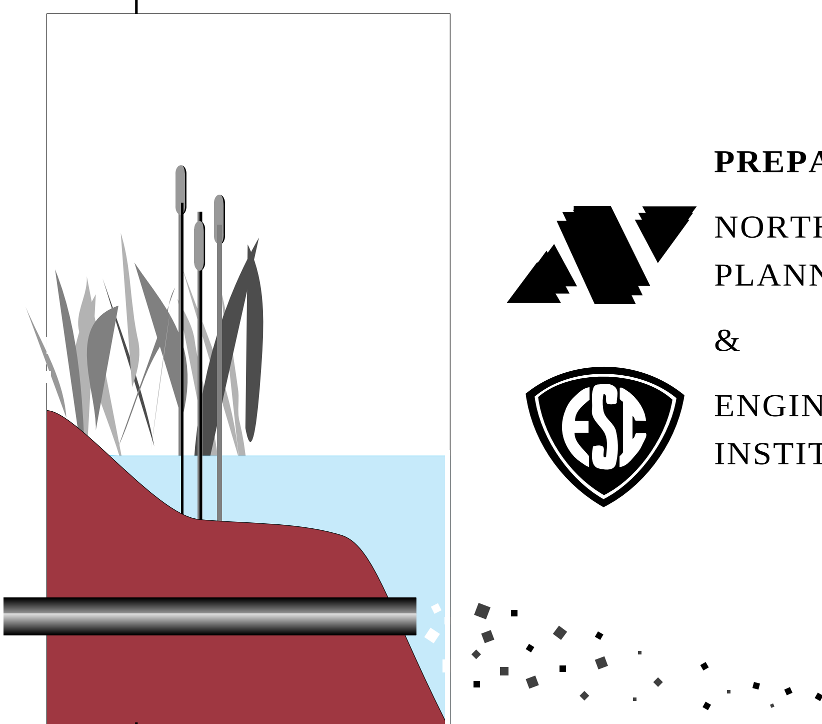
NORTHERN VIRGINIA BMP HANDBOOK
A D D E N D U M

S A N D   F I L T R A T I O N   S Y S T E M S



PREPARED BY

NORTHERN VIRGINIA
PLANNING DISTRICT COMMISSION

&

ENGINEERS AND SURVEYORS
INSTITUTE

January 12, 1996

ABSTRACT

TITLE: Northern Virginia BMP Handbook Addendum: Sand Filtration Systems

AUTHOR: Northern Virginia Planning District Commission (NVPDC)
Engineers and Surveyors Institute (ESI)

SUBJECT: Information, recommendations, and design aids for Sand Filtration System (SFS) Best Management Practices (BMPs) which are used to improve water quality by preventing pollutants from entering major water courses.

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SOURCES OF COPIES: Northern Virginia Planning District Commission
7535 Little River Turnpike, Suite 100
Annandale, Virginia 22003

Telephone: (703) 642-0700
FAX: (703) 642-5077

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ABSTRACT:

The purpose of this addendum is to remove Chapter 7, Section B "Water Quality Inlet/Oil Grit Separators" from the *Northern Virginia BMP Handbook* and to add "Sand Filtration Systems" to Chapter 4. Recent local studies have shown both water quality inlets (oil/grit separators) and underground extended detention to be ineffective water quality BMPs. Water quality inlets and underground extended detention are no longer acceptable BMPs in participating Northern Virginia jurisdictions unless specifically required. Conditions requiring oil/grit separators for spill control will not be affected. Additionally, underground detention for the sole purpose of peak shaving continues to be acceptable.

Sand filtration systems are relatively new to the field of stormwater quality control although the basic principles have been used extensively in the design of systems for water purification and sewage treatment. These systems have been modified to provide stormwater quality control and are particularly well adapted to highly impervious areas where space is at a premium and phosphorus removal rates must be maximized. The three basic types of sand filters addressed in the addendum are designated by the areas where they were first developed: Austin (Texas), Delaware, and the District of Columbia.

These sand filter designs were first incorporated in the *Alexandria Supplement to the Northern Virginia BMP Handbook*. The Alexandria designs have been reviewed by the ESI Joint Public/Private BMP Handbook Committee and stormwater staff from Northern Virginia jurisdictions and have been modified to provide standardization and simplification. Sand filters are recommended for areas 1.5 acres or less and greater than 65% imperviousness.

NORTHERN VIRGINIA BMP HANDBOOK

ADDENDUM

Sand Filtration Systems

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Requirements for Plan Submission

The basic requirements for a BMP plan submission in Northern Virginia are listed below. The designer should check with the individual jurisdiction in which the BMP is to be built for specific plan submission requirements.

1) A brief narrative summarizing how water quality control requirements are being provided for the site.

2) A map showing all subareas used in the computation of weighted average “C” factors, BMP storage, and phosphorus removal including offsite areas, open space, and uncontrolled areas.

3) Open space used for BMP credit should be delineated on the plan sheets with the note: “Water quality management area. BMP credit allowed for open space. No use or disturbance of this area is permitted without the express written permission of (insert local jurisdiction)."

4) Open space used for BMP credit which is not already in a flood plain easement should be placed in a conservation easement with metes and bounds shown on the plat.

5) Computations used to determine BMP outflow rates and size outlet structures.

6) Computation of BMP facility storage requirements.

7) Computation of BMP phosphorus removal for the site.

8) Computation of BMP site coverage.

9) A statement of maintenance responsibility for each BMP (public or private) should be stated on the plans.

Additional information may be required by the director of the plan review agency to justify the use of privately maintained nonstandard designs or in unusual circumstances. The following list indicates the agencies responsible for the review of BMP plans for further questions regarding submission requirements.

The *Northern Virginia BMP Handbook* provides general design and planning guidance for designers and reviewers of BMPs in Northern Virginia. It also presents a format for the presentation of BMP design computations required with development plan submissions. However, it should be noted that each individual jurisdiction's public facilities manual (PFM), or its equivalent, ultimately governs the design of facilities which are constructed for the purpose of meeting stormwater quality requirements. Each jurisdiction's PFM is the source reference guide for the designer and in the case of conflicting guidance with the Handbook, the PFM will prevail. It should be recognized that stormwater quality technology, design criteria, and requirements, as well as federal, state, and local laws and regulations, may periodically change. NVPDC and ESI will make every attempt to keep purchasers and recipients of the Handbook informed of these changes.

In all cases, it is advisable and necessary for users of the Handbook to consult the local PFM in conjunction with the Handbook. The following departments are responsible for BMP review in each jurisdiction and should be consulted prior to plan submission.

Local Agencies Responsible for BMP Plan Review

Jurisdiction	Agency	Phone Number
City of Alexandria	Department of Transportation and Environmental Services	838-4327
Arlington County	Department of Public Works	338-3629
Town of Dumfries	General	221-4133
City of Fairfax	Department of Public Works	385-7820
Fairfax County	Department of Environmental Management, Special Projects Branch	324-1700
City of Falls Church	Department of Public Works	241-5080
Fauquier County	Department of Community Development	347-8660
Town of Herndon	Department of Public Works	435-6853
Town of Leesburg	Department of Public Works	771-2790
Loudoun County	Department of Building and Development	777-0397
City of Manassas	Department of Public Works	257-8252
City of Manassas Park	Department of Public Works	257-8372
Prince William County	Department of Public Works, Watershed Management Division	792-7070
Town of Vienna	Department of Public Works	255-6381

I. Introduction to Sand Filtration Systems as BMPs

Sand filtration systems are relatively new to the field of stormwater quality control although the basic principles have been used extensively in the design of systems for water purification and sewage treatment. These systems have been modified to provide stormwater quality control and are particularly well adapted to highly impervious areas where space is at a premium and phosphorus removal rates must be maximized. The three basic types of sand filters are designated by the areas where they were first developed: Austin (Texas), Delaware, and the District of Columbia. These sand filter designs were incorporated in the *Alexandria Supplement to the Northern Virginia BMP Handbook*. The designs contained herein have been further modified from the Alexandria designs to provide standardization and simplification. Sand filters are recommended for areas 1.5 acres or less and greater than 65% imperviousness.

Sand filtration systems are intended to replace both water quality inlets (oil/grit separators) and underground extended detention. Recent local studies have shown both to be ineffective BMPs. Water quality inlets (oil/grit separators) and underground extended detention are no longer acceptable BMPs in participating Northern Virginia jurisdictions unless specifically required. Conditions requiring oil/grit separators for spill control will not be affected. Additionally, underground detention for the sole purpose of peak shaving continues to be acceptable.

II. Isolating the Water Quality Volume

Stormwater quality management in the ultra-urban environment involves the collection, pretreatment, storage, and treatment to remove pollutants of a specific quantity from the most polluted stormwater. Figure 1 illustrates this off-line ultra-urban BMP concept. In Virginia, the minimum quantity of stormwater to be treated is the first one-half inch of runoff from the impervious areas on the site — the Water Quality Volume (WQV).

The WQV may be computed using data from the following equation:

$$WQV = I_a \times 43{,}560 \times 0.0417 \qquad (1)$$

where:

WQV	=	the Water Quality Volume in cubic feet,
I_a	=	the area of impervious surface on the contributing watershed in acres,
43,560	=	the number of square feet in an acre, and
0.0417	=	the first half-inch of runoff in feet.

Reducing the constants yields:

$$WQV = 1816(I_a) \qquad (2)$$

Capture and isolation of the WQV is typically achieved by isolation and diversion baffles and weirs. A typical approach for achieving isolation of the WQV is to construct an isolation/diversion weir in the stormwater channel or pipe such that the height of the weir equals the heights of the water in the BMP when the entire WQV is being held. When additional runoff greater than the WQV enters the stormwater channel or pipe, it will spill over the isolation/diversion weir, and mixing with water stored in the BMP will be minimal. Figure 2 shows two examples of these structures.

In many instances, it may be more efficient to build a flow splitter/bypass facility into the structure of the BMP itself by providing an overflow weir or orifice, or a bypass pipe, which conveys overflow from a collection/sedimentation chamber to a clearwell and then to the storm sewer. Where retention of hydrocarbons is a concern, provision of a hooded (inverted elbow) pipe or orifice, or the use of a commercial catch basin trap, is usually required. Inverted elbows or catchbasin traps should penetrate the pool surface by 1/3 of the pool depth and no less than one foot.

For ultra-urban BMPs, bypass weirs, orifices, or pipes will be designed to pass the peak flow rate of the 10-year storm (5 min. T_c).

