Chapter 10 – Porous Pavement

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10.1 Overview of Practice

Porous pavement is a pervious traffic-bearing surface placed over a stone reservoir which is, in turn, underlain by highly permeable soil. The void space created by the stone reservoir provides storage for surface runoff generated on or diverted onto the porous surface. This runoff then infiltrates into the surrounding soil, through the bottom and sides of the stone reservoir. Porous pavement may substitute for conventional pavement on parking areas and areas with light traffic. Porous pavement is generally not suited for areas with high traffic volumes.

Porous pavement acts primarily as a water quality BMP. However, much like an infiltration trench (*Chapter 8 – Infiltration Trench*), when equipped with underground piping, the temporary storage volume of the reservoir may be increased to provide peak runoff reduction for the one and two year return frequency storms. Peak rate control of the 10-year and greater storm events is considered to be beyond the ability of the practice.

Studies have shown that particulates tend to settle to the bottom of a porous pavement system's stone reservoir while other pollutants often adsorb to the aggregate material. Consequently, the pollutant removal efficiency of a porous pavement system may not be as high as that of other types of infiltration practices. Per DCR recommendations, a porous pavement facility is considered to have a pollutant removal efficiency comparable to that of an extended dry detention facility (*Chapter 2 – Dry Extended Detention Basin*).

10.2 Site Constraints and Siting of the Facility

The implementation of a porous pavement system requires the designer to consider many of the same site constraints as with an infiltration basin or trench. These constraints are discussed as follows.

10.2.1 *Drainage Area*

Porous pavement systems are generally not cost-effective for sites smaller than 0.25 acres in area. According to the FHWA (1996), the contributing drainage area to a porous pavement infiltration bed should be limited to a maximum of 10 acres in order to reduce the potential for excessive sediment loading. A primary cause of infiltration bed failure is clogging by sediment. The porous pavement system should not be located where runoff from adjacent areas introduces excessive sediment to the system. Additionally, for drainage areas of 10 acres and greater the cost effectiveness of porous paving systems is considered marginal compared to that of other BMPs.

10.2.2 *Site Slopes*

Unlike other infiltration-based BMPs, which can be installed on slopes of up to 20 percent, porous pavement should not be installed when the traffic bearing surface of the system exceeds 3 percent in slope. Site topography should also permit the construction of a stone reservoir bed that is essentially level along its bottom surface. Porous pavement systems and their associated infiltration beds should be located a minimum of 50 feet away from any slope steeper than 15 percent. When site slopes do not permit the construction of a level infiltration bed, alternative BMP measures should be considered.

10.2.3 *Site Soils*

The underlying soil infiltration rate is of critical importance in the design of a porous pavement system. *A subsurface analysis and permeability test is required* when such a facility is planned. The required subsurface analysis should include soil characteristics to a depth of no less than three feet below the proposed bottom of the stone reservoir. Data from the subsurface investigation should be provided to the Materials Division early in the project planning stages to evaluate the feasibility of such a facility on native site soils.

The soil infiltration rate should be measured when the soil is in a saturated condition. Soil infiltration rates which are deemed acceptable for porous pavement systems range between *0.52 and 8.27 inches per hour*. Soils with infiltration rates in this range are typically categorized as loam, sandy loam, and loamy sand.

Soils exhibiting a clay content of greater than 30 percent are unacceptable for infiltration facilities. Similarly, soils exhibiting extremely high infiltration rates, such as sand, should be avoided. Table 10.1 presents typical infiltration rates observed for a variety of soil types. This table is provided as a reference only, and does not replace the need for a detailed site soil survey.

Texture Class	Effective Water Capacity (C_w) (inch per inch)	Minimum Infiltration Rate (*f*) (inch per hour)	Hydrologic Soil Grouping
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

Table 10.1. Hydrologic Soil Properties Classified by Soil Texture
Source: (Virginia Stormwater Management Handbook, 1999, Et seq.)

10.2.4 *Depth to Water Table*

Porous pavement systems should not be installed on sites with a high groundwater table. Inadequate separation between the reservoir bottom and the surface of the water table may result in contamination of the water table. This potential contamination arises from the inability of the soil underlying the reservoir to filter pollutants prior to their entrance into the water table. Additionally, a high water table may flood the stone reservoir and render it inoperable during periods of high precipitation and/or runoff. A separation distance of no less than four feet is required between the bottom of the stone reservoir and the surface of the *seasonally* high water table. Unique site conditions may arise which require an even greater separation distance. The separation distance provided should allow the reservoir to empty completely within a maximum of 48 hours following a runoff producing event.

