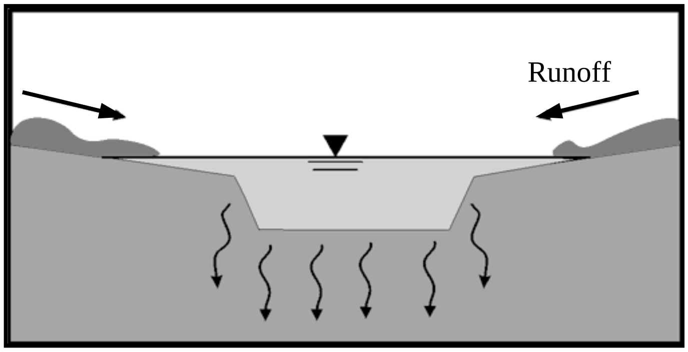
ACTIVITY: Infiltration Systems	ST – 03



CITY OF KNOXVILLE

Targeted Constituents

● Significant Benefit ◗ Partial Benefit ○ Low or Unknown Benefit

● Sediment	◗ Heavy Metals	◗ Floatable Materials	◗ Oxygen Demanding Substances
◗ Nutrients	◗ Toxic Materials	◗ Oil & Grease	○ Bacteria & Viruses
○ Construction Wastes			

Description

This BMP covers various methods, loosely grouped as infiltration systems, in which stormwater runoff is infiltrated into the ground rather than discharged to a surface channel. These systems include infiltration basins, infiltration trenches, drywells and vaults, and porous pavement. Infiltration rates in most of the Knoxville area are typically poor due to clay soils and bedrock. Areas containing karst topography and sinkholes may initially appear to have excellent infiltration, but should be considered as unreliable and will require very careful investigation and analysis.

Suitable Applications

- Infiltration basins and infiltration trenches may be used for stormwater quality and stormwater detention at small project sites only if soil, geologic and groundwater conditions are suitable. Soils must have adequate infiltration rates as measured or tested in the field. No unfavorable geologic conditions shall be present that would indicate sinkholes or underground passageways.
- Drywells and vaults are suitable for draining small impervious surfaces, such as parking lots or residential rooftops, for which the adjacent pervious area has soils with adequate infiltration rates.
- Porous pavements make a generally impervious surface into a semi-pervious surface, and do not usually function as a true infiltration system. There is a basic conflict for non-sandy soils to both support vehicle loads and allow water to infiltrate. Porous pavements should be restricted to light traffic conditions without heavy truck use, such as residential driveways and overflow parking lots.
- Natural sinkholes (or other evidences of karst topography and drainage) are not considered to be infiltration systems for use in treating stormwater quality or in providing stormwater detention. In general, stormwater drainage may continue to flow to a natural sinkhole at a rate that is representative of natural undeveloped conditions. No unusual or unfavorable geologic conditions shall be present near the sinkhole that indicates subsidence, piping, increased limestone dissolution, potential collapse or other safety concerns.

Approach

Infiltration can be a very desirable method of stormwater treatment for land uses which do not heavily pollute stormwater runoff. For instance, established residential areas typically have less pollution than industrial and commercial areas. The primary physical conditions necessary for infiltration are: 1) permeable soils which have not been compacted or graded, and 2) low groundwater tables. Stormwater runoff from parking lots or buildings should be pretreated with a water quality inlet, oil/water separator, grass swale or other type of stormwater treatment BMPs. The measures listed in this BMP can be informally grouped into two categories:

- Larger amounts of stormwater runoff from a project site that are ponded and then forced to infiltrate (infiltration basin, infiltration trench).
- Smaller amounts of stormwater runoff from selected impervious areas that are given an opportunity to infiltrate (drywell, dry vault, porous pavement).

It is very important to protect the natural infiltration rate of suitable soils by only using lightweight equipment and construction procedures that minimize or eliminate compaction. In addition, prevent erosion and sediment transport from occurring upstream of an infiltration basin or other infiltration system. Inspect frequently for clogged soils and for ineffective infiltration rates. Improperly functioning infiltration systems must be replaced by other stormwater treatment BMPs that are capable of providing water quality treatment.

Maintenance can be difficult and costly for infiltration systems, with a potential for high maintenance costs due to clogging. Maintenance costs and site access should be carefully considered prior to design. Pretreatment of stormwater runoff may reduce maintenance costs by capturing coarse sediments and floatable materials in a smaller structure that can be more easily cleaned. All infiltration systems should be inspected several times the first year and at least twice a year thereafter. Maintain records of inspections and maintenance performed.

Overview of Infiltration Theory

The recommended minimum infiltration rate is at least 0.5 inches per hour, but may depend on type of infiltration system and the desired water quality treatment involved. Drawdown should occur within 72 hours using a safety factor of 2.0 to account for wet-weather water table conditions. An infiltration basin or trench must have at least 3 feet separation from seasonal high groundwater and at least 4 feet separation from bedrock. Coarse soils are not as effective in filtering groundwater; therefore provide at least 6 to 8 feet separation from seasonal high groundwater for sand and gravel soils.