When designing overflow weirs, size the weir using the formula:

$$Q_{10} = 3.0LH^{1.5} \quad (3)$$

where:

Q_{10}	=	peak flow rate for the 10-year storm in cubic feet per second,
H	=	the depth of ponded water above the crest of the weir in feet, and
L	=	length of the weir in feet.

When a hooded overflow orifice is employed, size the overflow using the orifice formula:

$$Q_{10} = C_dA(2gh_{10})^{0.5} \quad (4)$$

where:

Q_{10}	=	peak flow rate for the 10-year storm in cubic feet per second,
g	=	acceleration of gravity (32.2 ft/sec.^{2}),
C_d	=	coefficient of discharge (0.60),
A	=	area of the orifice in square feet, and
h_{10}	=	depth of ponded water above the flow line of the orifice in feet.

When a bypass pipe is employed, use Manning's equation to size the overflow pipe:

$$V = \frac{1.49}{n} \times (R_h^{0.667})(S^{0.5}) \quad (5)$$

where:

V	=	velocity of flow in feet per second (fps),
n	=	roughness coefficient (use 0.013 for concrete, DIP, and PVC pipe, and 0.024 for corrugated metal),
S	=	slope of pipe (energy gradient)x(minimum 0.005), and
R_h	=	the hydraulic radius in feet = cross-sectional area of the pipe in square feet divided by the inside circumference of the pipe (wetted perimeter) in feet.

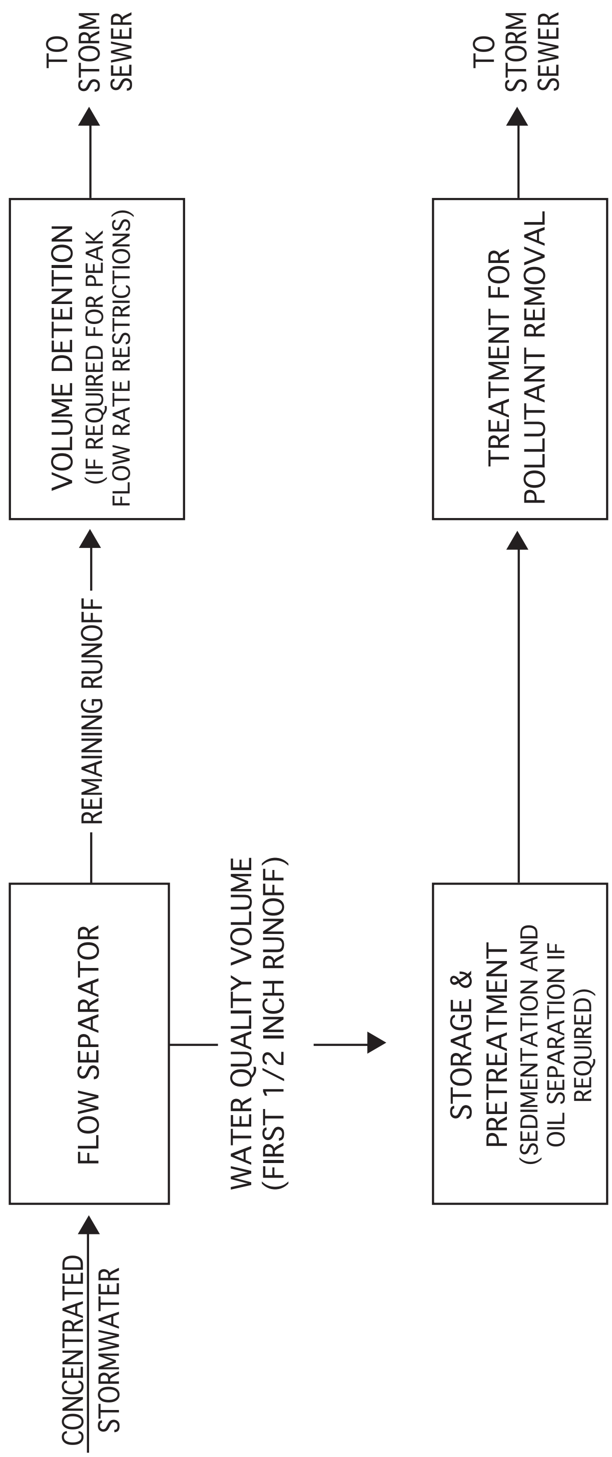
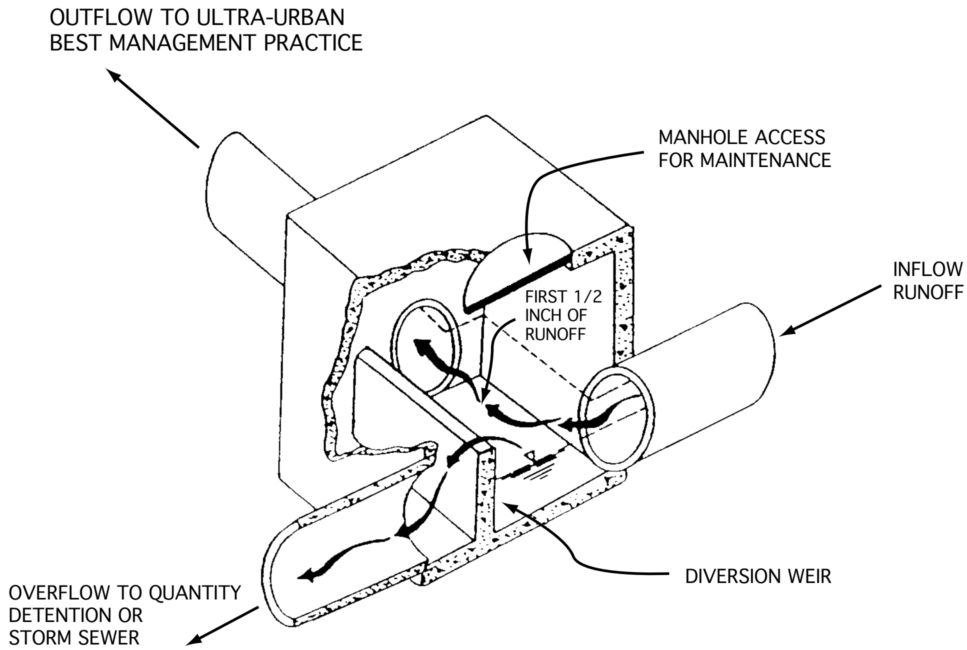
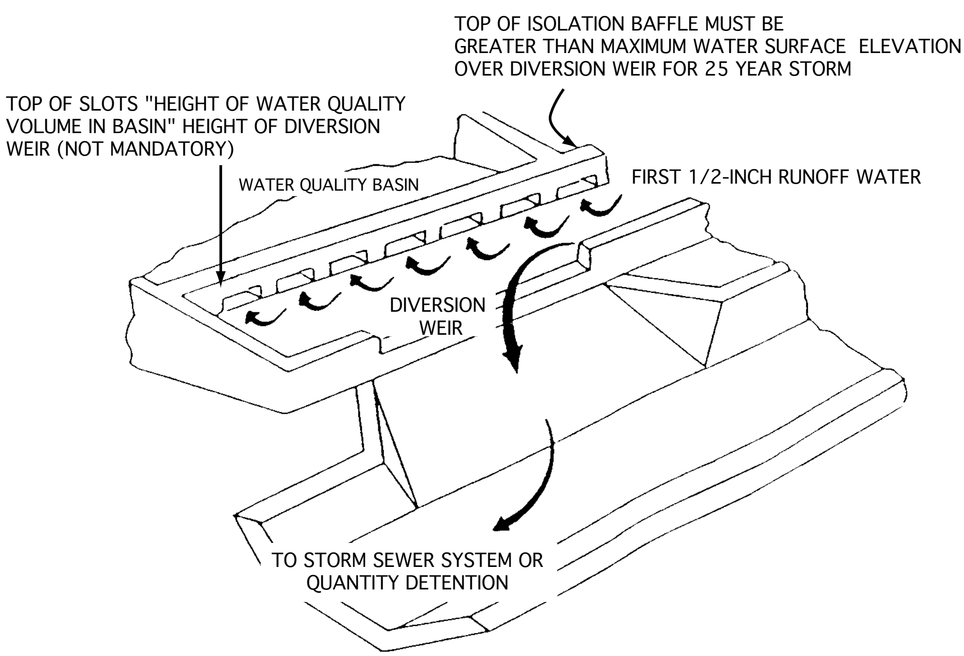


Figure 1: General Configuration of an Off-Line Ultra-Urban BMP
(Source: City of Alexandria, 1992)



PIPE INTERCEPTOR ISOLATION/DIVERSION STRUCTURE



SURFACE CHANNEL INTERCEPTOR ISOLATION/DIVERSION STRUCTURE

Figure 2: Examples of Isolation/Diversion Structure
(Source: Austin, Texas)

III. Austin Sand Filtration Systems

A) Facility Description

The City of Austin, Texas, and the State of Florida have used similar basin sand filtration systems as stormwater BMPs for a number of years. Basin sand filters (BSFs) may be constructed inside a concrete shell, or, where conditions allow, be built directly into the terrain over a geomembrane.

In order to ensure the long-term effectiveness and sand filtration systems, it is necessary to protect the filter media from excessive sediment loadings. The WQV runoff must therefore be routed through a sedimentation basin before treatment in the filtration basin; subsequent additional runoff can be diverted to a stormwater detention basin if required to comply with the peak flow runoff restrictions. Figure 3 illustrates this general configuration. Austin specifies two possible configurations of stormwater sand filtration systems:

1) Configuration 1 (Full Sedimentation)
   In this configuration, sedimentation occurs in a presettling basin designed to hold the entire WQV and release it to the filtration basin over an extended draw-down period.

2) Configuration 2 (Partial Sedimentation)
   This will be considered only if space limitations will not allow full sedimentation. In this configuration, the sedimentation chamber holds a minimum of 20 percent of the WQV and does not incorporate an extended draw-down period. This removes the heavier sediment and trash litter only and requires more intensive maintenance than the full sedimentation system. In order to compensate for the more rapid clogging of the filter media, a larger filter area is also required.

Sand filter systems for use as BMPs should be sized using the Austin Sand Filter Formula:

$$A_f = \frac{I_a H d_f}{k(h + d_f)t_f} \qquad (6)$$

where:

A_f	=	surface area of sand bed (acres or square feet),
I_a	=	impervious drainage area contributing runoff to the basin (acres or square feet),
H	=	runoff depth to be treated in feet,
d_f	=	sand bed depth in feet,
k	=	coefficient of permeability for sand filter in feet per hour,
h	=	average depth of water above surface of sand media between full and empty basin conditions in feet (1/2 max. depth), and
t_f	=	time required for runoff volume to pass through filter media in hours.

