Chapter 5:
Treatment System Selection

5.1 Introduction

Selecting the appropriate system type, size, and location at the site depends on the wastewater flow and composition information discussed in chapter 3, site- and landscape-level assessments outlined in chapter 3 and in this chapter, performance requirements as noted in chapter 3, and the array of available technology options reviewed in chapter 4. Key to selecting, sizing, and siting the system are identifying the desired level of performance and ensuring that the effluent quality at the performance boundaries meets the expected performance requirements.

5.2 Design conditions and system selection

An appropriate onsite wastewater treatment system concept for a given receiver site—proposed location of the system, regional geologic and hydrologic features, and downgradient soils used for treatment—depends on the prevailing design conditions. Designers must consider and evaluate the design conditions carefully before selecting a system concept. Design conditions include the characteristics of the wastewater to be treated, regulatory requirements, and the characteristics of the receiver site (figure 5-1). With sufficient knowledge of these factors, the designer can develop an effective preliminary design concept. This chapter focuses on general guidance for evaluation of the receiver site, identification of the site's design boundaries and requirements, and selection of suitable designs to meet the performance requirements. This chapter also provides guidance for evaluating and rehabilitating systems that are not meeting their performance requirements.

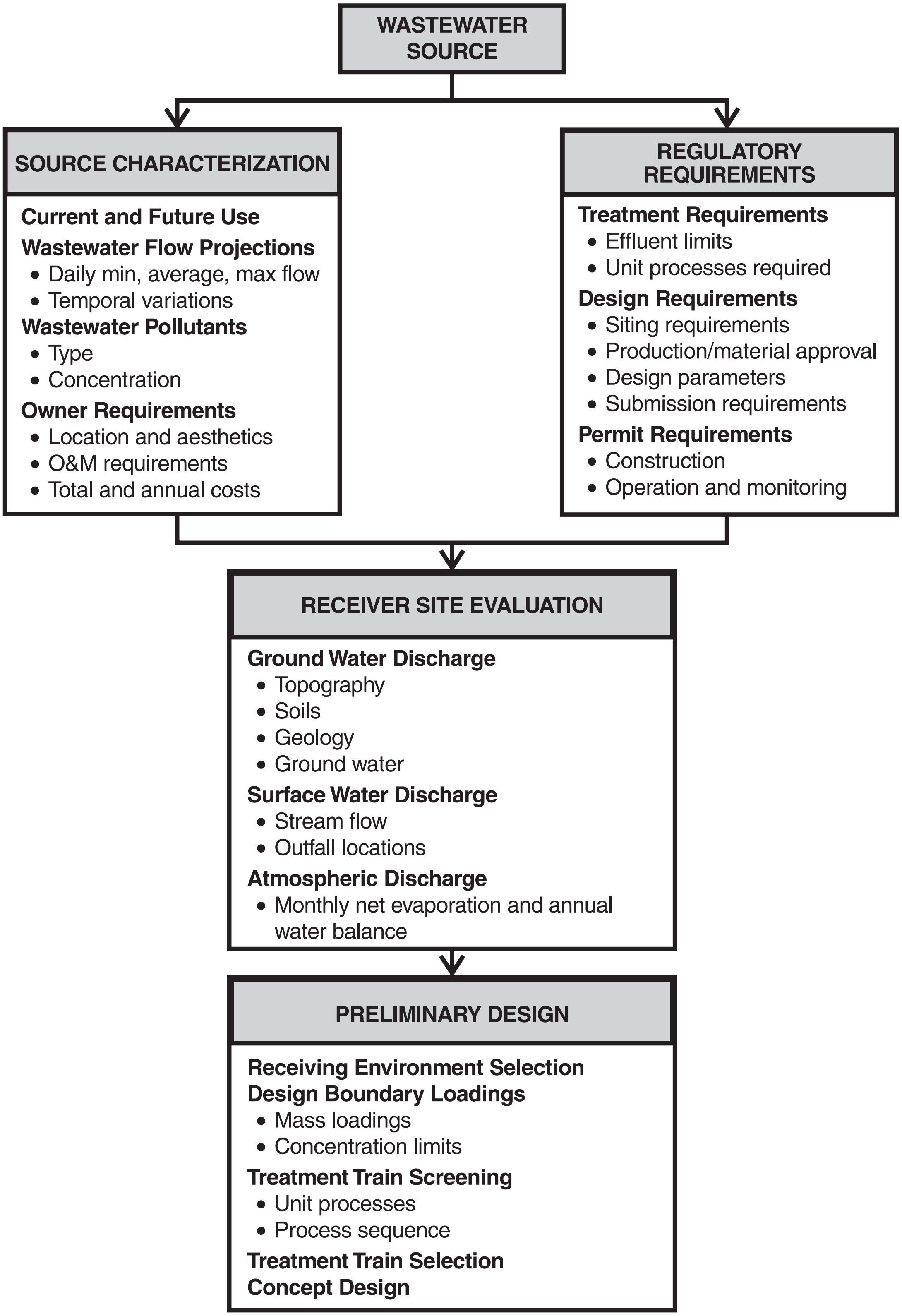
5.3 Matching design conditions to system performance

Design conditions include wastewater characteristics; system owner preferences for siting, operation and maintenance, and cost; regulatory requirements prescribed by the permitting agency's rules; and the receiver site's capability to treat or otherwise assimilate the waste discharge. Each of these must be evaluated in light of the others before an appropriate system design concept can be developed.

5.3.1 Wastewater source considerations

Wastewater source considerations include projections of wastewater flow, wastewater composition, and owner requirements. Chapter 3 provides guidance for estimating flow and waste strength characteristics. The owner's needs, capabilities, and expectations might be explicit or implied. The first consideration is the owner's use of the property (present and projected), which informs analyses of the character and volume of the wastewater generated. The footprint and location of existing or planned buildings, paved areas, swimming pools, and other structures or uses will limit the area available for the onsite system. Second, the owner's concern for the system's visual impact or odor

Figure 5-1. Preliminary design steps and considerations.



potential might restrict the range of alternatives available to the designer. Third, the owner's ability and willingness to perform operation and maintenance tasks could limit the range of treatment alternatives. Finally, costs are a critical concern for the owner. Capital (construction) costs and recurring (operation and maintenance) costs should be estimated, and total costs over time should be calculated if cost comparisons between alternative systems are necessary. The owner should have both the ability and willingness to pay construction and operation and maintenance costs if the system is to perform satisfactorily.

5.3.2 Regulatory requirements

Designs must comply with the rules and regulations of the permitting entity. Onsite wastewater systems are regulated by a variety of agencies in the United States. At the state level, rules may be enacted as public health codes, nuisance codes, environmental protection codes, or building codes. In most (but not all) states, the regulatory authority for onsite single-family residential or small cluster systems is delegated to counties or other local jurisdictions. The state might enact a uniform code requirement that all local jurisdictions must enforce equally, or the state might have a minimum code that local jurisdictions may adopt directly or revise to be stricter. In a few states, general guidance rather than prescriptive requirements is provided to local jurisdictions. In such cases, the local jurisdictions may enact more or less strict regulations or choose not to adopt any specific onsite system ordinance.

Traditionally, state and local rules have been prescriptive codes that require specific system designs for a set of specific site criteria. Such rules typically require that treated wastewater discharged to the soil be maintained below the surface of the ground, though a few states and local jurisdictions do allow discharges to surface waters under their National Pollutant Discharge Elimination System (NPDES) permitting programs, as authorized by the federal Clean Water Act. If applications are proposed outside the prescriptive rules, the agency usually requires special approvals or variances before a permit can be issued. Circumstances that require special action (approvals, variances) and administrative processes for approving those actions are usually specified in state or local codes.

5.3.3 Receiver site suitability

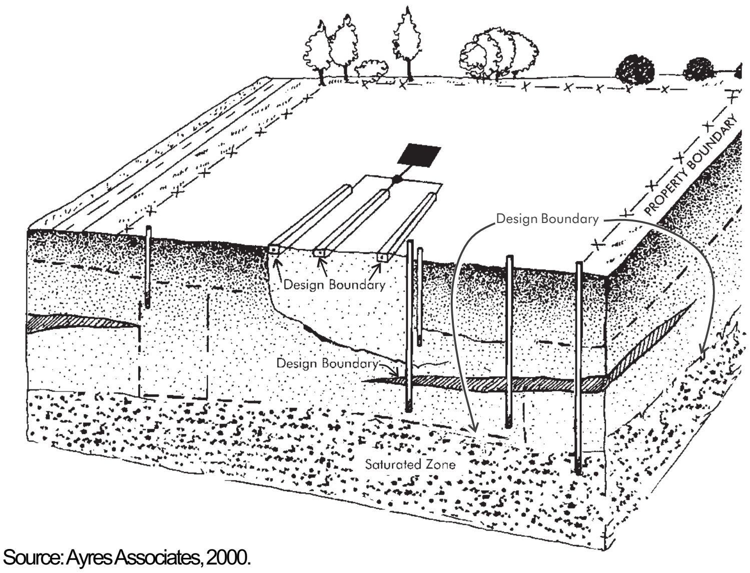
The physical characteristics of the site (the location of the proposed system, regional geologic and hydrologic features, and the soils to be used in the treatment process) determine the performance requirements and treatment needs. A careful and thorough site evaluation is necessary to assess the capacity of the site to treat and assimilate effluent discharges. Treatment requirements for a proposed system are based on the performance boundary requirements established by rule and the natural design boundaries identified through the site evaluation.

5.4 Design boundaries and boundary loadings

Wastewater system design must focus on the critical design boundaries: between system components, system/soil interfaces, soil layer and property boundaries, or other places where design conditions abruptly change (see figures 5-2 and 5-3). System failures occur at design boundaries because they are sensitive to hydraulic and mass pollutant loadings. Exceeding the mass loading limit of a sensitive design boundary usually results in system failure. Therefore, all critical design boundaries must be identified and the mass loadings to each carefully considered to properly select the upstream performance and design requirements needed to prevent system failure (Otis, 1999).

The approach discussed in this chapter is based on characterizing the assimilative capacity of the receiving environment (ground water, surface water) and establishing onsite system performance requirements that protect human health and ecological resources. Desired system performance, as measured at the final discharge point (after treatment in the soil matrix or other treatment train components), provides a starting point for considering performance requirements for each preceding system component at each design boundary (e.g., septic tank-SWIS interface, biomat at the infiltrative surface, surface of the saturated zone). Through this approach, system designers can determine treatment or performance requirements for each component of the treatment train by assessing whether each proposed component can meet performance requirements (acceptable mass loading limits) at each subsequent design boundary.

Figure 5-2. Performance (design) boundaries associated with onsite treatment systems



Source: Ayres Associates, 2000.

Determining the critical design boundaries of the physical environment is the primary objective of the site evaluation (see section 5.5). Design boundaries are physical planes or points, or they may be defined by rule. More than one design boundary can be expected in every system, but not all of the identified boundaries are likely to control design. The most obvious design boundaries are those to which performance requirements are applied (figure 5-2). These are defined boundaries that might or might not coincide with a physical boundary. For a ground water discharge, the design boundary might be the water table surface, the property line, or a drinking water well. For surface water discharges the performance boundary is typically designated at the outfall to the receiving waters, where permit limits on effluent contaminants are applied. Physical boundaries are particularly significant for conventional wastewater treatment systems that discharge to ground water or to the atmosphere. Soil infiltrative surfaces, hydraulically restrictive soil horizons, or zones of saturation are often the critical design boundaries for ground water discharging systems.

The site evaluation must be sufficiently thorough to identify all potential design boundaries that might affect system design. Usually, the critical design boundaries are obvious for surface water discharging and evaporation systems. Design boundaries for subsurface wastewater infiltration systems, however, are more difficult to identify because they occur in the soil profile and there might be more than one critical design boundary.

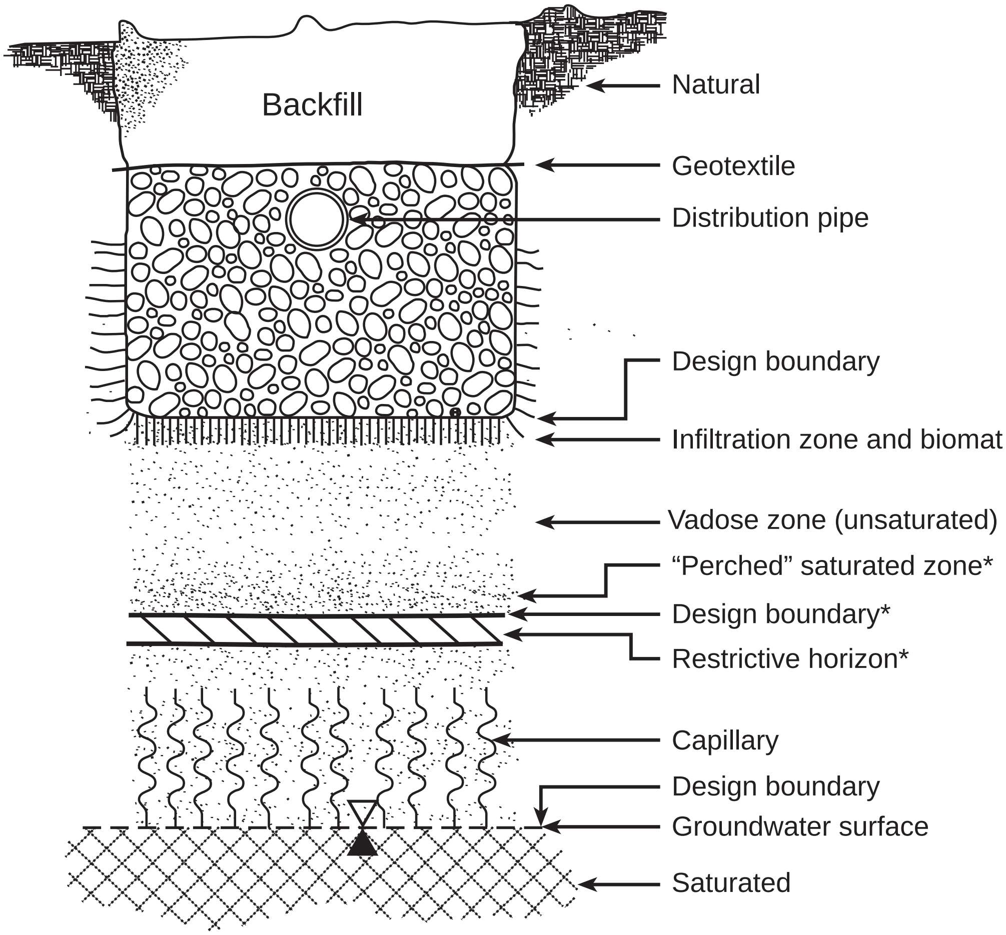
5.4.1 Subsurface infiltration system design boundaries and loadings

Subsurface wastewater infiltration systems (SWISs) have traditionally been used to treat and discharge effluent from residences, commercial buildings, and other facilities not connected to centralized sewage treatment plants. These systems accept and treat wastewater discharged from one or more septic tanks in below-grade perforated piping, which is usually installed in moderately shallow trenches 1.5 to 3.0 feet deep on a bed of crushed rock 0.5 to 1.5 inches in diameter. Leaching chambers, leach beds, and other SWIS technologies have also been approved for use in some states. Both the trench bottoms and sidewalls provide infiltrative surfaces for development of the biomat (see chapter 3) and percolation of treated wastewater to the surrounding soil matrix.

