If the saturated hydraulic conductivity is low and the drainable porosity (the percentage of pore space drained when the soil is at field capacity) is small, even effectively designed curtain drains might have limited effect on soil wetness conditions. Penninger et al. (1998) illustrated this at a site with a silty clay loam soil at field capacity that became completely re-saturated with as little as 1-inch of precipitation. Figure 4-6 provides a useful design chart that considers most of these parameters. For further design guidance, refer to the U.S. Department of Agriculture's *Drainage of Agricultural Land* (USDA, 1973).

4.4.5 Sizing of the infiltration surface

The minimum acceptable infiltration surface area is a function of the maximum anticipated daily wastewater volume to be applied and the maximum instantaneous and daily mass loading limitations of the infiltration surface (see chapter 5). Both the bottom and sidewall area of the SWIS excavation can be infiltration surfaces; however, if the sidewall is to be an active infiltration surface, the bottom surface must pond. If continuous ponding of the infiltration surface persists, the infiltration zone will become anaerobic, resulting in loss of hydraulic capacity. Loss of the bottom surface for infiltration will cause the ponding depth to increase over time as the sidewall also clogs (Bouma, 1975; Keys et al., 1998; Otis, 1977). If allowed to continue, hydraulic failure of the system is probable. Therefore, including sidewall area as an active infiltration surface in design should be avoided. If sidewall areas are included, provisions should be made in the design to enable removal of the ponded system from service periodically to allow the system to drain and the biomat to oxidize naturally.

Design flow

An accurate estimation of the design flow is critical to infiltration surface sizing. For existing buildings where significant changes in use are not expected, water service metering will provide good estimates for design. It is best to obtain several weeks of metered daily flows to estimate daily average and peak flows. For new construction, water use metering is not possible and thus waste flow projections must be made based on similar establishments. Tables of "typical" water use or wastewater flows for different water use fixtures, usage patterns, and building uses are available (see section 3.3.1). Incorporated into these guidelines are varying factors of safety. As a result, the use of these guides typically provides conservatively high estimates of maximum peak flows that may occur only occasionally. It is critical that the designer recognizes the conservativeness of these guides and how they can be appropriately adjusted because of their impacts on the design and, ultimately, performance of the system.

