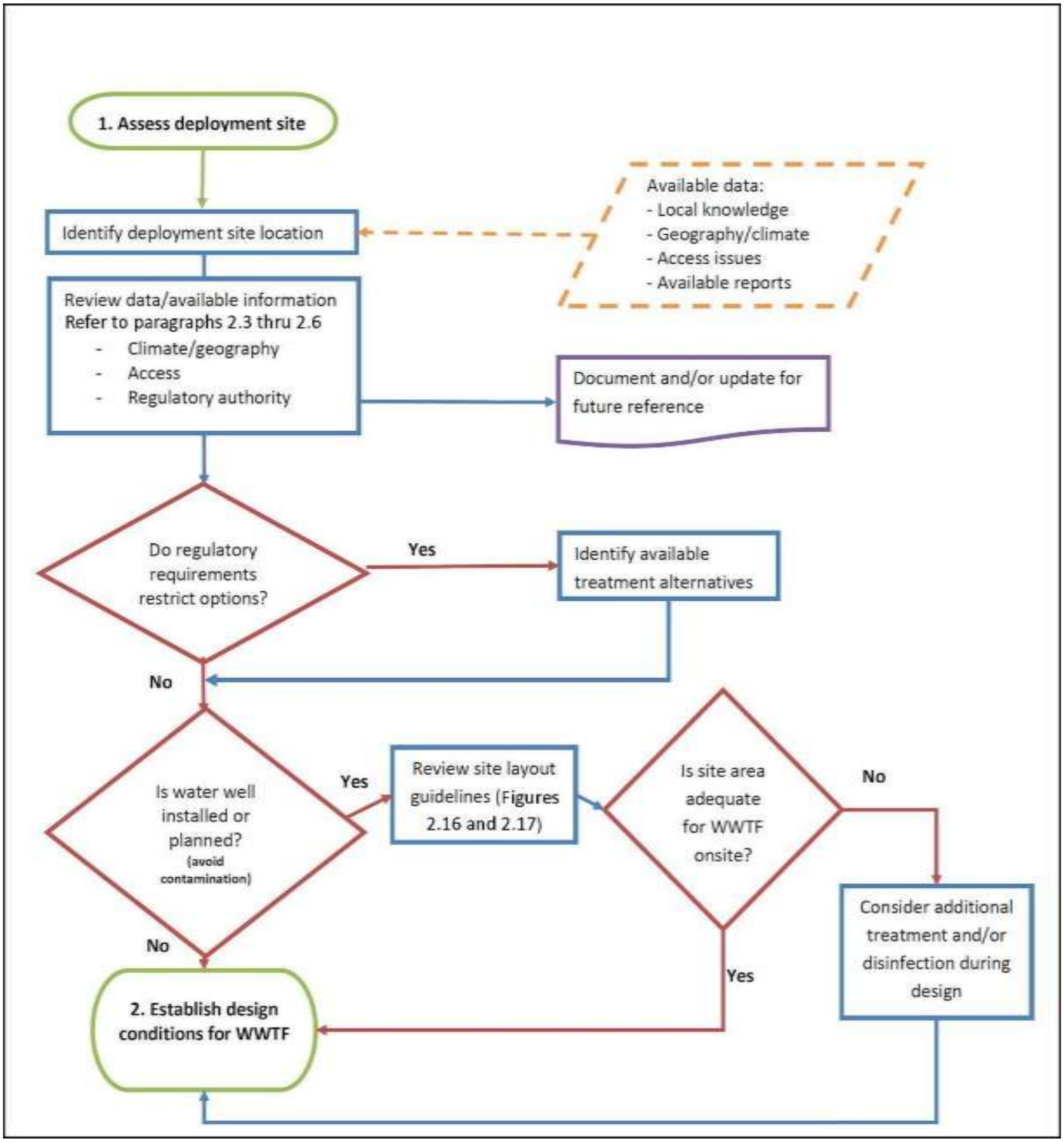


Figure A3.2. WWTF Planning and Selection Matrix. (Part 2)

