Chapter 12 –Stormwater Sand Filters

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

12.1 Overview of Practice

Stormwater sand filters are practices employed when the runoff from a site is expected to contain very high pollutant levels. These sand filters function by first pre-treating and temporarily storing runoff to remove the bulk of the large particle sediment, then percolating the runoff through the filter's sand media. As runoff filters through the sand media, water quality is improved through physical, chemical, and biological mechanisms. Various types of stormwater sand filters exist, and their application can be tailored to meet individual site needs. The most common types of stormwater sand filters are the Washington D.C. underground vault sand filter, the Delaware sand filter, and the Austin surface sand filter.

Stormwater sand filters act primarily as water quality BMPs; however, the water quality volume entering the filter is detained and released at a rate potentially capable of providing downstream channel erosion control. Peak rate control of the 10-year and greater storm events is typically beyond the capacity of a stormwater filtering system, and may require the use of a separate structural peak rate reduction facility.

Stormwater sand filters are commonly used in urbanized settings where entering runoff is generated from areas whose imperviousness ranges from 67 – 100 percent. The primary cause of failure in stormwater filtering systems is the clogging of the sand media through excessive sediment loading. The filters described in this document should not be used on sites having an impervious cover of less than 65 percent.

The Virginia Stormwater Management Handbook, (DCR, 1999, Et seq., Et seq.) identifies three types of stormwater stand filters appropriate for use in the state. These are the Washington D.C. Underground Vault Sand Filter, the Delaware Sand Filter, and the Austin Surface Sand Filter. Each filter type is described briefly in the following section.

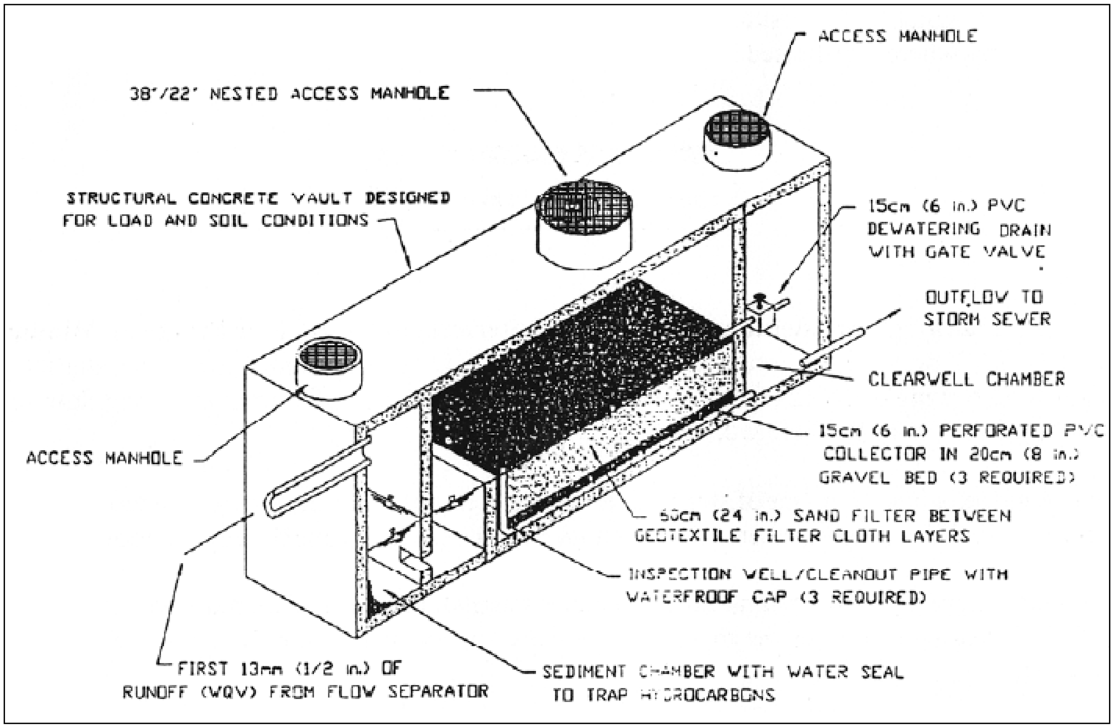

Figure 12.1. Washington D.C. Underground Vault Sand Filter
(Virginia Stormwater Management Handbook, 1999, Et seq.)

The Washington D.C. underground vault sand filter shown in Figure 12.1 can be either precast or cast in place and is composed of three chambers. The first chamber is a three foot deep "plunge pool" which absorbs energy and pre-treats runoff by trapping sediment and floating organic matter. The first chamber is hydraulically connected to the second chamber containing the sand filter media. Finally, the third chamber serves as a collection point for filtered runoff, where it is then directed to the downstream storm sewer. This type of filter is typically constructed *offline*, with only the site water quality volume directed to the structure.