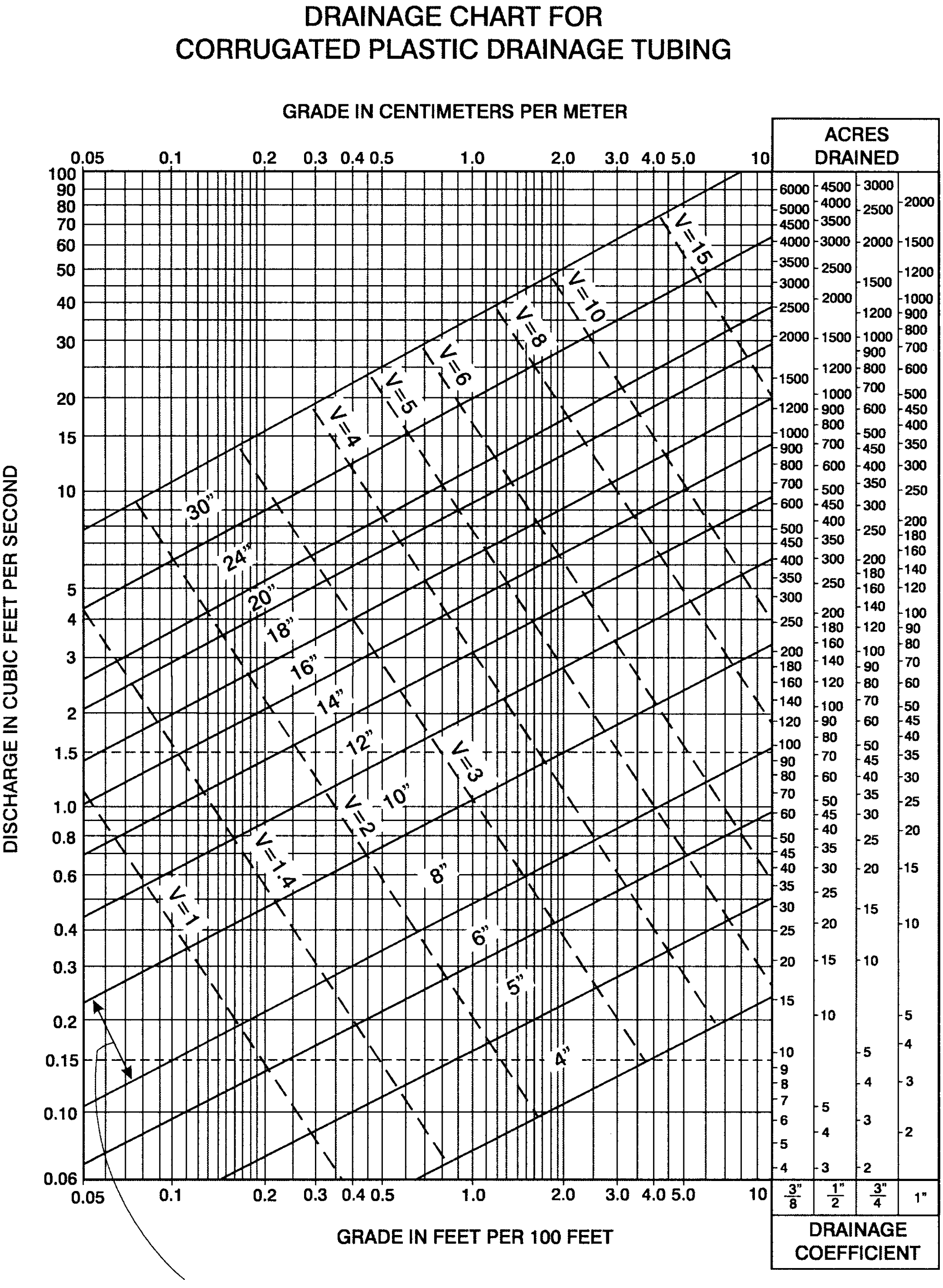
Curtain drain design

Curtain drain design (see preceding figures) is dependent on the size of the contributing drainage area, the amount of water that must be removed, the soil's hydraulic properties, and the available slope of the site.

The contributing drainage area is estimated by outlining the capture zone on a topographic map of the site. Drainage boundaries are determined by extending flow lines perpendicular to the topographic contours upslope from the drain to natural divides (e.g., ridge tops) or natural or man-made "no-flow" boundaries (e.g., rock outcrops, major roads). The amount of water that must be removed is an estimate of the volume of precipitation that would be absorbed by the soil after a rainfall event. This is called the *drainage coefficient*, which is expressed as the depth of water to be removed over a specified period of time, typically 24 hours. Soil structure, texture, bulk density, slope, and vegetated cover all affect the volume of water to be drained.

The slope of the drain can be determined after the upslope depth of the drain invert and the outfall invert are established. These can be estimated from the topographic map of the site. The contributing drainage area, water volume to be removed, and slope of the drain are estimated. Figure 4-6 can be used to determine the drain diameter. For example, the diameter of a curtain drain that will drain an area upslope of 50 acres with a drainage coefficient of ¾ inch on a slope of 5 percent would be 8 inches (see figure). At 0.5 percent, the necessary drain diameter would be 12 inches.

Figure 4-6. Capacity chart for subsurface drains



Space between lines is the range of drain capacity for the size shown between lines

V= velocity in feet per second
n=0.015

Source: USDA, 1973.

Infiltration surface loading limitations

Infiltration surface hydraulic loading design rates are a function of soil morphology, wastewater strength, and SWIS design configuration. Hydraulic loadings are traditionally used to size infiltration surfaces for domestic septic tank effluent. In the past, soil percolation tests determined acceptable hydraulic loading rates. Codes provided tables that correlated percolation test results to the necessary infiltration surface areas for different classes of soils. Most states have supplemented this approach with soil morphologic descriptions. Morphologic features of the soil, particularly structure, texture, and consistence, are better predictors of the soil's hydraulic capacity than percolation tests (Brown et al., 1994; Gross et al., 1998; Kleiss and Hoover, 1986; Simon and Reneau, 1987; Tyler et al., 1991; Tyler and Converse, 1994). Although soil texture analysis supplemented the percolation test in most states by the mid-1990s, soil structure has only recently been included in infiltrative surface sizing tables (table 4-3). Consistence, a measure of how well soils form shapes and stick to other objects, is an important consideration for many slowly permeable soil horizons. Expansive clay soils that become extremely firm when moist and very sticky or plastic when wet (exhibiting firm or extremely firm consistence) are not well suited for SWISs.