The overall degree of water quality treatment achieved by infiltration is a function of the amount of stormwater that is captured and infiltrated over time. Minimum infiltration storage is generally required to be the first flush volume (the first 0.5” of stormwater runoff from the entire contributing area). Consideration may be given to the following formula for 85% volume capture for the average rainfall event volume, with a minimum drain time of 12 hours, if there are extenuating circumstances such as impervious runoff from an adjoining property. Longer drain times require a larger capture volume.

$$V = (B)\ (C)\ (A)\ (P_m / 12)$$

V = stormwater runoff capture volume (acre-feet)

B = regression constant from least-square analysis = 1.312 (for 85% runoff volume capture ratio with a 12-hour drain time)

C = watershed runoff coefficient (dimensionless)

A = watershed area (acres)

P_m = mean storm precipitation volume = 0.53 inches for Knoxville as reported in reference 152

Typical infiltration rates are shown in Table ST-03-1. The USDA soil texture classification is based upon the triangle shown in Figure ST-03-1, with the following definitions:

	Approximate size	Rough description
Gravel	> 2 mm	> No. 8 sieve or so
Sand	0.05 mm to 2 mm	> No. 200 sieve
Silt	0.002 mm to 0.05 mm	Little plasticity or cohesion
Clay	< 0.002 mm	Can be rolled and compressed

For preliminary design, infiltration rates may be estimated using a published soil survey. However, final design must include soil gradation testing and measurement of unsaturated vertical infiltration rates in the field by the double-ring infiltrometer test. This test is not appropriate for clay soils or other soils which clearly appear to be unsuitable for infiltration methods. The allowable infiltration rate is 0.5 inches per hour, although an infiltration rate of 1 inch per hour is highly recommended. Table ST-03-1 shows that soils with a hydrologic soil group of C or D will not have sufficient infiltration rates.

Another well-known method of categorizing soils and evaluating soil properties is by the Unified Soil Classification System (USCS). The following soil groups are generally acceptable as good soils for infiltration:

- SW Well-graded sands and gravelly sands, little or no fines
- SP Poorly graded sands and gravelly sands, little or no fines
- SM Silty sands, sand-silt mixtures

Table ST-03-1
Typical infiltration Rates from USDA Soil Texture

	USDA Soil Texture	Typical Water Capacity (inches per inch of soil)	Typical Infiltration Rate (inches per hour)	Hydrologic Soil Group
*	Sand	0.35	8.27	A
**	Loamy sand	0.31	2.41	A
**	Sandy loam	0.25	1.02	B
**	Loam	0.19	0.52	B
	Silt loam	0.17	0.27	C
	Sandy clay loam	0.14	0.17	C
	Clay loam	0.14	0.09	D
	Silty clay loam	0.11	0.06	D
	Sandy clay	0.09	0.05	D
	Silty clay	0.09	0.04	D
	Clay	0.08	0.02	D

* - Suitable for infiltration with typical 6’ to 8’ separation from seasonal high groundwater