The equation was derived from Darcy's Law by the Austin Environmental and Conservation Services Department. The following values are used when designing sand filter systems:

I_aH	=	the Water Quality Volume (WQV in ft.^{3} = 1816 I_a; I_a in acres),
t_f	=	40 hours (maximum),
k_{fs}	=	3.5 feet per day for systems with full sedimentation protection preceding the filter (at least 95% silt removal efficiency when computed by the Camp-Hazen equation or when treating roof water only), and
k_{ps}	=	2 feet per day for systems with less than full sedimentation protection preceding the filter.

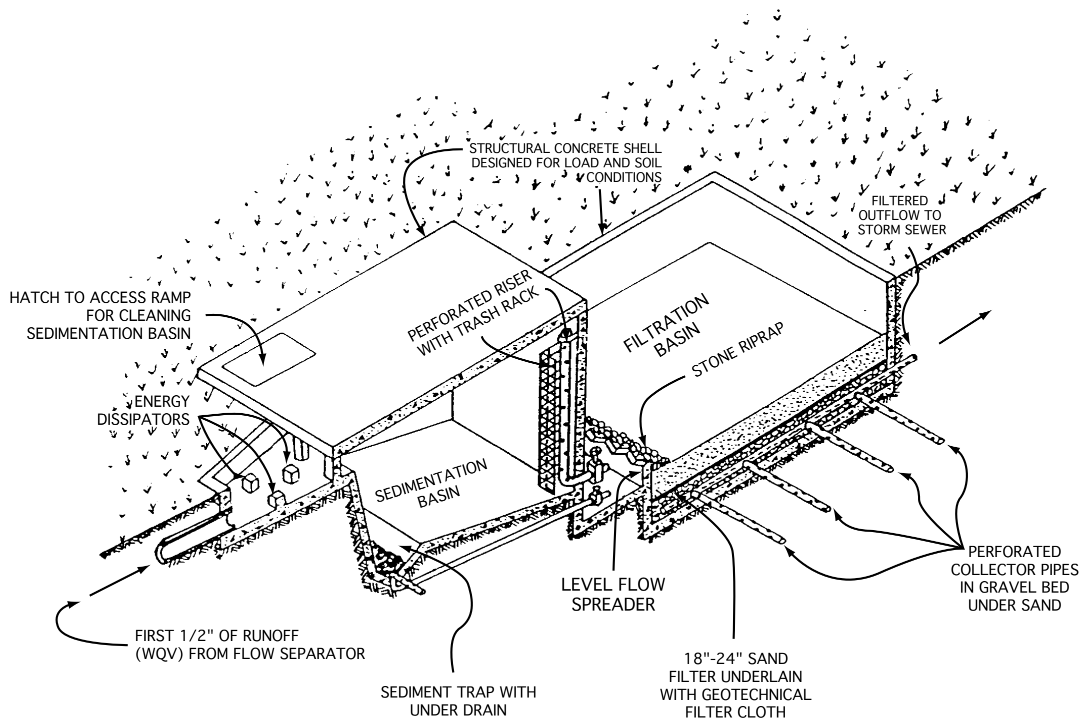


Figure 3a: Austin Sand Filter with Full Sedimentation Protection
(Source: Austin, Texas)

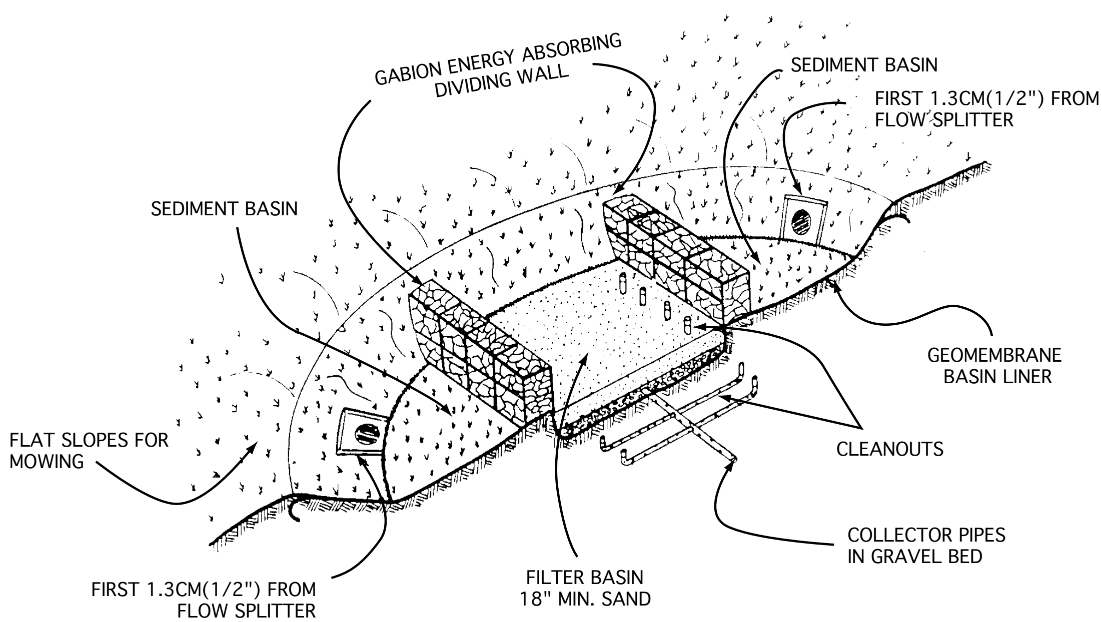


Figure 3b: Austin Sand Filter with Partial Sedimentation Protection
(Source: Austin, Texas)

These “k” values were computed by Austin engineers based on observations of the actual performance of that city’s sand filtration basins.

With the specified “k” values, the formula for sand filter systems with full sedimentation protection reduces to:

$$A_{f(FS)} = \frac{310 I_a d_f}{(h + d_f)} \tag{7}$$

where A_f is in square feet and I_a is in acres.

For sand filter systems with partial sedimentation protection, the formula reduces to:

$$A_{f(PS)} = \frac{545 I_a d_f}{(h + d_f)} \tag{8}$$

where A_f is in square feet and I_a is in acres.

B) Design Procedures for Full Sedimentation with Filtration

In this configuration, the sedimentation basin receives the WQV and detains it for a minimum draw-down time (time required to empty the basin from a full WQV condition) of 24 hours. The effluent from the sedimentation basin is discharged into the filtration basin.

1) Basin Surface Areas

For filtration basins, surface area is the primary design parameter. The required surface area is a function of sand permeability, bed depth, hydraulic head and sediment loading. A filtration rate of 0.0545 gallons per minute per square foot has been selected for design criteria (10.5 feet per day or 3.4 million gallons per acre per day). This filtration rate is based on a Darcy’s Law coefficient of permeability k = 3.5 feet per day, an average hydraulic head (h) of three (3) feet and a sand bed depth (d_f) of 18 inches, and a filter drawdown time, t_f of 40 hours. For further information on how the filtration rate and coefficient of permeability were determined the reader is encouraged to obtain a copy of the *Alexandria Supplement to the Northern Virginia BMP Handbook*.

Substituting these values in the basic Austin Filter Formula (equation 6) yields:

$$A_f = I_a H/18 \tag{9}$$

where:

A_f = the minimum surface area of the filtration media in acres,
I_a = the contributing impervious runoff area in acres, and
H = the runoff depth in feet (0.5 inch = 0.0417 feet when treating the WQV).

When treating the water quality volume, these formulae reduce to:

$$A_f = 0.0023 I_a \tag{10}$$

When designing for parameter values (h, d_f, runoff volumes, t_d, etc.) differing from those assumed by Austin, revert to the basic Austin Filter Formulae (equations 6, 7, 8) and the Camp-Hazen Equation.

2) Basin Volumes

The storage capacity of the sedimentation basin should be greater than or equal to the water quality volume. It is recommended that a minimum 0.5 foot of freeboard above the maximum water surface elevation be provided.

The storage capacity of the filtration basin, above the surface of the filter media, should be greater than or equal to 20 percent of the water quality volume. This capacity is necessary in order to account for backwater effects resulting from partially clogged filter media.

3) Sedimentation Basin Details

The sedimentation basin consists of an inlet structure, outlet structure, and basin liner. Impermeable basin liners are not required unless facilities are located in groundwater recharge areas, or where infiltration may cause slope instability or affect building foundations. The sedimentation basin design should maximize the distance from where the heavier sediment is deposited near the inlet to where the outlet structure is located. This will improve basin performance and reduce maintenance requirements.

Inlet Structure - The inlet structure design must be adequate for isolating the water quality volume from the 10-year design storm and to convey the peak flow for the 10-year design storm past the basin. The water quality volume should be discharged uniformly and at low velocity into the sedimentation basin in order to maintain near quiescent conditions which are necessary for effective treatment. It is desirable for the heavier suspended material to drop out near the front of the basin. Energy dissipation devices may be necessary in order to reduce inlet velocities which exceed three (3) feet per second.

Outlet Structure - The outlet structure conveys the water quality volume from the sedimentation basin to the filtration basin. The outlet structure should be designed to provide for a minimum draw-down time of 24 hours.

Basin Liner - Impermeable liners may be either clay, concrete, or geomembrane. If geomembrane is used, suitable geotextile fabric should be placed below and on top of the membrane for puncture protection. Clay liners should meet the following specifications:

Table 1: Clay Liner Specifications
(Source: City of Austin)

Property	Test Method	Unit	Specification
Permeability	ASTM D-24340	cm./sec.	$1x10^{-6}$
Plasticity Index of Clay	ASTM D-423 & D-424	%	Not less than 15
Liquid Limit of Clay	ASTM D-2216	%	Not less than 30
Clay Particles Passing	ASTM D-422	%	Not less than 30
Clay Compaction	ASTM D-2216	%	95% of Standard Proctor Density

The clay liner should have a minimum thickness of 12 inches.

If a geomembrane liner is used it should have a minimum thickness of 30 mils and be ultraviolet resistant.

The geotextile fabric (for protection of geomembrane) should meet the following specifications:

Property	Test Method	Unit	Specification
Material	Nonwoven geotextile fabric		
Unit Weight		Oz./Sq.Yd.	8 (min.)
Filtration Rate		In/Sec	0.08 (min.)
Puncture Strength	ASTM D-751 (Modified)	Lb.	125 (min.)
Mullen Burst Strength	ASTM D-751	PSI	400 (min.)
Tensile Strength	ASTM D-1682	Lb.	300 (min.)
Equiv. Opening Size	US Standard Sieve	No.	80 (min.)