Not all soil conditions are represented in table 4-3, which is a generic guide to the effects of soil properties on the performance of SWISs. Also

Table 4-3. Suggested hydraulic and organic loading rates for sizing infiltration surfaces

Texture	Structure		Hydraulic loading (gal/ft^2-day)		Organic loading (lb BOD/1000ft^2-day)	
	Shape	Grade	BOD=150	BOD=30	BOD=150	BOD=30
Coarse sand, sand, loamy coarse sand, loamy sand	Single grain	Structureless	0.8	1.6	1.00	0.40
Fine sand, very fine sand, loamy fine sand, loamy very fine sand	Single grain	Structureless	0.4	1.0	0.50	0.25
Coarse sandy loam, sandy loam	Massive	Structureless	0.2	0.6	0.25	0.15
	Platy	Weak	0.2	0.5	0.25	0.13
		Moderate, strong				
	Prismatic, blocky, granular	Weak	0.4	0.7	0.50	0.18
		Moderate, strong	0.6	1.0	0.75	0.25
Fine sandy loam, very fine sandy loam	Massive	Structureless	0.2	0.5	0.25	0.13
	Platy	Weak, mod., strong				
	Prismatic, blocky, granular	Weak	0.2	0.6	0.25	0.15
		Moderate, strong	0.4	0.8	0.50	0.20
Loam	Massive	Structureless	0.2	0.5	0.25	0.13
	Platy	Weak, mod., strong				
	Prismatic, blocky, granular	Weak	0.4	0.6	0.50	0.15
		Moderate, strong	0.6	0.8	0.75	0.20
Silt loam	Massive	Structureless		0.2	0.00	0.05
	Platy	Weak, mod., strong				
	Prismatic, blocky, granular	Weak	0.4	0.6	0.50	0.15
		Moderate, strong	0.6	0.8	0.75	0.20
Sandy clay loam, clay loam, silty clay loam	Massive	Structureless				
	Platy	Weak, mod., strong				
	Prismatic, blocky, granular	Weak	0.2	0.3	0.25	0.08
		Moderate, strong	0.4	0.6	0.50	0.15
Sandy clay, clay, silty clay	Massive	Structureless				
	Platy	Weak, mod., strong				
	Prismatic, blocky, granular	Weak				
		Moderate, strong	0.2	0.3	0.25	0.08

Source: Adapted from Tyler, 2000.

available are many other state and local guides that include loadings for soils specific to local geomorphology. North Carolina, for example, uses the *long-term acceptance rate* (LTAR) for soil loadings, which is the volume of wastewater that can be applied to a square foot of soil each day over an indefinite period of time such that the effluent from the onsite system is absorbed and properly treated (North Carolina DEHNR, 1996). In the North Carolina rules, LTAR and loading rate values are the same.

Increasingly, organic loading is being used to size infiltration surfaces. Based on current understanding of the mechanisms of SWIS operation, organic loadings and the reaeration potential of the subsoil to meet the applied oxygen demand are critical considerations in successful SWIS design. Anaerobic conditions are created when the applied oxygen demand exceeds what the soil is able to supply by diffusion through the vadose zone (Otis, 1985, 1997; Siegrist et al., 1986). The facultative and anaerobic microorganisms that are able to thrive in this environment are less efficient in degrading the waste materials. The accumulating waste materials and the metabolic by-products cause soil clogging and loss of infiltrative capacity.

Further, higher forms of soil fauna that would help break up the biomat (e.g., worms, insects, nonwetland plants) and would be attracted to the carbon and nutrient-rich infiltration zone are repelled by the anoxic or anaerobic environment. If wastewater application continues without ample time to satisfy the oxygen demand, hydraulic failure due to soil clogging occurs. Numerous studies have shown that wastewaters with low BOD concentrations (e.g., < 50 mg/L) can be applied to soils at rates 2 to 16 times the typical hydraulic loading rate for domestic septic tank effluent (Jones and Taylor, 1965; Laak, 1970, 1986; Louden et al., 1998; Otis, 1985; Siegrist and Boyle, 1987; Tyler and Converse, 1994).

The comparatively higher hydraulic loadings that highly treated wastewater (highly treated in terms of TSS, ammonium-nitrogen, and BOD) may permit should be considered carefully because the resulting rapid flow through the soil may allow deep penetration of pathogens (Converse and Tyler, 1998a, 1998b; Siegrist et al., 2000; Siegrist and Van Cuyk, 2001b; Tyler and Converse, 1994). The trench length perpendicular to ground water movement (footprint) should remain the same to minimize system impacts on the aquifer.