10.2.5 *Separation Distances*

Porous pavement systems should be located at least 20 feet down-slope and at least 100 feet up-slope from building foundations. Porous pavement systems should not be located within 100 feet of any water supply well. Local health officials should be consulted when the implementation of such a facility is proposed within the vicinity of a septic drainfield.

10.2.6 *Bedrock*

A minimum of four feet of separation is required between the bottom of a porous pavement's stone reservoir and bedrock, with four feet or greater recommended.

10.2.7 *Placement on Fill Material*

Porous pavement systems should not be constructed on fill sections due to the possibility of creating an unstable subgrade. Fill areas are vulnerable to slope failure along the interface of the in-situ and fill material. The likelihood of this type of failure is increased when the fill material is frequently saturated, as anticipated when an infiltration BMP is proposed.

10.2.8 *Implementation in Cold Weather Climates*

Porous pavement systems can be implemented in cold weather climates, provided that the reservoir layer extends to a depth beyond the frost line. During winter months, abrasives such as grit and/or sand and deicing chemicals *must not be used* on porous pavement. Plowing must be performed carefully, and as infrequently as possible.

10.2.9 *Karst*

The concentration of runoff into a stone reservoir may lead to collapse in karst areas, and therefore the implementation of porous pavement in known karst areas should be avoided.

10.2.10 *Existing Utilities*

Porous pavement systems may be constructed over existing easements, provided permission to construct the infiltration bed over these easements is obtained from the utility owner *prior* to design of the facility.

10.2.11 *Wetlands*

When the construction of a porous pavement system is planned in the vicinity of known wetlands, the designer must coordinate with the appropriate local, state, and federal agencies to identify wetlands boundaries, their protected status, and the feasibility of BMP implementation. In Virginia, the Department of Environmental Quality and the U.S. Army Corps of Engineers should be contacted when such a facility is planned in the vicinity of wetlands.

10.3 General Design Guidelines

The following section presents a collection of design issues to be considered when designing a porous pavement *system* for improvement of water quality. The design steps discussed in this report are those exclusive to the water quality improvement function of a porous pavement system. Design of the porous pavement surface layer is beyond the scope of this report, and is a function of the anticipated traffic intensity, the California Bearing Ratio (CBR) of the site soils, the susceptibility of site soils to frost heave, and numerous other factors. The design of the porous surface layer should be performed by a qualified professional familiar with all VDOT standards and specifications governing asphalt design.

10.3.1 *System Storage Capacity*

Porous pavement systems can be designed as *full*, *partial*, or *water quality exfiltration* systems. Full exfiltration systems retain and infiltrate 100 percent of captured runoff. When the reservoir underlying the porous surface is full, runoff bypasses the system completely and is handled by a conventional stormwater capture and conveyance system. (FHWA, 1996)

Partial exfiltration systems are equipped with a bypass piping system. The bypass system routes runoff in excess of what can be infiltrated to a downstream conveyance system. Two types of bypass pipe configurations are shown in Figure 10.1 and Figure 10.2. The first configuration locates the perforated bypass pipe at the bottom of the aggregate reservoir layer. This configuration requires that the outlet manhole be equipped with a concrete weir such that water only discharges through the bypass system when the aggregate layer is in a saturated state. An alternative configuration locates the bypass pipe at the surface of the aggregate reservoir layer. This configuration is similar to the bypass configuration for an infiltration trench (see *Design Example Seven – Infiltration Trench*). When the bypass pipe is not located at the reservoir bottom, the pipe should have perforations on the underside only, else the bypass pipe shall be perforated as necessary to permit flow to freely enter the bypass system.

Water quality exfiltration systems function as partial exfiltration systems, but are designed only to hold and infiltrate the computed water quality volume.