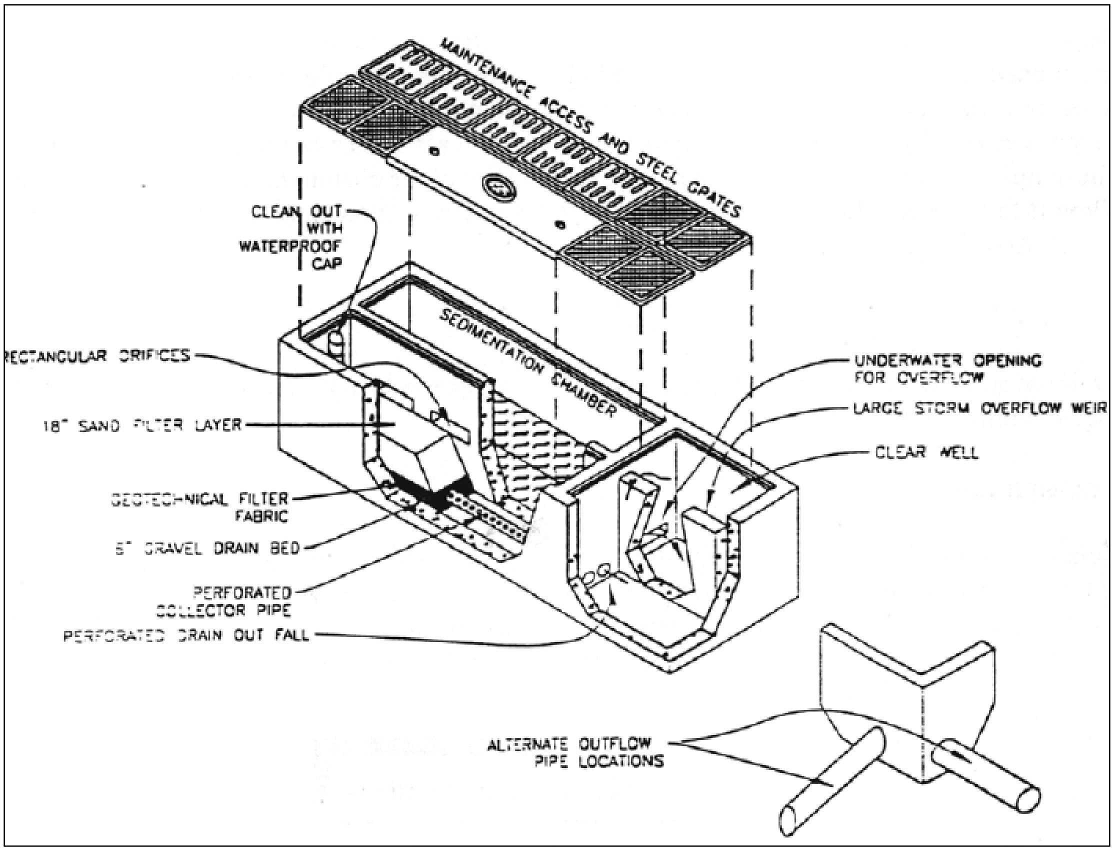

Figure 12.2. Delaware Sand Filter
(Virginia Stormwater Management Handbook, 1999, Et seq.)

The Delaware sand filter shown in Figure 12.2 was originally conceived as an *online* facility (unlike the Washington D.C. sand filter), processing all runoff leaving its contributing drainage shed up to the point that overflow is reached. When applied on VDOT projects, the Delaware sand filter should be equipped with a flow-splitting device such that only the site water quality volume is treated by the filter. The Delaware sand filter is characterized by two parallel chambers, one serving as pre-treatment sedimentation chamber and the other holding the sand filter media. The pre-treatment chamber holds a permanent pool analogous to that of a septic tank. Flow entering the pre-treatment chamber causes the water level in the chamber to rise and eventually spill into the filter chamber where full treatment occurs. Upon filtering through the sand media, treated runoff is collected in the clearwell located at the lower end of the structure. From there, the treated runoff is directed to the receiving storm sewer.

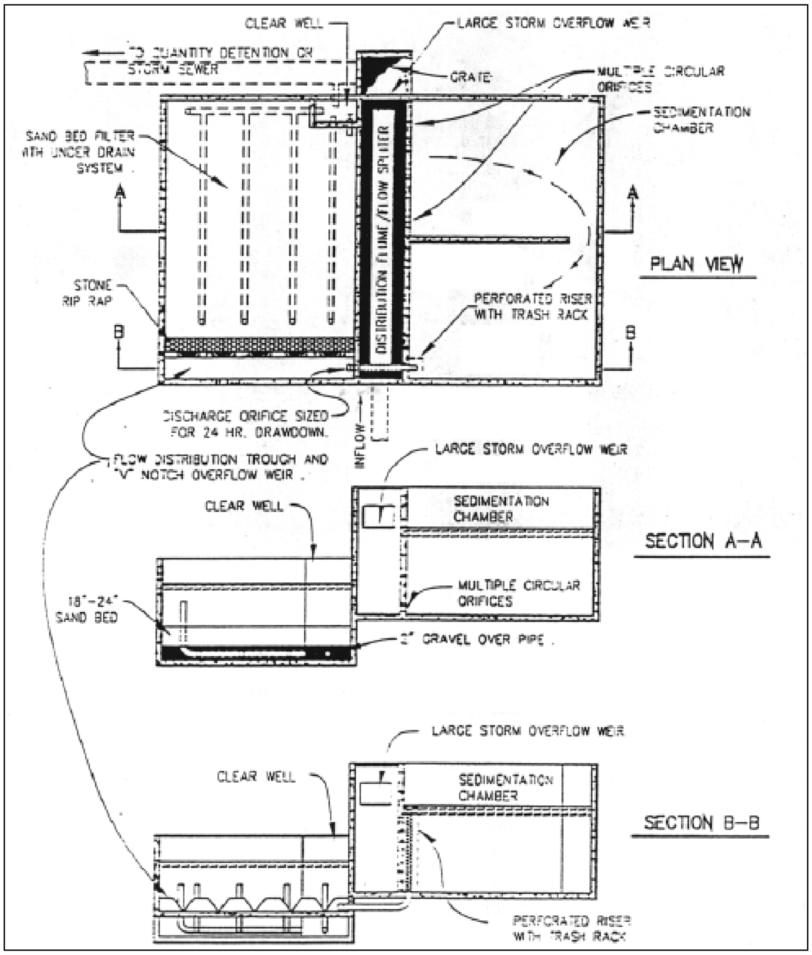

Figure 12.3. Austin Surface Sand Filter
(Virginia Stormwater Management Handbook, 1999, Et seq.)

The Austin surface sand filter, as shown in Figure 12.3, is composed of an open basin characterized by a pre-treatment sedimentation basin that is often large enough to hold the entire water quality volume from the contributing drainage shed. This volume is then released into the sand bed filtration chamber over a period of 24 hours. Alternative designs employ a much smaller sedimentation chamber, and compensate for the increased clogging potential by increasing the surface area of the filtration chamber. Typically, both chambers of the Austin filter are constructed of concrete; however, when soil conditions and/or the application of a geomembrane liner permit, the pre-treatment sedimentation chamber may be constructed into the ground.