Unfortunately, well-tested organic loading rates for various classes of soils and SWIS design configurations have not been developed. Most organic loading rates have been derived directly from the hydraulic loadings typically used in SWIS design by assuming a BOD_5 concentration (see box and table 4-3). The derived organic loading rates also incorporate the implicit factor of safety found in the hydraulic loading rates. Organic loadings do appear to have less impact on slowly permeable soils because the resistance of the biomat that forms at the infiltrative surface presents less resistance to infiltration of the wastewater than the soil itself (Bouma, 1975). For a further discussion of SWIS performance under various environmental conditions, see Siegrist and Van Cuyk, 2001b.

Constituent mass loadings

Constituent mass loadings may be a concern with respect to water quality. For example, to use the soil's capacity to adsorb and retain phosphorus when systems are located near sensitive surface waters, a phosphorus loading rate based on the soil adsorption capacity might be selected as the controlling rate of wastewater application to the infiltration surface to maximize phosphorus removal. Placement of the effluent distribution piping high in the soil profile can promote greater phosphorus removal because the permeability of medium- and fine-textured soils tends to decrease with depth and because the translocation of aluminum and iron—which react with phosphorus to form insoluble compounds retained in the soil matrix—occurs in some sandy soils, with the maximum accumulation usually above 45 cm (Mokma et al., 2001). Many lakes are surrounded by sandy soils with a low phosphorus adsorption capacity. If effluent distribution systems are installed below 45 cm in these sandy soils, less phosphorus will be removed from the percolating effluent. In the case of a soluble constituent of concern such as nitrate-nitrogen, a designer might decide to reduce the mass of nitrate per unit of application area. This would have the effect of increasing the size of the SWIS footprint, thereby reducing the potential concentration of nitrate in the ground water immediately surrounding the SWIS (Otis, 2001).

Factors of safety in infiltration surface sizing

Sizing of onsite wastewater systems for single-family homes is typically based on the estimated peak daily flow and the "long term acceptance rate" of the soil for septic tank effluent. In most states, the design flow is based on the number of bedrooms in the house. A daily flow of 150 gallons is commonly assumed for each bedroom. This daily flow per bedroom assumes two people per bedroom that generate 75 gpd each. Bedrooms, rather than current occupancy, are used for the basis of SWIS design because the number of occupants in the house can change.

Using this typical estimating procedure, a three-bedroom home would have a design flow of 150 gpd/bedroom x 3 bedrooms or 450 gpd. However, the actual daily average flow could be much less. Based on the 1990 census, the average home is occupied by 2.8 persons. Each person in the United States generates 45 to 70 gpd of domestic wastewater. Assuming these averages, the average daily flow would be 125 to 195 gpd or 28 to 44 percent of the design flow, respectively. Therefore, the design flow includes an implicit factor of safety of 2.3 to 3.6. Of course, this factor of safety varies inversely with the home occupancy and water use.

Unfortunately, the factors of safety implicitly built into the flow estimates are seldom recognized. This is particularly true in the case of the design hydraulic loading rates, which were derived from existing SWISs. In most codes, the hydraulic loading rates for sand are about 1.0 to 1.25 gpd/ft^2. Because these hydraulic loading rates assume daily flows of 150 gpd per bedroom, they are overestimated by a factor of 2.3 to 3.6. Fortunately, these two assumptions largely cancel each other out in residential applications, but the suggested hydraulic loading rates often are used to size commercial systems and systems for schools and similar facilities, where the ratios between design flows and actual daily flows are closer to 1.0. This situation, combined with a lack of useful information on allowable organic loading rates, has resulted in failures, particularly for larger systems where actual flow approximates design.

4.4.6 Geometry, orientation, and configuration of the infiltration surface

The geometry, orientation, and configuration of the infiltration surface are critical design factors that affect the performance of SWISs. They are important for promoting subsoil aeration, maintaining an acceptable separation distance from a saturated zone or restrictive horizon, and facilitating construction. Table 4-4 lists the design considerations discussed in this section.