Concrete liners may be used for sedimentation chambers and for sedimentation and filtration basins. Concrete should be at least five (5) inch thick Class A3 and should be appropriately reinforced. An ordinary surface finish is required. Bedding is required in accordance with VDOT standards or as directed by the structural engineer. Where visible, the concrete should be inspected annually and all cracks should be sealed.

Basin Geometry - The shape of the sedimentation basin and the flow regime within this basin will influence how effectively the basin volume is utilized in the sedimentation process. The length to width ratio of the basin should be 2:1 or greater. Inlet and outlet structures should be located at extreme ends of the basin in order to maximize particle settling opportunities.

Short-circuiting flow (i.e., flow reaching the outlet structure before it passes through the sedimentation basin volume) should be avoided. Dead storage areas (areas within the basin which are by-passed by the flow regime and are, therefore, ineffective in the settling process) should be minimized. Baffles may be used to mitigate short-circuiting and/or dead storage problems. Figure 4 illustrates basin geometry considerations and the use of baffles to improve sedimentation basin performance.

Sediment Trap (Optional) - A sediment trap is a storage area which captures sediment and removes it from the basin flow regime. In so doing the sediment trap inhibits resuspension of solids during subsequent runoff events, improving long-term removal efficiency. The trap also maintains adequate volume to hold the water quality volume which would otherwise be partially lost due to sediment storage. Sediment traps may reduce maintenance requirements by reducing the frequency of sediment removal. It is recommended that the sediment trap volume be equal to ten (10) percent of the sedimentation basin volume.

Water collected in the sediment trap should be conveyed to the filtration basin in order to prevent standing water conditions from occurring. All water collected in the sediment trap should drain out within 60 hours. The invert of the drain pipe should be above the surface of the sand bed filtration basin. The minimum grading of the piping to the filtration basin should be 1/4 inch per foot (two (2) percent slope). Access for cleaning the sediment trap drain system is necessary. Figure 5 illustrates sediment trap details.

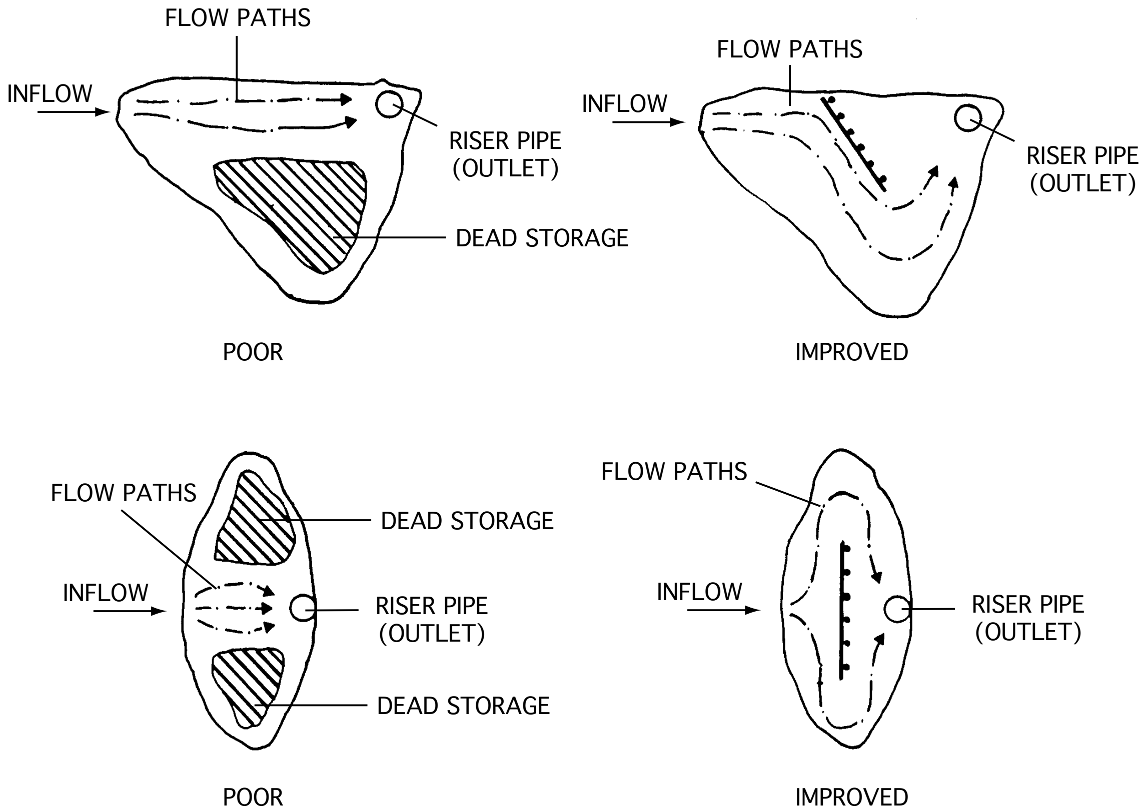


Figure 4: Sedimentation Basin Baffles
(Source: Austin, Texas)

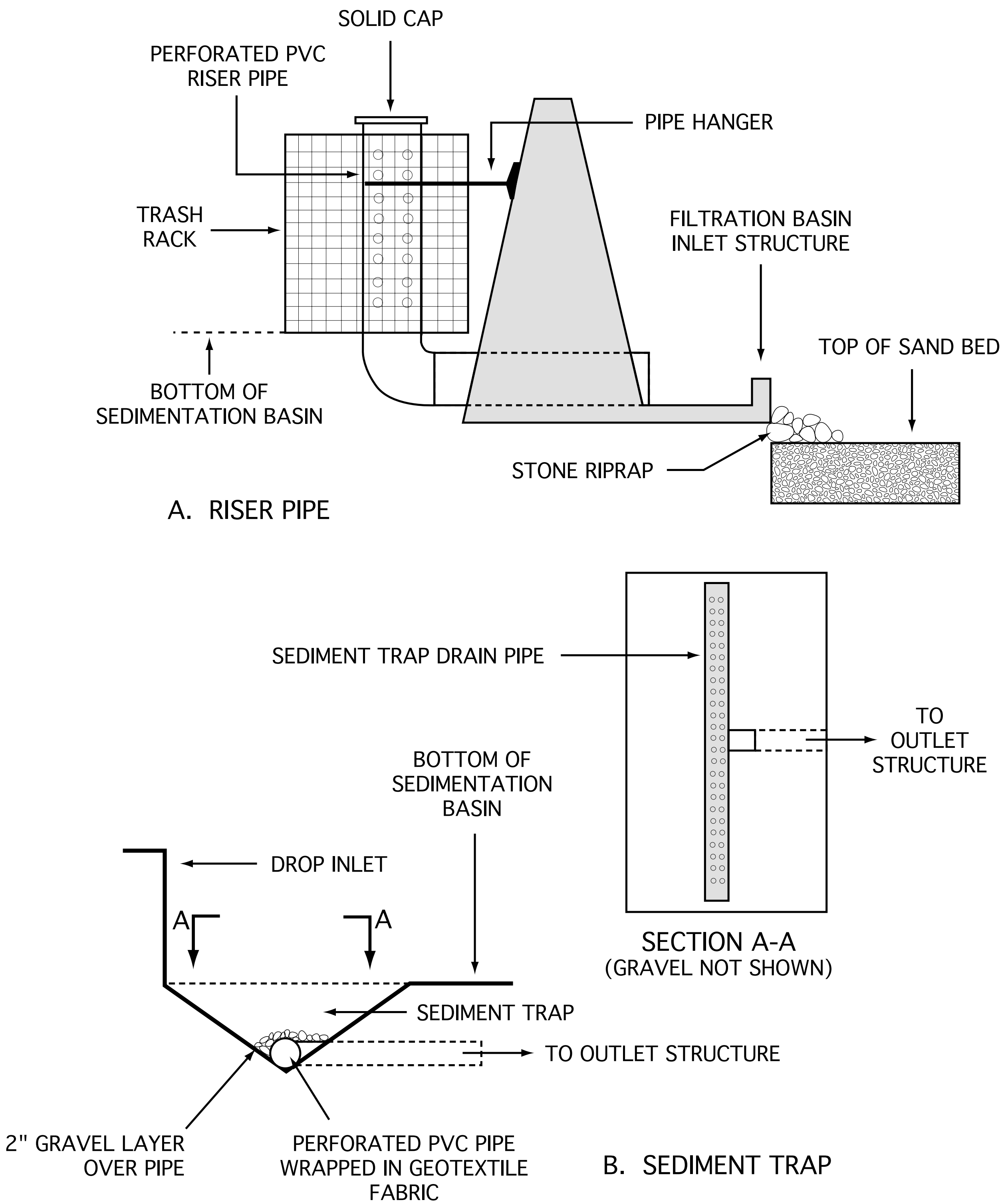


Figure 5: Example Riser Pipe and Sediment Trap Details
(Source: Austin, Texas)

Maintenance Access Ramp - Provision must be made to allow equipment access for removing accumulated sediments. An equipment access ramp should be provided along one wall of the sediment basin to allow the use of at least compact front-end loaders such as "Bobcats."

4) Sand Filtration Basin Details

The sand bed filtration system consists of the inlet structure, sand bed, underdrain piping, and basin liner.

Inlet Structure - The inlet structure should spread the flow uniformly across the surface of the filter media. Flow spreaders, weirs, or multiple orifice openings are recommended.

Upper Stone Layer - The washed stone layer at the top of the filter should be two inches thick and meet VDOT #57 stone specifications or ASTM equivalent (1 inch maximum diameter).

Geotechnical Fabric - The filter fabric beneath the two-inch layer of stone on top of the filter should be Enkadrain 9120 filter fabric or equivalent with the following specifications:

Property	Test Method	Unit	Specification
Material	Nonwoven geotextile fabric		
Unit Weight	ASTM D-1777	Oz./sq.yd.	4.3 (min.)
Flow Rate	Falling Head Test	GPM/sq.ft.	120 (min.)
Puncture Strength	ASTM D-751 (Modified)	Lb.	60 (min.)
Thickness		in.	0.8 (min.)

Sand Bed - Filter bed sand should meet the requirements of ASTM C-33 Concrete Sand or VDOT section 202 Grade A Fine Aggregate Sand. The sand bed must be level and may be a choice of one of the two configurations given below.