The soil functions as a biological, physical, and chemical treatment medium for the wastewater, as well as a porous medium to disperse the wastewater in the receiving environment as it percolates to the ground water. Therefore, the site evaluation must determine the capacity of the soil to hydraulically accept and treat the expected daily mass loadings of wastewater. Site and soil characteristics must provide adequate drainage of the saturated zone to maintain the necessary unsaturated depth below the infiltrative surface, allow oxygenation of aerobic biota in the biomat and reaeration of the subsoil, and prevent effluent surfacing at downgradient locations.

Traditional site evaluation and design procedures consider only the infiltrative surface of the SWIS as a design boundary (figure 5-3). Hydraulic loading rates to this boundary are usually estimated from percolation tests and/or soil profile analyses. The recommended daily hydraulic loading rates typically assume septic tank effluent is to be applied to the soil (through the SWIS biomat, across the trench bottom/sidewall soil interface, and into the surrounding soil). The estimated daily wastewater volume is divided by the applicable hydraulic loading rate to calculate the needed infiltration surface area. This method of design has endured since Henry Ryon first proposed

Figure 5-3. Subsurface wastewater infiltration system design/performance boundaries.



* If present

Source: Ayres Associates, 1993.

the percolation test and its empirical relationship to infiltration system size nearly 100 years ago (Fredrick, 1948). Although this method of design has been reasonably successful, hydraulic and treatment failures still occur because focusing on the infiltrative surface overlooks other important design boundaries. Identifying those critical boundaries and assessing their impacts on SWIS design will substantially reduce the number and frequency of failures.

Usually there is more than one critical design boundary for a SWIS. Zones where free water or saturated soil conditions are expected to occur above or below unsaturated zones identify performance boundary layers (Otis, 2001). In SWISs, these include

- The infiltrative surfaces where the wastewater first contacts the soil.
- Secondary infiltration surfaces that cause percolating wastewater to perch above an unsaturated zone created by changes in soil texture, structure, consistency, or bulk density.
- The ground water table surface, which the percolating wastewater must enter without excessive ground water mounding or degradation of ground water quality.

The infiltrative surface is a critical design and performance boundary in all SWISs since free water enters the soil and changes to water under tension (at pressures less than atmospheric) in the unsaturated zone. Many wastewater quality transformations occur at this boundary. For example, biochemical activity usually causes a hydraulically restrictive biomat to form at the infiltrative surface. Failure to consider the infiltrative surface in system design and to accommodate the changes that occur there can lead to hydraulic or treatment failure.

Other surfaces that are often critical design boundaries include those associated with hydraulically restrictive zones below the infiltrative surface that can cause water to perch. If hydraulic loadings are too great for these boundaries, surface seepage might occur at downslope locations as effluent slides along the perched boundary. Also, the saturated zone could mound to encroach on the unsaturated zone to the extent that sufficient reaeration of the soil does not occur, which can result in severe soil clogging. If hydraulic problems do not occur, these conditions offer some treatment advantages. For example, denitrification is aided when saturation results in anaerobic conditions in interstices in the normally unsaturated zones. Perched or otherwise layered boundaries require careful characterization, analysis, and assessment of system operation to determine how they will affect the movement of effluent plumes from the SWIS.

The water table surface is where treatment is usually expected to be complete, that is, where pollutant loadings, with proper mixing and dispersion, should not create concentrations in excess of water quality standards. System designers should seek to ensure that hydraulic loadings from the system(s) to the ground water will not exceed the aquifer's capacity to drain water from the site. If a SWIS is to perform properly, the mass loadings to the critical design boundaries must be carefully considered and incorporated into the design of the system. The types of mass loadings that should be considered in SWIS design are presented in table 5-1.

The various design boundaries are affected differently by different types of mass loadings (table 5-2).

Table 5-1. Types of mass loadings to subsurface wastewater infiltration systems.

Mass loading type	Units	Typical loading rates
Hydraulic		
• Daily	Volume per day per unit area of boundary surface	Septic tank effluent: 0.15–1.0 gpd/ft^2 (0.6–4.0 cm/d) Secondary effluent: 0.15–> 2.0 gpd/ft^2 (0.6–>8.0 cm/d)
• Instantaneous	Volume per dose per unit area of boundary surface	1/24–1/8 of the average daily wastewater volume
• Contour (Linear)	Volume per day per unit length of boundary surface contour (which can be a critical design parameter in areas with high water tables)	Depends on soil K_{sat}[a], maximum allowable thickness of saturated zone, and slope of the boundary surface (see section 5.3)
Constituent		
• Organic	Mass of BOD per day per unit area of boundary surface	0.2–5.0 lb BOD/1000 ft^2 (1.0–29.4 kg BOD/1000 m^2)
• Other pollutants	Mass of specific wastewater pollutant of concern per unit area of boundary surface (e.g., number of fecal coliforms, mass of nitrate nitrogen, etc.)	Variable with the constituent, its fate and transport, and the considered risk it imposes

[a] K_{sat} is the saturated conductivity of the soil.

Source: Otis, 2001.

Table 5-2. Potential impacts of mass loadings on soil design boundaries

Boundary loading	Infiltrative boundary	Secondary boundaries	Water table boundary
Hydraulic			
• Daily	✔ (hydraulic capacity)	✔ (saturated zone encroachment)	✔ (saturated zone encroachment)
• Instantaneous	✔ (hydraulic capacity)	N/A (attenuated through soil)	N/A (attenuated through soil)
• Linear	N/A (unit gradient below boundary)	✔ (saturated zone encroachment)	✔ (saturated zone encroachment)
Constituent			
• Solids	✔ (surface clogging)	N/A (removed through soil)	N/A (removed through soil)
• Organic	✔ (surface clogging)	N/A (removed through soil)	N/A (removed through soil)
• Other	N/A (usually no impact on infiltration)	N/A (no treatment requirements)	✔ (treatment requirements)

Notes: ✔ denotes that mass loading has potential impact.
N/A denotes that mass loading typically has no impact and does not apply.
Text in parentheses describes reason for impact or lack of impact of mass loading.
Loading impacts apply to both gravity-based and mechanical systems. See chapter 4 for hydraulic and organic loading rates relative to soil texture and structure.

Source: Otis, 1999.

The infiltrative surface is the primary design boundary. At this boundary, the partially treated wastewater must pass through the biomat, enter the soil pores, and percolate into unsaturated soil. The wastewater cannot be applied at rates faster than the soil can accept it, nor can the soil be overloaded with solids or organic matter to the point where soil pores become clogged with solids or an overly thick development of the biomass. Because solids are usually removed through settling processes in the septic tank, the critical design loadings at this boundary are the daily and instantaneous hydraulic loading rates and the organic loading rate. System design requires that daily hydraulic and instantaneous/peak loadings be estimated carefully so that the total hydraulic load can be applied as uniformly as feasible over the entire day to maximize the infiltration capacity of the soil. Uniform dosing and resting maximizes the reaeration potential of the soil and meets the oxygen demand of the applied wastewater loading more efficiently. The organic loading rate is an important consideration if the available area for the SWIS is small. In moderately permeable or more permeable soils, lower organic loading rates can increase infiltration rates into the soil and may allow reductions in the size of the infiltrative surface. Organic loadings to slowly permeable, fine-textured soils are of lesser concern because percolation rates through the biomat created by the organic loading are usually greater than the infiltration rate into the soil. Preventing effluent backup (hydraulic failure) by increasing the size of the SWIS and implementing water conservation measures are important considerations in these situations.

Secondary design boundaries are usually hydraulically restrictive horizons that inhibit vertical percolation through the soil (figure 5-2). Water can perch above these boundaries, and the perching can affect performance in two significant ways. If the perched water encroaches into the unsaturated zone, treatment capacity of the soil is reduced and reaeration of the soil below the infiltrative surface might be impeded. Depending on the degree of impedance, anoxic or anaerobic conditions can develop, resulting in excessive clogging of the infiltrative surface. Also, water will move laterally on top of the boundary, and partially treated wastewater might seep from the exposed boundaries of the restrictive soil strata downslope and out onto the ground surface. Therefore, the contour (linear) loading along the boundary surface contour must be low enough to prevent water from mounding above the boundary to the point that inadequately treated wastewater seeps to the surface and creates a nuisance and possible risk to human health. Organic loadings at these secondary boundaries are seldom an issue because most organic matter is typically removed as the wastewater passes through the infiltrative surface boundary layer.

Hydraulic and wastewater constituent loadings are the critical design loadings at the water table boundary. Low aquifer transmissivity creates ground water mounding (figure 5-4), which can encroach on the infiltrative surface if the daily hydraulic loading is too high. Mounding can affect treatment and percolation adversely by inhibiting soil reaeration and reducing moisture potential. A further potential consequence is undesirable surface seepage that can occur downslope. Constituent loadings must be considered where protection of potable water supply wells is a concern. Typical wastewater constituents of human health concern include pathogenic microbes and nitrates (see chapter 3). Water resource pollutants of concern include nitrogen in coastal areas, phosphorus near inland waters, and toxic organics and certain metals in all areas. If the wastewater constituent loadings are too high at the water table boundary, pretreatment before application to the infiltrative surface might be necessary.

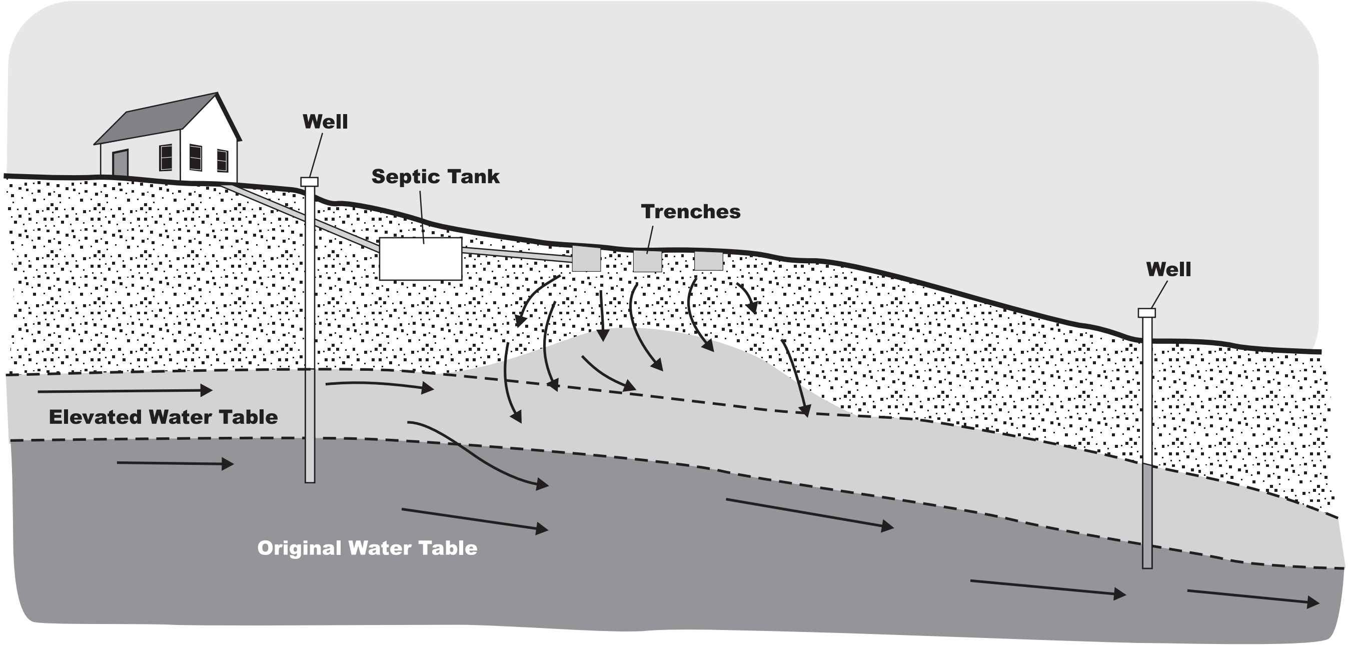
5.4.2 Surface water discharging system design boundaries and loadings

Surface water discharging systems typically consist of a treatment plant (aeration/activated sludge/sand filter "package" system with disinfection) discharging to an outfall (pipe discharge) to a surface water. The important design boundaries for these systems are the inlet to the treatment plant and the outfall to the surface water. The discharge permit and the performance history of the treatment process typically establish the limits of mass loading that can be handled at both the inlet to and the outlet from the treatment process. The loadings are often expressed in terms of daily maximum flow and pollutant concentrations (table 5-3). The effluent limits and wastewater characteristics establish the extent of treatment (performance requirements) needed before final discharge.

5.4.3 Atmospheric discharging system design boundaries and loadings

Evapotranspiration systems are the most commonly used atmospheric discharging systems. They can take several forms, but the primary design bound-

Figure 5-4. Effluent mounding effect above the saturated zone



Source: Adapted from NSFC diagram.

ary is the evaporative surface. Water (effluent) flowing through the treatment system and site hydrology must be considered in the design. Water balance calculations in the system control design (table 5-4). These loadings are determined by the ambient climatic conditions expected. Procedures for estimating these loadings are provided in chapter 4 (Evapotranspiration Fact Sheet).

5.5 Evaluating the receiving environment

Evaluation of the wastewater receiver site is a critical step in system selection and design. The objective of the evaluation is to determine the capacity of the site to accept, disperse, and safely and effectively assimilate the wastewater discharge. The evaluation should

- Determine feasible receiving environments (ground water, surface water, or atmosphere)
- Identify suitable receiver sites
- Identify significant design boundaries associated with the receiver sites
- Estimate design boundary mass loading limitations

Considering the importance of site evaluation with respect to system design, it is imperative that site evaluators have appropriate training to assess receiver sites and select the proper treatment train, size, and physical placement at the site. This section does not provide basic information on soil science but rather suggests methods and procedures that are standardized or otherwise proven for the practice of site evaluation. It also identifies specific steps or information that is crucial in the decision-making process for the site evaluator.

5.5.1 Role and qualifications of the site evaluator

The role of the site evaluator is to identify, interpret, and document site conditions for use in subsurface wastewater treatment system selection, design, and installation. The information collected should be presented in a manner that is scientifically accurate and spatially correct. Documentation should use standardized nomenclature to provide geophysical information so that the information can be used by other site evaluators, designers, regulators, and contractors.