Geometry

The width and length of the infiltration surface are important design considerations to improve performance and limit impacts on the receiving environment. Trenches, beds, and seepage pits (or dry wells) are traditionally used geometries. Seepage pits can be effective for wastewater dispersal, but they provide little treatment because they extend deep into the soil profile, where oxygen transfer and treatment are limited and the separation distance to ground water is reduced. They are not recommended for onsite wastewater treatment and are not included as an option in this manual.

Width

Infiltration surface clogging and the resulting loss of infiltrative capacity are less where the infiltration surface is narrow. This appears to occur because reaeration of the soil below a narrow infiltration surface is more rapid. The dominant pathway for oxygen transport to the subsoil appears to be diffusion through the soil surrounding the infiltration surface (figure 4-7). The unsaturated zone below a wide surface quickly becomes anaerobic because the rates of oxygen diffusion are too low to meet the oxygen demands of biota and organics on the infiltration surface. (Otis, 1985; Siegrist et al., 1986). Therefore, trenches perform better than beds. Typical trench widths range from 1 to 4 feet. Narrower trenches are preferred, but soil conditions and construction techniques might limit how narrow a trench can be constructed. On sloping sites, narrow trenches are a necessity because in keeping the infiltration surface level, the uphill side of the trench bottom might be excavated into a less suitable soil horizon. Wider trench infiltration surfaces have been successful in at-grade systems and mounds probably because the engineered fill material and elevation above the natural grade promote better reaeration of the fill.

Comparing hydraulic and organic mass loadings for a restaurant wastewater

Infiltration surface sizing traditionally has been based on the daily hydraulic load determined through experience to be acceptable for the soil characteristics. This approach to sizing fails to account for changes in applied wastewater strength. Since soil clogging has been shown to be dependent on applied wastewater strength, it might be more appropriate to size infiltration surfaces based on organic mass loadings.

To illustrate the impact of the different sizing methods, sizing computations for a restaurant are compared. A septic tank is used for pretreatment prior to application to the SWIS. The SWIS is to be constructed in a sandy loam with a moderate, subangular blocky structure. The suggested hydraulic loading rate for domestic septic tank effluent on this soil is 0.6 gpd/ft^2 (table 4-3). The restaurant septic tank effluent has the following characteristics:

BOD_5	800 mg/L
TSS	200 mg/L
Average daily flow	600 gpd

Infiltration area based on hydraulic loading:

$$\text{Area} = 600\ \text{gpd}/0.6\ \text{gpd/ft}^2 = 1{,}000\ \text{ft}^2$$

Infiltration area based on organic loading:

At the design infiltration rate of 0.6 gpd/ft^2 recommended for domestic septic tank effluent, the equivalent organic loading is (assuming a septic tank BOD_5 effluent concentration of 150 mg/L)

$$\text{Organic Loading} = 150\ \text{mg/L} \times 0.6\ \text{gpd/ft}^2 \times (8.34\ \text{lb/mg/L} \times 10^{-6}\ \text{gal})$$
$$= 7.5 \times 10^{-4}\ \text{lb}\ BOD_5/\text{ft}^2\text{-d}$$

Assuming 7.5×10^{-4} lb BOD_5/ft^2-d as the design organic loading rate,

$$\text{Area} = \frac{(800\ \text{mg-}BOD_5/\text{L} \times 600\ \text{gpd} \times 8.34\ \text{lbs/mg/L} \times 10^{-6}\ \text{gal})}{(7.5 \times 10^{-4}\ \text{lb}\ BOD_5/\text{ft}^2\text{-d})}$$
$$= \frac{4.0\ \text{lb}\ BOD_5/\text{d}}{(7.5 \times 10^{-4}\ \text{lb}\ BOD_5/\text{ft}^2\text{-d})} = 5337\ \text{ft}^2\ \text{(a 540\% increase)}$$

Impact of a 40% water use reduction on infiltration area sizing

Based on hydraulic loading,

$$\text{Area} = \frac{(1 - 0.4) \times 600\ \text{gpd}}{0.6\ \text{gpd/ft}^2} = 600\ \text{ft}^2$$

Based on organic loading (note the concentration of BOD_5 increases with water conservation but the mass of BOD_5 discharged does not change),

$$\text{Area} = \frac{(800\ \text{mg-}BOD_5/\text{L} \times 600\ \text{gpd}) \times (8.34\ \text{lb/mg/L} \times 10^{-6}\ \text{gal})}{[(1 - 0.4) \times 600\ \text{gpd}] \times (7.5 \times 10^{-4}\ \text{lb}\ BOD_5/\text{ft}^2\text{-d})}$$
$$= \frac{4.0\ \text{lb}\ BOD_5/\text{d}}{(7.5 \times 10^{-4}\ \text{lb}\ BOD_5/\text{ft}^2\text{-d})} = 5337\ \text{ft}^2\ \text{(an 890\% increase)}$$

However, infiltration bed surface widths of greater than 10 feet are not recommended because oxygen transfer and clogging problems can occur (Converse and Tyler, 2000; Converse et al., 1990).