** - Suitable for infiltration with at least 3’ separation from seasonal high groundwater

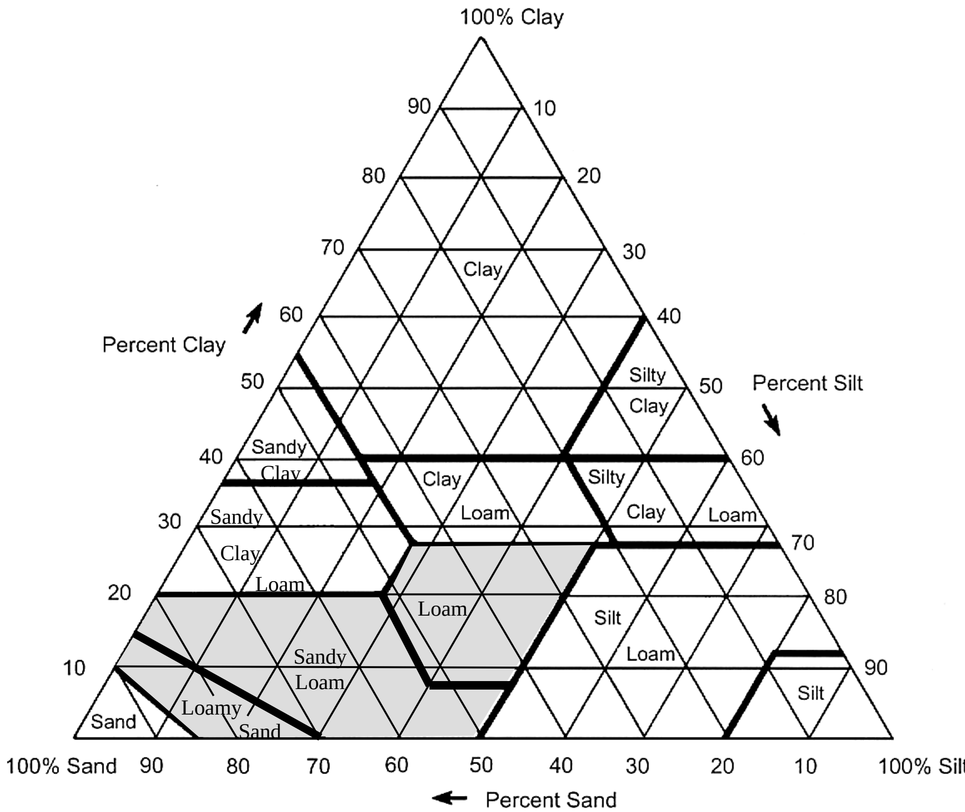


Figure ST-03-1
USDA Soils Triangle

Design Guidelines

Infiltration Basin

Infiltration basins may be used for stormwater quality and stormwater detention at small project sites only if soil, geologic and groundwater conditions are suitable. Soils must have adequate infiltration rates as measured or tested in the field. No unfavorable geologic conditions shall be present that would indicate sinkholes or underground passageways. Unless adequate engineering documentation is submitted, an infiltration basin must be located at least 100 feet away from any drinking water well, septic tank or drainfield. It is also recommended that an infiltration basin should not be located near building foundations, buildings with basements, major roadways, wetlands, streams, or potentially unstable slopes and hillsides.

In general, infiltration basins are not effective in the Knoxville area due to clay soils and shallow bedrock conditions. Smaller infiltration systems (trenches or drywells) may be applicable if local soil conditions allow. Avoid steep slopes or other geologic conditions that could potentially be made unstable by infiltrating water into the ground.

Figure ST-03-2 shows a typical infiltration basin. Pretreatment is highly recommended for areas with fine-grained soils, dust, sediment, debris or other materials with the potential to clog the soils of an infiltration basin. Design an emergency overflow or a bypass for larger storms (using overland relief swales or possibly even street drainage in the case of 100-year floods).

The criteria in Table ST-03-2 (taken from reference 32) can be used to make comparative evaluations if there is more than one potential site for an infiltration system. A score of

20 or below is definitely unsuitable for use as an infiltration basin. A score of 30 or more indicates an adequate site for an infiltration basin.

Table ST-03-2
Comparative Evaluations of Potential Infiltration Sites

A. Ratio of tributary connected impervious area (A_{IMP}) and the infiltration area (A_{INF}):

- $A_{INF} > 2 A_{IMP}$ ∏ 20 points
- $A_{IMP} < A_{INF} < 2 A_{IMP}$ ∏ 10 points
- $0.5 A_{IMP} < A_{INF} < A_{IMP}$ ∏ 5 points

B. Nature of surface soil layer:

- Coarse soils with low ratio of organic material ∏ 7 points
- Normal humus soil ∏ 5 points
- Fine-grained soils (silt or clay) ∏ 0 points

C. Underlying soil layer:

- If the underlying soils are coarser than surface soil, assign the same number of points as for the surface soil layer assigned under item 1 above.
- If the underlying soils are finer grained than the surface soils, then use:
  - Gravel, sand, or coarse glacial till ∏ 7 points
  - Silty sand or loam ∏ 5 points
  - Fine-grained soils (silt or clay) ∏ 0 points

D. Slope of the infiltration surface:

- Slope < 7% ∏ 5 points
- 7% < slope < 20% ∏ 3 points
- Slope > 20% ∏ 0 points

E. Vegetation cover:

- Healthy natural vegetation cover ∏ 5 points
- Lawn is well established ∏ 3 points
- Lawn is new ∏ 0 points
- No vegetation, bare ground ∏ -5 points

F. Degree of traffic on infiltration surface:

- Little or no foot traffic ∏ 5 points
- Average foot traffic (park, lawn) ∏ 3 points
- Much foot traffic (playing fields) ∏ 0 points

The infiltration basin volume should be sized to handle at least 85% of the average annual runoff, using the formula for volume capture (as discussed previously). The maximum allowable depth should be calculated using a safety factor of 2.0 to represent the uncertainty of infiltration due to construction methods and potential clogging:

Maximum ponding depth = (24 hours) x (infiltration rate) / (factor of safety)

Minimum surface area = (required volume) / (maximum ponding depth)

An infiltration basin should be excavated by a backhoe or excavator with adequate reach to operate from outside the basin. Side slopes should typically have 5:1 side slopes or flatter in order to minimize soil erosion. The bottom slopes should be as flat as possible. Sodding may help to quickly establish dense grass on the slopes, low-flow channels, basin entrance and emergency spillway. Do not plant trees or woody vegetation within the infiltration basin.

An observation and sampling well (typically a perforated PVC pipe riser, 6" diameter, threaded cap) should be installed to allow for periodic monitoring and testing. Installation of a PVC riser may occur during the initial geotechnical investigation and then modified during the construction of the infiltration basin. Prevent surface water runoff from using the riser to gain direct access to the groundwater table, particularly in areas with high pollution potential such as industrial facilities, parking lots, roadways (due to truck spills or deicing salts), major utility lines, etc.

For infiltration basins treating less than a few acres of pavement, pretreatment can usually be accomplished with a catch basin and a submerged outlet. The diameter and depth of the sump in the catch basin should be at least four times the diameter of the outlet pipe to the infiltration system (reference 66). Grass swales can also be used, although they may not be feasible in industrial sites, which tend to be fully utilized.