12.2 Site Constraints and Siting of the Filter

The designer must consider a number of site constraints in addition to the contributing drainage area's impervious cover when a stormwater sand filter is proposed. These constraints are discussed as follows.

12.2.1 Minimum Drainage Area

The minimum drainage area contributing to an intermittent stormwater sand filter is not restricted. These types of filters are best suited to small drainage areas.

12.2.2 Maximum Drainage Area

The maximum drainage area to a single stormwater sand filter varies by filter type. Table 12.1 shows the impervious acreage which may be directed to a single filter, as a function of filter type.

Filter Type	Appropriate Drainage Shed (Impervious Acres)
D.C. Underground Vault	0.25 – 1.25
Delaware	1.25 Maximum
Austin Surface	Greater than 1.25

Table 12.1. Appropriate Drainage Area by Filter Type

Austin surface sand filters have been applied on sites with drainage areas as large as 30 acres; however on sites greater than 10 acres, despite a reduction in cost per volume of runoff treated arising from the economy of scale, the cost-effectiveness of an Austin sand filter is often poor when compared to alternative BMP options.

12.2.3 Elevation of Site Infrastructure

Whenever possible, stormwater filtering systems should be designed to operate exclusively by gravity flow. This requires close examination of the difference in elevation between the filter's discharge point (manhole, pipe, or receiving channel) and the storm sewer discharging runoff into the filter. This difference in elevation dictates the hydraulic head available on the filter while still remaining in a state of gravity flow. When the filter's clearwell discharge point is below the elevation of the downstream receiving point, an effluent pump is a viable alternative; however, this option requires routine scheduled maintenance by trained crews knowledgeable in the maintenance of such mechanical equipment.

12.2.4 Depth to Water Table and/or Bedrock

The liner or concrete shell of a sand filter should generally be located 2 to 4 feet above the site seasonally high water table. The presence of a high water table can flood the filter during construction. Additionally, placing a sand filter within the groundwater table may give rise to infiltration, thus flooding the filter and rendering it inoperable during periods of inflow. When it is deemed feasible and desirable to employ an intermittent sand filter on a site exhibiting a shallow groundwater table, the effects of infiltration and flotation must be accounted for. The liner or concrete shell of the filter must be waterproofed in accordance with the methods and materials specified by the Materials

Division. Additionally, buoyancy calculations must be performed and additional weight provided within the filter as necessary to prevent floatation.

12.2.5 Existing Utilities

Sand filters may be constructed over existing easements, provided permission to construct the facility over these easements is obtained from the utility owner *prior* to design.

12.2.6 Wetlands

When the construction of a sand filter 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 their vicinity.

12.2.7 Upstream Sediment Loading

The primary cause of filter failure is premature clogging arising from the presence of excessive sediment in the runoff directed to the filter. Therefore, runoff directed to stormwater filters should originate primarily from small impervious watersheds. In most applications, runoff flows through an open air "pretreatment" chamber prior to entering the filter chamber. This process allows large particles and debris to settle out. The filters described in this document should not be used on sites exhibiting an impervious cover of less than 65 percent.

12.2.8 Aesthetic Considerations

Stormwater sand filters provide an attractive BMP option on high profile sites where visually obtrusive BMPs such as extended dry detention facilities and other basins are undesirable. Typically, sand filtration BMPs are visually unobtrusive and may be located on sites where aesthetic considerations and/or the preservation of open space is deemed a priority.

12.2.9 Control of Surface Debris

Sand filters constructed as underground vaults often receive "Confined Space" designation under Occupational Safety and Health Administration (OSHA) regulations. Consequently, maintenance operations involving personnel entering the vault may become quite costly. In an effort to reduce the frequency of this type of maintenance operation, prevention of trash and other debris from entering the filter should be prioritized. This is accomplished through the use of trash racks and flow-splitting devices on offline facilities.

12.2.10 Hydrocarbon Loading

Sand filters are capable of receiving hydrocarbon-laden runoff; however, the facility owner must realize that such loading conditions will inevitably lead to rapid clogging of the filter media. When the presence of hydrocarbons is anticipated in the runoff entering a sand filter, the filter's pre-treatment chamber should be designed to remove unemulsified hydrocarbons prior to their entrance into the primary filter chamber. An alternative option is to provide an upstream "treatment train" composed of a BMP(s) capable of reducing the level of hydrocarbons present in the runoff entering the sand filter.

12.2.11 Perennial and Chlorinated Flows

Sand filters must not be subjected to continuous or very frequent flows. Such conditions will lead to anaerobic conditions which support the export of previously captured pollutants from the facility. Additionally, sand filters must not be subjected to chlorinated flows, such as those from swimming pools or saunas. The presence of elevated chlorine levels can potentially kill the desirable bacteria responsible for the majority of nitrogen uptake in the facility.

12.2.12 Surface Loading

Sand filters constructed as underground vaults must have their load-bearing capacity evaluated by a licensed structural engineer. This evaluation is of paramount importance when the filter is to be located under parking lots, driveways, roadways, or adjacent to highways.

12.3 General Design Guidelines

The following presents a collection of design issues to be considered when designing a sand filter for improvement of water quality.

12.3.1 Isolation of the Water Quality Volume (WQV)

Sand filters should have only the site water quality volume directed to them. In Virginia, this is also true for the Delaware sand filter which has traditionally been installed online with stormwater conveyance systems. The most popular means of isolating the water quality volume is through the use of a diversion weir in the manhole, channel, or pipe conveying runoff to the BMP. Typically, the elevation of this weir is set equal with the water surface elevation in the BMP when the water quality volume is present. This approach ensures that flows beyond the water quality volume bypass the filter and are conveyed downstream by the storm drainage system. It is noted that the flow-splitter or diversion weir is used to convey a designated *volume* of runoff into the filter rather than to simply regulate the flow *rate* into the filter. The diversion structure may be prefabricated, or cast in place during construction. A schematic illustration of the flow-splitting weir is shown as follows:

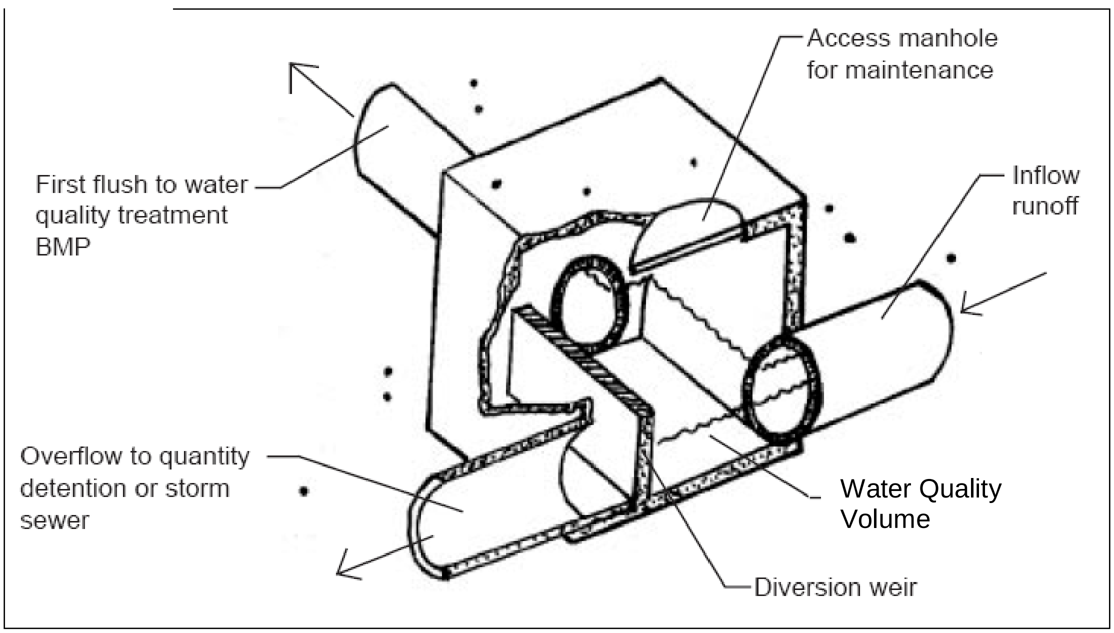

Figure 12.4. Flow-splitting Diversion Weir (Bell, Warren, 1993)

Typically, the construction of the diversion weir will place its crest elevation equal to the maximum allowable ponding depth on the sand filter. This results in flow over the diversion weir when runoff volumes greater than the computed water quality volume enter the stormwater conveyance channel. This configuration results in minimal mixing between the held water quality volume and flows from large runoff producing events in excess of this volume.

An alternative approach is to provide a “low flow” pipe leading directly from the upstream structure to the sand filter. Water enters the BMP through this low-flow conduit, and once the water level rises to that equal with the allowable ponding depth on the filter, flow is conveyed downstream by a bypass pipe located at a higher elevation. A schematic illustration of this configuration is shown as follows:

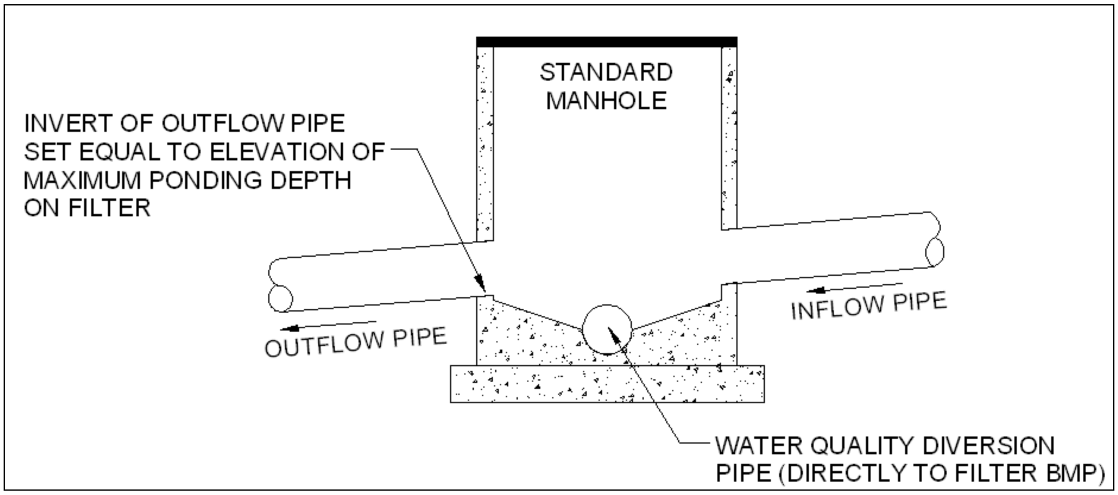

Figure 12.5. Flow-Splitting Manhole Structure

12.3.2 Sand Filter Media

The sand filter media of an intermittent sand filter should meet the specifications of VDOT Grade A Fine Aggregate or as otherwise approved by the Materials Division.

12.3.3 Discharge Flows

All filter outfalls 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.

12.3.4 Filter Sizing

Sand filters should be sized using a Darcy's Law approach, ensuring that the site water quality volume is filtered completely through the sand media within a maximum of 40 hours. Sizing the filter such that full drawdown of the water quality volume occurs within 40 hours ensures that aerobic conditions are maintained in the filter between storm events.

The coefficient of permeability of a filter's sand media may range as high as 3.0 feet/hour upon installation; however, due to filter clogging after only a few runoff producing events, the rate of permeability through the media has been observed to decrease considerably. Therefore, the coefficient of permeability employed in filter sizing calculations is a function of the degree to which pre-treatment is planned for the facility (full pre-treatment or partial pre-treatment). The following section presents specific sizing guidelines for each of the previously described types of sand filters in the context of a design scenario

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12.4 Design Process

This section presents the design process applicable to sand filters 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 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.

A design example is presented for each of the three aforementioned types of sand filter recommended for use in Virginia. The filter designs will meet the technology-based water quality requirements arising from a one-acre VDOT maintenance yard. The site water quality volume is directed into the filter by means of a diversion weir situated in the storm sewer. This example is an *offline* configuration. The design will include a Washington D.C. sand filter, a Delaware sand filter, and an Austin sand filter.