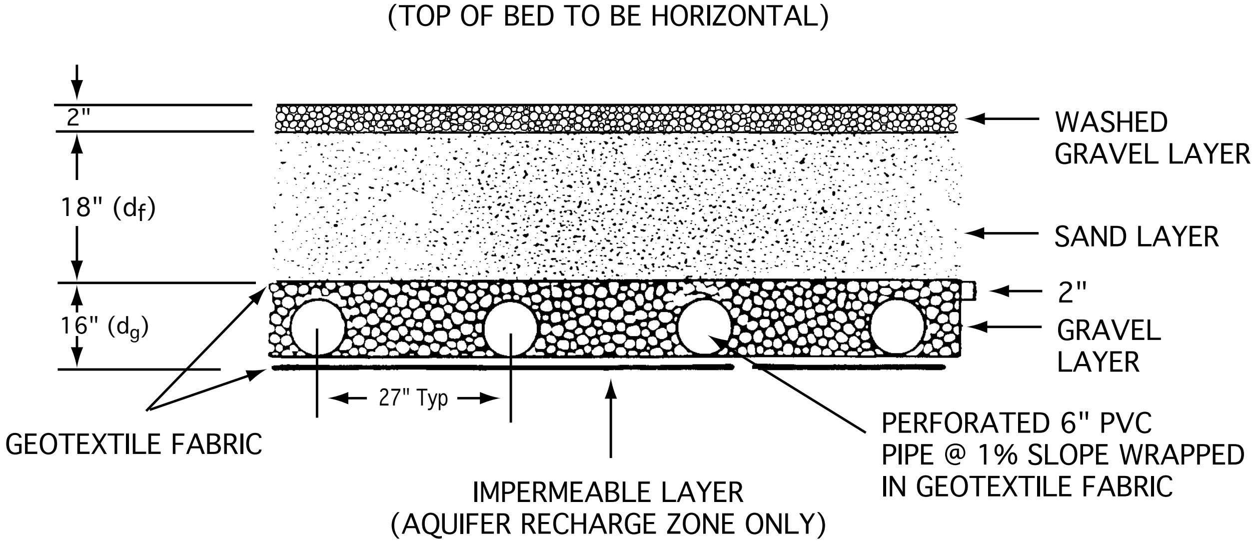
Note: Sand bed depths are final, compacted depths. Consolidation effects must be taken into account.

Sand Bed with Gravel Layer (Figure 6) - The top layer should be a minimum of 18 inches of sand. Under the sand a 16 inch thick layer of 1/2 to two (2) inch diameter stone (VDOT #57) which provides a minimum of two (2) inches of cover over the top of the underdrain lateral pipes. No stone is required under the lateral pipes. The sand and stone must be separated by a layer of geotextile fabric meeting the specifications listed above under "Basin Liner."

The laterals should be underlain by a layer of draining matting and the pipes wrapped in geotextile fabric. The geotextile fabric is needed to prevent the filter media from infiltrating into the lateral piping.

The drainage matting is needed to provide for adequate vertical and horizontal hydraulic conductivity to the laterals. The geotextile fabric specifications are listed below under "Basin Liner." The drainage matting specifications are listed in Table 2.

Figure 6: Sand Bed Filtration Configuration
(Source: Austin, Texas)



SAND BED PROFILE (WITH GRAVEL FILTER)

Table 2: Drainage Matting Specifications
(Source: City of Austin)

Property	Test Method	Unit	Specification
Material	Nonwoven geotextile fabric		
Unit Weight		Oz./Sq.Yd.	20
Flow Rate (fabric)		GPM/Ft^2	180 (min.)
Permeability	ASTM D-2434	Cm/Sec	12.4×10^{-2}
Grab Strength (fabric)	ASTM D-1682	Lb.	Dry Lg.90 Dry Wd:70 Wet Lg.95 Wet Wd:70
Puncture Strength (fabric)	COE CV-02215	Lb.	42 (min.)
Mullen Burst Strength	ASTM D-1117	PSI	140 (min.)
Equiv. Opening Size	US Standard Sieve	No.	100 (70-120)
Flow Rate (drainage core)	Drexel Univ. Text Method	GPM/ft.width	14

Underdrain Piping - The underdrain piping consists of the main collector pipe(s) and perforated lateral branch pipes. The piping should be reinforced to withstand the weight of the overburden. Internal diameters of lateral branch pipes should be six (6) inches or greater and perforations should be 3/8 inch. Each row of perforations should contain at least six (6) holes and the maximum spacing between rows of perforations should be six (6) inches. All piping is to be schedule 40 polyvinyl chloride or greater strength. The minimum grade of piping should be 1/8 inch per foot (one (1) percent slope). Access for cleaning all underdrain piping is needed.

Note: No draw-down time is to be associated with sand filtration basins, only with sedimentation basins. Thus, it is not necessary to have a specially designed orifice for the filtration outlet structure.

Basin Liner - If an impermeable liner is required it should meet the specifications given on page 8 under "Basin Liner." If an impermeable liner is not required, then a geotextile fabric liner should be installed which meets the specifications listed above under "Basin Liner" unless the pond has been excavated to bedrock.

C) Design Considerations for Partial Sedimentation with Filtration (will be considered only if space limitations will not allow a full sedimentation design)

In this system a sediment chamber is located in front of the filtration basin. The purpose of the settling chamber is to remove larger suspended material (e.g., sand and trash litter), thus it only serves as a partial sedimentation basin. The sediment chamber is not required to hold the entire water quality volume and will not incorporate an extended draw-down period. The sediment chamber is typically separated from the filtration basin by a berm or wall with flow spreading outlets installed, or by a gabion. Figure 7 illustrates this system.

1) Basin Surface Areas and Volume

A filtration rate of .0312 gallons per minute per square foot has been selected for design criteria (six (6) feet per day or two (2) million gallons per acre per day). This filtration rate is based on a Darcy's Law coefficient of permeability of two (2) feet per day, an average hydraulic head of three (3) feet, a sand bed depth of 18 inches, and a filter drawdown time (t_f) of 40 hours. This filtration rate is less than that assumed for the filtration basin in the full sedimentation-filtration system due to higher sediment loading and consequent clogging of the filter media. The *Alexandria Supplement to the Northern Virginia BMP Handbook* contains a detailed explanation of how the filtration rate and coefficient of permeability were determined.

The following equation gives the minimum surface area required for the filtration basin:

$$A_f = I_a H/10 \qquad (11)$$

where:

A_f = the required surface area of the media in acres,
I_a = the impervious area in the drainage area, in acres, contributing runoff to the filtration basin, and
H = the runoff depth in feet (0.5 inch = 0.0417 feet when treating the water quality volume).

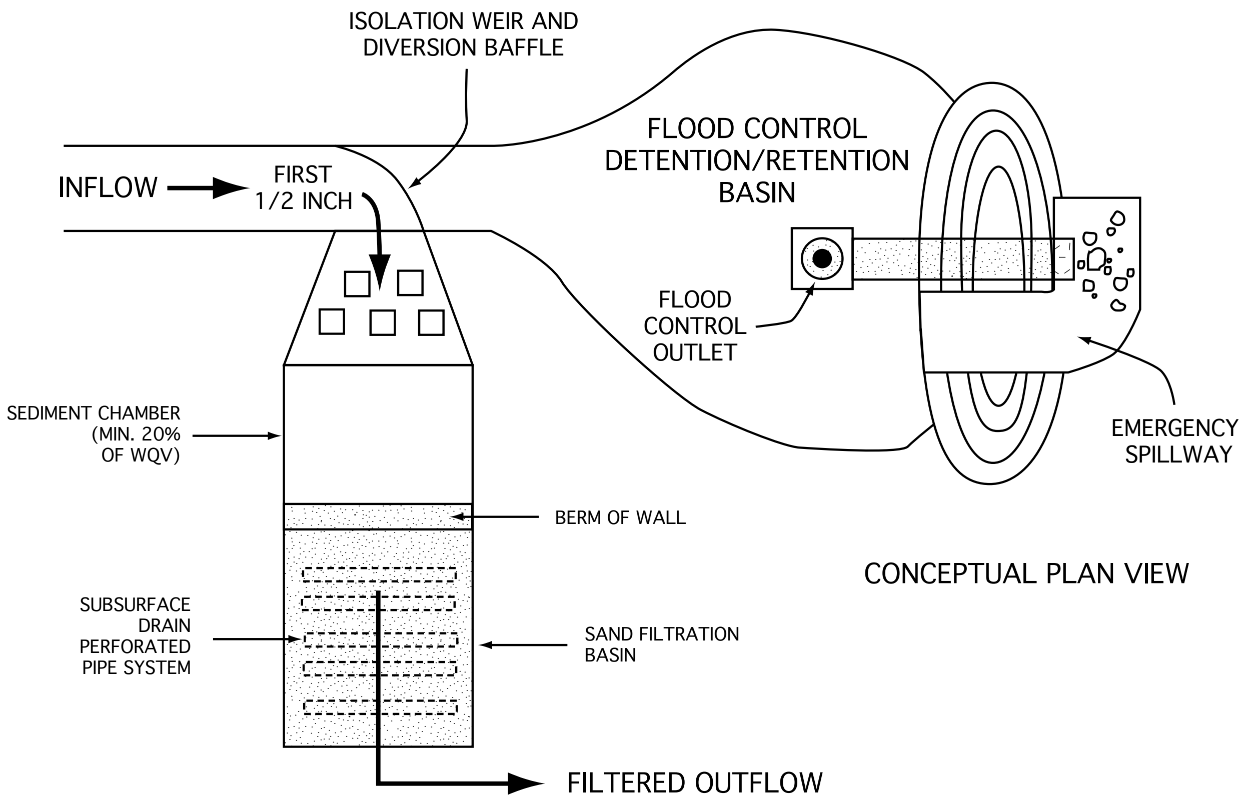


Figure 7: Partial Sedimentation-Filtration (Plan View)
(Source: Austin, Texas)

When treating the WQV, this reduces to:

$$A_f = 0.0042 I_a \tag{12}$$

When designing for parameter values differing from those assumed by Austin, use the partial sedimentation (PS) Austin Filter Formula (equation 8). The combined volume of the sediment chamber and filtration basin must be equal to the water quality volume, i.e., $V_s + V_f$ = WQV when V_s is the settling chamber volume and V_f is the filtration basin volume.

The surface area for the sediment chamber, A_s, is found by dividing the volume of the chamber, V_s, by its depth D_s. D_s can be assumed to equal D_f where D_f is the depth of the filtration basin.

The following equation has been derived to give the sediment chamber average surface area.

$$A_s = I_a H \left[\frac{1}{D_s} - \frac{1}{10} \right] \tag{13}$$

where:

A_s	=	the sediment chamber surface area in acres,
I_a	=	the contributing impervious drainage area in acres,
H	=	the runoff depth in feet (0.5 inch = 0.0417 feet), and
D_s	=	the sediment chamber basin depth in feet (= Df, the filtration basin depth).