The site evaluator needs considerable knowledge and a variety of skills. A substantial knowledge of soils, soil morphology, and geology is essential because most onsite systems use the soil as the final treatment and dispersal medium. Many states no longer accept the percolation test as the primary

Table 5-3. Types of mass loadings for point discharges to surface waters

Mass loading type	Units	Typical loading rates
Hydraulic		
• Daily	Volume per day through outfall	Determined by local regulatory agency based on water resource classification and mixing zone.
Constituent		
• Designated pollutant	Concentration of pollutant in mg/L through outfall	Determined by local regulatory agency based on water resource classification and mixing zone.

Source: Otis, 1999.

Table 5-4. Types of mass loadings for evapotranspiration systems

Mass loading type	Units	Typical loading rates
Hydraulic		
• Daily	Volume per day per unit area of boundary surface	Dependent on net evaporation, evapotranspiration potential, solar energy, wind, exposure, mean temperature, and other factors.
• Annual	Volume per day per unit area of boundary surface	Based on monthly water budget.

Source: Otis, 1999.

North Carolina guidelines for OWTS site evaluations

The Division of Environmental Health of the North Carolina Department of Environment, Health, and Natural Resources uses a 10-point guide for conducting site evaluations. The ten guidelines can be grouped into the following components:

Collecting information before the site visit

Assessing the site and soil at the location

Recording site evaluation data for system design

Relaying the information to the system designer and the applicant.

1. Know the rules and know how to collect the needed information. Applicable codes for sewage treatment and dispersal systems are usually established by the local agency.
2. Determine the wastewater flow rate and characteristics. Information on wastewater quantity and quality is used to determine the initial size and type of the onsite system to be installed at a particular site.
3. Review preliminary site information. Existing published information will help the evaluator understand the types of soils and their properties and distribution on the landscape.
4. Understand the septic system design options. Site evaluators must understand how onsite systems function in order to assess trade-offs in design options.
5. View the onsite system as part of the soil system and the hydrologic cycle. Typically, onsite systems serving single-family homes do not add enough water to the site to substantially change the site's hydrology, except in areas of high densities of onsite systems.
6. Predict wastewater flow through the soil and the underlying materials. The soil morphological evaluation and landscape evaluation are important in predicting flow paths and rates of wastewater movement through the soil and underlying materials.
7. Determine if additional information is needed from the site. Site and soil conditions and the type of onsite system being considered determine whether additional evaluation is required. Some additional evaluations that may be required are ground water mounding analysis, drainage analysis, hydrogeologic testing, contour (linear) loading rate evaluation, and hydraulic conductivity measurements.
8. Assess the treatment potential of the site. The treatment potential of the site depends on the degree of soil aeration and the rate of flow of the wastewater through the soil.
9. Evaluate the site's environmental and public health sensitivity. Installing onsite systems in close proximity to community wells, near shellfish waters, in sole-source aquifer areas, or other sensitive areas may raise concerns regarding environmental and public health issues.
10. Provide the system designer with soil/site descriptions and your recommendations. Based on the information gathered about the facility and the actual site and soil evaluation, the evaluator can suggest loading rates, highlight site and design considerations, and point out special concerns in designing the onsite system.

Source: North Carolina DEHNR, 1996.

suitability criterion. A significant number of permitting agencies now require a detailed soil profile description and evaluation performed by professional soil scientists or certified site evaluators.

In addition to a thorough knowledge of soil science, the site evaluator should have a basic understanding of chemistry, wastewater treatment, and water movement in the soil environment, as well as knowledge of onsite system operation and construction. The evaluator should also have basic skills in surveying to create site contour maps and site plans that include temporary benchmarks, horizontal and vertical locations of site features, and investigation, sample, or test locations. A general knowledge of hydrology, biology, and botany is helpful. Finally, good oral and written communication skills are necessary to convey site information to others who will make important decisions regarding the best use of the site.

5.5.2 Phases of a site evaluation

Site evaluations typically proceed in three phases: a preliminary review of documented site information, a reconnaissance of potential sites, and a detailed evaluation of the most promising site or sites. The scale and detail of the evaluation depend on the quantity and strength of the wastewater to be treated, the nature of local soils and the hydrogeologic setting, the sensitivity of the local environment, and the availability of suitable sites. Using a phased approach (table 5-5) helps to focus the site evaluation effort on only the most promising sites for subsurface systems.

5.5.3 Preliminary review

The preliminary review is performed before any fieldwork. It is based on information available from the owner or local agencies or on general resource information. The objectives of the preliminary review are to identify potential receiver sites, determine the most feasible receiving environments, identify potential design boundaries, and develop a relative suitability ranking. Preliminary screening of sites is an important aspect of the site evaluator's role. 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 reasonably and methodically 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. Also, the applicable local codes often prohibit point discharges to surface waters from small systems. Knowledge of local conditions and regulations is essential during the screening process. Resource materials and information to be reviewed may include, but are not limited to, the following:

- *Property information*. This information should include owner contact information, site legal description or address, plat map or boundary survey, description of existing site improvements (e.g., existing onsite wastewater systems, underground tanks, utility lines), previous and proposed uses, surrounding land use and zoning, and other available and relevant data.
- *Detailed soil survey*. Detailed soil surveys are published by the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS), formerly the Soil Conservation Service (SCS). Detailed soil surveys provide soil profile descriptions, identify soil limitations, estimate saturated soil conductivities and permeability values, describe typical landscape position and soil formation factors, and provide various other soil-related information. Soil surveys are typically based on deductive projections of soil units based on topographical or landscape position and should be regarded as general in nature. Because the accuracy of soil survey maps decreases as assessments move from the landscape scale to the site scale, soil survey data should be supplemented with detailed soil sampling at the site (table 5-5). Individual surveys are performed on a county basis and are available for most counties in the continental United States, Alaska, Hawaii, and the U.S. territories. They are available from county extension offices or

Table 5-5. Site characterization and assessment activities for SWIS applications

Preliminary activities	**Information from research**
Preliminary review	✓ Site survey map ✓ Soil survey, USGS topographic map ✓ Aerial photos, wetland maps ✓ Source water protection areas ✓ Natural resource inventories ✓ Applicable regulations/setbacks ✓ Hydraulic loading rates ✓ Criteria for alternative OWTS ✓ Size of house/facility ✓ Loading rates, discharge types ✓ Planned location of water well
Scheduling	✓ Planned construction schedule ✓ Date and time for meeting
Field activities	**Information from field study**
Identification of unsuitable areas	✓ Water supply separation distances ✓ Regulatory buffer zones/setbacks ✓ Limiting physiographic features
Subsurface investigations	✓ Ground water depth from pit/auger ✓ Soil profile from backhoe pit ✓ Presence of high water table ✓ Percolation tests
Identification of recommended SWIS site	✓ Integration of all collected data ✓ Identification of preferred areas ✓ Assessment of gravity-based flow ✓ Final selection of SWIS site

Source: Adapted from ASTM, 1996a.

the local NRCS office. Information on available detailed soil surveys and mapping status can be obtained from the National Soil Survey Center through its web site at **http://www.statlab.iastate.edu/soils/nssc/.** The NRCS publication *Fieldbook for Describing and Sampling Soils* is an excellent manual for use in site evaluation. It is available at **http://www.statlab.iastate.edu/soils/nssc/field_gd/field_gd.pdf.**

- *Quadrangle maps*. Quadrangle maps provide general topographic information about a site and surrounding landscape. These maps are developed and maintained by the U.S. Geological Survey (USGS) and provide nationwide coverage typically at a scale of 1 inch = 2000 feet, with either a 10- or 20-foot contour interval. At this scale, the maps provide information related to land use, public improvements (e.g., roadways), USGS benchmarks, landscape position and slope, vegetated areas, wetlands, surface drainage patterns, and watersheds. More information about USGS mapping resources can be found at **http://mapping.usgs.gov/mac/findmaps.html**. Quadrangle maps also are available through proprietary software packages.
- *Wetland maps*. Specialized maps that identify existing, farmed, and former wetlands are available in many states from natural resource or environmental agencies. These maps identify wetland and fringe areas to be avoided for wastewater infiltration areas. On-line and published wetland maps for many parts of the United States are available from the U.S. Fish and Wildlife Service's National Wetlands Inventory Center at **http://www.nwi.fws.gov/**.
- *Aerial photographs*. If available, aerial photographs can provide information regarding past and existing land use, drainage and vegetation patterns, surface water resources, and approximate location of property boundaries. They are especially useful for remote sites or those with limited or difficult access. Aerial photographs may be available from a variety of sources, such as county or regional planning, property valuation, and agricultural agencies.
- *Geology and basin maps*. Geology and basin maps are especially useful for providing general information regarding bedrock formations and depths, ground water aquifers and depths, flow direction and velocities, ambient water quality, surface water quality, stream flow, and seasonal fluctuations. If available, these maps can be obtained from USGS at **http://www.nationalatlas.gov/** or Terra Server at **http://www.terraserver.microsoft.com**.
- *Water resource and health agency information*. Permit and other files, state/regional water agency staff, and local health department sanitarians or inspectors can provide valuable information regarding local onsite system designs, applications, and performance. Regulatory agencies are beginning to establish Total Maximum Daily Loads (TMDLs) for critical wastewater constituents within regional drainage basins under federal and state clean water laws. TMDLs establish pollutant "budgets" to ensure that receiving waters can safely assimilate loads of incoming contaminants, including those associated with an onsite system (e.g., bacteria, nutrients). If the site lies in the recharge area of a water resource listed as impaired (not meeting its designated use) because of bacteria or nutrient contamination, site evaluators need to be aware of all applicable loading limits to ground water or surface water in the vicinity of the site under review.
- *Local installer/maintenance firms*. Helpful information often can be obtained from interviews with system installation and maintenance service providers. Their experience with other sites in the vicinity, existing technology performance, and general knowledge of soils and other factors can inform both the site evaluation and the selection of appropriate treatment system components.
- *Climate*. Temperature, precipitation, and pan evaporation data can be obtained from the National Oceanic and Atmospheric Administration (NOAA) at **http://www.nic.noaa.gov**. This information is necessary if evapotranspiration systems are being considered. The evaluator must realize, however, that the data from the nearest weather station might not accurately represent the climate at the site being evaluated.

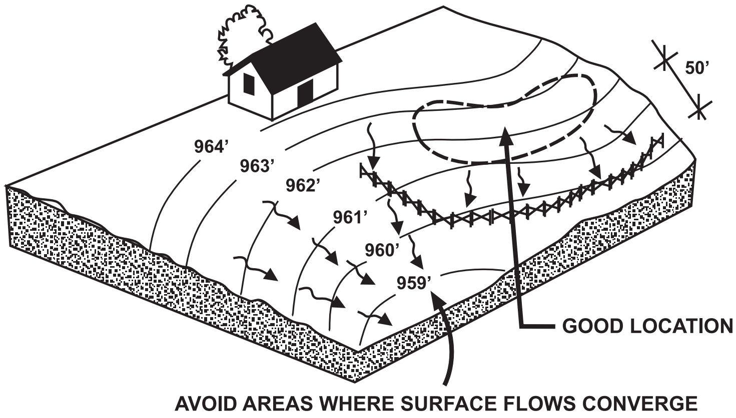
5.5.4 Reconnaissance survey

The objectives of the reconnaissance survey are to obtain preliminary site data that can be used to determine the appropriate receiving environment, screen potential receiver sites, and further focus the detailed survey to follow. A reconnaissance survey typically includes visual surveys of each potential site, preliminary soils investigation 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.

The site reconnaissance begins 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 the projected design flow and anticipated soil characteristics. It is advisable to complete the site walkover with the owner and local regulatory staff if possible, particularly with larger projects. Selection of an area for soil investigation is based on the owner's requirements (desired location, vegetation preservation, and general site aesthetics), regulatory requirements (setbacks, slope, and prior land use), and the site evaluator's knowledge and experience (landscape position, local soil formation factors, and geologic conditions). Visual inspections are used to note general features that might affect site suitability or system layout and design. General features that should be noted include the following:

- *Landscape position*. Landscape position and landform determine 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 (figures 5-5 and 5-6).
- *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.
- *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.
- *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.

Figure 5-5. General considerations for locating a SWIS on a sloping site

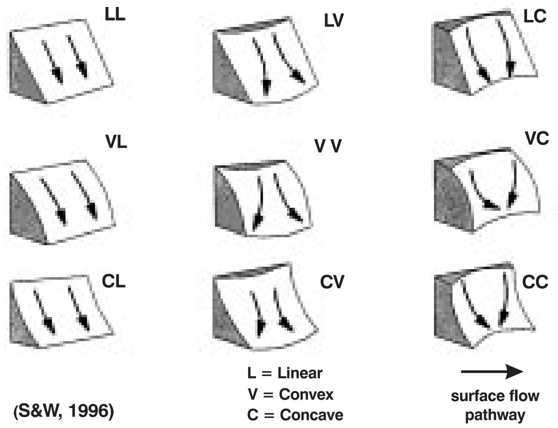


Source: Purdue University, 1990.

A good approach to selecting locations for soil investigations is to focus on landscape position. The underlying bedrock often controls landscapes, which are modified by a variety of natural forces. The site evaluator should investigate landscape positions during the reconnaissance phase to identify potential receiver sites (figures 5-5, 5-6 and 5-7; table 5-6). 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

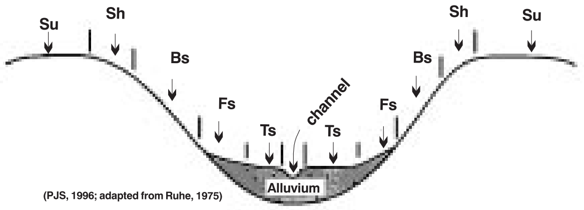
Figure 5-6. Landscape position features (see table 5-6 for siting potential)

Slope Shape - Slope shape is described in two directions: up and down slope (perpendicular to the contour), and across slope (along the horizontal contour); e.g., *linear, convex,* or *LV*.



Hillslope - Profile Position (Hillslope Position in PDP) - Two-dimensional descriptions of parts of line segments (slope position) along a transect that runs up and down the slope; e.g., *backslope* or *BS*. This is best applied to transects or points, not areas.

Position	Code
summit	SU
shoulder	SH
backslope	BS
footslope	FS
toeslope	TS



Source: NRCS, 1998.

Table 5-6. SWIS siting potential vs. landscape position features

Landscape position	SWIS siting potential	Comments
LC VC CC	Poor	Converging flows could overload SWIS hydraulically
LV VV CV	Fair	Might not be able to add additional trench length later
LL VL CL	Best	Parallel flow across SWIS provides best siting potential

soils are found on ridgelines, lower sideslopes, and footslopes. Bottomlands might have deeper soils but might also have poor subsurface drainage.