Inspect and repair infiltration basins at least twice a year. Remove sediment and debris as necessary. Do not allow heavy equipment or vehicles within the infiltration basin by using physical restrictions such as a fence or gate. Do not allow heavy foot traffic (as would be typical for a soccer or football field) within the infiltration basin area. Maintenance must also include regular mowing and removal of trees.

Natural Depressions, Sinkholes, and Karst Topography

The City of Knoxville has gentle rolling hills and the usual topography for east Tennessee, ridges that run in a southwest-to-northeast direction at regular intervals. Most bedrock in the Knoxville area is composed of fractured limestone formations that are likely to contain unusual strike angles and/or nonconformities. Karst topography is defined as the presence of limestone or other soluble geology that is likely to form caverns, sinkholes, or other dissolved formations. A sinkhole is a surface depression, typically linked to an underground cavern system, which occurs primarily in limestone regions. See Figure ST-03-3 for a typical sketch of a sinkhole.

For natural depressions and sinkholes, it is generally required that the postdeveloped peak flows and total stormwater runoff volume must be limited to the predeveloped values. In addition, the City of Knoxville also requires that any development near a sinkhole should include calculations demonstrating that no structures will be flooded from a 100-year storm assuming plugged conditions (zero outflow). It is greatly desired that runoff should be treated using one or more stormwater treatment BMPs, prior to discharging toward a sinkhole or other natural depression.

Consideration may be given to recommendations that are based upon advanced subsurface testing or visual inspection by experts or professional engineers with demonstrated experience in hydrogeology. Tennessee Department of Environment and Conservation (TDEC) requires anyone who performs a dye trace study to obtain a TDEC registration for this activity (see TDEC website). Major sinkholes are considered to be waters of the state; filling or otherwise altering a large sinkhole requires an Aquatic Resource Alteration Permit from TDEC.

Infiltration Trench

An infiltration trench essentially has the same design characteristics as an infiltration basin, except that part of the stormwater runoff storage is located within a gravel trench.

The volume available for water storage is found by multiplying the total gravel volume by the porosity (η). Typical details for an infiltration trench are shown in Figure ST-03-4 (for surface drainage) and Figure ST-03-5 (for roof drainage). Bottom of the infiltration trench should be located at least 3 feet above the seasonal high groundwater table. There are provisions for emergency overflow in both details.

At a minimum, the infiltration trench should have adequate volume to treat the first flush (which is the first 0.5" of stormwater runoff from the entire contributing area). Infiltration trenches may be used around the perimeter of parking lots, between subdivision lots, or along medians or roadside swales. An infiltration trench does not have organic soil layers or surface vegetation to trap some types of pollutants. A trench may be ineffective for soluble pollutants such as hydrocarbons, nitrates, salts or organic compounds.

An infiltration trench should have an observation and sampling port, to assist in cleanout and to check water quality and groundwater levels. Geotextile fabric should be selected on the basis of durability, with an adequate opening size to resist clogging. Use clean washed aggregate (little or no fines). Do not compact the trench bottom or the aggregate; protect the area from heavy equipment and traffic by physical means.

Maintenance considerations should include the possibility of replacing an infiltration trench every 5 years, as the gravel and geotextile fabric will eventually become clogged and cease to function. Clogging may also occur at the bottom of the trench, along the gravel / soil interface. Clogging will occur even faster if there are fine silts, oil and grease, fertilizers and other materials present in stormwater runoff. Do not allow trees or other woody vegetation to become rooted along an infiltration trench. Inspect operation and recovery of infiltration trench at least a few times a year.

Drywell or Dry Vault

A drywell or dry vault can be used to infiltrate stormwater runoff from small areas of impervious runoff, such as roofs or parking lots. The designer should be very careful to avoid adverse impacts to foundations, basements, unstable slopes or hillsides, septic tanks, utility lines, etc. A small pretreatment chamber with a screen is recommended in many instances to handle leaves (roofs) or trash and sediment (parking lots).

A typical drywell adjacent to a house foundation is shown in Figure ST-03-6 (without a pretreatment chamber). A dry vault (larger than a drywell) can be constructed using masonry blocks and a poured concrete lid to hold a larger volume of stormwater runoff. Inspect the drywell or dry vault on a regular basis. Maintenance plans should include provisions to repair or replace this type of structure after 5 years or so.

Porous Pavement

Porous pavements are not actually considered as a true infiltration system unless there is a mechanism for ensuring that captured water is vertically transmitted through the soil into groundwater. Otherwise, porous pavements shall generally be analyzed as a gravel surface (road or parking lot) with normal runoff coefficients used for the Rational formula or for NRCS methods of drainage design.

Porous pavement is usually a modular pavement grid, although pour-in-place concrete can be made into porous pavement also. See Figure ST-03-7 for a few types of porous pavement (taken from reference 45), for which grass is allowed to grow between the grids. A less durable variation can be made with bricks, placed on sand bedding and filled in with soil, with approximately 50% brick surface. Porous pavements have generally proven to be not durable under street traffic within the Knoxville area, and should be restricted to light traffic conditions without heavy trucks. Porous pavements are particularly recommended for residential driveways or overflow parking lots.