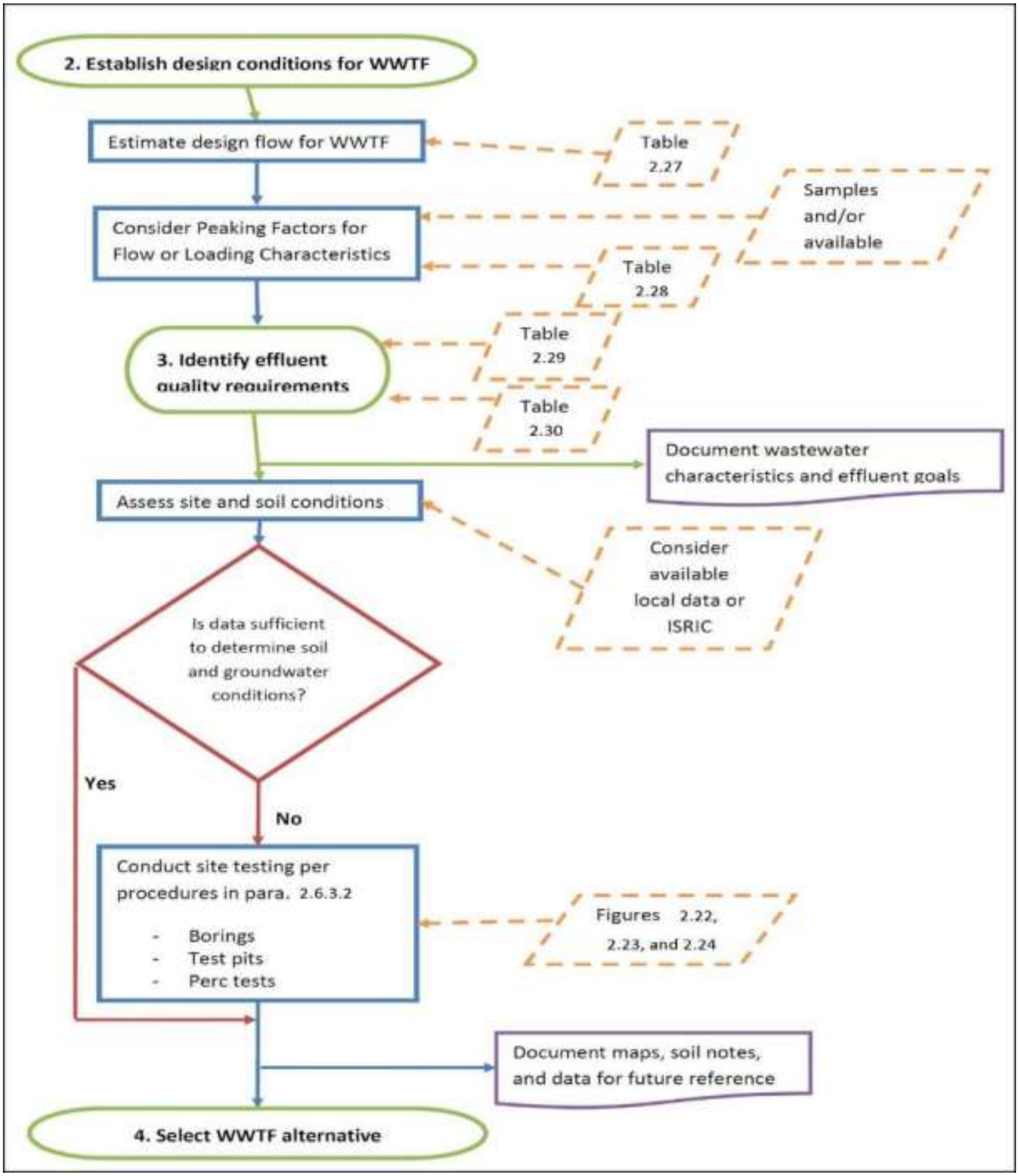