The total project site, including right-of-way and all permanent easements, consists of 1.0 acre. Pre and post-development land cover and hydrologic characteristics are summarized below in Table 12.2.

	Pre-Development	**Post-Development**
Project Area (acres)	1.0	1.0
Land Cover	Unimproved Grass Cover	1.0 acres impervious cover
Impervious Percentage	0	100

Table 12.2. Hydrologic Characteristics of Example Project Site

Site topography is such that the invert of the pipe exiting the sand filter from its clearwell chamber is 4.5 feet lower than the invert of the storm sewer pipe discharging runoff into the filter's pre-treatment chamber.

Step 1. Compute the Required Water Quality Volume

The project site's water quality volume is a function of the developed impervious area. This *basic* water quality volume is computed as follows:

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

IA= Impervious Area (ac.)

The project site in this example is composed of a total drainage area of 1.0 acres. The total impervious area within the site is 1.0 acres. Therefore, the *basic* water quality volume is computed as follows:

$$WQV = \frac{1.0ac \times \frac{1}{2}in}{12\frac{in}{ft}} = 0.042\,\mathrm{ac}\cdot ft \times \frac{43{,}560\,ft^2}{ac} = 1{,}830\,ft^3$$

Referencing Table 1.1, sand filters treating drainage sheds whose impervious fraction ranges between 67 and 100 percent should be sized for *twice* the basic water quality volume. Therefore, the filters in this example will be sized to treat a volume of 3,660 ft^3.

Upon evaluating various site constraints, cost, and maintenance considerations the designer will select which of the aforementioned types of sand filter best meets the site water quality needs. The following section demonstrates the sizing procedure for each of three types of intermittent sand filter.

Step 2A. Size Filter and Pre-Treatment Sedimentation Chamber – Washington D.C. Underground Vault Sand Filter

The variables expressed in the D.C. sand filter sizing equations are related to the following figure.

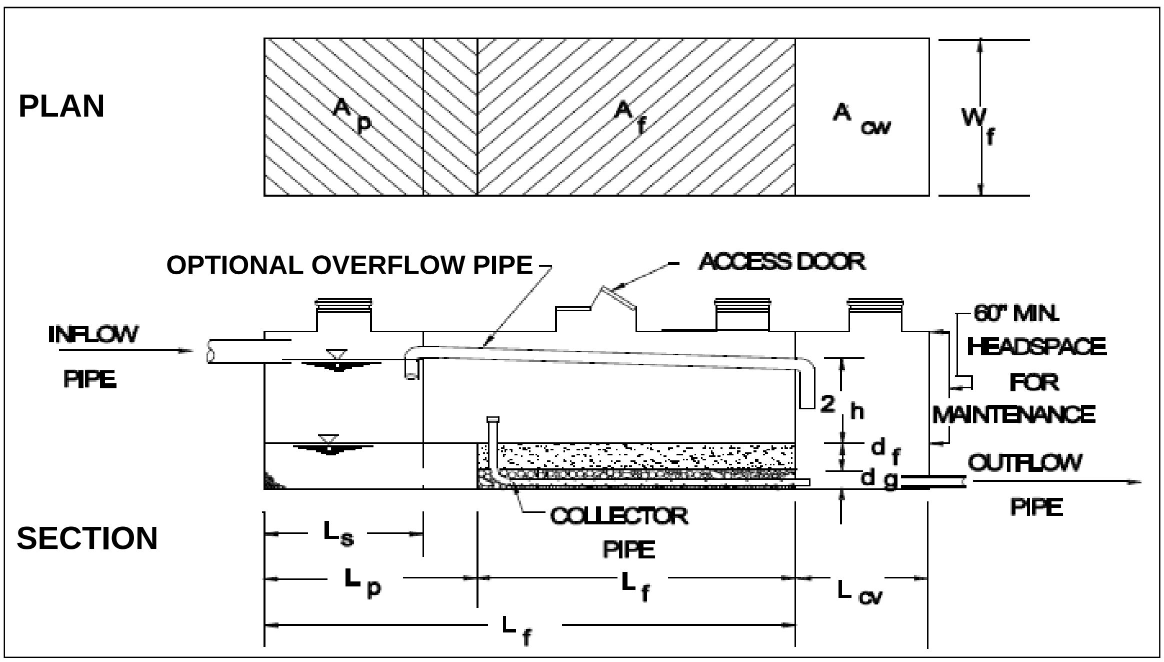

Figure 12.6. D.C. Sand Filter – Cross Section
(Virginia Stormwater Management Handbook, 1999, Et seq.)

The D.C. sand filter is a *partial pre-treatment* intermittent sand filter. The total surface area of the sand media is computed by the following equation:

$$A_f = \frac{545 I_a d_f}{\left(h + d_f\right)}$$

A_f= Minimum surface area of sand bed (square feet)
I_a= Impervious fraction of contributing drainage shed (acres)
d_f= Sand bed depth (typically 1.5 to 2.0 feet)
h= Average depth of water above surface of sand media (ft)

In this application, we will select a sand media depth of 2 feet. The sand filter media must be wrapped in a filter cloth approved by the Materials Division. Additionally, the sand layer is then underlain by a layer of ½ - 2 inch diameter washed gravel (10 inches thick) and overlain by a layer of 1 – 2 inch diameter washed gravel (1 – 2 inches thick).

The overall depth of all filter media is the sum of the sand media and the gravel underlay and overlay. This depth calculation is as follows:

$$d_m = d_f + d_g = 24in + 10in + 2in = 36in = 3\,ft$$

It was previously determined that the total elevation difference between the pipe discharging runoff into the filter and the pipe carrying effluent from the filter is 4.5 feet. Therefore, as shown in Figure 12.5, the *maximum* possible ponding depth, *2h*, on the filter is calculated by subtracting the total filter media depth from this total elevation difference:

$$2h = 4.5\,ft - 3\,ft = 1.5\,ft$$

Therefore, the average ponding depth on the filter, *h*, is determined to be *0.75 feet*.