The volume of the sediment chamber, V_s, should be a minimum of 20 percent of the water quality volume. The design should ensure that under no circumstances does the sediment chamber allow water to return to the isolation/diversion structure, i.e., isolation of the water quality volume must be ensured. Figure 8 provides alternative solutions to sizing the basin.

2) Sediment Basin Details

The sediment basin consists of an inlet structure, outlet structure, and basin liner.

Inlet Structure - See Inlet Structures under Full Sedimentation above.

Outlet Structure - The outlet structure should be a berm or wall with multiple outlet ports or a gabion so as to discharge the flow evenly to the filtration basin. Rock gabions should be constructed using 6-8 inch diameter rocks. The berm/wall/gabion height should not exceed six (6) feet and high flows should be allowed to overtop the structure (weir flow). Outlet ports should not be located along the vertical center axis of the berm/wall so as to induce flow-spreading. The outflow side should incorporate features to prevent gouging of the sand media (e.g., concrete splash pad or riprap). Figure 9 illustrates these design considerations.

Basin Liner - Same as for Full Sedimentation.

3) Sand Filtration Basin Details (same as for Full Sedimentation)

D) Maintenance and Construction Requirements

The developer/owner must check with the individual jurisdiction in which the facility is being constructed for their specific maintenance requirements. In Fairfax County, for example, a Maintenance Agreement with the County concerning the site stormwater quantity/quality management facilities must be executed by the developer/owner before the Final Site Plan for the construction will be approved.

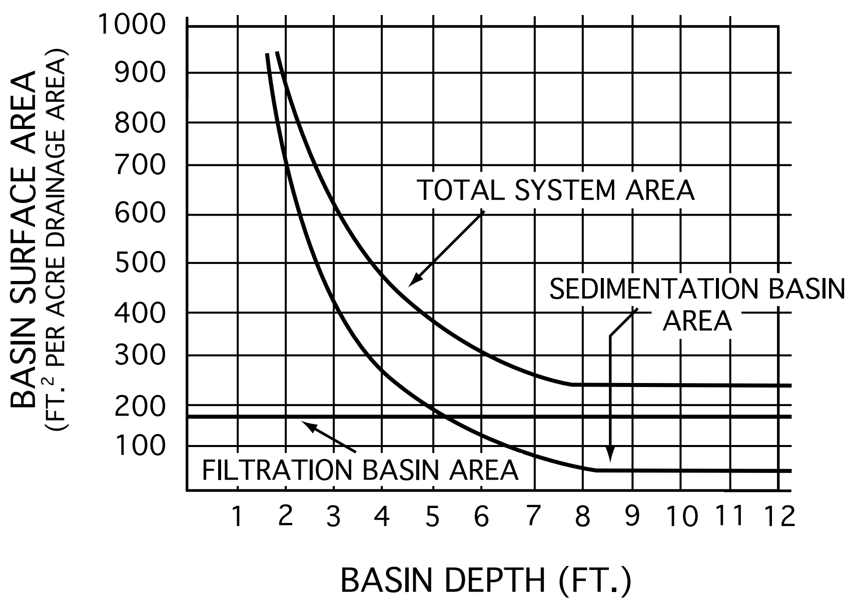


Figure 8: Sedimentation/Filtration Basin Surface Areas
(Source: Austin, Texas)

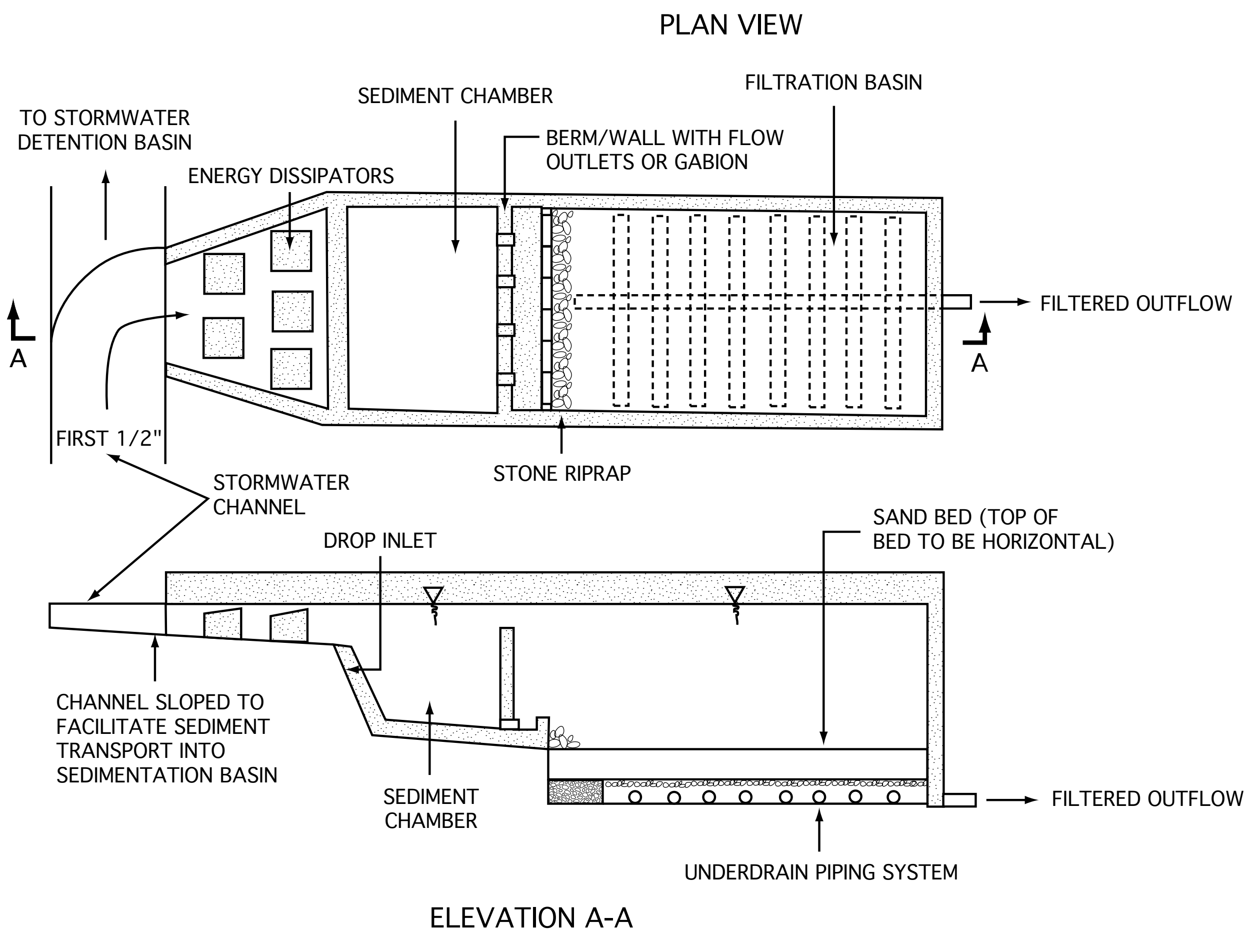


Figure 9: Conceptual Partial Sedimentation – Filtration System
(Source: Austin, Texas)

IV. District of Columbia (D.C.) Underground Sand Filters

A) Facility Description

The D.C. Environmental Regulation Administration has developed an underground stormwater sand filter contained in a structural shell with three chambers (Figure 10). The shell may consist of precast or cast-in-place concrete. Over one hundred of the structures have been installed in the District since 1987.

The three feet deep plunge pool chamber and the throat of the second chamber, which are hydraulically connected by an underwater rectangular opening, absorbs energy and provides pretreatment, trapping grit and floating organic material such as oil, grease, and tree leaves.

The second chamber also contains a typical sand filter. As with the Austin system, the filter material consists of stone, sand, and filter fabric. At the bottom is a subsurface drainage system of six (6) inch diameter perforated PVC pipe in a 16 inch thick stone bed. The primary filter media is 18 inches of sand. A layer of plastic reinforced geotechnical filter cloth secured by 2" thick gravel ballast is placed on top of the sand. The top filter cloth is a pre-planned failure plane which can readily be replaced when the filter surface becomes clogged. A dewatering drain controlled by a gate valve must be installed to facilitate maintenance. The third chamber, or clearwell, collects the flow from the underdrain pipes and directs it to the storm sewer.

B) Design Considerations

1) Applicability

A major advantage of the D.C. sand filter is that it does not take up any space on the surface. It can be placed under on-site roadways (e.g., not public rights of way), parking lots, or sidewalks, and under planting spaces adjacent to buildings. The system works best for watersheds of approximately one acre of impervious surface. For larger watersheds, two or more DCSFs will be required.

These systems will be utilized only for off-line applications to treat the WQV. If a flow splitter is not installed ahead of the DCSF, an integral large storm bypass pipe from the sediment chamber to the clearwell must be provided. The bypass pipe should be located to one side to avoid blocking the access manholes or maintenance access doors. Quantity detention must be provided in a separate facility.

2) Practicality

Several years of success with this system in D.C. have demonstrated its practicality for use in the Middle Atlantic states area. Costs vary with the size of the structure and the character of the site. When first introduced in 1987, systems constructed in D.C. cost approximately $35,000 per impervious acre treated. Use of precasting has reduced costs to approximately $12,000 to $16,000 per impervious acre at present.