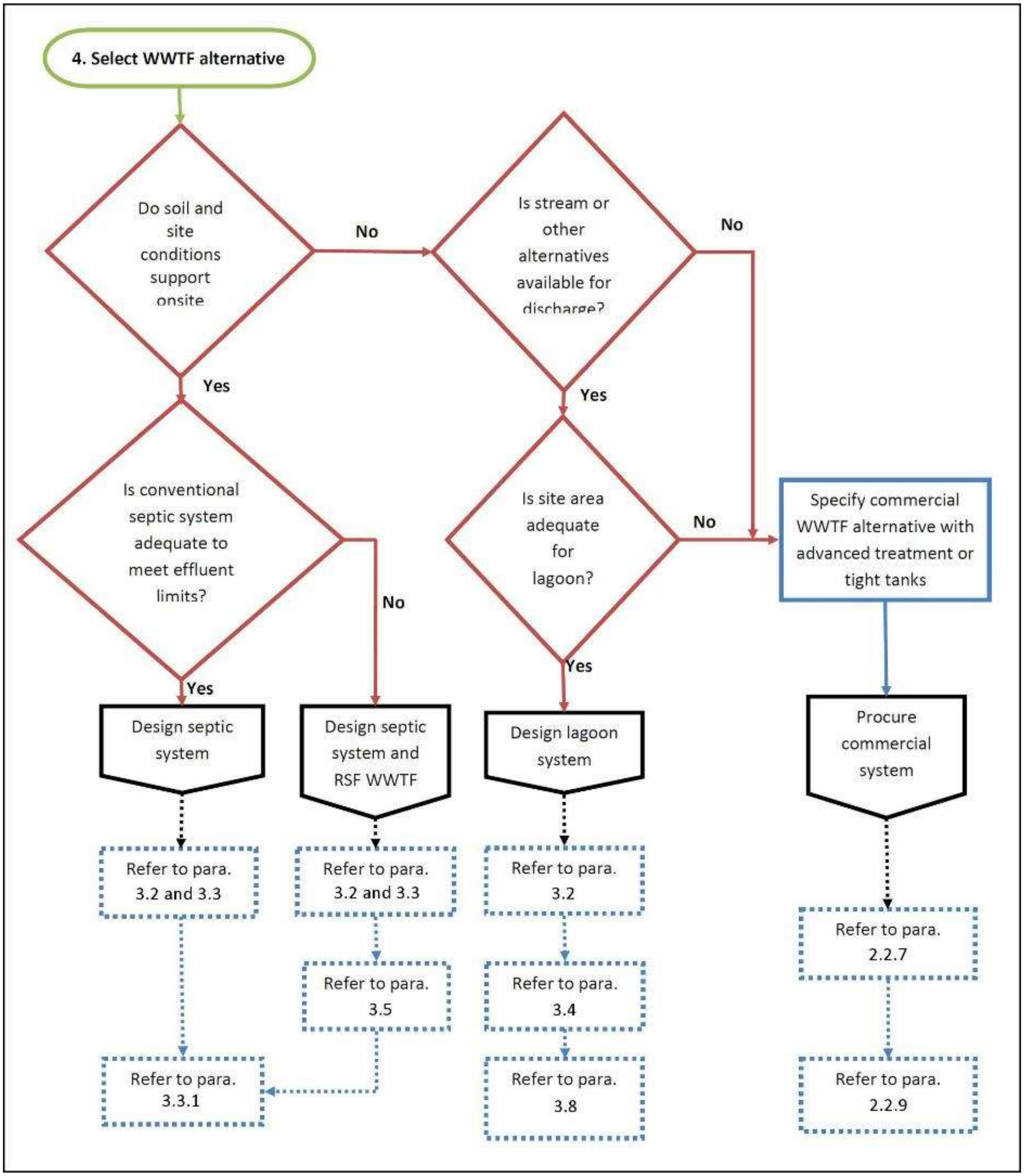