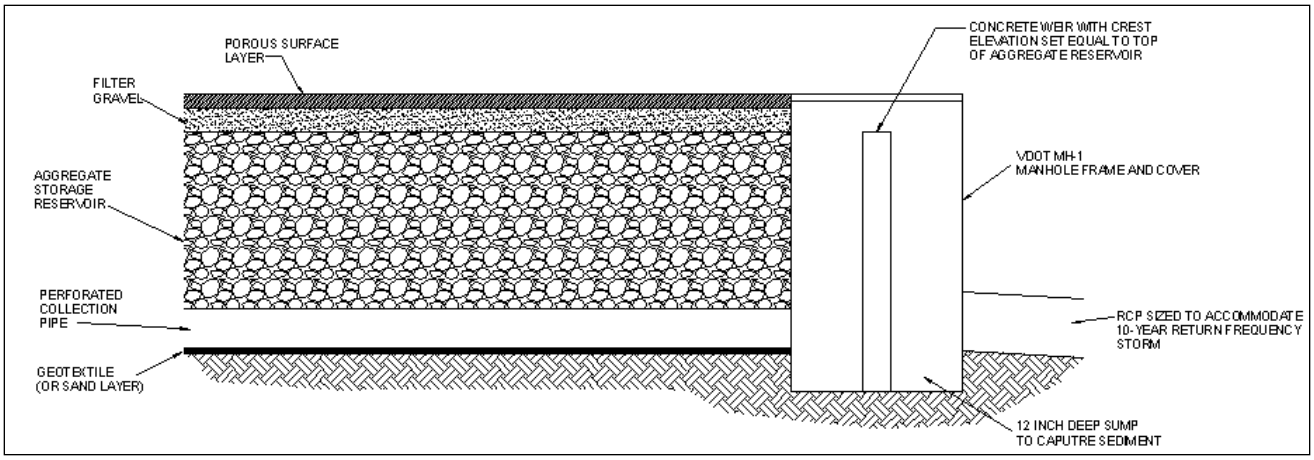

Figure 10.1. Common Bypass Pipe Configuration

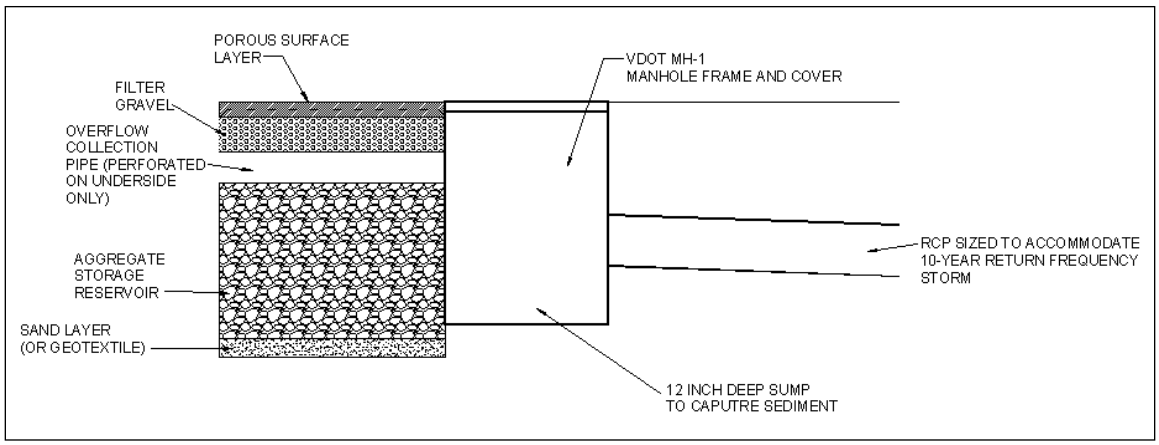

Figure 10.2. Alternative Bypass Pipe Configuration

10.3.2 ***Design Infiltration Rate***

To provide a factor of safety, and to account for the decline in performance as the facility ages, the design infiltration rate used to size a porous pavement system should be one-half the infiltration rate obtained from the geotechnical analysis (DCR, 1999, Et seq.).

10.3.3 ***Maximum Storage Time***

The stone reservoir of a porous pavement system should be designed to empty within 48 hours following a runoff producing event.

10.3.4 *Stone Reservoir Sizing*

The reservoir's aggregate depth should extend to a depth of at least that of the local frost line as specified by the Virginia Uniform Statewide Building Code. The surface area of the reservoir is that area which, when multiplied by the trench depth and the aggregate porosity, provides the computed treatment volume.

10.3.5 *Aggregate Material*

The porous pavement's reservoir layer should be overlain by a 2 inch thick filter layer comprised of VDOT Open-graded Course Aggregate #57. The reservoir should be comprised of 1 – 2 inch diameter clean aggregate (VDOT open-graded course aggregate No. 3). The reservoir layer should be underlain by an 8 inch layer of sand *or* filter fabric as approved by the Materials Division. This configuration is illustrated in Figure 10.3.