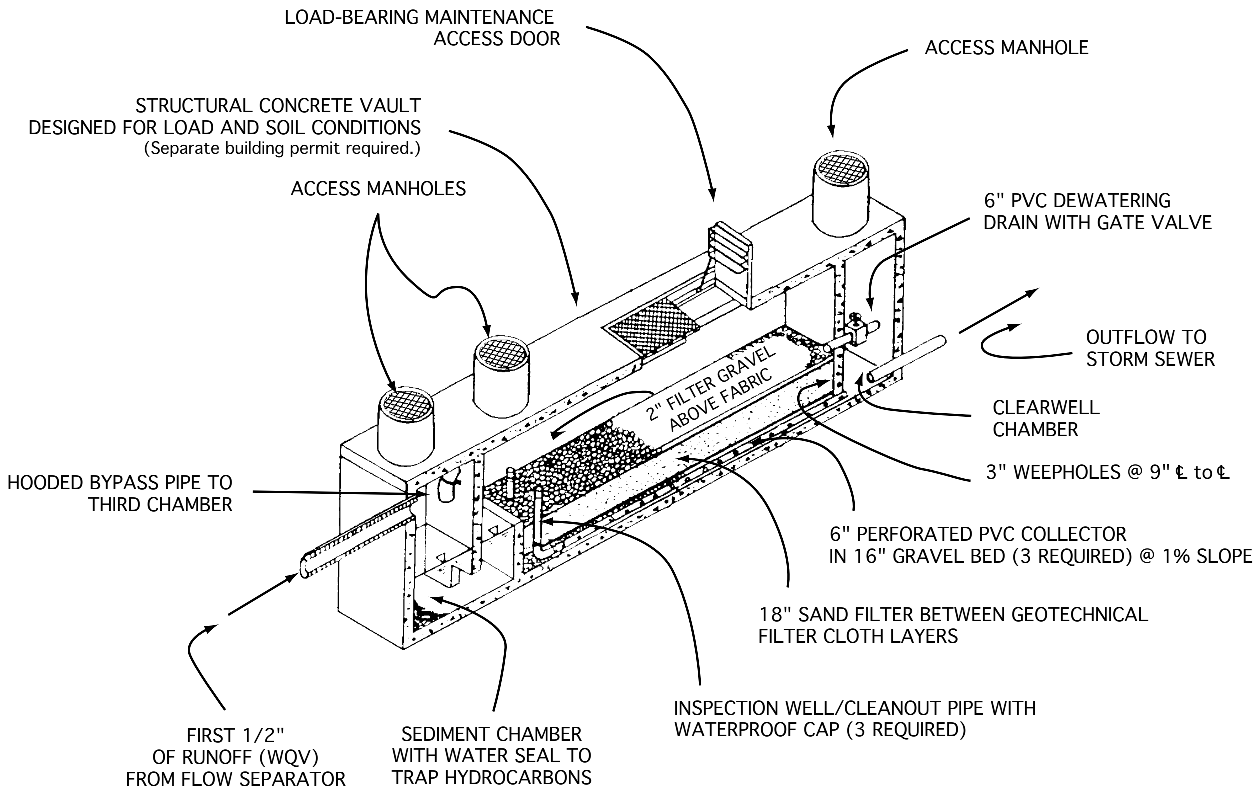


Figure 10: Original D.C. Sand Filter (DCSF) System

3) Groundwater and Bedrock

Where high groundwater can reasonably be expected to be present in the area of the facility, the highest expected groundwater elevation is to be determined by taking a minimum of one (1) soil boring at the center of the proposed facility location and then designing against buoyancy effects with a safety factor of 1.2. Assumption of saturation to the surface will be acceptable in lieu of borings.

4) Drawdown Time

As with WQV storage tanks, drawdown time should not exceed 40 hours so that the BMP will be free to process follow-on storms.

5) Structural Requirements

The load-carrying capacity of the filter structure must be considered when it is located under parking lots, driveways, roadways, and certain sidewalks (such as those adjacent to State highways). Traffic intensity may also be a factor. The structure must be designed by a licensed structural engineer and the plans require a separate building permit. This requirement for a separate (structural) building permit is to be noted on the site plan.

6) Design Storm

The inlet design or integral large storm bypass should be adequate for isolating the WQV from the 10 year storm (5 min. T_c) and for conveying the peak flow of the storm past the filter system.

7) Infrastructure Elevations

For cost, reliability, and maintenance considerations, it is preferable that the DCSF work by gravity flow. This requires sufficient vertical clearance between the invert of the prospective inflow storm piping and the invert of the storm sewer which will receive the outflow.

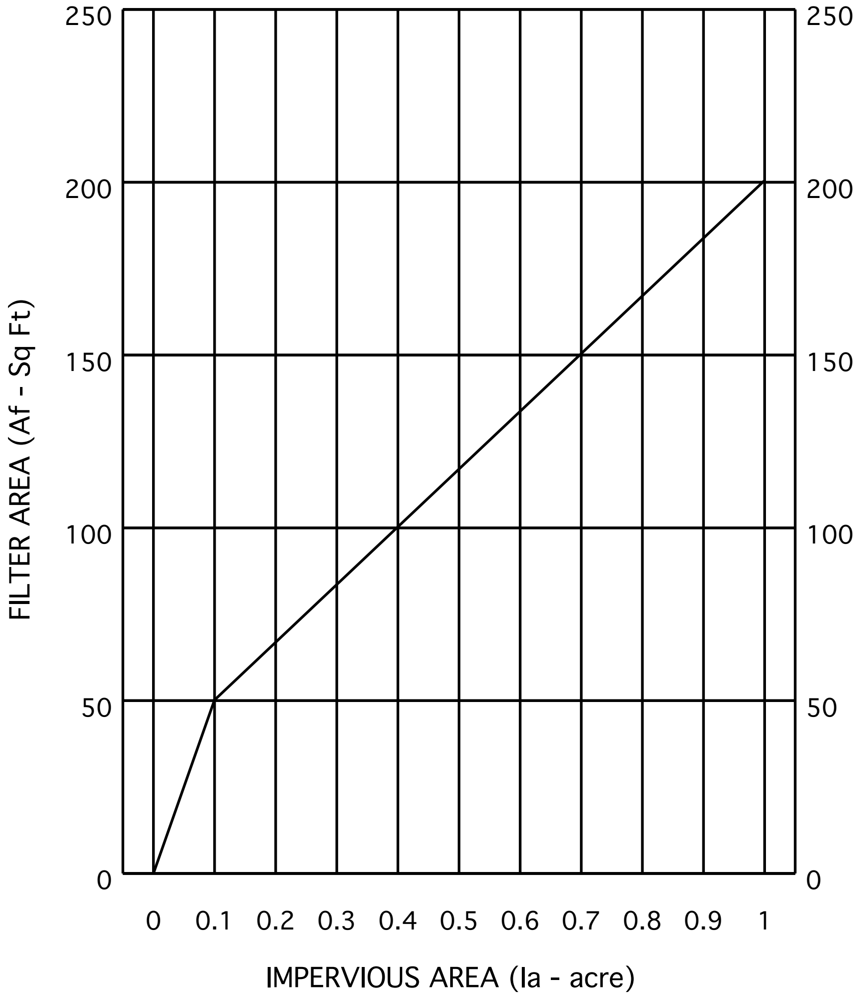
8) Accessibility and Headroom for Maintenance

All three DCSF chambers need to have personnel access manholes and built-in access ladders. The DCSF also needs to be accessible to vacuum trucks for removal of accumulated sediments and hydrocarbons. Approximately every 3-5 years, the filter can be expected to clog to the point that replacement of the top layer of washed stone and the top layer of filter cloth will be required. A minimum headspace of 72 inches above the filter should be provided if the ceiling to the chamber is a fixed structure. This may be reduced down to 60 inches to obtain gravity flow where it can not be otherwise obtained. A rectangular load bearing access door (minimum 4 ft. x 4 ft.) should be positioned directly over the center of the filter.

C) Design Procedures (Original DCSF Single Pool Configuration)

1) Determine Governing Site Parameters

Determine the impervious area on the site (I_a in acres), the water quality volume to be treated (WQV in ft.^{3} = 1816 I_a), and the site parameters necessary to establish 2h, the maximum ponding depth over the filter (storm sewer invert at proposed connection point, elevation to inflow invert to BMP, etc.). If a bypass weir or pipe is to be built directly into the DCSF shell, it should be designed at this point.



AF = 50 + (Ia - 0.1 acre) * 167 SQ FT PER ACRE

FILTER AREA vs WATERSHED IMPERVIOUSNESS

Figure 11: D.C. Sand Filter Curve and Formula

Figure 11 shows the dimensional relationships required to compute the remaining steps of the design.

2) Select Filter Depth and Determine Maximum Ponding Depth

Considering the data from Step 1) above, select the Filter Depth at 18" (d_f) and determine the maximum achievable ponding depth over the filter (2h).

3) Compute the Minimum Area of the Sand Filter (A_{fm})

To determine the area of the Austin Filter Formula for partial sedimentation treatment (equation 13) is utilized:

$$A_{fm(PS)} = \frac{545 I_a d_f}{(h + d_f)} \quad (14)$$

where:

A_{fm}	=	minimum surface area of sand bed (square feet),
I_a	=	impervious cover on the watershed in acres,
d_f	=	sand bed depth (normally 1.5 to 2 ft.), and
h	=	average depth of water above surface of sand media between full and empty basin conditions (ft.).

4) Select Filter Width and Compute Filter Length and Adjusted Filter Area

Considering site constraints, select the Filter Width (W_f). Then compute the Filter Length (L_f) and the Adjusted Filter Area (A_f)

$$L_f = \frac{A_{fm}}{W_f} \quad (15)$$

$$A_f = W_f \times L_f \quad (16)$$

Note: From this point, formulae assume rectangular cross section of filter shell.

5) Compute the Storage Volume of Top of the Filter (V_{Tf})

$$V_{Tf} = A_f \times 2h \quad (17)$$

6) Compute the Storage in the Filter Voids (V_V)
(Assume 40% voids in the filter media)

$$V_v = 0.4 \times A_f \times (d_f + d_s) \quad (18)$$

7) Compute Flow Through Filter During Filling (V_Q)
(Assume 1-hour to fill per D.C. practice)

$$V_Q = \frac{k A_f (d_f + h)}{d_f} \quad (19)$$

use k=2 ft./day=0.0833/hr.

8) Compute Net Volume to be Stored Awaiting Filtration (V_{st})

$$V_{st} = WQV - V_{Tf} - V_V - V_Q \quad (20)$$

9) Compute Minimum Length of Permanent Pool (L_{pm})

$$L_{pm} = \frac{(V_{st})}{(2h \times W_f)} \quad (21)$$

10) Compute Minimum Length of Sediment Chamber (L_s)
(to contain 20% of WQV per Austin practice)

$$L_{pm} = \frac{0.2WQV}{(2h \times W_f)} \quad (22)$$

11) Set Final Length of Permanent Pool (L_p)

If $L_{pm} \geq L_s + 2$ft., make $L_p = L_{pm}$ (23)

If $L_{pm} < L_{sm} + 2$ft., make $L_p = L_{sm} + 2$ft. (24)

12) Establish Structure Dimensions and Size Clearwell (L_{cw})

It may be economical to adjust final dimensions to correspond with standard precast structures or to round off to simplify measurements during construction.

Set the length of the clearwell (L_{cw}) for adequate maintenance and/or access for monitoring flow rate and chemical composition of effluent (minimum = 3ft.).

D) Filter Specifications and Details

Figure 12 depicts a cross-section of the filter chamber.

1) Upper Stone Layer

The washed stone layer at the top of the filter should be two inches thick and meet VDOT #57 stone specifications or ASTM equivalent (1 inch maximum diameter).