Figure A3.3. WWTF Planning and Selection Matrix. (Part 3)



Attachment 4

FIELD-EXPEDIENT SOIL TESTING METHODS

A4.1. Field Identification of Soils. Using field-expedient testing to assess soil properties and classify soil material may be necessary during the initial stages of a contingency operation. Field-testing methods include, visual examinations, plasticity tests, and sedimentation tests. Each of these tests provide insight into the potential engineering behavior of the soil tested.

A4.2. Visual Examinations. The visual examination should establish the color, grain sizes, grain shapes of the coarse-grained portion, approximate gradation, and some properties of the undisturbed soil.

A4.2.1. **Color.** Color helps to identify and distinguish between various soil types. It may also indicate the presence of certain chemicals, minerals, or impurities. Describe the color of the sample when initially taken in the field at the as-sampled water content, because the color may change with changes in water content. Include the apparent moisture content at the time of identification (**Table A4.1**). Colors generally become darker as the moisture content increases and lighter as the soil dries. Some fine-grained soil with dark, drab shades of brown or gray, including almost black, contain organic material. In contrast, clean, bright shades of gray, olive green, brown, red, yellow, and white are associated with inorganic soils. Gray-blue or gray-and yellow mottled colors frequently result from poor drainage. Red, yellow, and yellowish-brown result from the presence of iron oxides. White to pink may indicate considerable silica, calcium carbonate, or aluminum compounds.

Table A4.1. Water Content of Soil.

Description	Conditions
Dry	No sign of water and soil is dry to touch
Moist	Signs of water and soil is relatively dry to touch
Wet	Signs of water and soil is definitely wet to touch; granular soil exhibits some free water when densified

A4.2.2. **Grain size.** Establish the maximum particle size of each soil sample to determine the upper limit of the gradation curve. Gravels range down to the size of peas; sands start just below this size and decrease until the individual grains are just distinguishable by the naked eye. Silt and clay particles are indistinguishable as individual particles.

A4.2.3. **Grain shape.** The shape of individual grains in a soil mass plays an important role in the engineering characteristics (strength and stability) of the soil. Two general shapes are normally recognized, bulky and platy. Platy shaped grains (clay and silt) are virtually indistinguishable to the naked eye. Visible bulky-shaped grains have five subdivisions as described below and illustrated in **Figure A4.1**.

- Angular particles have jagged projections, sharp ridges, and flat surfaces. Such particles are seldom found in nature, because physical and chemical weathering processes usually wear off the sharp ridges in a relatively short period time. Angular material is usually produced artificially, by crushing.

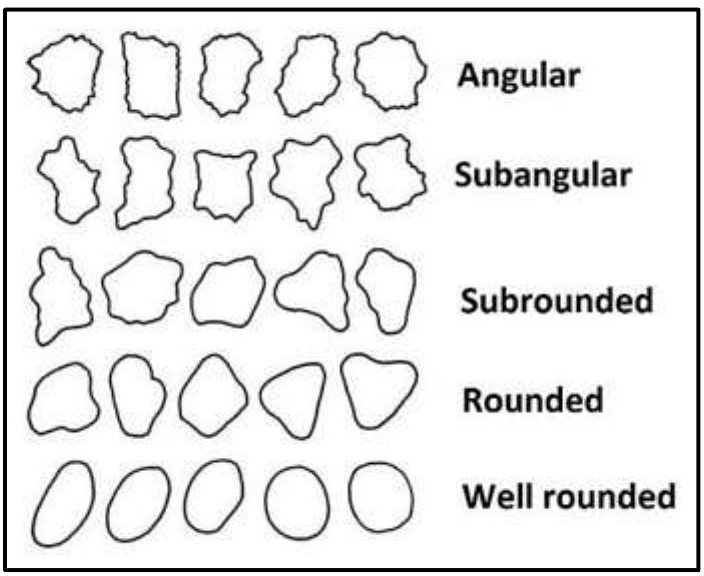
- Sub-angular particles have been weathered to the extent that the sharper points and ridges have been worn off.

- Sub-rounded particles have been weathered to a further degree than sub-angular particles. They are still somewhat irregular in shape but have no sharp corners and few flat areas. Materials with this shape are frequently found in streambeds.