The visual survey might eliminate candidate receiver sites from further consideration. Preliminary soil borings should be examined on the remaining 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 (1.7 meters), 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 because of the expense and damage to noncommitted sites. Enough borings must be made to adequately characterize site conditions and identify design boundaries. To account for grade variations, separation distances, piping routes, management considerations, and contingencies, an area sufficient to provide approximately 200 percent of the estimated treatment area needed should be investigated. A boring density of one hole per half-acre may be adequate to accomplish the objectives of this phase. On sites where no reasonable number of soil borings is adequate to characterize the continuity of the soils, consideration should be given to abandoning the site as a potential receiver site.

Onsite treatment with a point discharge (permitted under the National Pollutant Discharge Elimination System) requires evaluation of the potential receiving water and an outfall location. The feasibility of a point discharge is determined by federal and state rules and local codes, if enacted by the local jurisdiction. Where the impacts and location of the discharge are considered acceptable by the regulating agency, effluent concentration limits will be stipulated and an NPDES permit will be required.

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 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.

5.5.5 Detailed 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 system. Because detailed investigations can be costly, they should not be performed unless the preliminary and reconnaissance evaluations indicate a high probability that the site is suitable. Detailed site evaluations should attempt to identify critical site characteristics and design boundaries that affect site suitability and system design. At a minimum, the detailed investigation should include soil profile descriptions and topographic mapping. (See figure 5-8, Site Evaluation/Site Plan Checklist.) Several backhoe pits, deep soil borings, soil permeability measurements, ground water characterizations, and pilot infiltration testing processes 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. This information should be presented with an accurate site plan.

The detailed evaluation should address surface features such as topography, drainage, vegetation, site improvements, property boundaries, and other significant features identified during the reconnaissance survey. Subsurface features to be addressed include soil characteristics, depth to bedrock and ground water, subsurface drainage, presence of rock in the subsoil, and identification of hydraulic and treatment boundaries. Information must be conveyed using standardized nomenclature for soil descriptions and hydrological conditions. Testing procedures must follow accepted protocol and standards. Forms or formats and evaluation processes specified by regulatory or management agencies must also be used (for a state example see **http://www.deh.enr.state.nc.us/oww/LOSWW/soil_form.pdf**).

5.5.6 Describing the soil profile

Descriptions and documentation of soil profiles provide invaluable information for designing onsite systems that use soil as the final wastewater treatment and dispersal medium. Detailed soil characterizations are provided through observation, description, and documentation of exposed soil profiles within backhoe-excavated test pits. Profiles can be described using a hand auger or drill probe for any single-home SWISs site in known soil and hydrogeology. However, backhoe-excavated test pits should be used wherever large SWISs or difficult single-home sites are proposed because of the quality of information gained. The grinding action or compression forces from soil borings taken with a hand auger or drill probe limit the information obtained for some soil characteristics, especially structure, consistency, and soil horizon relationships. Depending on project size, it might be necessary to supplement soil evaluation test pits with deep borings to provide more detail regarding soil substratum, ground water, and bedrock conditions. Table 5-7 summarizes the processes and procedures discussed below.

It might not be possible to identify all design boundaries, such as the permanent water table

Figure 5-7. Conventional system layout with SWIS replacement area

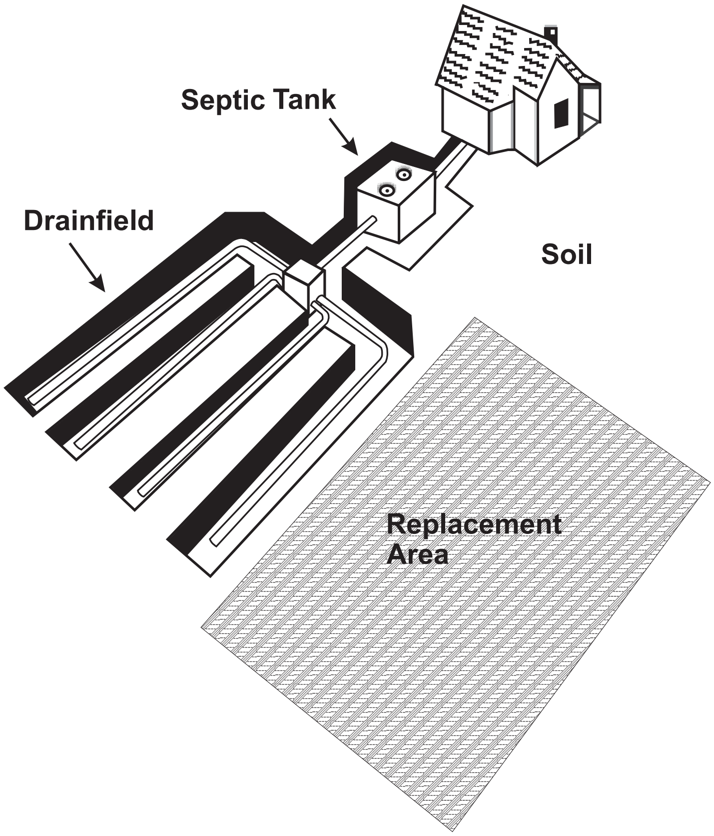


Figure 5-8. Site evaluation/site plan checklist

Owner/Client Information

Name__________________________________Contact nos.________________________

Address____

____

Projected design flow ________________GPD

Existing use_______________________ Intended use_________________________

Legal description____

____

____

____

Directions to site____

____

____

____

Surface Features

_______Benchmark description

_______Property boundaries

_______Existing/proposed structures

_______Existing/proposed wastewater systems

_______Soil investigation points

_______Contour elevations

_______Proposed system component locations

_______North arrow

_______Assigned elevation _________ft

_______Surface water features

_______Existing/proposed water supply wells

_______Utility locations

_______Location of area of suitable soils

_______Slope aspect & percent

_______Other significant features

_______Scale

Comments____

____

____

Figure 5-8. Site evaluation/site plan checklist (cont.)

Subsurface Features

_______Detailed soil descriptions (horizon depth, texture, color, structure, redoximorphic features, consistence, moisture, roots, and boundaries) (Use USDA nomenclature)

_______Depth and thickness of strong textural contrasts

_______Depth to seasonal saturation

_______Soil testing results

_______Parent material

_______Deep completed

_______Depth to bedrock

_______Depth to permanent water table

_______Ground water flow direction

_______Depth to perched water table

_______Soil samples collected

_______Soil formation factors

_______Depth

_______Type of bedrock

_______Sample

_______Ground water gradient

Comments____

Site Evaluator____

__________________________________Date________________________________

Site Evaluation Type: Desktop____________Preliminary__________Detailed______

Table 5-7. Practices to characterize subsurface conditions through test pit inspection

Description of activity	Process steps	Information to be collected
Select backhoe pit site	Pick site near but not in proposed drain field; orient pit so sunlight illuminates vertical face of pit	Location of soil absorption field
Excavate pit	Excavate to depth required by agency regulations	Required ground water or seasonally high water table separation distance, soil profile depth
Enter test pit	Take safety precautions; beware of cave-ins; select area of pit wall to examine	Safe depths for unbraced pit walls
Expose natural soil structure	Use soil knife, blade, screwdriver or other tool to pick at area 0.5 m wide along full height of pit wall	Soil structural type (e.g., prismatic, columnar, angular blocky, subangular blocky, platy, granular)
Describe soil horizons	Note master soil horizon layers; describe 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 ✓ 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 ✓ Identify highly permeable layers
Issue site report	Log all data onto required survey forms in required format	Develop system type, size location, and installation recommendations

Source: ASTM, 1996b.

surface or bedrock, if they are beyond shallow exploration depths (5 to 8 feet). However, it is imperative to identify and characterize secondary design boundaries that occur within the range of subsurface investigation. Soil characteristics should be described using USDA NRCS nomenclature and assessed by using standardized field soil evaluation procedures as identified in the *Field Book for Describing and Sampling Soils* (Shoeneberger et al., 1998), which is available on the Internet at **http://www.statlab.iastate.edu/soils/nssc/field_gd/field_gd.pdf**.

Another source for the description of soils in the field is American Society for Testing and Materials (ASTM) Standard D 5921-96, *Standard Practice for Subsurface Site Characterization of Test Pits for On-Site Septic Systems* (ASTM, 1996), which is summarized in table 5-7. The primary ASTM soil characterization reference is *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)*, ASTM D 2487-00. The ASTM and

NRCS soil classification systems have many similarities; both describe and categorize soils according to silt, clay, and sand composition and relative plasticity. However, the NRCS guide cited above is a field guide and is based on soil characterization procedures that can be conducted through tactile and visual techniques in the field (e.g., the feel of a soil sample, visual identification of the presence and color of concretions and mottles) with minimal equipment. The ASTM approach requires laboratory analysis of soil particle size (with a series of sieves), plasticity, and organic content (ASTM , 2000) and is more commonly used in the engineering profession. Both approaches meet the technical requirements for conducting the site evaluation process described in this section.

Based on the proposed design flow, an area equal to approximately 200 percent of the estimated required treatment area should be investigated. Test pits should be spaced in a manner that provides a reasonable degree of confidence that conditions are similar between pits. For small cluster systems, three to five test pits may be sufficient if located around the periphery and in the center of the proposed infiltration area. Large projects require more test pits. Test pit spacing can be adjusted based on landscape position and observed conditions. Hand auger borings or soil probes may be used to confirm conditions between or at peripheral test pit locations. Soil profiles should be observed and documented under similar conditions of light and moisture content. Features that should be noted include the following:

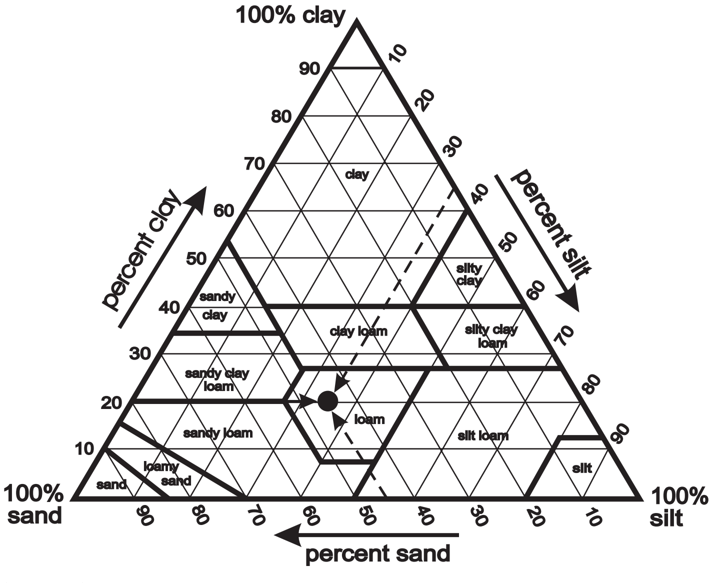
- *Soil depth.* Test pits should be excavated to a safe depth to describe soil conditions, typically 4 feet below the proposed infiltrative surface. A vertical wall exposed to the sunlight is best for examination. The wall should be picked with a shovel or knife to provide an undisturbed profile for evaluation and description. Horizon thickness should be measured and the soil properties described for each horizon.

  Restrictive horizons that may be significant secondary design boundaries must be noted. The depths of each horizon should be measured to develop a relationship with conditions in other test pits. Soil below the floor of the backhoe pit can be investigated by using hand augers in the excavated pit bottom or by using deep boring equipment.

  Key soil properties that describe a soil profile are horizons, texture, structure, color, and redoximorphic features (soft masses, nodules, or concretions of iron or manganese oxides often linked to saturated conditions). Other properties include moisture content, porosity, rupture resistance (resistance to applied stress), penetration resistance, roots, clay mineralogy, boundaries, and coatings. Attention to the listed key soil properties will provide the most value in determining water movement in soil.

- *Horizons.* A soil horizon is a layer of soil that exhibits similar properties and is generally denoted based on texture and color. Soil horizons result from natural soil-forming processes and human practices. Horizons are designated as master horizons and layers with subordinate distinctions. All key soil properties and associated properties that are relevant to water movement and wastewater treatment should be described. Particular attention should be given to horizons with strong textural contrast, stratified materials, and redoximorphic indicators that suggest a restriction to vertical water movement. Certain soil conditions that create a design boundary can occur within a soil horizon or layer. These include horizons with low perme-

Figure 5-9. Soil textural triangle



Source: USDA, 1951.

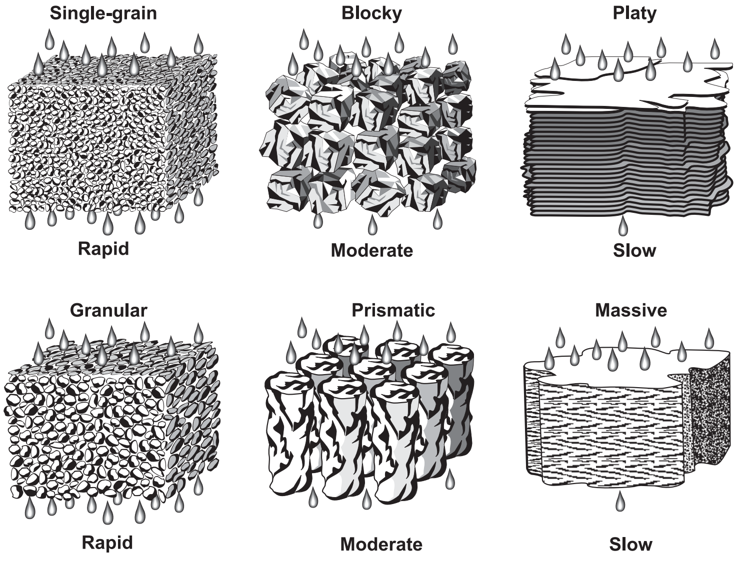
ability that perch water, indurated or massive horizons, or substrata of dense glacial till.

- *Texture*. Soil texture is defined as the percentage by weight of separates (sand, silt, and clay) that make up the physical composition of a given sample. It is one indicator of a soil's ability to transmit water. The textural triangle (figure 5-9) is used to identify soil textures based on percentage of separates (Schoeneberger et al., 1998).

