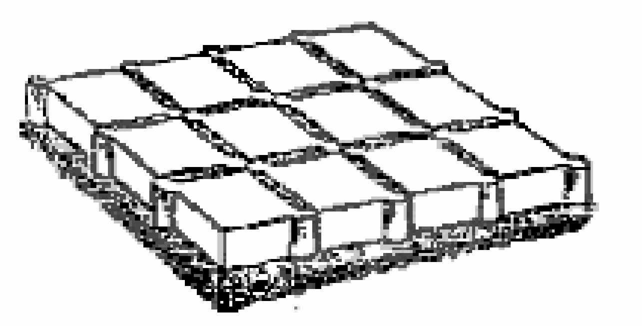
ACTIVITY: Porous Pavement

I – 04



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

Implementation Requirements		
● High	◗ Medium	○ Low

◗ Capital Costs	◗ O & M Costs	◗ Maintenance	○ Training

Description

This BMP covers porous pavement systems for increasing infiltration and decreasing surface runoff volume. Porous pavement is a specially designed pavement which allows stormwater to pass through it. It is effective in reducing flood peak flows and does so by allowing stormwater to infiltrate through a porous upper asphalt layer and into a stone aggregate reservoir below. Runoff eventually infiltrates into the ground or may be directed through an underdrain collection system.

There are three main types of porous pavement: poured asphalt pavement, poured concrete pavement, and interlocking-grid. The first two are special mixes of asphalt and concrete pavement, while the last type is a network of blocks (usually concrete) used to decrease impervious area.

Infiltration rates in much of the state are typically poor due to clay soils and bedrock. Such locations may not be suitable of infiltration BMPs. Infiltration systems work best at sites having sandy loam types of soils. 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.

Selection Criteria

- 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. In addition, porous pavements can receive runoff from adjacent paved areas or rooftop storage.

- Porous pavement has the capability to remove both soluble and fine particulate pollutants in urban runoff, enhance groundwater recharge, control streambank erosion, and increase low flow.

- It has been shown to have high removal rates for sediment, nutrients, organic matter, and trace metals.

- Adsorption, trapping/straining in the void spaces between soil particles, and reducing organic matter by aerobic bacteria within the soil are a few of the pollutant removal mechanisms of porous pavement.
- Natural sinkholes (or other evidences of karst topography and drainage) are not considered to be suitable locations for 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.
- The use of porous pavement requires deep, permeable soils, low-density traffic, and suitable adjacent land uses.

Design and Sizing Considerations

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 and non-interfering groundwater tables. Stormwater runoff from parking lots or buildings should be pretreated with a water quality enhancing inlet, oil/water separator, grass swale or other type of stormwater treatment BMPs. Small amounts of stormwater runoff from selected impervious areas are given an opportunity to infiltrate.

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.

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.

Due to its complexity, the design of porous pavement should only be completed by a licensed professional engineer who is trained and experienced in porous pavement design and construction.

Following are some design criteria for porous pavement:

- Maximum drainage time of two days to allow for drying of the underlying soils and to maintain aerobic conditions; also allowing the reservoir to empty for the next storm.
- Highly permeable soils to allow for maximum infiltration.
- Clean-washed aggregate to prevent clogging from pre-existing sediment.
- Organic matter in the subsoils.
- Pretreatment of off-site runoff to reduce the pollutant load onto the pavement.
- Heavy trucks and equipment should be diverted from areas with porous pavement.
- Slopes underlying porous pavement should be as flat as possible, with maximum

grades being less than five percent.

- There should be a minimum of three feet clearance between the bottom of the stone reservoir and the bedrock level.

- A minimum of two to four feet between the stone reservoir level and the seasonally high water table is needed.

- The standard porous pavement design should withstand normal freeze/thaw conditions. However, it is very susceptible to clogging during snow removal operations such as sand and salt application

- Most soils in urbanized areas are not capable of providing adequate infiltration rates because of compaction or other prior modifications. Therefore, retrofitting is extremely limited.

- Porous pavement should be designed to exfiltrate a minimum runoff volume equal to the first one-half inch of runoff from impervious areas that contribute to the site.

- To ensure that proper pollutant removal occurs, the minimum drainage time for the stone reservoir should be 12 hours; and the maximum drainage time should be 48 hours to ensure that the stone reservoir is completely drained before the next storm event. This maximizes pollutant removal and readies the pond for the next storm.