The required surface area of the sand filter media is then computed as:

$$A_f = \frac{545(1.0ac)(2\,ft)}{(0.75\,ft + 2\,ft)} = 396.4\,ft^2$$

Next, the length and width of the filter are computed. This design will employ a rectangular configuration with at 2:1 length-to-width ratio.

$$L_f = 2W_f$$
$$2W_f^{\,2} = 396.4\,ft^2 \Rightarrow W_f = 14.1\,ft$$
$$L_f = 28.2\,ft$$

Rounding the computed dimensions to nominal values yields the following filter surface parameters:

L_f (ft)	W_f (ft)	A_f (ft2)
28.5	14	399

Table 12.3. D.C. Filter Surface Dimensions

The next step is to compute the maximum available storage volume on the surface of the filter, V_{Tf}. This is computed based on the filter surface area and the maximum possible ponding depth, *2h* (1.5 feet):

$$V_{Tf} = 399\,ft \times 1.5\,ft = 598.5\,ft^3$$

Next, the total storage volume provided in the void space of the gravel and sand media is computed. The porosity of the sand and gravel filter media is typically taken to be 40 percent.

$$V_V = 0.4 \times A_f \times \left(d_f + d_g\right)$$
$$V_V = 0.4 \times 399\,ft^2 \times \left(2\,ft + 1\,ft\right) = 478.8\,ft^3$$

The next step is to compute the volume of inflow that passes through the filter media while the total water quality volume is accumulating in the BMP. This calculation is based on a coefficient of permeability, *k*, of 2 ft/day (0.0833 ft/hr) for the sand media and a total filling time of one hour. The pass-through volume during filling is computed by the following equation:

$$V_Q = \frac{kA_f\left(d_f + h\right)}{d_f}$$

For the design parameters previously established, the pass-through volume is computed as:

$$V_Q = \frac{0.0833\frac{ft}{hr}\left(399\,ft^2\right)\left(2\,ft + 0.75\,ft\right)}{2\,ft} = 45.7\,ft^3$$

The volume which must be stored awaiting filtration is computed from the following equation:

$$V_{st} = WQV - V_{Tf} - V_V - V_Q$$

For the design parameters previously established, the required storage volume, V_{st}, is computed as:

$$V_{st} = 3{,}660\,ft^3 - 598.5\,ft^3 - 478.8\,ft^3 - 45.7\,ft^3 = 2{,}537\,ft^3$$

The volume to be stored awaiting filtration dictates sizing of the filter's permanent pool volume. The length of this pool is defined as L_p (see Figure 12.6), and is computed as follows:

$$L_p = \frac{V_{st}}{(2h \times W_f)}$$

For the design parameters previously established, the permanent pool length, is computed as:

$$L_p = \frac{2{,}537\, ft^3}{(1.5\, ft \times 14\, ft)} = 120.8\, ft$$

The next design step is to compute the length of the sedimentation chamber, L_s, to provide storage for 20 percent of the site water quality volume (standard for a partial pre-treatment practice). The length of the sedimentation chamber is computed by the following equation:

$$L_s = \frac{0.2WQV}{(2h \times W_f)}$$

For the design parameters previously established, the length of the filter's sedimentation chamber is computed as:

$$L_s = \frac{0.2 \times 3{,}660\, ft^3}{(1.5\, ft \times 14\, ft)} = 34.9\, ft$$

The final design step is to adjust the length of the permanent pool. If the computed length of the permanent pool is greater than the length of the sedimentation chamber plus 2 feet, then the permanent pool length is not adjusted; however, if the computed length of the permanent pool is less than the length of the sedimentation chamber plus 2 feet, the permanent pool length should be increased to dimensions of L_s + *2 feet*. In this example no adjustment is necessary.

Table 12.4 presents the final design summary of the Washington D.C. sand filter, with variables as defined in Figure 12.6.

Filter Length (L_f) ft	**Filter Width (W_f) ft**	**Filter Area (A_f) ft^2**	**Permanent Pool Length (L_p) ft**	**Sedimentation Chamber Length (L_s) ft**
28.5	14	399	120.8	34.9

Table 12.4. Design Summary – D.C. Sand Filter

Special Considerations for Implementation of a Washington D.C. Intermittent Sand Filter

- For maintenance access, a minimum of 60 inches of headroom is required in the sedimentation and filter chambers. In the filtration chamber, this headroom should be measured from the top of the filter media.

- Passage of flow from the sedimentation chamber to the filter chamber should occur through an opening located a minimum of 18 inches below the depth of the weir dividing the two chambers. The cross-sectional area of this opening should, at a minimum, be 1.5 times the area of the pipe(s) discharging into the BMP.

- The total depth of the filter media must at least equal the height of weir separating the sedimentation and filtration chambers

- The filtration bed's underdrain piping should consist of three 6-inch diameter schedule 40 perforated PVC pipes placed on 1 percent slope. Perforations should be 3/8 inch diameter with maximum spacing between perforated rows of 6 inches. The underdrain piping should be placed within the gravel filter media with a minimum of 2 inches of cover over the pipes.

- When the filter is placed underground, a dewatering drain controlled by a gate valve must be located between the filter chamber and the clearwell chamber.

- Access should be provided to each filter chamber through manholes of at least 22 inches in diameter.