  The texture of soil profiles is typically identified in the field through hand texturing. The evaluator's skill and experience play an important role in the accuracy of field texturing. Several field guides, typically in the form of flow charts, are available to assist the evaluator in learning this skill and to assist with identifying the texture of soils that occur at or near texture boundaries. (ASTM, 1997)

- *Structure*. Structure is more important than texture for determining water movement in soils. Soil structure is the aggregation of soil particles into larger units called peds. The more common types of structure are granular, angular blocky, subangular blocky, and platy (figure 5-10). Structureless soils include single-grain soils (e.g., sand) and massive soils (e.g., hardpan). The grade, size, shape, and orientation of soil peds influence water movement in the soil profile. This is especially true in fine-textured soils. Smaller peds create more inter-pedal fractures, which provide more flow paths for percolating water. Grade, which defines the distinctness of peds, is important for establishing a soil loading rate for wastewater dispersal. A soil with a "strong" grade of structure has clearly defined fractures or voids between the peds for the transmittance of water. The interpedal fractures and voids in a soil with a "weak" grade are less distinct and offer more resistance to water flow. Soils with a strong grade can accept higher hydraulic loadings than soils with a weak grade. Platy and massive soils restrict the vertical movement of water.

Figure 5-10. Types of soil structure



Source: USDA, 1951.

- *Color*. Color is an obvious property of soil that is easily discernible. It is an excellent indicator of the soil's aeration status and moisture regime. Soil colors are described using the Munsell color system, which divides colors into three elements—hue, value, and chroma (Munsell, 1994). Hue relates to the quality of color, value indicates the degree of lightness or darkness, and chroma is the purity of the spectral color. Munsell soil color books are commercially available and are universally accepted as the standard for identifying soil color. The dominant or matrix color is determined for each horizon, and secondary colors are determined for redoximorphic features, ped coatings, mineral concretions, and other distinctive soil features. Dark colors generally indicate higher organic content, high-chroma colors usually suggest highly oxygenated soils or high iron content, and low-chroma soils imply reduced conditions often associated with saturation. The site evaluator must be aware that colors can be modified by temperature, mineralogy, vegetation, ped coatings, and position in the soil profile.

- *Redoximorphic features*. Redoximorphic features are used to identify aquic moisture regimes in soils. An aquic moisture regime occurs when the soil is saturated with water during long periods, an indicator of possible restrictive horizons, seasonal high water tables, or perched water tables. The presence of redoximorphic features suggests that the surrounding soil is periodically or continuously saturated. This condition is important to identify because saturated soils prevent reaeration of the vadose zone below infiltration systems and reduce the hydraulic gradients necessary for adequate drainage. Saturated conditions can lead to surfacing of wastewater or failure due to significant decreases in soil percolation rates. Redoximorphic features include iron nodules and mottles that form in seasonally saturated soils by the reduction, translocation, and oxidation of iron and manganese oxides (Vespaskas, 1996). Redoximorphic features have replaced mottles and low-chroma colors in the USDA NRCS soil taxonomy because mottles include carbonate accumulations and organic stains that are not related to saturation and reduction. It is important to note that redoximorphic features are largely the result of biochemical activity and therefore do not occur in soils with low amounts of organic carbon, high pH (more than 7 standard pH units), low soil temperatures, or low amounts of iron, or where the ground water is aerated. Vespraskas (1996) provides an excellent guide to the identification of redoximorphic features and their interpretation. As noted, the NRCS online guide to redoximorphic and other soil properties at **http://www.statlab.iastate.edu/soils/nssc/field_gd/field_gd.pdf** addresses key identification and characterization procedures for redoximorphic and other soil features.

- *Soil consistence*. Soil consistence in the general sense refers to attributes of soil as expressed in degree of cohesion and adhesion, or in resistance to deformation or rupture. Consistence includes the resistance of soil material to rupture; the resistance to penetration; the plasticity, toughness, or stickiness of puddled soil material; and the manner in which the soil material behaves when subjected to compression. Consistence is highly dependent on the soil-water state. The general classifications of soil consistence are loose, friable, firm, and extremely firm. Soils classified as firm and extremely firm tend to block subsurface wastewater flows. These soils can become cemented when dry and can exhibit considerable plasticity when wet. Soils that exhibit extremely firm consistence are not recommended for conventional infiltration systems.
- *Restrictive horizons*. Soil properties like penetration resistance, rooting depth, and clay mineralogy are important indicators of soil porosity and hydraulic conductivity. Penetration resistance is often correlated with the soil's bulk density. The greater the penetration resistance, the more compacted and less permeable the soil is likely to be. Rooting depth is another measure of bulk density and also soil wetness. Clay mineralogies such as montmorillonite, which expand when wetted, reduce soil permeability and hydraulic conductivity significantly. A discussion of these properties and their description can also be found in the USDA Soil Survey Manual (USDA, 1993) and the USDA NRCS *Field Book for Describing and Sampling Soils* (Schoeneberger et al., 1998).
- *Other soil properties*. Other soil properties that affect nutrient removal are organic content and phosphorus adsorption potential. Organic content can provide a carbon source (from decaying organic matter in the uppermost soil horizons) that will aid denitrification of nitrified effluent (nitrate) in anoxic regions of the SWIS. Phosphorus can be effectively removed from wastewater effluent by soil through adsorption and precipitation reactions (see chapter 3). Soil mineralogy and pH affect the soil's capacity to retain phosphorus. Adsorption isotherm tests provide a conservative measure of the potential phosphorus retention capacity.
- *Characterization of unconsolidated material*. Geologists define unconsolidated material as the material occurring between the earth's surface and the underlying bedrock. Soil forms in this parent material from the actions of wind, water, or alluvial or glacial deposition. Soil scientists refer to the soil portion of unconsolidated material as the solum and the parent material as the substratum. Typically, site evaluators expose the solum and the upper portion of the substratum. Knowledge of the type of parent material and noted restrictions or boundary conditions is important to the designer, particularly for large wastewater infiltration systems. Often, if the substratum is deep, normal test pit depth will be insufficient and deep borings may be necessary.

5.5.7 Estimating infiltration rate and hydraulic conductivity

Knowledge of the soil's capacity to accept and transmit water is critical for design. The infiltration rate is the rate at which water is accepted by the soil. Hydraulic conductivity is the rate at which water is transmitted through the soil. As wastewater is applied to the soil, the infiltration rate typically declines well below the saturated hydraulic conductivity of the soil. This occurs because the biodegradable materials and nutrients in the wastewater stimulate microbiological activity that produces new biomass (see chapter 3). The biomass produced and the suspended solids in the wastewater create a biomat that can fill many of the soil pores and close their entrances to water flow. The flow resistance created by the biomat can reduce the infiltration rate to several orders of magnitude less than the soil's saturated hydraulic conductivity. The magnitude of the resistance created by the biomat is a function of the BOD and suspended solids in the applied wastewater and the initial hydraulic conductivity of the soil.

Estimating the design infiltration rate is difficult. Historically, the percolation test has been used to estimate the infiltration rate. The percolation test was developed to provide an estimate of the soil's saturated hydraulic conductivity. Based on experience with operating subsurface infiltration systems, an empirical factor was applied to the percolation test result to provide a design infiltration rate. This method of estimating the design infiltration rate has many flaws, and many programs that regulate onsite systems have abandoned it in favor of detailed soil profile descriptions. Soil texture and structure have been found to correlate better with the infiltration rate of domestic septic tank effluent (Converse and Tyler, 1994). For other applied effluent qualities such as secondary effluent, the correlation with texture and structure is less well known.

Information on the hydraulic conductivity of the soil below the infiltrative surface is necessary for ground water mounding analysis and estimation of the maximum hydraulic loading rate for the infiltration area. There are both field and laboratory methods for estimating saturated hydraulic conductivity. Field tests include flooding basin, single- or double-ring infiltrometer, and air entry permeameter. These and other field test procedures are described elsewhere (ASTM, 1997; Black, 1965; USEPA, 1981; 1984). Laboratory methods are less accurate because they are performed on small soil samples that are disturbed from their natural state when they are taken. Of the laboratory tests, the concentric ring permeameter (Hill and King, 1982) and the cube method (Bouma and Dekker, 1981) are the most useful techniques. The American Society for Testing and Materials posts permeameter information on its Internet site at **http://www.astm.org** (see *ASTM Store, ASTM Standards*).

5.5.8 Characterizing the ground water table

Where ground water is present within 5 feet below small infiltration systems and 10 to 15 feet below large systems, the hydraulic response of the water table to prolonged loading should be evaluated. The ground water can be adversely affected by treated wastewater and under certain conditions can influence system performance. This information is valuable for understanding potential system impacts on ground water and how the system design can mitigate these impacts.

The depth, seasonal fluctuation, direction of flow, transmissivity, and, where possible, thickness of the water table should be estimated. With shallow, thin water tables, depth, thickness, and seasonal fluctuations can be determined through soil test pit examination. However, deeper water tables require the use of deep borings and possible installation of piezometers or monitoring wells. At least three piezometers, installed in a triangular pattern, are necessary to determine ground water gradient and direction of flow, which might be different from surface water flow direction. Estimating the saturated hydraulic conductivity of the aquifer materials is necessary to determine ground water travel velocity. Slug tests or pumping tests can be performed in one or more existing or new wells screened in the shallow water table to estimate the hydraulic conductivity of the aquifer (Bouwer, 1978; Bouwer and Rice, 1976; Cherry and Freeze, 1979). In some cases, it may be possible to estimate the saturated hydraulic conductivity from a particle size analysis of aquifer materials collected from the test pit, if the material is accessible (Bouwer, 1978; Cherry and Freeze, 1979). Pumping tests may also be used to determine the effective porosity or specific yield of the saturated zone.

Ground water mounding beneath an infiltration system can reduce both treatment and the hydraulic efficiency of the system. Ground water mounding occurs when the rate of water percolating vertically into the saturated zone exceeds the rate of ground water drainage from the site (figure 5-4). Mounding is more likely to occur where the receiver site is relatively flat, the hydraulic conductivity of the saturated zone is low, or the saturated zone is thin. With continuous application, the water mounds beneath the infiltrative surface and reduces the vertical depth of the vadose zone. Reaeration of the soil, treatment efficiency, and the infiltration system's hydraulic capacity are all reduced when significant mounding occurs. A mounding analysis should be completed to determine site limits and acceptable design boundary loadings (linear hydraulic loading) for sites where the water table is shallow or the soil mantle is thin, or for any large infiltration system.

Both analytical and numerical ground water mounding models are available. Because of the large number of data points necessary for numerical modeling, analytical models are the most commonly used. Analytical models have been developed for various hydrogeologic conditions (Brock, 1976; Finnemore and Hantzshe, 1983; Hantush, 1967; Kahn et al., 1976). Also, commercial computer software is available to estimate mounding potential. The assumptions used in each model must be compared to the specific site conditions found to select the most appropriate model. For examples of model selection and model computations, see EPA's process design manual (USEPA, 1981, 1984). A USEPA Office of Ground Water and Drinking Water annotated bibliography of ground water and well field characterization modeling studies can be found on the Internet at **http://www.epa.gov/ogwdw000/swp/wellhead/dewell.html#analytical**. USGS has available a number of software packages, which are posted at **http://water.usgs.gov/software/ground_water.html**. For links to software suppliers or general information, visit the National Ground Water Association web site at **http://www.ngwa.org**/.

5.5.9 Assessments for point source and evapotranspiration discharges

Sites proposed for point discharges to surface waters require a permit from the National Pollutant Discharge Elimination System (see **http://www.epa.gov/owm/npdes.htm**) and a suitable location for an outfall to a receiving water body. Considerations for locating an outfall structure include NPDES regulatory requirements, outfall structure siting, routing from the treatment facility, construction logistics and expense, and aesthetics. Regulatory requirements generally address acceptable entry points to receiving waters and hydraulic and pollutant loadings. The state regulatory agency typically sets effluent limits based on the water resource classification, stream flow, and assimilative capacity of the receiving water. Assimilative capacities take into account the entire drainage basin or watershed of nearby receiving waters to ensure that pollutant levels do not exceed water quality criteria. (See table 3-21 for applicable Drinking Water Standards; USEPA Drinking Water Standards are posted at **http://www.epa.gov/ogwdw000/creg.html.**) In the case of state-listed impaired streams (those listed under section 303(d) of the Clean Water Act), discharges must consider pollutant loads established or proposed under the Total Maximum Daily Load provisions of the Clean Water Act. Piping from the treatment facility needs to consider gravity or forcemain, route, existing utilities, and other obstacles to be avoided.

Evapotranspiration (ET) systems treat and discharge wastewater by evaporation from the soil or water surface or by plant transpiration. These systems are climate-sensitive and require large land areas. ET systems function best in arid climates where there is large annual net evaporation and active vegetative growth year-round. In the United States this generally means only the southwestern states, where humidity is low, rainfall is minimal, and temperatures are warm enough to permit active plant growth during the winter season (figure 5-11). Although the macroclimate of an area might be acceptable for the use of ET systems, evaluation of the microclimate is often required because it can significantly influence system performance. In addition to temperature, precipitation, and pan evaporation data, exposure position and prevalent wind direction should be considered as part of the evaluation process. Southern exposures in the northern hemisphere provides greater solar radiation. Exposure to wind provides greater drying of the soil and plant surfaces. Surface drainage patterns should also be assessed. Well-drained sites have a lower ambient humidity to enhance evaporation than poorly drained sites.

5.6 Mapping the site

At the completion of the site evaluation, a site map or sketch should be prepared to show physical features, locations of soil pits and borings, topography or slopes, and suitable receiver sites. If a map or aerial photograph was used, field measurements and locations can be noted directly on it. Otherwise it will be necessary to take measurements and sketch the site. The level of effort for developing a good site map should be commensurate with the results of the site evaluation and whether the site map is being completed for a preliminary or detailed site evaluation.

In addition to the features of the site under consideration, the site map should show adjacent lands and land uses that could affect treatment system layout, construction, and system performance. Maps with a 1- or 2-foot contour interval are preferred.

5.7 Developing the initial system design

Developing a concept for the initial system design is based on integration of projected wastewater volume, flow, and composition information; the controlling design boundaries of the selected receiving environment; the performance requirements for the chosen receiving environment; and the needs and desires of the owner (figure 5-12). The site evaluation identifies the critical design boundaries and the maximum mass loadings they can accept. This knowledge, together with the performance requirements promulgated by the regulating authority for the receiving environment, establishes the design boundary loadings. Once the boundary loadings are established, treatment trains that will meet the performance requirements can be assembled.