- To remove oil, dirt, and grit from off-site facilities, a pre-treatment facility such as a sand filter or water quality inlet should be installed to prevent the sediments from entering the stone reservoir.

- Different design options can prolong the life of the porous pavement system. One idea brought forth in the *Virginia Stormwater Management Handbook* is to "daylight" the aggregate base along the downslope edge of the pavement, forming a chimney drain into the stone storage reservoir beneath the pavement. If the pavement clogs, the runoff can flow into the stone reservoir.

Overview of Infiltration Theory

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.

Typical infiltration rates are shown in Table I-04-1. The USDA soil texture classification is based upon the soils triangle shown in Figure I-04-1, 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 I-04-1 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 I-04-1
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

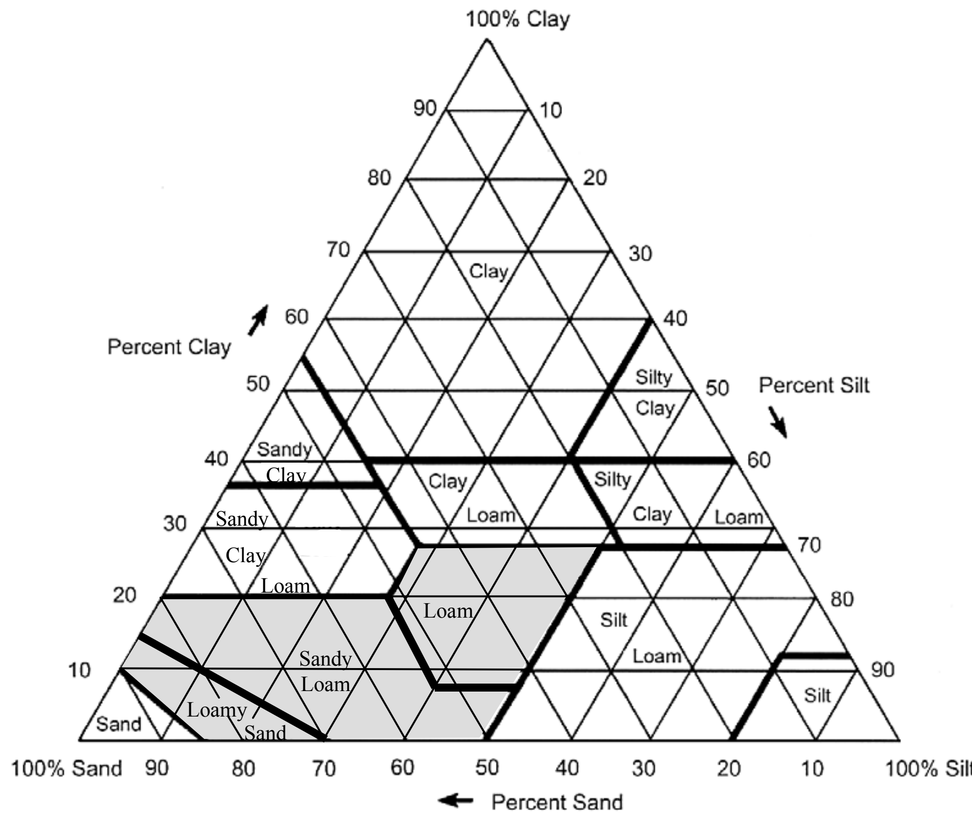


Figure I-04-1
USDA Soils Triangle

Natural Depressions, Sinkholes, and Karst Topography

Much bedrock in Tennessee 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 I-03-3 for a typical sketch of a sinkhole.

For natural depressions and sinkholes, it is generally required that the post-developed peak flows and total stormwater runoff volume must be limited to the pre-developed values. In addition, it may be required 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 Resources Alteration Permit from TDEC.

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 SCS methods of drainage design.

Porous pavement is usually a modular pavement grid, although pour-in-place concrete and asphalt can be made into porous pavement also. See Figure I-04-2 for a few sample types of porous pavement (taken from *The Florida Development Manual: A Guide to Sound Land and Water Management, 1988*), 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 been proven to be not durable under street traffic, 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.