- Rounded particles have all projections removed with few irregularities in shape remaining. The particles resemble spheres and are of varying sizes. Rounded particles are usually found in or near streambeds or beaches.

- Well-rounded particles are rounded particles in which the few remaining irregularities have been removed. Like rounded particles, well-rounded particles are also usually found in or near streambeds or beaches.

Figure A4.1. Bulky Grain-Shaped Particles.



A4.2.4. **Grain size distribution.** Examining a dry sample spread on a flat surface can make an approximate identification. Pulverize all lumps until individual grains are exposed, but not broken. Recommend using a rubber-faced or wooden pestle and a mixing bowl, but mashing the sample underfoot on a smooth surface will suffice for an approximate identification. Separate the larger grains (gravels and some sands) by picking them out individually. Examine the remainder of the soil and estimate the proportions of visible individual particles and fines (**Figure A4.2**). Convert these estimates into percentages by weight of the total sample. If the fines exceed 50 percent, consider the soil fine-grained. If the coarse material exceeds 50 percent, the soil is coarse-grained. Examine coarse-grained soil for gradation of the particle sizes from the largest to the smallest. A good distribution of all sizes means the soil is well graded. Overabundance or lack of any size means the material is poorly graded.

Figure A4.2. Grain Size Distribution.

A4.2.5. **Undisturbed soil properties.** Characteristics of the soil in the undisturbed state may be helpful in identification. The compactness of gravels or sands may be loose, medium, or dense. Clays may be hard, stiff, or soft. Record the ease or difficulty of sample removal. The moisture content of the soil influences the in-place characteristics. It is helpful to know the weather just prior to and during the field evaluation to determine how the soil has reacted or will react to weather changes. The presence of decayed roots, leaves, grasses, and other vegetable matter in organic soils produces soil which is usually dark when moist, having a soft spongy feel and a distinctive odor of rotting organic matter. The odor may be musky and slightly offensive. The odor is especially apparent in undisturbed conditions or in fresh samples. The odor becomes less obvious as the sample is exposed to air. Make the odor stronger by heating a wet sample.

A4.3. Plasticity Tests. Fine-grained soil particles are generally not classified using gradation criteria but primarily by characteristics related to plasticity. Expedient field tests can help determine the cohesive and plastic characteristics of fine-grained soil. Except where noted, these tests are performed on material passing the No. 40 sieve, and include the breaking or dry strength test, roll or thread test, ribbon test, wet shaking test, cast test, wash test, bite or grit test, shine test, feel test, and sedimentation test.

A4.3.1. **Breaking or dry strength test.** Prepare a pat of soil about 2 inches in diameter and 0.5 inch thick by molding it in a wet, plastic state. Allow the pat to dry completely (in the sun, in an oven, or inside the engine compartment), then grasp the pat between the thumbs and forefingers of both hands and attempt to break it. If the pat breaks, try to powder it by rubbing it between the thumb and forefinger of one hand. **Note:** Dry pats of highly plastic clays often display shrinkage cracks. Breaking the pat along such a crack may not give a true indication of the strength. It is important to distinguish between a break along such a crack and a clean, fresh break that indicates the true dry strength of the soil. If the:

- Pat cannot be broken nor powdered by finger pressure, it is a very highly plastic soil
- Pat can be broken with great effort, but cannot be powdered, it is a highly plastic soil
- Pat can be broken and powdered, but with some effort, it is a medium plastic soil
- Pat breaks easily and powders readily, it is a slightly plastic soil
- Pat has little or no dry strength and crumbles or powders when picked up, it is a non-plastic soil

A4.3.2. **Roll or thread test.** Mix a representative portion of the sample with water until you can mold or shape it without it sticking to your fingers. Describe this moisture content as being just below the sticky limit. Prepare a nonabsorbent rolling surface by placing a sheet of glass or heavy wax paper on a flat or level support, then shape the sample into an elongated cylinder and rapidly roll the prepared soil cylinder on the surface into a thread approximately 0.125 inch in diameter. If the moist soil rolls into a thread, it has some plasticity. The number of times you can roll it into a thread without crumbling is a measure of the degree of plasticity. The higher the soil is on the plasticity chart, the stiffer the threads are as they dry out and the tougher the lumps are if the soil is remolded after rolling. Soils that cannot be rolled are non-plastic. **Note:** Micaceous silts and sands can be rolled due to the flaky nature of the mica. The wet shaking test is the only way to distinguish this property. If the:

- Soil can be molded into a ball or cylinder and deformed under very firm finger pressure without crumbling or cracking, it is high plasticity
- Soil can be molded, but it cracks or crumbles under finger pressure, it is medium plasticity
- Soil cannot be lumped into a ball or cylinder without breaking up, it is low plasticity
- Soil forms a soft, spongy ball or thread when molded, it is an organic material
- Soil cannot be rolled into a thread at any moisture content, it is a non-plastic soil

A4.3.3. **Ribbon test.** Prepare a soil sample as in the roll or thread test. Form a roll of soil about 0.5 to 0.75 inch in diameter and 3 to 5 inches long. Lay the roll across the palm of one hand (palm up) and starting at one end, squeeze the roll between the thumb and forefinger over the edge of the hand to form a flat unbroken ribbon about 0.125 to 0.25 inch thick. Allow the ribbon as formed to hang free and unsupported. Continue squeezing and handling the roll carefully to form the maximum length of ribbon that can be supported only by the cohesive properties of the soil. If the:

- Sample holds together for a length of 8 to 10 inches without breaking; it is highly plastic and highly compressive
- Soil can be ribboned only with difficulty to 3- to 8-inch lengths; it is low plasticity

A4.3.4. **Wet shaking test.** Form a ball of soil about 0.75 inch in diameter, moistened with water to just below the sticky limit. Smooth the soil pat in the palm of the hand with a knife blade or small spatula, shake it horizontally, and strike the back of the hand vigorously against the other hand. When shaking, water comes to the surface of the sample producing a smooth, shiny, or livery appearance. Squeeze the sample between the thumb and forefinger of the other hand. The surface water will disappear. The surface will become dull and the sample will become firm, resisting deformation. Cracks will occur as pressure is continued and the sample will crumble. If the water content is still adequate, shaking the broken pieces will cause them to liquefy again and flow together. This process can only occur when the soil grains are bulky and non-cohesive. It is easy to identify very fine sands and silts by this test. Even small amounts of clay will tend to retard the reaction to this test. A rapid reaction is typical of non-plastic, fine sands and silts. A sluggish reaction indicates slight plasticity, indicating the silt has small amounts of clay or organic silts. **Note:** No reaction at all does not indicate a complete absence of silt or fine sand.

A4.3.5. **Cast test.** Compress a handful of damp (not sticky) soil into a cylinder and observe its ability to be formed and handled. If the:

- Soil crumbles when touched - GP, SP, SW, GW
- Soil cast withstands careful handling - SM, SC
- Soil cast can be handled freely - ML, MH
- Soil cast withstands rough handling - CL, CH

A4.3.6. **Wash test.** Place a small dry sample of soil into the palm of the hand and cover with water. Note how quickly the water discolors and how long the fines are suspended. One variation is to look for mud puddles or create them, disturb the soil surface and note how the water discolors and how long the fines are suspended. If the water becomes completely discolored and hides the sand particles there is evidence of greater than 5 percent silt content.

A4.3.7. **Bite or grit test.** Grind a small pinch of soil lightly between the teeth. For sandy soils, the sharp hard particles of even fine sands will grate very harshly between the teeth and will be highly objectionable. For silty soils, silt grains are not particularly gritty, but their presence is still quite unpleasant and easily detected. With clayey soils, the clay grains feel smooth and powdery like flour, and dry lumps will stick when lightly touched with the tongue. **Note:** Ideally, perform this test on material passing the No. 200 sieve to avoid biting into sand and providing separation between silty and clayey fines.

A4.3.8. **Shine test.** Rub a clay sample with a fingernail or smooth metal surface such as a knife blade. Highly plastic clay will produce a definite shine; lean clays will remain dull.