Porous pavements are likely to absorb large amounts of pollutants from automobiles, such as heavy metals and petroleum products. Porous pavements should be cleaned regularly using methods that will not dislodge the grass, sand or soil from between the concrete grids. Collect washwater and dispose properly to avoid washing pollutants downstream.

Maintenance

- Inspect and observe the infiltration system several times during the first year, particularly after heavy rainfall events. Use observation wells and cleanout ports to monitor water levels and drawdown times. Record all observations and measurements taken. Perform any maintenance and repairs promptly.
- Inspect the infiltration system annually thereafter, and after extreme rainfall events. If stormwater does not infiltrate within 72 hours after a storm, it is generally time to clean, repair or replace the facility. Remove debris and sediment at least annually to avoid high concentrations of pollutants and loss of infiltration capacity.
- The primary objective of maintenance and inspection activities is to ensure that the infiltration facility continues to perform as designed. Regular inspection can substantially lengthen the required time interval between major rehabilitations.
- Prevent compaction of the infiltration surfaces by physical controls such as gates or fences. Maintain dense grass vegetation for infiltration basins. Use rotary tillers on infiltration surfaces when needed to restore infiltration capacity and to control weed growth.

Sediment Removal

A primary function of stormwater treatment BMPs is to collect and remove sediments. The sediment accumulation rate is dependent on a number of factors including watershed size, facility sizing, construction upstream, nearby industrial or commercial activities, etc. Sediments should be identified before sediment removal and disposal is performed. Special attention or sampling should be given to sediments accumulated from industrial or manufacturing facilities, heavy commercial sites, fueling centers or automotive maintenance areas, parking areas, or other areas where pollutants are suspected. Treat sediment as potentially hazardous soil until proven otherwise.

Some sediment may contain contaminants for which TDEC requires special disposal procedures. Consult TDEC – Division of Water Pollution Control (594-6035) if there is any uncertainty about what the sediment contains or if it is known to contain contaminants. Clean sediment may be used as fill material, hole filling, or land spreading. It is important that this material not be placed in a way that will promote or allow resuspension in stormwater runoff. Some demolition or sanitary landfill operators will allow the sediment to be disposed at their facility for use as cover. This generally requires that the sediment be tested to ensure that it is innocuous.

Limitations

The four major concerns with infiltration systems are clogging, potential impact on other structures and properties, accumulation of heavy metals, and the potential for groundwater contamination.

- Clogging and high maintenance costs are very likely to occur in fine soils that are marginally allowable for infiltration rates. Erosion control is extremely important to prevent clogging; infiltration systems fail if they receive high sediment loads. Perform regular maintenance and inspections to minimize the potential for clogging and loss of infiltration capacity. Pretreatment is highly recommended for stormwater runoff from many land uses, prior to discharging to an infiltration system. Erosion of the side slopes is a major factor in clogged infiltration basins.

- Infiltration systems are not appropriate for areas with high groundwater tables, steep slopes, lots of underground infrastructure, and nearby buildings.
- Heavy metals are likely to settle in any of the stormwater treatment BMPs, but particularly for infiltration systems (which have the lowest velocity). High levels of heavy metals have been observed in other states where adequate maintenance was not performed. Toxic levels are not likely to be exceeded, but the sediments will need to be handled as hazardous waste after a few years of neglect.
- There is a higher risk of groundwater contamination in very coarse soils (references 2 and 79). It is highly recommended that a monitoring and inspection program should be used to verify that no contamination occurs. Infiltration systems may not be appropriate where there is significant potential for hazardous chemical spills.

References

2, 3, 28, 31, 32, 33, 42, 44, 45, 49, 51, 56, 62, 66, 69, 71, 77, 79, 88, 101, 104, 109, 121, 130, 163, 166 (see BMP Manual Chapter 10 for list)