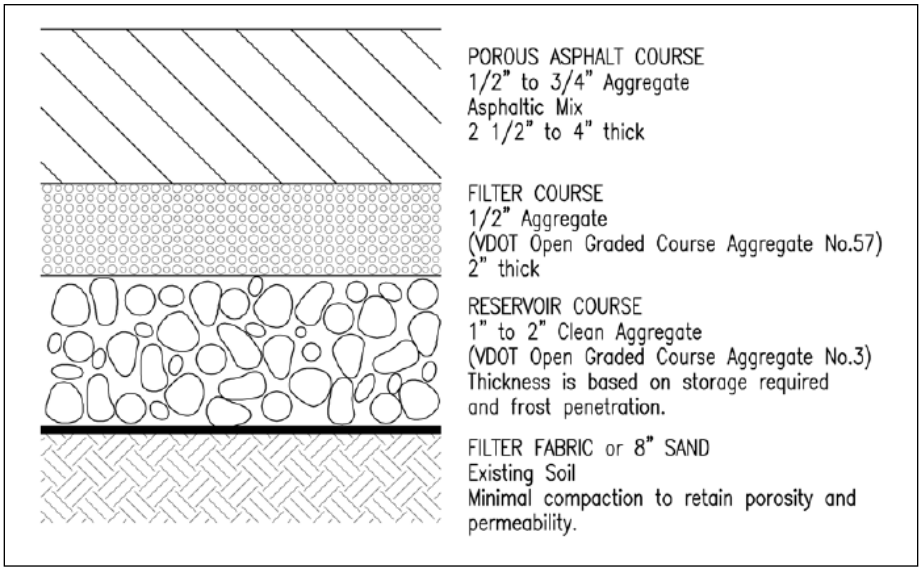

Figure 10.3. General Configuration of Porous Pavement Section
(Virginia Stormwater Management Handbook, 1999, Et seq.)

10.3.6 *Filter Fabric*

When the reservoir aggregate material is not underlain by a layer of sand, it must be underlain with filter fabric as shown in Figure 10.3. The filter fabric should be comprised of material approved by the VDOT Materials Division in accordance with all applicable DCR requirements.

10.3.7 *Provision for Surface Clogging*

Porous pavement systems must have a backup method for water to enter the infiltration bed in the event that the porous surface fails or is altered. In parking lots without curbing, this can be accomplished by constructing an unpaved two foot wide stone drain along the downstream edge of the parking lot. The stone drain is then connected directly to the infiltration bed. When curbing is present, sump inlets with sediment traps can be installed in low-lying areas, and then connected directly to the infiltration bed.

10.4 Design Process

This section presents an example of the design process applicable to porous pavement systems serving as water quality BMPs. The pre and post-development runoff characteristics are intended to replicate stormwater management needs routinely encountered on VDOT *facilities* projects. The design steps discussed in this report are those exclusive to the water quality improvement function of a porous pavement system. Design of the porous pavement surface layer is beyond the scope of this report, and is a function of the anticipated traffic intensity, the California Bearing Ratio (CBR) of the site soils, the susceptibility of site soils to frost heave, and numerous other factors. The design of the porous surface layer should be performed by a qualified professional familiar with all VDOT standards and specifications governing asphalt design.

The hydrologic calculations and assumptions presented in this section serve only as input data for the detailed BMP design steps. Full hydrologic discussion is beyond the scope of this report, and the user is referred to Chapter 4 of the Virginia Stormwater Management Handbook (DCR, 1999, Et seq.) for expanded hydrologic methodology.

The porous pavement design will provide the technology-based water quality requirements arising from the parking lot of a VDOT-maintained interstate rest area facility located near Charlottesville. The total parking lot area consists of 4.8 acres, with no offsite drainage entering the parking facility. The total project site, including right-of-way and all permanent easements, consists of 6.2 acres. Geotechnical investigations reveal the site's saturated soil infiltration rate to be 2.7 inches per hour. The project site does not exhibit a high or seasonally high groundwater table. Table 10.2 presents the 10-year hydrologic characteristics of the parking facility.