Construction/ Inspection Considerations

- It is very important to protect the natural infiltration rate by using light equipment and construction procedures that minimize compaction. Stormwater must be allowed to enter the facility until all construction in the catchment area is completed and the work area is stabilized. If this prohibition is not feasible in particular situations, do not excavate the facility to final grade until after all construction is complete upstream. With trenches, make sure the rock fill does not become dirty while temporarily stored at the site.
- Protect infiltration surface during construction.
- Inspect frequently for clogging during construction.
- Prevent erosion and sediment transport from occurring upstream of an infiltration basin or other infiltration system.

Maintenance

- Maintenance can be difficult and costly for most 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.
- 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.

- Remove debris and sediment at least annually to avoid high concentrations of pollutants and loss of infiltration capacity.
- Vacuum sweeping and jet hosing are the two primary maintenance requirements that protect the porous pavement from premature clogging. These simple practices are commonly overlooked and failure of the facility soon follows.
- 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.
- Maintain records of inspections and maintenance performed.
- Porous pavement resurfacing must only completed with the proper materials, as approved by the municipality’s engineering department.

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, upstream construction, 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 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.

Cost Considerations

There is potential for high maintenance costs due to clogging, but pretreatment will reduce maintenance costs by capturing gross settleable solids and floatables in a smaller space that can be more easily cleaned. In addition, the asphalt used in porous pavement costs more than conventional pavement. It can cost up to fifty percent more than conventional asphalt. However, without the additional need for stormwater drainage, conveyance, and off-site treatment, porous pavement can be very cost effective.

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.
- Porous pavement has high failure potential (~ 75%) (Schueler et al, 1992). The main causes of failure are clogging of the surface by sediment deposits and non-porous resurfacing materials, poor design, low permeability soils, and heavy vehicular traffic. Porous pavement has a tendency to clog after just one to three years (ASCE, 1998).
- There is a concern for toxic chemical leaching from the asphalt.
- Hydrocarbons from vehicles can be transported on porous pavement and lead to clogging of the surface.
- Infiltration systems are not appropriate for areas with high groundwater tables, steep slopes, lots of underground infrastructure, and nearby buildings.
- Porous pavement is not recommended in areas with expectations of high wind erosion, colder climates, and sole-source aquifers.
- 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. 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.
- Porous pavement is suitable only for small sites between ¼ and 10 acres.
- Use of salt and sand for snow removal can promote clogging of the pores and prevent passage of runoff for exfiltration.

Additional Information

- Infiltration systems or wet detention should be considered where dissolved pollutants discharging to surface waters are of concern. However, satisfactory removal efficiencies require soils that contain loam. Coarse soils are not effective at removing dissolved pollutants and fine particulates before the stormwater reaches the ground water aquifer.

- Problems can be expected with infiltration systems placed in finer soils. The State of Maryland has emphasized these systems for about 10 years where they have been installed in soils with infiltration rates as low as 0.27 inches (0.69 cm) per hour. A recent survey (Lindsey, et al., 1991) found that a third of the facilities examined (177) were clogged and another 18% were experiencing slow infiltration. Dry wells that treat roof runoff had the fewest failures (4%) and porous pavement the most (77%). Dry wells may have the lowest failure rate because they only handle roof runoff. The primary causes of failure appear to be inadequate pretreatment and lack of soil stabilization in the tributary watershed, as well as poor construction practices (Shaver, personal communication). Erosion of the slopes of infiltration ponds was a significant problem in almost half the facilities surveyed.
- Based on a review of several studies of infiltration facilities in sandy and loamy soils, it has been concluded that "monitoring . . . has not demonstrated significant contamination . . . although highly soluble pollutants such as nitrate and chloride have been shown to migrate to ground water" (USEPA, 1991). However, pollution has been found in ground water where infiltration devices are in coarse gravels (Adophson, 1989; Miller, 1987).
- Clogging has not been a problem with well maintained systems discharging to sands and coarser soils, suggesting that pretreatment for these infiltration devices in the aforementioned soil conditions is not necessary. Pretreatment when infiltrating to finer soils is suggested. An infiltration facility sized only for treatment is much smaller than one sized for flood control and therefore may be more susceptible to clogging.
- For small systems treating less than a few acres of pavement, pretreatment can be accomplished with a stormwater quality inlet, catch basin and a submerged outlet. The diameter and depth of the sump should be at least four times the diameter of the outlet pipe to the infiltration system (Lager, et al., 1977). Swales can also be used although they will not likely be feasible in industrial sites that tend to be fully utilized.
- For porous pavement, experience in Maryland suggests that asphalt pavement has continuous plugging problems and a limited life. Frequent maintenance is required. Porous pavement should be cleaned at least twice per year by vacuum sweeping and high-pressure washing.
- Two long-term studies conducted in the Washington area by the Occoquan Watershed Monitoring Laboratory indicate quite high removal capabilities: 85% - 95% mass removal of solids, 65% total phosphorus, 75% - 85% total nitrogen, and ~98% removal of trace metals (Schueler et al, 1987).
- Porous pavement protects downstream aquatic life by maintaining water balance at the site, minimizing streambank erosion, and filtering out pollutants.
- Using porous pavement rather than conventional pavement causes vehicles to be less susceptible to hydroplaning and have better skid resistance.
- Porous pavement can improve visibility during rain because of its ability to infiltrate water quickly.