A4.3.9. **Feel test.** For consistency, squeeze a piece of undisturbed soil between the thumb and forefinger; it may be hard, stiff, brittle, friable, sticky, plastic, or soft. Remold the soil by working it between the hands. This can indicate the natural water content. Clays that become fluid on remolding are probably near their liquid limit; if they remain stiff and crumble, they are probably below their liquid limit. Check the texture by rubbing a portion of fine-grained soil between the fingers or on a more sensitive area such as the inside of the wrist. Results are similar to the bite or grit test. **Note:** Ideally, perform this test on material passing the No. 200 sieve to avoid sand particles giving an erroneous reaction.

A4.4. Sedimentation Test. From visual examination, it is relatively easy to approximate the proportions of gravels and sands in a soil sample. Determining the proportion of fine-grained particles is more difficult but just as important. Although you can separate the fines from the sample using a No. 200 sieve, the sedimentation test is an alternate field method to separate fines from the sand particles in a soil sample.

A4.4.1. Placing a small amount of the fine fraction of a soil (such as a heaping teaspoon) in a transparent cup or jar, covering it with about 5 inches of water, and agitating it by stirring or shaking will completely suspend the soil in water. With cohesive soils, it will be necessary to break up all lumps of soil before adding the water. After soil particles have been dispersed in the water and then left, they will start to settle to the bottom, beginning with the larger sized particles, in time-periods indicated in **Table A4.2**. Smaller particles will settle through water at a slower rate than large particles. Since all of the particles of soil larger than the No. 200 sieve will have settled to the bottom of the cup or jar 30 seconds after the mixture has been agitated, it follows that the particles remaining in suspension are fines. Carefully pour the water containing the suspended fines into another container 30 seconds after agitation, add more water to the cup or jar containing the coarse fraction, and repeat the procedure until the water-soil mixture becomes clear 30 seconds after mixing. The cup or jar will contain the coarse fraction of the soil and the other container will hold the fines. After absorbing or evaporating the water off, the relative amounts of fines and sands can be accurately determined. In clay soils, the clay particles will often form small lumps (flocculate) that will not break up in water. If after several repetitions of the test substantial amounts of clay are still present in the coarse material, the sand will feel slippery. Further mixing and grinding with a stick will be necessary to help break up these lumps.

Table A4.2. Sedimentation Test.

Approximate Time of Settlement in 5 Inches of Water	Grain Diameter	Differentiates
2 seconds	0.4 mm	Coarse sand – fine sand
30 seconds	0.072 mm (No. 200 sieve)	Sand – fines
10 minutes	0.03 mm	Coarse silt – fine silt
1 hour	0.01 mm	Silt – clay

A4.4.2. **Table A4.3** is a convenient way to track various field identification tests. As tests are completed, mark the results on the chart. The results from the different tests may vary, but by plotting the test results, you will have a general indication of the soil type. Essentially, soil types and their characteristics can affect how the soil will behave as a construction material. Once soil testing and surveys are completed, consider the preparations and actions needed to accomplish the specific expedient roadway construction or repair project.

Table A4.3. Summary of Field Identification Test Results.

Field Identification of Soils						
Test	Material	Soil Types				
		ML	MH	CL	CH	OL/OH
Dry strength	< 40 sieve (wet)	No to low	Low to medium	Medium to high	Very high	Low
Roll/thread	< 40 sieve (sticky)	Low	Low to medium	Medium	High	Spongy
Ribbon	< 40 sieve (sticky)	No cohesion	Little cohesion	3 to 8 inches	8 to 10 inches	
Wet shake	< 40 sieve (sticky)	Slow to rapid	No to slow	No to slow	No	
Cast	Damp	Handle freely		Handle roughly		
Bite/feel	< 40 (< 200) sieve	Unpleasant		Smooth		
Shine		Dull			Shine	
Wash		Discolors quickly, > 5% silt				
Dust		> 10% silt				
Sedimentation		30 seconds		1 hour		