		Albemarle County - 10 Year				
Acreage	**Rational C**	**A Constant**	**B Constant**	**t_c (min)**	**i_{10} (iph)**	**Q_{10} (cfs)**
4.8	0.9	161.6	18.73	5	6.81	29.4

Table 10.2. Peak Parking Lot Runoff Characteristics

Step 1. Compute the Required Water Quality Volume

The project site's water quality volume is calculated as one half inch over the developed impervious area. In this example, the total parking lot area will be considered impervious cover:

$$WQV = \frac{IA \times \frac{1}{2} in}{12 \frac{in}{ft}}$$

IA= Impervious Area (ft^2)

The project site in this example is comprised of a total drainage area of 4.8 acres. Therefore, the basic water quality volume is computed as follows:

$$WQV = \frac{4.8ac \times \frac{1}{2} in \times \frac{43{,}560\, ft^2}{ac}}{12 \frac{in}{ft}} = 8{,}712\, ft^3$$

The parking lot area (4.8 acres) comprises 77 percent of the total project site area (6.2 acres). Therefore, adhering to the requirements for infiltration practices detailed in Table 1.1, we will set the design water quality volume as twice the basic water quality volume:

$$WQV_{Design} = 2 \times 8{,}712\, ft^3 = 17{,}424\, ft^3$$

Step 2. Compute the Design Infiltration Rate

The design infiltration rate, f_d, is computed as one-half the infiltration rate obtained from the required geotechnical analysis. For the given site conditions, the infiltration rate is computed as:

$$f_d = 0.5 f = (0.5)\left(2.7 \frac{in}{hr}\right) = 1.35 \frac{in}{hr}$$

Step 3. Compute the Maximum Allowable Reservoir Depth

The aggregate reservoir must be designed such that it is completely empty within a maximum of 48 hours following a runoff producing event. To ensure compliance with this requirement, the maximum allowable trench depth is computed by the following equation:

$$d_{\max} = \frac{f_d \times T_{\max}}{V_r}$$

d_{max} = maximum allowable reservoir depth (ft)
f_d = design infiltration rate (in/hr)
T_{max} = maximum allowable drain time (48 hours)
V_r = void ratio of the stone trench (0.40 for VDOT Coarse-graded Aggregate)

The maximum allowable trench depth is therefore computed as:

$$d_{\max} = \frac{\left(1.35 \frac{in}{hr}\right)\left(\frac{1 ft}{12 in}\right)(48 hrs)}{0.40} = 13.5\, ft$$

Step 3b. Determine the Minimum Allowable Reservoir Depth

The bottom of the aggregate reservoir layer must be located below the frost line as specified by the Virginia Uniform Statewide Building Code. The frost line depth for the City of Charlottesville is 18 inches. Therefore, the bottom of the aggregate layer must extend to a depth of not less than 18 inches below the finished surface of the pavement.

Step 4. Compute the Required Reservoir Surface Area

The maximum loading ratio, defined as total drainage area to infiltration area is generally restricted to 6:1. The total parking lot area is 4.8 acres, therefore the minimum surface area of stone infiltration reservoir is computed as:

$$A_{\min} = \frac{4.8ac \times \frac{43{,}560\, ft^2}{ac}}{6} = 34{,}848\, ft^2$$

The surface area of the stone reservoir, along with its depth must provide storage for the computed water quality volume. Employing the minimum reservoir surface area, we compute the depth of the stone reservoir as:

$$d = \frac{WQV_{Design}}{(V_r)(A_{\min})} = \frac{17{,}424\, ft^3}{(0.40)(34{,}848\, ft^2)} = 1.25\, ft$$

The computed depth is less than the minimum allowable reservoir depth as stipulated by the local frost line depth (18 inches for the City of Charlottesville). Therefore, the reservoir depth is set at 18 inches.

Surface Area	34,848 ft^2
Depth	1.5 ft
Storage Volume*	20,909 ft^3

*Volume Based on Aggregate Porosity of 0.4

Table 10.3. Summary of Stone Reservoir Dimensions

Step 5. Provision for Overflow / Bypass

Because the design configuration presented in this example is a partial exfiltration system intended only to retain and infiltrate the water quality volume, provisions must be made for runoff events producing volumes in excess of this amount.

The overflow/bypass system will function as a conventional storm sewer system upon saturation of the stone reservoir layer. Therefore, the bypass system should be designed to carry a peak 10-year flow rate of 29.4 cfs (reference Table 10.2). The bypass system/storm sewer must discharge into an adequate receiving channel as defined by Regulation MS-19 in the Virginia Erosion and Sediment Control Handbook, (DCR, 1992, Et seq.). Existing natural channels conveying pre-development flows may be considered receiving channels if they satisfactorily meet the standards outlined in the VESCH MS-19. Unless unique site conditions mandate otherwise, receiving channels should be analyzed for overtopping during conveyance of the 10-year runoff producing event and for erosive potential under the 2-year event.