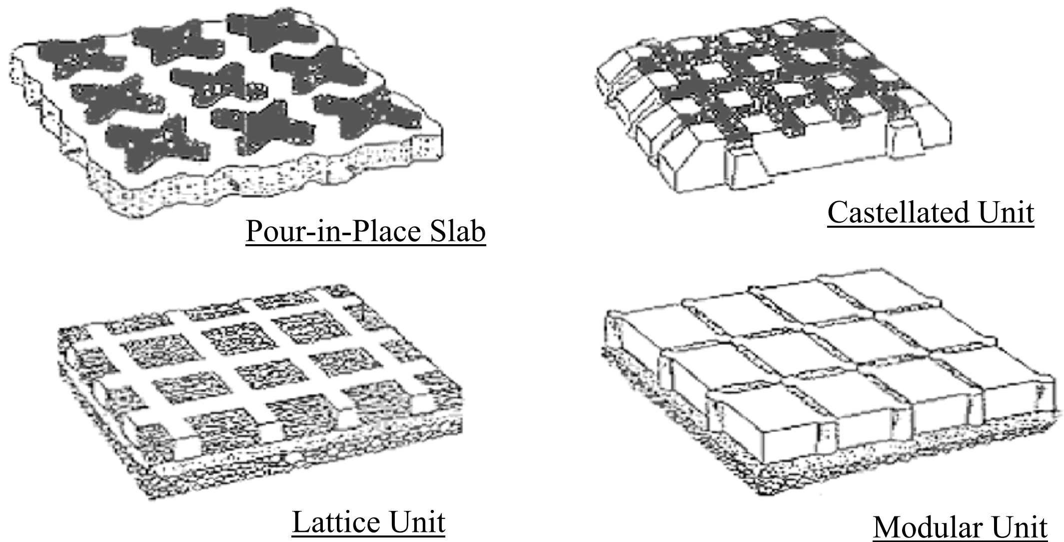


Figure I-04-2
Examples of Porous Pavement Systems
(Florida Manual, 1988)

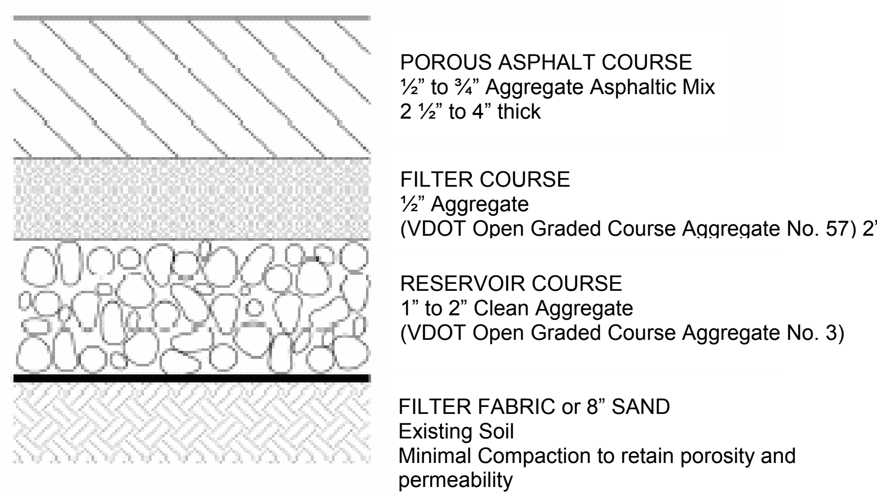


Figure I-04-3
Porous Pavement Section

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