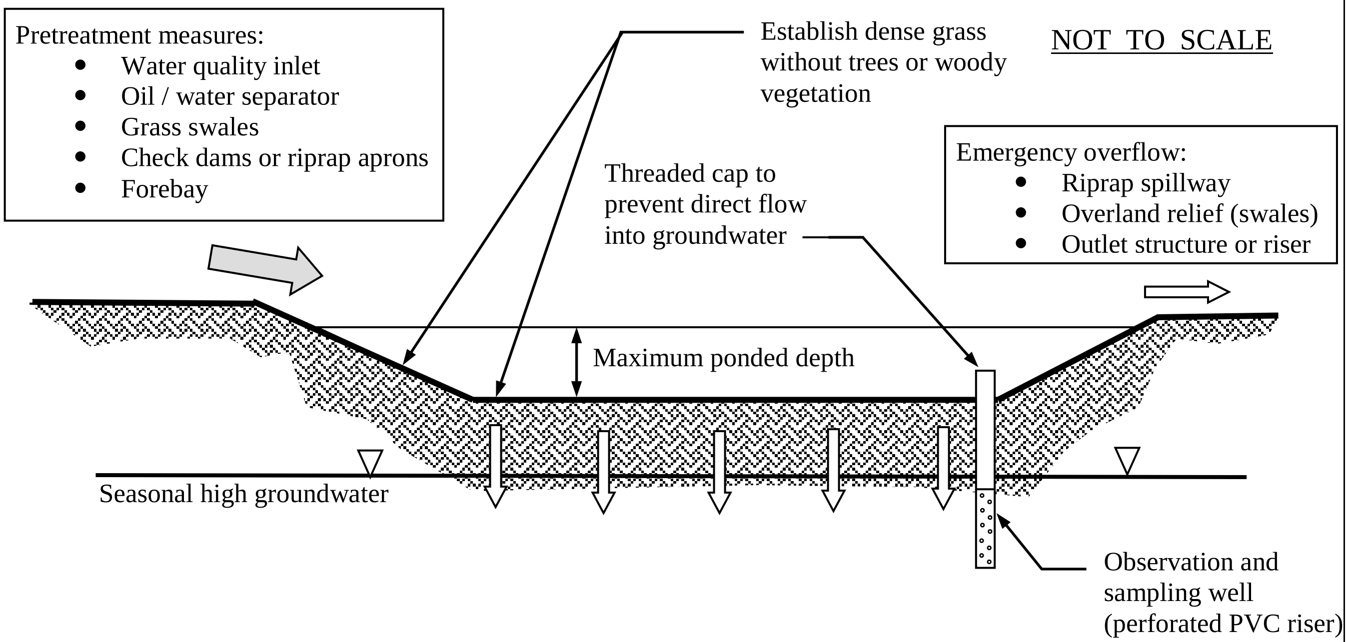
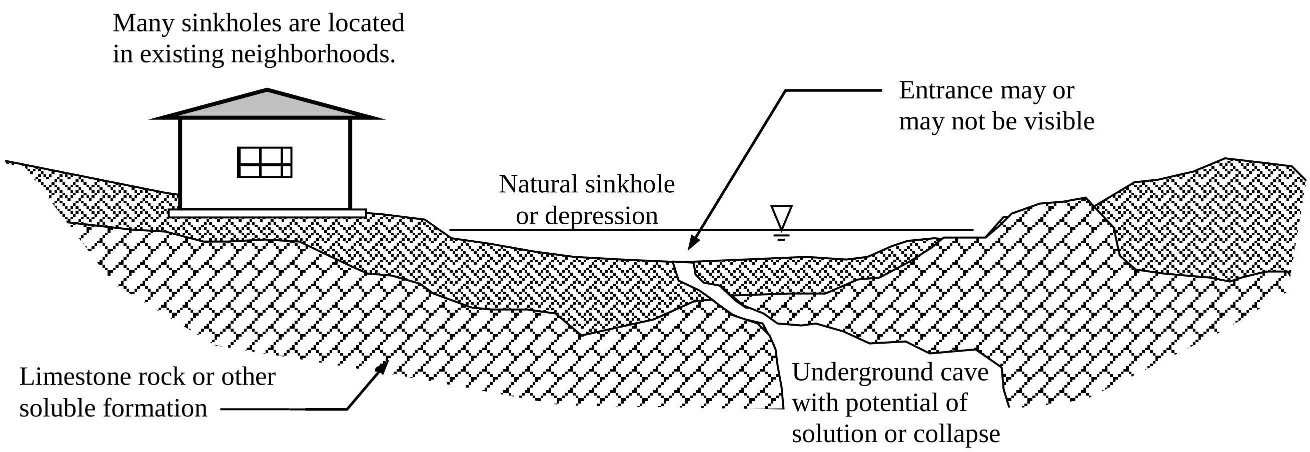


Figure ST-03-2
Typical Infiltration Basin



Increasing stormwater runoff to a natural depression may increase sinkhole formation by further dissolving limestone. Even if amount of stormwater runoff has not been increased, stormwater quality treatment is necessary to prevent pollutants from entering groundwater and to reduce potential pH changes and chemicals within stormwater runoff.