The bypass system may be constructed as shown in either Figure 10.1 or 10.2. In this example, the bypass will be designed as a PVC pipe placed on a 1.5 percent slope along the entire downstream edge of the stone reservoir. The pipe shall be perforated on its underside only. The bottom of the pipe will be placed at an elevation equal to the top surface of the stone reservoir layer (as shown in Figure 10.2). Therefore, flow will only enter the bypass system upon saturation of the stone reservoir layer Sizing of the underdrain pipe is accomplished by use of the Manning equation shown below:

$$Q = \frac{1.49}{n} \cdot AR_h^{\frac{2}{3}} \cdot S^{\frac{1}{2}}$$

A typical Manning's *n* value for PVC pipe is 0.009 (Mays, 2001). For a fixed discharge, *Q*, the minimum required diameter, *D*, of a circular pipe flowing full can be computed by the following equation:

$$D = \left[\frac{(Q)(n)}{0.463} \times \frac{1}{\sqrt{s}} \right]^{3/8}$$

D= Minimum Pipe Diameter (ft)
Q= Pipe Discharge (cfs)
n= Manning's Roughness Coefficient
s= Pipe slope (ft/ft)

The minimum pipe diameter required to convey the facility's 10-year runoff is therefore computed as:

$$D = \left[\frac{(29.4)(0.009)}{0.463} \times \frac{1}{\sqrt{0.015}} \right]^{3/8} = 1.78 - ft = 21.4 - inches$$

The underdrain pipe shall be 24 inches in diameter.

The 24" perforated PVC underdrain shall connect to a conventional stormwater conveyance system and carry runoff volumes in excess of the water quality volume to an adequate receiving channel.

A cross section of this porous section is presented in Figure 10.4.

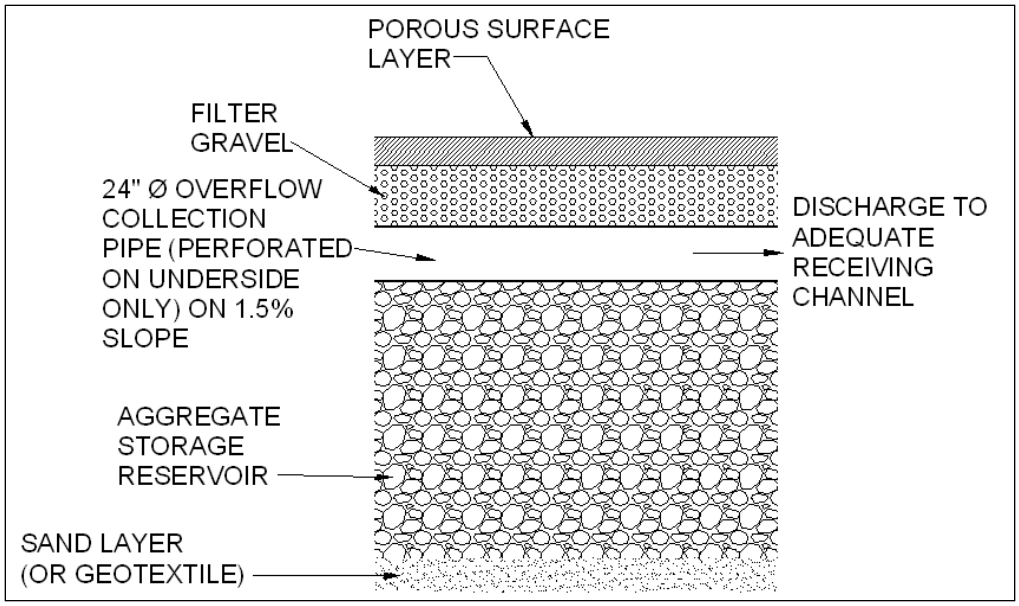

Figure 10.4. Profile Along Downstream Edge of Stone Reservoir

Course	Thickness (in)	Comments
Porous Surface	2.5-4	Permeability > 8 in/hr
Top Filter Course	1-2	1/2" diameter gravel
Underdrain Piping	24	Perforation on bottom side only
Stone Reservoir	17	Cleanly washed - 40% void space
Bottom Filter Course	2	1/2" diameter gravel
Filter Fabric*	N/A	MIRIFI #14 or equivalent
Undisturbed Soil	N/A	Min. Permeability 0.50 in/hr

* The filter fabric should be comprised of material approved by the VDOT Materials Division in accordance with all applicable DCR requirements.

Table 10.4. Summary of Porous Pavement Section