Figure 5-11. Potential evaporation versus mean annual precipitation

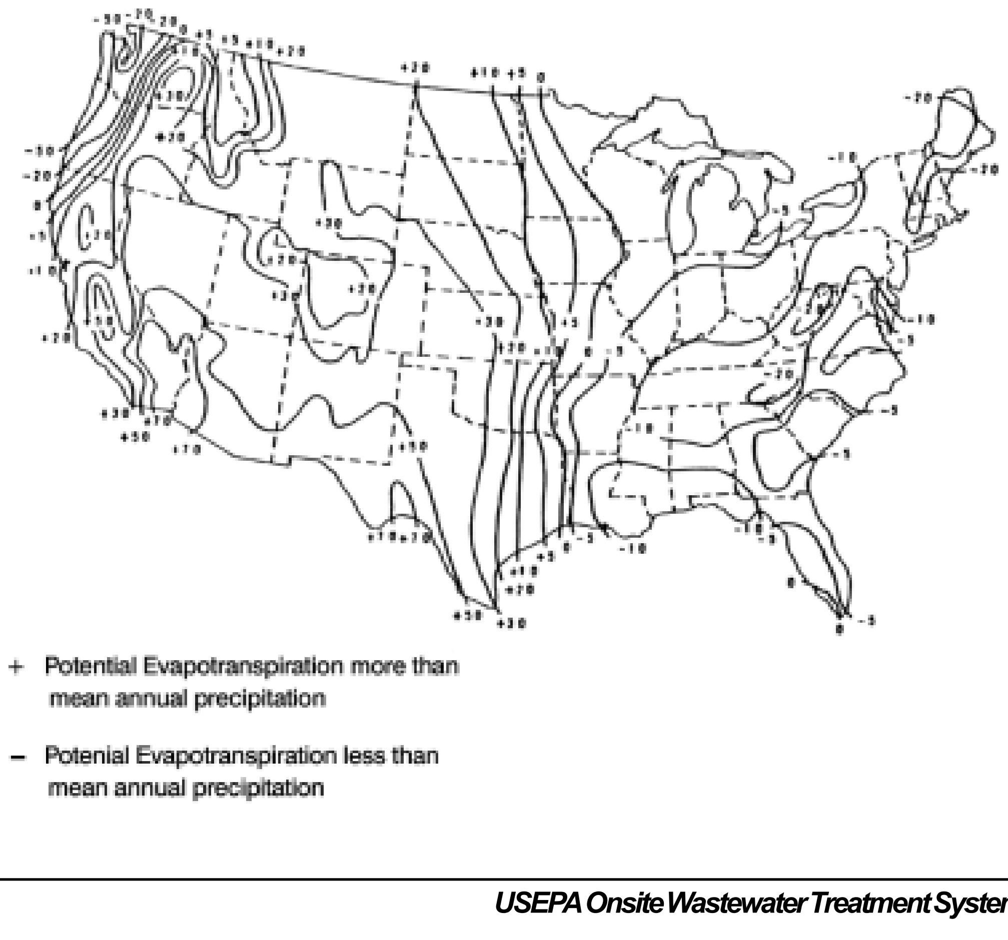
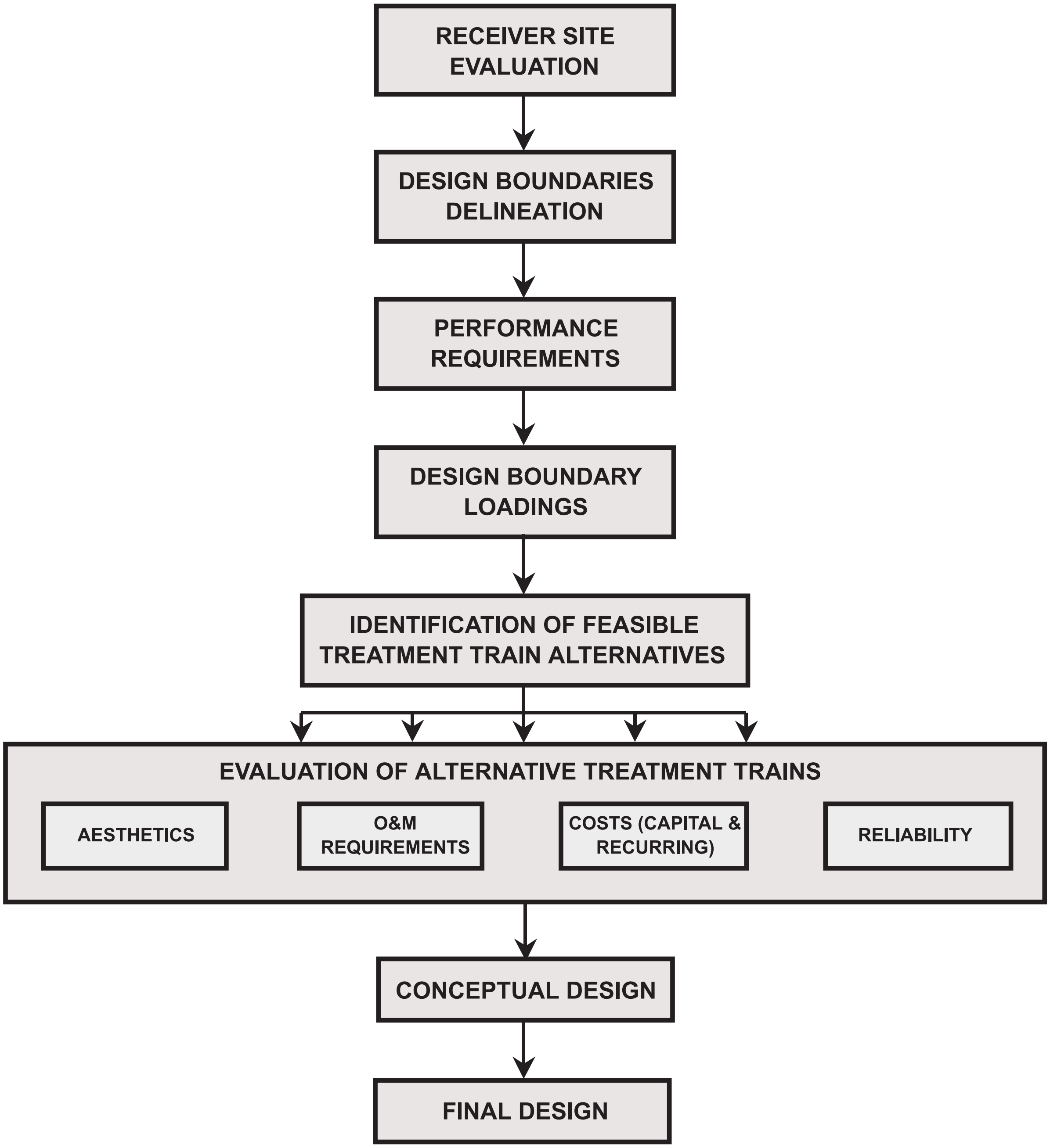


Figure 5-12. Development of the onsite wastewater system design concept



Assembling SWIS treatment trains for a site with shallow, slowly permeable soils over bedrock

Site description

A single-family residence is proposed for a lot with shallow, finely textured, slowly permeable soil over creviced bedrock. The depth of soil is 2 feet. The slope of the lot is moderate and is controlled by bedrock. Ground water is more than 5 feet below the bedrock surface.

Design boundaries

Three obvious design boundaries that will affect the SWIS design are present on this site: the infiltrative surface, the bedrock surface, and the water table. The site evaluation determined that no hydraulically restrictive horizon is present in the soil profile above the bedrock.

Performance requirements

The regulatory agency requires that the wastewater discharge remain below ground surface at all times, that the ground water contain no detectable fecal coliforms, and that the nitrate concentrations of the ground water be less than 10 mg-N/L at the property boundary. In this case study, wastewater modification (reducing mass pollutant loads or implementing water conservation measures; see chapter 3) was not considered.

Design boundary mass loadings

Infiltrative surface: Referring to table 5-2, the mass loadings that might affect the infiltrative surface are the daily, instantaneous, and organic mass loadings. The selected hydraulic and instantaneous (dose volume per square foot) loading rates must be appropriate for the characteristics of the soil to prevent surface seepage. Assuming domestic septic tank effluent is discharged to the infiltrative surface and that the surface is placed in the natural soil, the organic mass loading is accounted for in the commonly used daily hydraulic loading rates. Typical hydraulic loading rates for domestic septic tank effluent control design. Reducing the organic concentration through pretreatment will have little impact because the resistance of the biomat created by the organic content is typically less than the resistance to flow through the fine-textured soil.

Bedrock boundary: The bedrock boundary is a secondary design boundary where a zone of saturation will form as the wastewater percolates through the soil. This boundary is affected by the daily and linear hydraulic loadings (table 5-2). If these hydraulic loadings exceed the rate at which the water is able to drain laterally from the site or percolate to the water table through the bedrock crevices, the saturated zone thickness will increase and could encroach on the infiltrative surface, reducing its treatment and hydraulic capacity. Because the site is sloping, the linear, rather than the daily, hydraulic loading will control design.

Water table boundary: The wastewater percolate will enter the ground water through the bedrock crevices. The daily and linear hydraulic loading and constituent loadings are the mass loadings that can affect this boundary (table 5-2). Because of the depth of the water table below the bedrock surface and the porous nature of the creviced bedrock, the daily and linear hydraulic loadings are not of concern. However, nitrate-nitrogen and fecal coliforms are critical design loadings because of the water quality requirements. Table 5-2 summarizes the critical design boundary mass loadings that will affect design.

Assembling feasible treatment train alternatives

Because control of the wastewater is lost after it is applied to the soil, the bedrock and water table boundary loading requirements must be satisfied through appropriate design considerations at or before the infiltrative boundary. Therefore, the secondary and water table boundary loadings must be considered first.

Constituent loading limits at the ground water boundary will control treatment requirements. Although the performance boundary (the point at which performance requirements are measured) may be at the property boundary, mixing and dilution in the ground water cannot be certain because the bedrock crevices can act as direct conduits for transporting undiluted wastewater percolate. Therefore, it would be prudent to ensure these pollutants are removed before they can leach to the ground water. Research has demonstrated that soils similar to those present at the site (fine-textured, slowly permeable soils) can effectively remove the fecal coliforms if the wastewater percolates through an unsaturated zone of 2 to 3 feet (Florida HRS, 1993). Because the soil at the site extends to only a 2-foot depth, the infiltrative surface would need to be elevated 1 foot above the ground surface in a mound or at-grade system. Alternatively, disinfection prior to soil application could be used. Nitrate is not effectively removed by unsaturated, aerated soil; therefore, pretreatment for nitrogen removal is required.

Maintaining the linear loading at the bedrock surface below the maximum acceptable rate determines the orientation and geometry of the infiltrative surface. The infiltrative surface will need to be oriented parallel to the bedrock surface contour. Its geometry needs to be long and narrow, with a width no greater than the maximum acceptable linear loading (gpd/ft) divided by the design hydraulic loading on the infiltrative surface (gpd/ft^2). Note: If a mound is used on this site, an additional design boundary is created at the mound fill/natural soil interface. The daily hydraulic loading will affect this secondary design boundary.

If the perched saturated zone above the bedrock is expected to rise and fall with infiltrative surface loadings, the instantaneous loading to the infiltrative surface should be controlled through timed dosing to maximize the site's hydraulic capacity. Failure to control instantaneous loads could lead to transmission of partially treated wastewater through bedrock crevices, driven by the higher hydraulic head created during periods of peak system use. Applying the wastewater through a dosing regime will maximize retention time in the soil while ensuring cyclical flooding of the infiltration trenches, creating optimum conditions for denitrifying bacteria to accomplish nitrogen removal. The daily and instantaneous hydraulic loadings to the infiltrative surface are dependent on the characteristics of the soil or fill material in which the SWIS is placed.

Alternative	Pretreatment	Dosing	Infiltration
1	Nitrogen removal	Timed dosing	Mound with pressure distribution
2	Nitrogen removal with disinfection	Timed dosing	In-ground trenches with pressure distribution

From this boundary loading analysis, potential treatment train alternatives can be assembled. Table 4-1 and the fact sheets in chapter 4 should be used to select appropriate system components.

Alternative 1 elevates the infiltrative surface in a mound of suitable sand fill. With at least a foot of fill and the unsaturated 2 feet of natural soil below, fecal coliform removal will be nearly complete. The mound would be designed as long and narrow, oriented parallel to the bedrock surface contours (equivalent to the land surface contours since the slope is bedrock-controlled) to control the linear loading on the interface between the sand fill and natural soil or at the bedrock surface. The infiltrative surface would be time-dosed through a pressure or drip distribution network to distribute the wastewater onto the surface uniformly in time and space.

Alternative 2 places the infiltrative surface in the natural soil. With this design, there would be an insufficient depth of unsaturated soil to remove the fecal coliforms. Therefore, disinfection of the treated wastewater prior to application to the soil would be necessary. The trenches would be oriented parallel to the bedrock surface contours (equivalent to the land surface contours since the slope is bedrock-controlled) to control the linear loading on the bedrock surface. If multiple trenches are used, the total daily volume of treated wastewater applied per linear foot of trench parallel to the slope of the bedrock surface would be no greater than the design linear loading for the site. Loadings to the infiltrative surface would be time-dosed through a pressure or drip distribution network to distribute the wastewater uniformly in time and space.

Note that for the alternatives listed, multiple options exist for each of the system's components (see table 4-1).

Source: Otis, 2001.

Subsurface wastewater infiltration system design in a restricted area

Often, the available area with soils suitable for subsurface infiltration of wastewater is limited. Because local authorities usually do not permit point discharges to surface waters, subsurface infiltration usually is the only option for wastewater treatment. However, a SWIS can perform as required only if the daily wastewater flow is less than the site's hydraulic capacity.

The hydraulic capacity of the site is determined by the subsurface drainage capacity of the site. The drainage capacity is defined by the soil profile and the daily hydraulic or linear mass loading to secondary or ground water boundary surfaces. In some cases, however, the infiltration rate of the wastewater into the soil at the infiltrative boundary is more limiting. Therefore, it is important to distinguish between the two boundaries if use of the site is to be maximized. Where hydraulic loadings to secondary boundaries are the principal control feature, the only option is to limit the amount of water applied to the secondary boundaries. This can be accomplished through the following:

Orientation, geometry, and controlled dosing of the infiltrative surface

The infiltrative surface should be oriented parallel to and extended as much as possible along the surface contour of the secondary boundary. Southern, eastern, and western exposures may provide better evaporation than north-facing slopes. The daily hydraulic loading rate onto the total downslope projection of "stacked" infiltration surfaces (multiple, evenly spaced SWIS trenches placed on the contour on sloping terrain) should be limited to the maximum linear loading of the secondary boundary. Timed dosing to the infiltrative surfaces should be used to apply wastewater uniformly over the full length of the infiltrative surfaces to minimize the depth of soil saturation over the secondary boundary. Note that the presence of other SWIS-based treatment systems above or below the site should be considered in load calculations and design concept development.

Installation of water-conserving plumbing fixtures in the building served

The total daily volume of wastewater generated can be significantly reduced by installation of water-conserving fixtures such as low-volume flush toilets and low-flow showerheads (see chapter 3). Also, wastewater inputs from tub spas and automatic regenerating water softeners should be eliminated.

Maximizing the evapotranspiration potential of the infiltration system

Where the growing season is long or use of the property is limited to the summer months, evapotranspiration can help to reduce the total hydraulic loading to the secondary boundary. The infiltrative surfaces should be shallow and located in open, grassed areas with southern exposures (in the Northern Hemisphere).