NOT TO SCALE

Figure ST-03-3
Typical Concerns of Sinkholes and Karst Areas

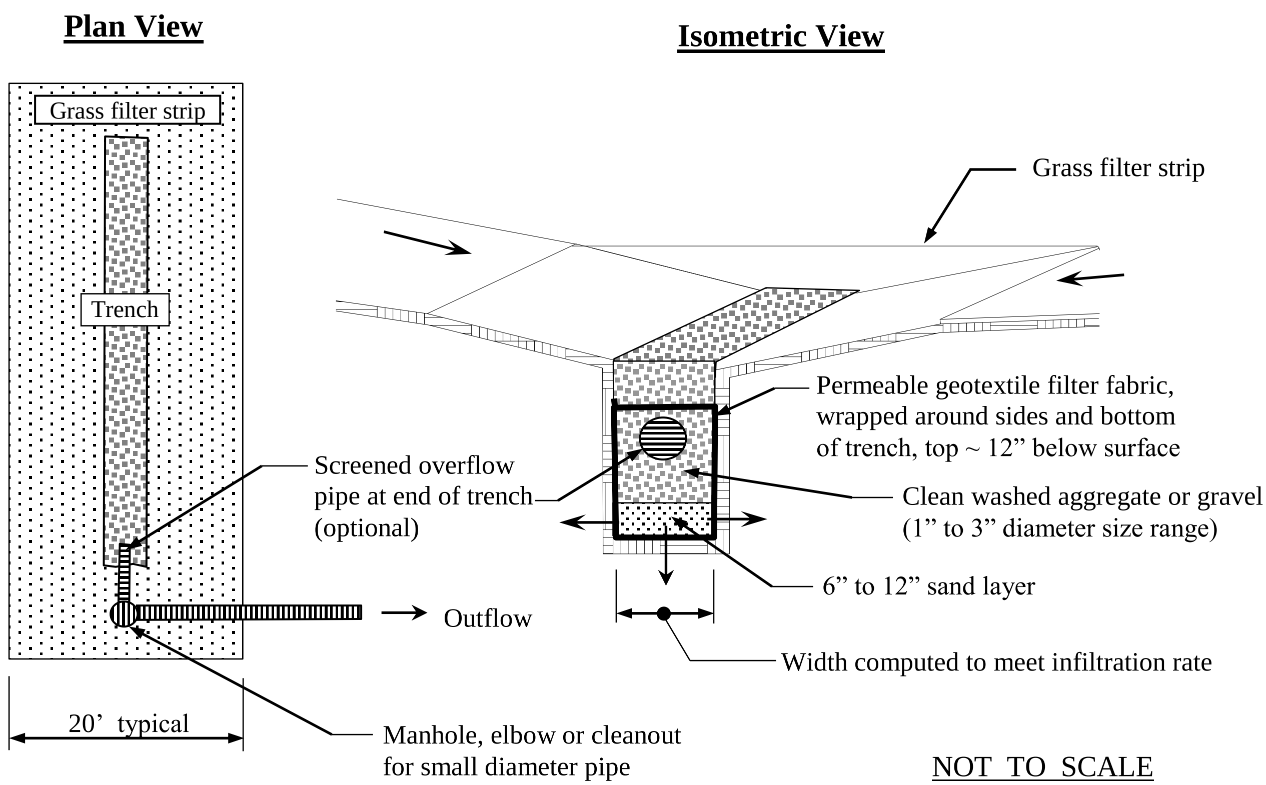


Figure ST-03-4
Typical Infiltration Trench (With Surface Drainage)

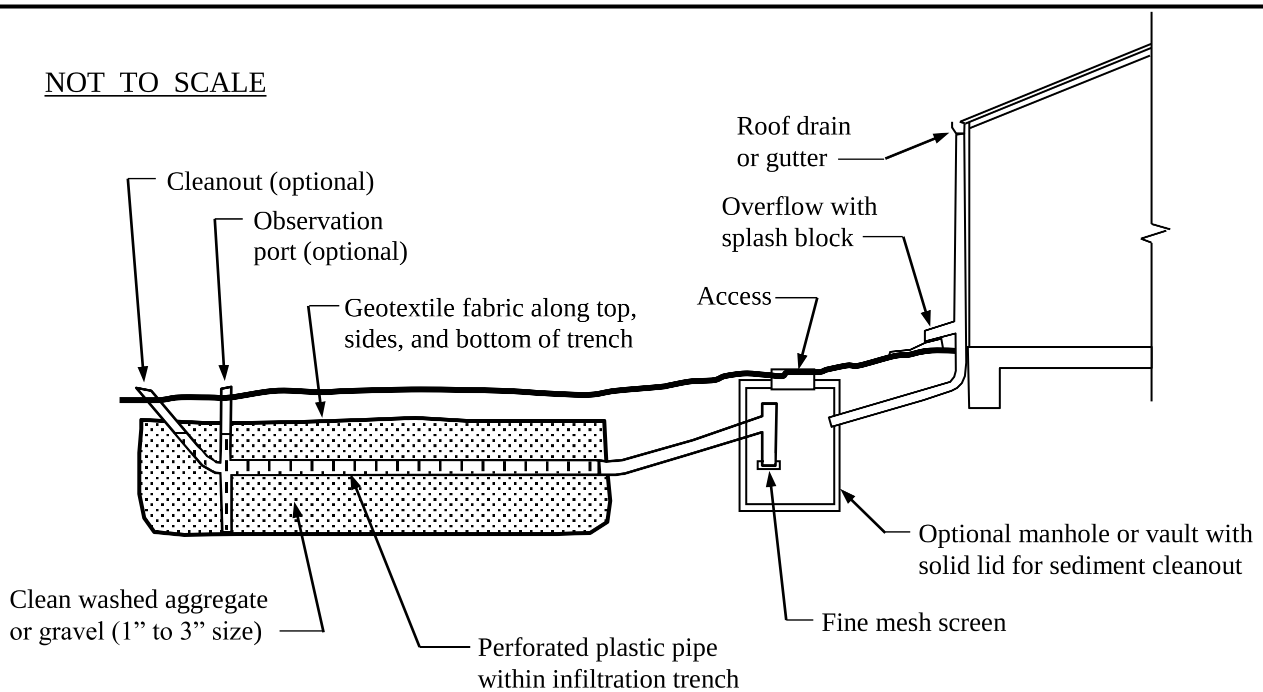


Figure ST-03-5
Typical Infiltration Trench (With Rooftop Drainage)