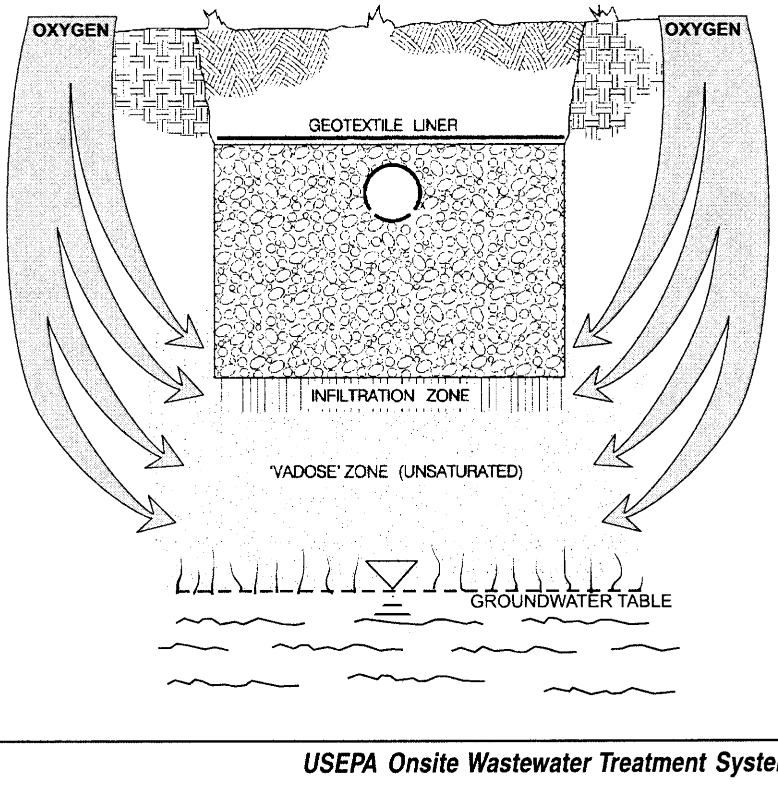
Length

The trench length is important where downslope linear loadings are critical, ground water quality impacts are a concern, or the potential for ground water mounding exists. In many jurisdictions, trench lengths have been limited to 100 feet. This restriction appeared in early codes written for gravity distribution systems and exists as an artifact with little or no practical basis when pressure distribution is used. Trench lengths longer than 100 feet might be necessary to minimize ground water impacts and to permit proper wastewater drainage from the site. Long trenches can be used to reduce the linear loadings on a site by spreading the

Table 4-4. Geometry, orientation, and configuration considerations for SWISs

Design type	Design considerations
Trench	
Geometry	
Width	Preferably less than 3 ft. Design width is affected by distribution method, constructability, and available area.
Length	Restricted by available length parallel to site contour, distribution method, and distribution network design.
Sidewall height	Sidewalls are not considered an active infiltration surface. Minimum height is that needed to encase the distribution piping or to meet peak flow storage requirements.
Orientation/ configuration	Should be constructed parallel to site contours and/or water table or restrictive layer contours. Should not exceed the site's maximum linear hydraulic loading rate per unit of length. Spacing of multiple, parallel trenches is also limited by the construction method and slow dispersion from the trenches.
Bed	
Geometry	
Width	Should be as narrow as possible. Beds wider than 10 to 15 feet should be avoided.
Length	Restricted by available length parallel to site contour, distribution method, and distribution network design.
Sidewall height	Sidewalls are not considered an active infiltration surface. Minimum height is that needed to encase the distribution piping or to meet peak flow storage requirements.
Orientation/ configuration	Should be constructed parallel to site contours and/or water table or restrictive layer contours. The loading over the total projected width should not exceed the estimated downslope maximum linear hydraulic loading.
Seepage pit	Not recommended because of limited treatment capability.

Figure 4-7. Pathway of subsoil reaeration



Source: Ayres Associates, 2000