If the infiltration capacity at the soil's infiltrative surface is the limiting condition, measures to increase infiltration can be taken. These measures include the following:

Reducing the mass loadings of soil clogging constituents on the infiltrative surface

The mass loadings to the infiltrative surface can be reduced either by increasing the infiltrative surface area to reduce the mass constituent loading per unit of area or by removing the soil-clogging constituents before soil application. Where the suitable area for the SWIS is limited, increasing the infiltrative surface area might not be possible.

Controlled dosing of the infiltrative surface

Timed dosing and alternate "resting" of infiltrative surfaces allow organic materials that might clog the soil surface to oxidize, helping to rejuvenate infiltrative capacity. Using multiple timed doses throughout the day with intervals between doses to allow air diffusion maximizes the reaeration potential of the subsoil (Otis, 1997). Dual infiltration systems that can be alternately loaded allow for annual resting of the infiltrative surfaces to oxidize the biomat. On small lots dual systems are often not feasible because of space limitations.

Source: Otis, 2001.

5.7.1 Identifying appropriate treatment trains

Multiple treatment trains (system designs) are often feasible for a particular receiver site and expected wastewater flow. More than one receiving environment may be suitable for a treated discharge. For example, subsurface infiltration or a point discharge to surface water might be feasible. Multiple sites on a property might be suitable as a receiver site. In addition, more than one treatment train might meet established or proposed performance requirements. Each of these alternatives must be considered to select the most appropriate system for a given application.

Evaluation of the feasible alternatives is a continuous activity throughout the preliminary design process. It is beneficial to eliminate as many potential options as possible early in the preliminary design process so that time can be spent on the most probable alternatives. Typically, receiving environments are the first to be eliminated. For example, in temperate climates atmospheric discharges are rarely feasible because there is insufficient net evaporation to evaporate the wastewater. Surface water discharges usually can be eliminated as well because often they are not permitted by the local regulatory agency. Where such discharges are permitted, subsurface infiltration is usually less costly if the site meets the regulatory agency's requirements because monitoring costs for compliance with point discharge permit requirements can be substantial.

At the completion of the site evaluation, the receiving environment has been tentatively selected (see section 5.5). For each potential receiver site, the design boundaries have been identified. Integrating information on physical limitations and established or proposed performance requirements helps to define the maximum mass loadings to the design boundaries (see section 5.3). Defining and characterizing the controlling design boundaries and their maximum acceptable mass loadings, estimating the characteristics of the wastewater to be treated, and evaluating the site conditions inform the development of a feasible set of potential treatment trains. Treatment train assembly is usually straightforward for surface water discharges because the effluent concentration limits at the outfall control design. With soil-based systems such as SWISs, however, treatment train selection is more complex because multiple design boundaries can be involved.

Because direct control of SWIS performance is lost once the partially treated wastewater enters the soil at the infiltrative surface, management of the loadings to any secondary design boundaries and water table boundaries must be accomplished indirectly through appropriate adaptations at the primary infiltrative surface. For hydraulic loadings, control can be achieved by changing the geometry or size of the infiltrative surface or the dosing volume, frequency, and pattern. For organic or constituent loadings, control is achieved either by pretreating the wastewater before it is applied to the infiltrative surface or by increasing the size of the infiltrative surface.

5.7.2 Treatment train selection

Where multiple treatment trains are feasible and technically equivalent, each must be evaluated with respect to aesthetics, operation and maintenance requirements, cost, and reliability before selection of the final design concept.

5.7.3 Aesthetic considerations

Aesthetics are an intangible factor that must be addressed with the owner, users, adjacent property owners, and regulators. They include considerations such as system location preferences, appearance, disruption during construction, equipment and alarm noise, and odor potential. It is important that these and possibly other aesthetics issues be discussed with the appropriate parties before selecting the design concept to be used. If the expectations of the concerned parties are not met, their dissatisfaction with the system could affect its use and care.

5.7.4 Operation and maintenance requirements

Specific and appropriate operation and maintenance tasks and schedules are essential if a wastewater system is to perform properly over its intended service life. Important considerations include

- Types of maintenance functions that must be performed
- Frequency of routine maintenance
- Time and skills required to perform routine maintenance
- Availability of operation and maintenance service providers with appropriate skills
- Availability of factory service and replacement parts

Traditional onsite systems are passive in design, requiring little operator attention or skill. Unskilled owners can usually access maintenance services or be trained to perform basic maintenance tasks. Septage removal usually requires professional services, but these are readily available in most areas. More complex wastewater systems, however, require elevated levels of operator attention and skill. The designer must weigh the availability of operator services in the locale of the proposed system against the consequences of inadequate operation and maintenance before recommending a more complex system. The availability of factory service is also an important consideration. Where operation and maintenance services are not locally available and the use of alternative systems that have fewer operation and maintenance requirements is not an option, the prospective system owner should be advised fully before proceeding.

5.7.5 Costs

Costs of the feasible alternatives should be arrayed based on the *total cost* of each alternative. Total costs include both the capital costs incurred in planning, designing, and constructing the system and the long-term costs associated with maintaining the system over its design life (20 to 30 years in most cases; see table 5-8). This method of cost analysis is an equitable method of comparing alternatives with higher capital costs but lower annual operating costs to other alternatives with lower capital costs but higher annual operating costs. Often, owners are deceived by systems with lower capital costs. These systems might have much higher annual operating costs, a shorter design life, and possibly higher replacement costs, resulting in much higher total costs. Systems with higher capital costs might have lower total costs because the recurring operation and maintenance costs are less. Choosing between alternatives with varying total cost options is a financing decision. In some cases, capital budgets are tighter than operating budgets. Therefore, this is a decision the prospective owner must make based on available financing options. Table 5-8 is an example of such a comparative analysis.

The USEPA Office of Wastewater Management posts financing information for onsite wastewater treatment systems or other decentralized systems (cluster systems not connected to a wastewater treatment plant) on the Internet at **http://www.epa.gov/owm/decent/funding.htm**. Links are available at that site to financing programs supported by a variety of federal, state, and other public and private organizations.

5.7.6 Reliability

The reliability of the proposed system and the risks to the owner, the public, and the environment if malfunctions or failures occur must be considered. Potential risks include public health and environmental risks, property damage, personal injury, medical expenses, fines, and penalties. Where these or other potential risks are significant, contingency plans should be developed to manage the risks. Contingencies include storage, pump and haul (holding tank), redundant components, reserve capacity, and designation of areas for repair or replacement components (e.g., replacement leach field). These come at additional cost, so their benefit must be weighed against the potential risks.

5.7.7 Conceptual design

After evaluating the feasible options, the preliminary treatment train components can be selected. At this point in the development of the design, the unit processes to be used and their sequence are defined. A preliminary layout should be prepared to confirm that the system will fit on the available site. Sufficient detail should be available to prepare a preliminary cost estimate if needed. It is recommended that the conceptual system design and preliminary layout be submitted to the regulatory agency for conditional acceptance of the chosen system. Final design can proceed upon acceptance by the owner and regulatory agency.

Table 5-8. Example of a total cost summary worksheet to compare alternatives[a].

System	Total materials & installation	Present value of total O&M cost	Total cost over life of system	Amortized monthly materials & installation costs	Avg monthly present value of O&M costs	Avg monthly cost over life of system
Septic tank & gravity distribution	$2,504	$6,845	$9,349	$20	$19	$39
Septic tank & gravity distribution with chambers	$3,336	$7,032	$10,368	$27	$20	$46
Septic tank & gravity distribution with styrene foam	$2,846	$6,920	$9,767	$23	$19	$42
Septic tank & gravity distribution with large diameter pipes	$3,816	$7,156	$10,971	$31	$20	$51
Septic tank & gravity distribution with pressure manifold	$4,774	$7,707	$12,482	$38	$21	$60
Septic tank & gravity distribution with pressure manifold and chambers	$5,593	$7,889	$13,482	$45	$22	$67
Septic tank & gravity distribution with pressure manifold and styrene foam	$5,103	$7,777	$12,881	$41	$22	$63
Septic tank & gravity distribution with pressure manifold large diameter pipes	$6,073	$8,013	$14,085	$49	$22	$71
			$15,356			
Septic tank & gravity distribution with sand filter pretreatment	$7,296	$12,069	$19,364	$59	$34	$92
Septic tank & gravity distribution with peat filter pretreatment	$11,808	$12,604	$24,412	$95	$35	$150
Septic tank & gravity distribution with recirculating sand filter pretreatment	$6,226	$12,059	$18,285	$50	$33	$84
Septic tank & LPP distribution	$4,523	$12,319	$16,843	$36	$34	$71
Septic tank & LPP distribution with sand filter pretreatment	$10,223	$13,338	$23,561	$82	$37	$119
Septic tank & LPP distribution with recirculating sand filter pretreatment	$8,232	$13,007	$21,239	$66	$36	$102
Septic tank & drip distribution	$11,163	$13,082	$24,245	$90	$36	$126
Septic tank & drip distribution with sand filter pretreatment	$15,994	$14,101	$30,095	$129	$39	$168
Septic tank & drip distribution with recirculating sand filter pretreatment	$14,872	$14,094	$28,966	$120	$39	$159
Septic tank & drip distribution with sand filter pretreatment & chlorine disinfection	$16,408	$21,244	$37,652	$132	$59	$191
Septic tank & drip distrib. with recirc. sand filter pretreatment & chlorine disinfection	$15,285	$21,237	$36,522	$123	$59	$182
Septic tank & drip distribution with sand filter pretreatment & UV disinfection	$17,867	$21,655	$39,522	$144	$60	$204
Septic tank & drip distribution with recirc. sand filter pretreatment & UV disinfection	$16,744	$21,757	$38,501	$135	$60	$195
Septic tank & spray irrigation with sand filter pretreatment and chlorine disinfection	$11,890	$20,670	$32,580	$96	$57	$153
Septic tank & spray irrigation with recirc. sand filter pretreatment and chlorination	$10,768	$20,663	$31,431	$87	$57	$144
Septic tank & spray irrigation with sand filter pretreatment and UV	$13,349	$21,190	$34,539	$107	$59	$166
Septic tank & spray irrigation with recirculating sand filter pretreatment and UV	$12,227	$21,183	$33,410	$98	$59	$157
Septic tank and gravity distribution with wetland cell	$5,574	$23,231	$28,805	$45	$65	$109
Aerobic treatment unit and gravity distribution	$8.037	$36,406	$44,443	$65	$101	$166
Denitrification system blackwater & graywater separation and gravity distribution	$9,963	$13,508	$23,471	$80	$38	$118
Denitrification system blackwater & graywater separation and LPP distribution	$12,565	$15,070	$27,635	$101	$42	$143
Septic tank & gravity distribution with 18 inch fill mound	$4,507	$6,850	$11,357	$36	$19	$55
Septic tank & gravity distribution with 18 inch fill mound and chambers	$5,326	$7,032	$12,357	$43	$20	$62
Septic tank & LPP distribution in at-grade system	$4,590	$12,345	$16,935	$37	$34	$71
Septic tank & pressure-dosed sand mound system	$4,863	$12,407	$17,269	$39	$34	$74

Source: Hoover, 1997.

[a] Costs displayed are not typical for all states. Costs in other states are significantly higher.

Table 5-9. Common onsite wastewater treatment system failures

Type of failure	Evidence of failure
Hydraulic failure	Untreated or partially treated sewage pooling on ground surfaces, sewage backup in plumbing fixtures, sewage breakouts on hill slopes
Pollutant contamination of ground water	High nitrate levels in drinking water wells; taste or odor problems (e.g., sulfur, household cleaners) in well water caused by untreated, poorly treated, or partially treated wastewater; presence of toxics (e.g., solvents, cleaners) in well water
Microbial contamination of ground and surface water	Shellfish bed bacterial contamination, recreational beach closures due high bacterial levels, contamination of drinking water wells with fecal bacteria or other fecal indicators
Nutrient contamination of surface water	Algae blooms, high aquatic plant productivity, low dissolved oxygen concentrations

5.8 Rehabilitating and upgrading existing systems

Onsite wastewater treatment systems can fail to meet the established performance requirements. When this occurs, corrective actions are necessary. Successful rehabilitation requires knowledge of the performance requirements, a sound diagnostic procedure, and appropriate selection of corrective actions.

5.8.1 Defining system failure

Failure occurs when performance requirements are not met (see table 5-9). Under traditional prescriptive rules, onsite wastewater systems must comply with specific siting and design requirements, maintain the discharged wastewater below ground surface, and not cause backup in fixtures. Typically, failures are declared when wastewater is observed on the ground surface or is backing up in the household plumbing. However, systems also may be declared as failed if they do not comply with the prescriptive design rules. Thus, except for hydraulic failures, systems can be declared failed based on their design, but rarely based on treatment performance to date.

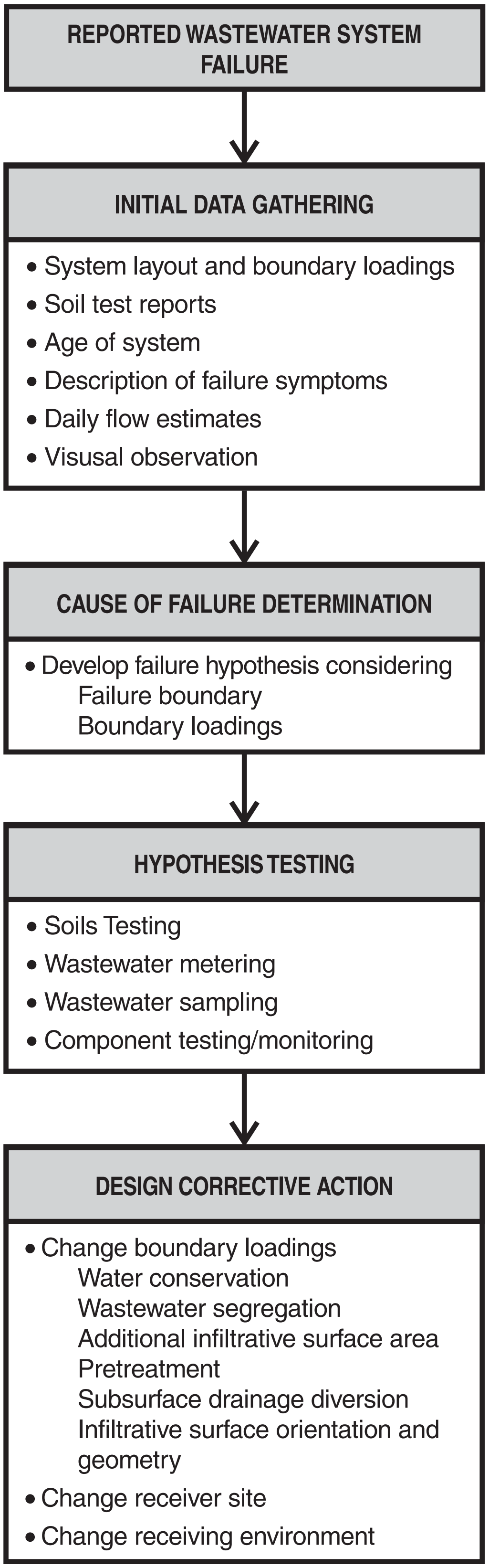
When failure is strictly a code compliance issue rather than a performance issue, enforcing corrective actions can be problematic because corrective actions for code-based compliance might not reduce (and might even elevate) the potential risk to human health or the environment. Also, code compliance failures can be much more difficult to correct because site or wastewater characteristics might prevent compliance with the prescriptive requirements. In such instances, variances to the rule requirements are needed to remove the noncompliant condition. Performance codes, on the other hand, define failures based on performance requirements consisting of specific and measurable criteria. Usually, treatment options are feasible to achieve compliance, though costs can be a significant impediment.