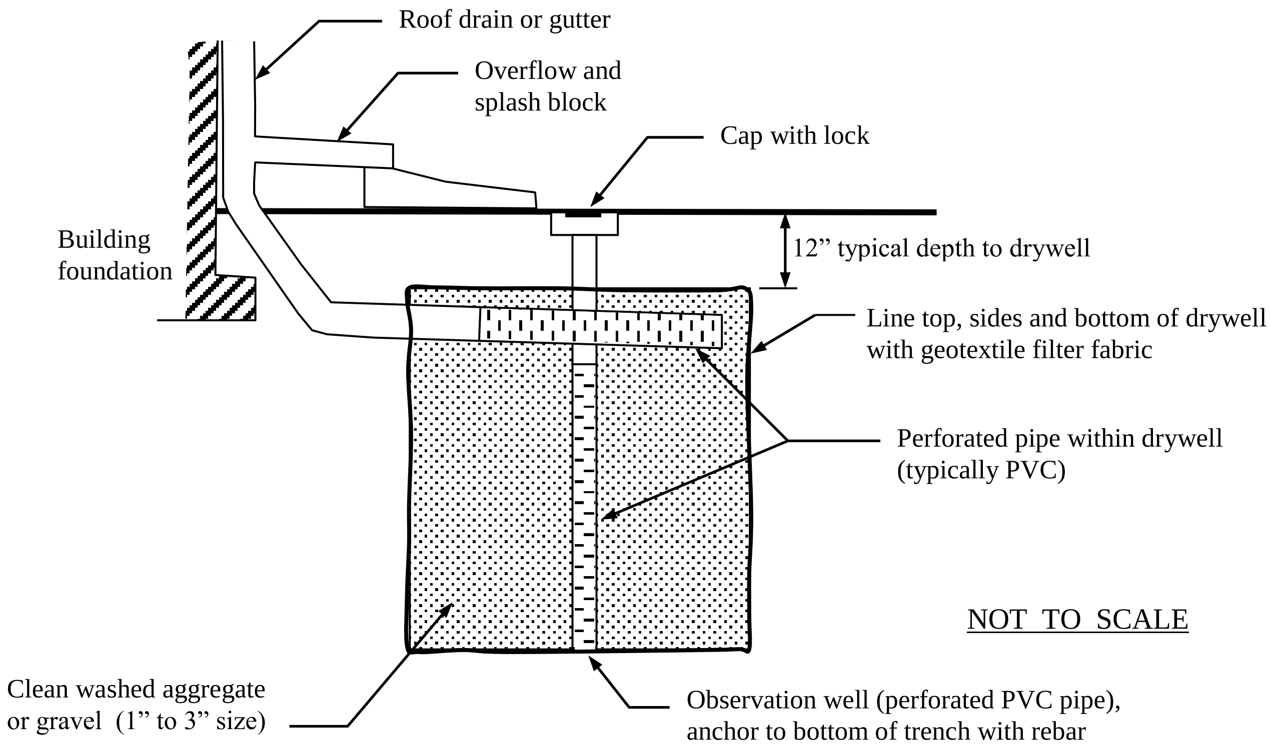


Figure ST-03-6
Typical Drywell (With Rooftop Drainage)

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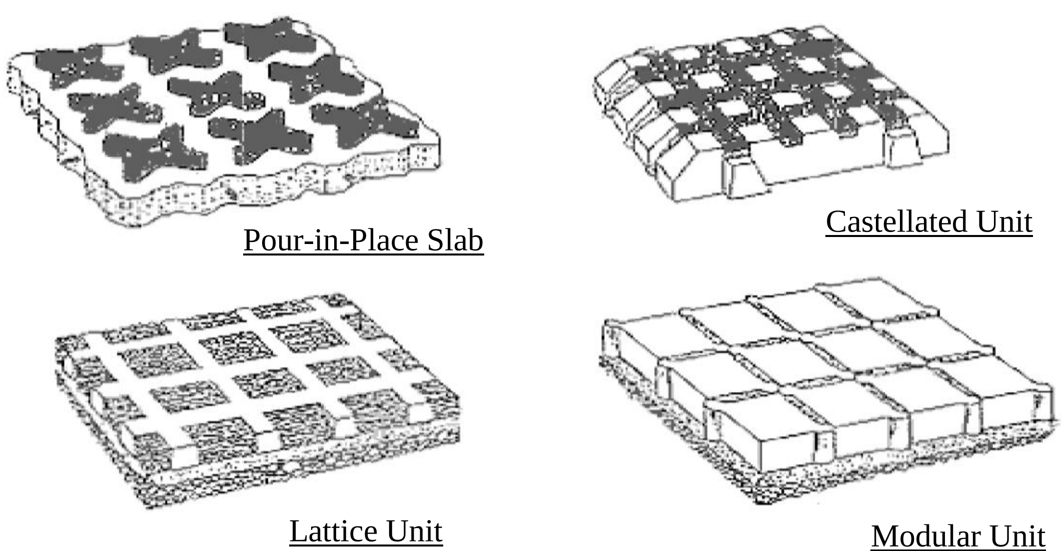

Figure ST-03-7
Examples of Porous Pavement