Step 2B. Size Filter and Pre-Treatment Sedimentation Chamber – Delaware Sand Filter

The variables expressed in the Delaware sand filter sizing equations are related to the following figure:

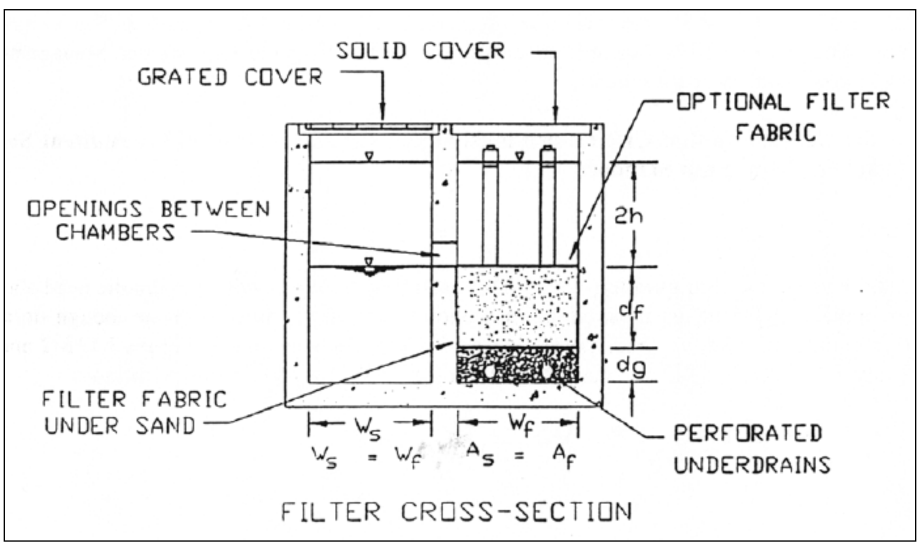

Figure 12.7. Delaware Sand Filter – Cross Section
(Virginia Stormwater Management Handbook, 1999, Et seq.)

The Delaware sand filter's shallow configuration typically results in minimal hydraulic head acting on the filter. This configuration makes the Delaware filter ideal on sites with limited elevation difference between filter inflow and outflow points. Depending on site-specific constraints, and the maximum available hydraulic head, one of two different equations governs sizing of the filter surface area.

If the maximum hydraulic head acting on the filter (*2h* as shown in Figure 12.7) is less than 2'-8", the following equation should be used to compute the minimum filter surface area:

$$A_f = \frac{WQV}{\left(4.1h + d_f\right)}$$

WQV= Water quality volume
A_f = Minimum surface area of sand bed (square feet)
d_f = Sand bed depth (typically 1.5 to 2.0 feet)
h = Average depth of water above surface of sand media (ft)

When the maximum available head is greater than 2'-8", the following equation governs sizing of the filter surface area:

$$A_f = \frac{545 I_a d_f}{\left(h + d_f\right)}$$

I_a = Impervious fraction of contributing drainage shed (acres)

It was previously determined that the total elevation difference between the pipe discharging runoff into the filter and the pipe carrying effluent from the filter is 4.5 feet. Therefore, the *maximum* possible ponding depth, *2h*, on the filter is calculated by subtracting the total filter media depth from this total elevation difference:

$$2h = 4.5\,ft - 3\,ft = 1.5\,ft$$

Therefore, the first equation applies as the available head on the filter is less than 2'-8". In this application, we will select a sand media depth of 2 feet. The average ponding depth on the filter, *h*, is determined to be *0.75 feet* and the filter surface area is computed as:

$$A_f = \frac{3{,}660\,ft^3}{\left((4.1)(0.75\,ft) + 2\,ft\right)} = 721.2\,ft^2$$

Next, the length and width of the filter are computed. This design will employ a rectangular configuration with a 2:1 length-to-width ratio.

$$L_f = 2W_f$$
$$2W_f^{\ 2} = 721.2\,ft^2 \Rightarrow W_f = 19.0\,ft$$
$$L_f = 38.0\,ft$$

Rounding the computed dimensions to nominal values yields the following filter surface parameters:

L_f (ft)	W_f (ft)	A_f (ft2)
38	19	722

Table 12.5. Delaware Filter Surface Dimensions

The Delaware sand filter is characterized by two parallel chambers, one serving as a pre-treatment sedimentation chamber and the other holding the sand filter media. The dimensions of the sedimentation chamber (L_s, W_s, and A_s) are identical to those of the filtration chamber shown in Table 12.5.

Special Considerations for Implementation of a Delaware Intermittent Sand Filter

- The filtration bed's underdrain piping should consist of two 4-inch diameter schedule 40 perforated PVC pipes placed on 1 percent slope. Perforations should be 3/8 inch diameter, minimum 4 holes per row, and row spacing a maximum of 6 inches. The underdrain piping should be placed within the gravel filter media with a minimum of 2 inches of cover over the pipes.

- Weepholes are recommended between the filter chamber and the clearwell to permit draining if the underdrain piping should fail or become clogged.

- It is recommended that the sand filter media be wrapped in a filter cloth approved by the Materials Division. Additionally, the sand layer should be underlain by a layer of ½ - 2 inch diameter washed gravel (10 inches thick) and overlain by a layer of 1 – 2 inch diameter washed gravel (1 – 2 inches thick).

Step 2C. Size Filter and Pre-Treatment Sedimentation Chamber – Austin Surface Sand Filter

The Austin sand filter can be designed for full or partial pre-treatment of sediment. Full pre-treatment of inflow is characterized by capturing and detaining the entire WQV and releasing it into the filtration chamber over a period of not less than 24 hours. Partial pre-treatment of sediment entails providing pre-treatment storage for 20 percent of the WQV in a sedimentation chamber hydraulically connected to the filtration chamber (as with the D.C. and Delaware sand filters). Sizing of the sand media is a direct function of the volume of pre-treatment. The following equations govern filter sizing:

Filters equipped with full pre-treatment of inflow: $A_f = \dfrac{100\,ft^2}{\text{Acre Treated}}$

Filters equipped with partial pre-treatment of inflow: $A_f = \dfrac{545 I_a d_f}{\left(h + d_f\right)}$

This design example will employ full pre-treatment of inflow. Therefore, the required filter area is computed as:

$$A_f = \frac{100\,ft^2}{acre} \times 1 acre = 100\,ft^2$$

Austin sand filters should be sized with a minimum length-to-width ratio of 2:1. Employing this ratio, the following dimensions are computed for the filter:

$$L_f = 2W_f$$
$$2{W_f}^2 = 100\,ft^2 \Rightarrow W_f = 7.1\,ft$$
$$L_f = 14.2\,ft$$

Rounding the computed dimensions to nominal values yields the following filter surface parameters:

L_f (ft)	W_f (ft)	A_f (ft2)
14.5	7	101.5

Table 12.6. Austin Filter Surface Dimensions

The next step is to size the pre-treatment sedimentation chamber. The surface area of the sedimentation basin is calculated from the Camp-Hazen equation as shown:

$$A_s = \frac{Q_o}{W} \times \left[- ln\left(1 - E\right)\right]$$

With: A_s = sedimentation basin surface area (ft^2)

Q_o = discharge rate from basin (WQV / 24hr)

$= \dfrac{ft^3}{24hr} x \dfrac{1hr}{3600s} = cfs$; where WQV = water quality volume in ft^3

W = particle settling velocity (ft/sec)

E = ediment trapping efficiency of suspended solids (90 percent)

The particle settling velocity is a function of the impervious area contributing to the filtering practice. The following values are used in sizing the pretreatment basin:

Impervious Percentage	Particle Settling Velocity (ft/sec)
≤75	0.0004
>75	0.0033

Table 12.7. Particle Settling Velocities (MDE, 2000)

The filter under design will serve a site with 100 percent impervious cover. Therefore, the filter area is computed as:

$$A_s = \frac{3{,}660\,ft^3}{24hour} \times \frac{1hr}{3{,}600\sec} \times \frac{1}{0.0033} \times \left[-\ln(1-0.9)\right] = 29.6\,ft^2$$

Pre-treatment must be provided for the entire WQV. Therefore, the depth of the sedimentation chamber is computed as:

$$d_s = \frac{3{,}660\,ft^3}{29.6\,ft^2} = 123.6\,ft$$

The depth of a sedimentation chamber should not exceed 10 feet. When the Camp-Hazen approach yields depths exceeding 10 feet, the following equation should be used to size the filter's pre-treatment chamber:

$$A_s = \frac{WQV}{10\,ft}$$

$$A_s = \frac{3{,}660}{10\,ft} = 366\,ft^2$$

The filter pre-treatment chamber will be located parallel to the filter sedimentation chamber as shown in Figure 12.3. Therefore, the length of the pre-treatment chamber is set equal to the length of the sedimentation chamber, 14.5 feet. The width of the pre-treatment chamber is then computed as follows:

$$W_s = \frac{366\,ft^2}{14.5\,ft} = 25.2\,ft$$

Table 12.8 presents a design summary of the Austin sand filter.

Filter Length (L_f) ft	Filter Width (W_f) ft	Filter Area (A_f) ft^2	Sedimentation Chamber Length (L_s) ft	Sedimentation Chamber Width (W_s) ft
14.5	7	101.5	14.5	25.2

Table 12.8. Design Summary – Austin Sand Filter

The next step is to design an outlet configuration that will discharge the WQV from the pre-treatment chamber to the sedimentation chamber over a period of not less than 24 hours. Typically this conveyance occurs through a perforated stand pipe as shown in Figure 12.3. Control of flow should be dictated by a throttle plate or other flow-restricting mechanism, *not* the perforations in the stand pipe. The following steps illustrate sizing of the orifice.

Discharge of the water quality volume from the pre-treatment chamber to the filter chamber must occur over a period of not less than 24 hours. The Virginia Stormwater Management Handbook identifies two methods for sizing a water quality release orifice. The VDOT preferred method is METHOD 2, "average head/average discharge."

The water quality volume is attained at a ponded depth of 10 feet in the pre-treatment chamber, therefore the average head associated with this volume is computed as:

$$h_{avg} = \frac{10\,ft}{2} = 5\,ft$$

$$Q_{avg} = \frac{WQV}{(24hr)(3{,}600\sec/hr)} = \frac{3{,}660\,ft^3}{(24hr)(3{,}600\sec/hr)} = 0.04cfs$$

Next, the orifice equation is rearranged and used to compute the required orifice diameter.

$$Q = Ca\sqrt{2gh}$$

Q = discharge (cfs)
C = orifice Coefficient (0.6)
a = orifice Area (ft^2)
g = gravitational acceleration (32.2 ft/sec^2)
h = head (ft)

The head is estimated as that acting upon the *invert* of the water quality orifice when the total water quality volume of 1,830 ft^3 is present in the chamber. While the orifice equation should employ the head acting upon the center of the orifice, the orifice diameter is presently unknown. Therefore, the head acting upon the orifice invert is used. The small error incurred from this assumption does not compromise the usefulness of the results.

Rearranging the orifice equation, the orifice area is computed as

$$a = \frac{Q_{avg}}{C\sqrt{2gh}} = \frac{0.04}{0.6\sqrt{(2)(32.2)(5)}} = 0.004\,ft^2$$

The diameter is then computed as:

$$d = \sqrt{\frac{4a}{\pi}} = \sqrt{\frac{(4)(0.004)}{3.14}} = 0.071\,ft = 0.852in$$

An orifice with an outlet diameter of 0.75 inches will be employed to release the water quality volume into the filter chamber over the minimum 24-hour period.

Special Considerations for Implementation of an Austin Intermittent Sand Filter

- The depth of the sand filter media should range between 18 and 24 inches
- When constructed as an underground vault, a minimum of 60 inches of headroom is required in the sedimentation and filter chambers. In the filtration chamber, this headroom should be measured from the top of the filter media.
- The minimum length-to-width ratio of the filter chamber is 2:1.
- The pre-treatment sedimentation chamber should include a sediment sump for accumulation and subsequent removal of filtered sediment.

Step 3. Establish the Crest Elevation of the Water Quality Diversion Weir

The intermittent sand filters presented in this design should have *only* the site water quality volume directed to them. The most popular means of isolating the water quality volume is through the use of a diversion weir in the manhole, channel, or pipe conveying runoff to the BMP. The crest elevation of the weir should be set equal with the water surface elevation corresponding to the maximum available ponding depth on the filter(s), *2h*, as previously defined. This approach ensures that flows beyond the water quality volume bypass the filter and are conveyed downstream by the storm drainage system with minimal mixing of the water quality volume held in the BMP. The weir and downstream receiving structures should typically be sized to accommodate the 10-year return frequency storm.