5.8.2 Failure diagnosis

Wastewater system failures occur at the design boundaries when the acceptable boundary loadings are exceeded. Prescribing an effective corrective measure requires that the failure boundary and the unsuitable boundary loading be correctly identified.

The manifestations of boundary failures can be similar in appearance despite different locations or causes of failure. For example, the primary infiltrative surface might fail to accept the daily wastewater load, causing the discharged wastewater to seep onto the ground surface. The cause of failure might be that the daily hydraulic capacity of the infiltrative surface was exceeded, the instantaneous hydraulic loading (dose volume) was too great, or the organic load was too high. In other instances, the linear loading on a site might be exceeded, causing a saturated zone above a secondary restrictive horizon to rise and encroach on the infiltrative surface (effluent mounding). The potential gradient across this surface is reduced in this situation, and the reaeration of the subsoil is inhibited. As a result of the reduced gradient and increased clogging, the infiltrative surface can no longer accept the daily loading and allows wastewater to back up in the trenches and possibly to surface. Though the causes of failure in these two instances are different, the symptoms are similar. Thus, it is important that a systematic approach to failure diagnosis be used. Failures occur for a reason. The reason for failure should be determined before corrective actions are implemented; if not, failures can recur. The diagnostic procedure should be comprehensive, but based on deductive reasoning to avoid excessive testing and data gathering (figure 5-13). Another example of a failure diagnosis, *Failure Analysis Chart for Troubleshooting Septic Systems* (FACTS) is provided in Adams et al., 1998.

Figure 5-13. Onsite wastewater failure diagnosis and correction procedure



In addition to specific design boundary failures, failures can be caused by system age. Tanks and pipes buried in the ground begin to deteriorate after 20 or more years of use and may require repair or replacement. In addition, the treatment capabilities of soils below infiltration fields that have been in use for several decades might not be adequate for continued use. Years of treatment use can cause the interstitial spaces between soil particles to become filled with contaminants (e.g., TSS, precipitates, biomass). Soil structure can also be affected after many years of use. Finally, changes in design and construction practices in the past 25 years have led to marked improvements in system performance and treatment capacity. These issues make consideration of system age a vital component of the overall failure investigation.

5.8.3 Initial data gathering

When a failure is reported, relevant information regarding the system should be gathered.

- *Visual observation.* A visual observation of the failure should be made to confirm the information provided. Also, the owner should be interviewed regarding the owner's observations, use of the building, and other relevant information. Each of the system components should be inspected and mechanical components (e.g., float switches, flow diverters) tested.

- *Past operation and maintenance practices.* Assessing operation and maintenance actions taken over the past 3 to 5 years can often aid in detecting relatively simple problems. Perhaps the tank has not been pumped, the tank filter (if used) has not been cleaned, the electrical supply to the pumps has not been checked, or the switches have not been examined.

- *System layout and boundary design loadings.* The system layout can be obtained from the design drawings or from a site survey. From the layout, the design boundary loadings should be determined or estimated based on the original design flow.
- *Soil test reports.* Soil test reports should be obtained. If none are available, soil auger testing between the trenches or just outside the SWIS perimeter might be necessary to provide a simple description of the soil profile to determine whether any significant secondary design boundaries might be present.
- *Age of system.* If the system age is less than 2 years, it is likely the design boundary loadings were in error or improper construction techniques (e.g., operation of heavy equipment on SWIS area, installation during wet conditions) that significantly altered the soil characteristics were used. If the age of the system is greater than 2 years, it is likely that the design conditions changed. Changed conditions could include changes in the building's use, increased wastewater flows, infiltration and inflow into the system, surface runoff over the system, improper maintenance, compaction of SWIS soils by vehicle traffic, and others.
- *Description of failure symptoms.* The symptoms of failure are important. Historically, reported failures have usually been hydraulic in nature and tended to be manifested by surface seepage. Information on the location and frequency of the surface seepage helps to determine the specific design boundary at which the failure occurred and possible causes of the failure. For example, surface seepage above the infiltration system suggests that the infiltrative surface is overloaded, either hydraulically or organically. Seepage downslope from the system suggests that a secondary design boundary exists and is overloaded hydraulically. If the failure is seasonal, wet weather conditions are likely to be the cause; that is, clear water is infiltrating into the system or causing inadequate subsurface drainage.
- *Daily flow estimates.* Estimates of daily wastewater flows derived from water meter data or other sources are needed to compare the design loadings with actual loadings. In the absence of data, water use should be estimated (see chapter 3) with the caveat that such estimates are seldom accurate. Where practical, water meters should be read or installed as soon as the failure is reported so that metered data can be collected. Initially, daily flow estimates might need to suffice for the purposes of failure analysis. Leaking plumbing fixtures, such as improperly seated toilet tank flapper valves, should be investigated.

5.8.4 Determining the cause of failure

From the gathered data, hypotheses of potential causes of failure should be formulated. Formulating hypotheses is an important step in diagnosing the problem because the hypotheses can be tested to provide a systematic and efficient analysis of possible causes of failure (see case study). Testing can take many forms (see table 5-10 as an example of a local approach) depending on the hypotheses to be tested. It may include soil profile descriptions, soil hydraulic conductivity testing, wastewater characterization, equipment testing and monitoring, and other tests.

5.8.5 Designing corrective actions

If the design boundary failure can be identified and its cause identified, selecting an appropriate corrective action is straightforward. Table 5-11 can be used to select the appropriate corrective action for a given boundary failure. This table presents classes of corrective actions and the impacts they can be expected to have on boundary mass loadings. Several options typically exist for each class of corrective action. Specific actions will be determined by the particular needs of the system and site.

The failure diagnosis and correction procedure outlined in figure 5-13 provides a summary of activities required to identify and characterize the cause of failure. As noted in the previous discussion, data collection, failure cause determination, and testing of hypotheses (e.g., as in the case study above) provides key information needed to develop corrective actions. Failures at design boundaries (e.g., exceeding mass pollutant or hydraulic load limits) can be rectified by changing boundary

Table 5-10. General OWTS inspection and failure detection process[a]

Inspection process steps	Field procedures
Notification of inspection	✓ Owner is sent a notice of inspection 1 month before inspection date indicating time and date of inspection (waived for failure investigations) ✓ Information and requirements concerning provision of access to system are included with notice
File review	✓ Review system design features ✓ Review prior inspection reports ✓ Review other relevant file information ✓ Note unusual circumstances on inspection form
General site review	✓ Walk property to confirm location of tank, SWIS, other system features, water resources, wells (if present), drainage patterns (relative to SWIS) ✓ Check tank and SWIS area for effluent surfacing, odors, graywater bypass, selective fertility, unusual conditions ✓ Check diversion valves (if present); confirm location of operating SWIS (if more than one)
Inspection of septic tank and appurtenances	✓ Open tank; examine for structural problems (cracking, settling, decay) ✓ Check inlet and outlet ports for positioning, scum accumulation, rocks, root matter, obstructions ✓ Check liquid level in tank; measure scum/sludge levels ✓ Inspect risers (if present) for structural integrity and watertightness ✓ Check pump basins for structural integrity ✓ Check pumps and switches (if present); operate float switches to confirm operation
SWIS inspection	✓ Visually inspect SWIS for signs of wetness, odor, effluent pooling, selective fertility, presence of shrubs or trees, settling, signs of vehicles driving over SWIS, new structures (driveways, outbuildings) encroaching on SWIS, runoff across SWIS surface ✓ Conduct hydraulic load test to assess SWIS operation (see table 5-11)

[a] Inspection program requirements of The Sea Ranch in California. See table 5-11.

Source: Adapted from Hantzsche, 1995.

Table 5-11. Response of corrective actions on SWIS boundary mass loadings.

CORRECTIVE ACTION	BOUNDARY LOADINGS							
	INFILTRATION BOUNDARY			SECONDARY BOUNDARY		WATER TABLE BOUNDARY		
	Daily hydraulic (gal/d-ft²)	Instantaneous hydraulic (gal/dose-ft²)	Organic (lb cBOD/ft²)	Daily hydraulic (gal/d-ft²)	Linar hydraulic (gal/d-ft)	Daily hydraulic (gal/d-ft²)	Linear hydraulic (gal/d-ft)	Constituent (lb xyz/ft²)
Water conservation	↓	*No Impact*	*No Impact*	↓	↓	↓	↓	*No Impact*
Wastewater segregation	↓	*No Impact*	↓	↓	↓	↓	↓	↓
Elimination of I/I	↓	*No Impact*	*No Impact*	↓	↓	↓	↓	*No Impact*
Surface drainage diversion	*No Impact*	*No Impact*	*No Impact*	↓	↓	↓	↓	*No Impact*
Subsurface drainage diversion	*No Impact*	*No Impact*	*No Impact*	↓	↓	↓	↓	*No Impact*
Timed dosing	*No Impact*	↓	*No Impact*	*No Impact*	*No Impact*	*No Impact*	*No Impact*	*No Impact*
Additional infiltration area; resting existing SWIS	↓	↓	↓	↓	↓	↓	↓	↓
Pretreatment	*No Impact*	*No Impact*	↓	*No Impact*	*No Impact*	*No Impact*	*No Impact*	↓
Infiltration surface orientation and geometry	*No Impact*	*No Impact*	*No Impact*	↓	↓	↓	↓	*No Impact*

Notes: Assumes uniform application of wastewater over the infiltrative surfaces for the action to have a significant impact.
↓ indicates reduced loading rate.

Source: Otis, 2001.

Failure hypothesis testing at a system serving a highway rest area

A wastewater system serving a highway rest area used a drip distribution system for final treatment and dispersal of the wastewater. After the first summer of use, water was observed above the dispersal system. The original soil test results indicated that the soils were deep, loamy sands with no apparent secondary boundaries. The system design appeared to use appropriate loadings on the infiltrative surfaces.

A visual inspection and interviews with the maintenance staff at the rest area provided important clues:

- ✔ The site of the dispersal system had been significantly regraded after the soil testing had been completed. Up to 5 feet of material had been removed from the site.
- ✔ The system was a replacement for another system that had also failed. The existing septic tanks were used in the new system.
- ✔ Water use was metered and recorded daily.
- ✔ The rest area had a sanitary dump station that discharged into the wastewater system. The dump station received very heavy use on weekends during the summer. This load was not accounted for in the metering data.

From these clues, several hypotheses were formulated for testing.

a. *Water discharges to the system exceed the hydraulic and constituent design loadings.*

This hypothesis can be tested by estimating daily wastewater discharges. The recorded water meter data provide an accurate estimate of water use at the rest area. The metered data would need to be corrected for turf irrigation at the rest area. Turf irrigation can be estimated from staff interviews of irrigation schedules. Unaccounted water from the sanitary dump station must be estimated. Counting the number of vehicles using the dump station and assuming an average volume of wastewater discharged per vehicle would provide a reasonable estimate. Because of the strength of the dump station wastewater, wastewater samples at the septic tank outlets should be taken to determine organic loadings.

Another issue that might need to be considered is load inputs from disinfectants or other chemicals used in holding tanks that are discharged into the dump station. Significant concentrations of these chemicals could affect biological processes in the tank and infiltrative zone.

b. *Infiltration/inflow of clear water into the system or into the SWIS is excessive.*

Only the septic tanks were left in place during the reconstruction of the existing system. All new components were leak tested during construction. It can be assumed that the new portion of the system does not leak if inspection records exist and can be verified. The existing septic tanks could be expected to be the source of any inflow or infiltration. Infiltration of surface runoff from the area over the septic tanks, revealed by the existence of saturated soils around the tanks, could result in significant infloinfiltration contributions. If there is evidence that such conditions exist, the septic tanks should be pumped and tested for leakage. Runoff of storm water onto the SWIS surface could also cause ponding and might require regrading of the surrounding site or a diversion to route runoff elsewhere

c. *The actual soil characteristics at the receiver site are different from the soil test results.*

The characteristics of the soils after regrading might be different from those reported by the original soil tests because of the depth of soil removed. Also, the regrading operations might have compacted the subsoil, creating a secondary design boundary that was not anticipated. Soil tests could be performed to determine if the existing profile below the dispersal system is different in texture, structure, and bulk density from that reported earlier. Also, the source of the surface seepage should be investigated. If the seepage occurs immediately above a dripperline but the soil is not saturated between the lines, the infiltrative surface surrounding the dripperline is hydraulically or organically overloaded. If the soil between the lines is saturated, a secondary boundary that is hydraulically overloaded probably exists. If such a boundary is present, the soil below the boundary would be unsaturated.

By developing these hypotheses, determination of the failure can be systematic and efficient. The most probable hypothesis can be tested first, or appropriate tests for all the hypotheses formulated can be performed at one time for later evaluation.

Source: Otis, 2001.

loadings to accommodate the hydraulic or mass pollutant assimilative capacities at the design boundary. Loading adjustments may require lowering water usage through water conservation measures, eliminating clear water inputs, or separating graywater; increasing the area of the infiltrative surface; or diverting precipitation and/or shallow ground water from the SWIS with berms or curtain drains.

Approaches for lowering mass pollutant loads include improving pretreatment by upgrading the existing system and/or adding treatment units, improving user habits (e.g., removing food, kitchen, or dishwashing wastes from the wastewater stream), reducing or eliminating inputs of cleaners or other strong chemical products, and reducing solid waste in the wastewater stream (e.g., ground garbage from garbage disposals). If measures to correct failures within the existing receiver site are not possible, corrective actions may involve changing the receiver site or changing the receiver site conditions. These options include adoption of different treatment technologies, physical alteration of the receiver site, and installation of a new infiltration system, thereby resting the existing system for future alternate dosing.

Attention to established performance requirements and the design boundaries where they are measured helps to ensure that corrective actions meet the overall goals of the management entity and protect human health and the environment. Implementation of corrective actions should follow the same processes and procedures outlined in the preceding sections for new or replacement OWTSs.

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