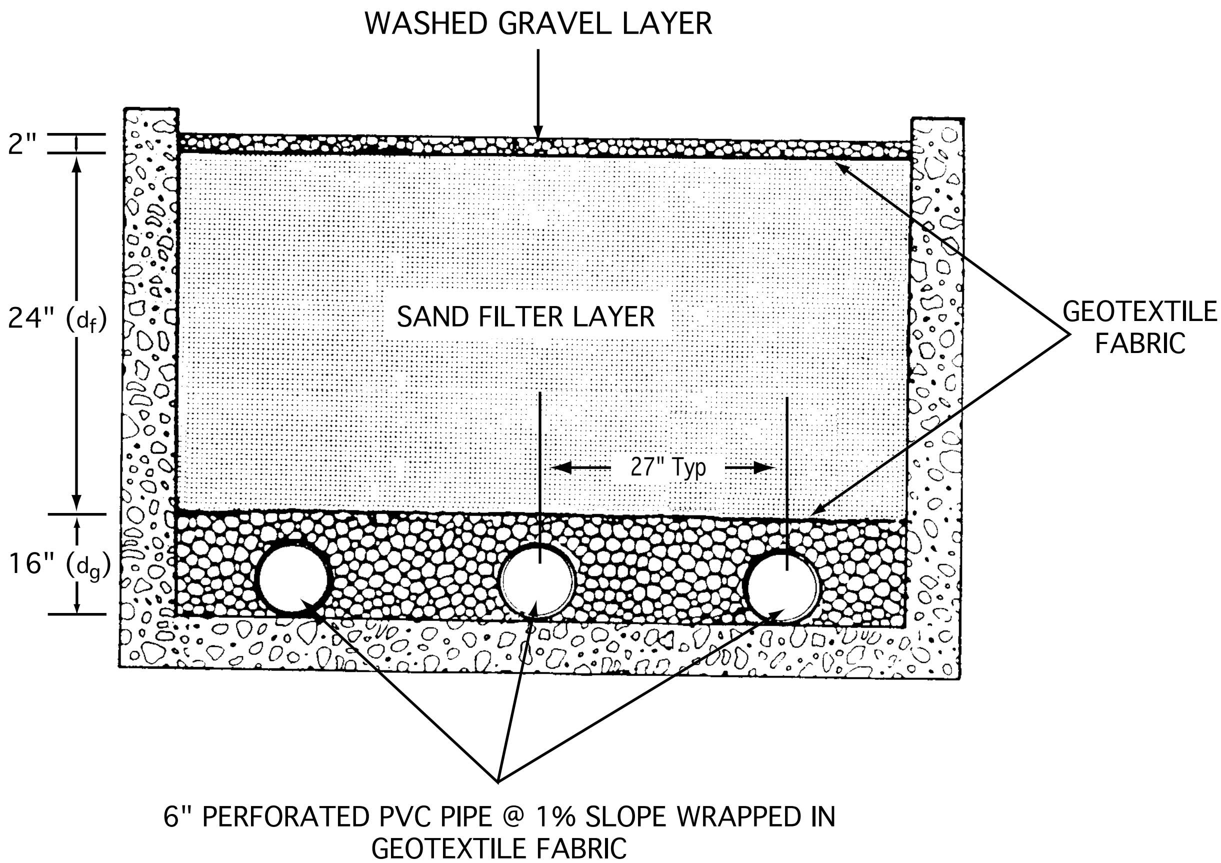


Figure 12: Cross-Section of DCSF Filter

2) Geotechnical Fabrics

The filter fabric beneath the two-inch layer of stone on top of the filter should be Enkadrain 9120 filter fabric or equivalent with the following specifications:

Property	Test Method	Unit	Specification
Material	Nonwoven geotextile fabric		
Unit Weight	ASTM D-1777	Oz./sq.yd.	4.3 (min.)
Flow Rate	Falling Head Test	GPM/sq.ft.	120 (min.)
Puncture Strength	ASTM D-751 (Modified)	Lb	60 (min.)
Thickness		in.	0.8 (min.)

The filter cloth layer beneath the sand should conform to the following specification (same as for Austin Sand Filter):

Property	Test Method	Unit	Specification
Material	Nonwoven geotextile fabric		
Unit Weight		Oz./sq.yd.	8 (min.)
Filtration Rate		In./Sec.	0.08 (min.)
Puncture Strength	ASTM D-751 (Modified)	Lb.	125 (min.)
Mullen Burst Strength	ASTM D-751	PSI	400 (min.)
Tensile Strength	ASTM D-1682	Lb.	300 (min.)
Equiv. Opening Size	US Standard Sieve	No.	80 (min.)

The fabric rolls should be cut with sufficient dimensions to cover the entire wetted perimeter of the filtering area with a six-inch wall overlap.

3) Sand Filter Layer

ASTM C33 Concrete Sand or VDOT Section 202 Grade A Fine Aggregate Sand is utilized for applications in Northern Virginia with a uniform depth of 18 inches of sand.

4) Gravel Bed Around Collector Pipes

The gravel layer surrounding the collector pipes should be at least 16 inches thick and be composed of 1/2 to two (2) inch diameter stone (e.g., VDOT #57 stone) and provide at least two (2) inches of cover over the tops of the drainage pipes. The stone and the sand layer above must be separated by a layer of geotextile fabric meeting the specification listed above.

5) Underdrain Piping

The underdrain piping consists of three (3) 6-inch schedule 40 or better polyvinylchloride (PVC) perforated pipes reinforced to withstand the weight of the overburden. Perforations should be 3/8 inch, and each row of perforations should contain at least six (6) holes. Maximum spacing between rows of perforations should be six (6) inches. Pipes should be spaced 27 inches center to center.

The minimum grade of piping should be 1/8 inch per foot (one (1) percent slope). Access for cleaning all underdrain piping is needed. Clean-outs for each pipe should extend at least six (6) inches above the top of the upper filter surface, e.g., the top layer of stone and have a securely fastened waterproof cap. The middle pipe should be extended through the top so that monitoring can be performed directly from the surface without entering the vault.

Each pipe should be thoroughly wrapped with 8 oz./sq.yd. geotechnical fabric meeting the above detailed specification before placement in the filter.

6) Weepholes

In addition to the underdrain pipes, weepholes should be installed between the filter chamber and the clearwell to provide relief in case of pipe clogging. The weepholes should be three (3) inches in diameter. Minimum spacing should be nine (9) inches center to center. The openings on the filter side of the dividing wall should be covered to the width of the trench with 12 inch high plastic hardware cloth of 1/4 inch mesh or galvanized steel wire, minimum wire diameter 0.03-inch, number 4 mesh hardware cloth anchored firmly to the dividing wall structure and folded a minimum of six (6) inches back under the bottom stone.

7) Bypass Pipe

Where a bypass pipe is needed, it shall be DIP or PVC with supports every 18 inches minimum.

8) Dewatering Drain

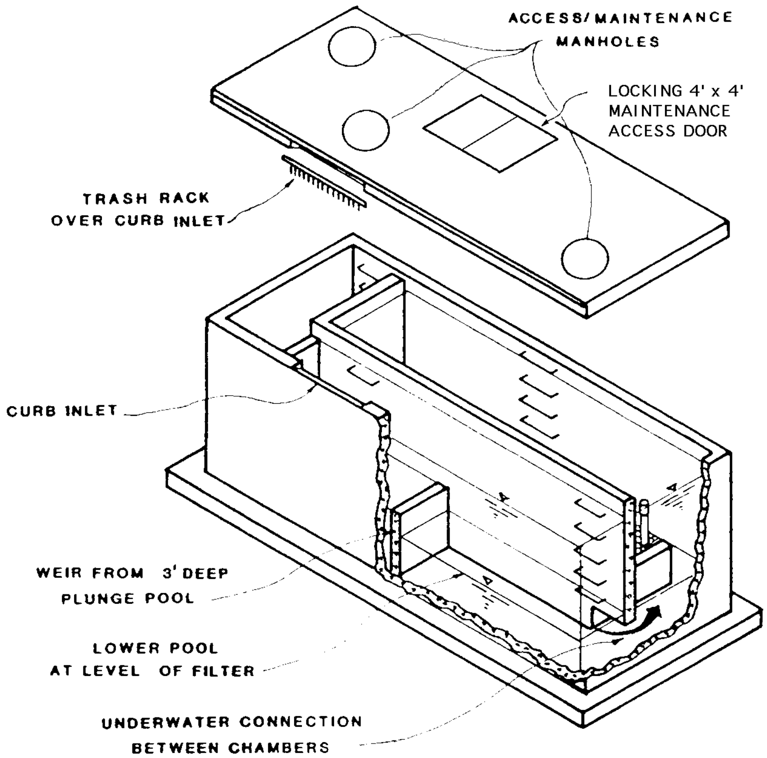
A six (6) inch diameter DIP or PVC dewatering drain with a gatevalve is to be installed at the top of the stone/sand filter bed through the partition separating the filtration chamber from the clearwell chamber.

E) Applications in Available Structural Shells

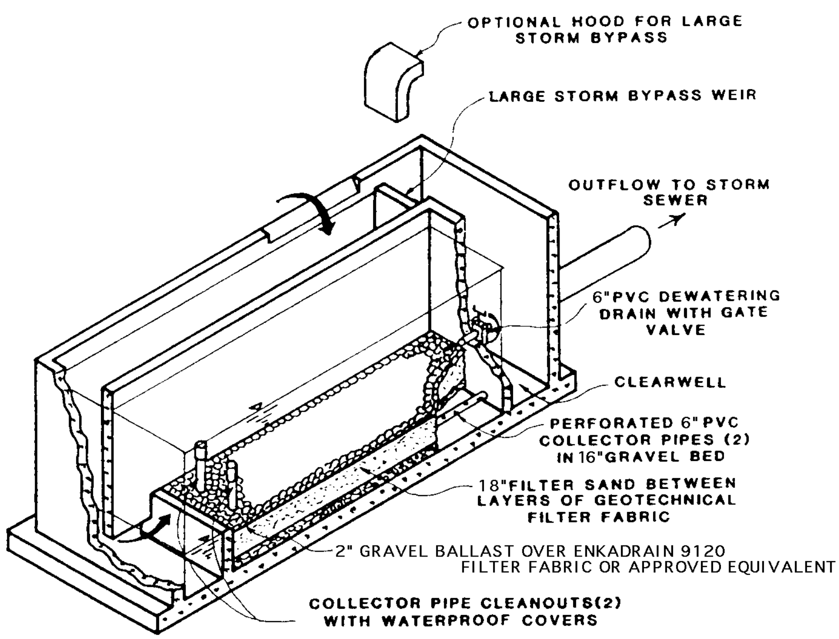
Available concrete structural shells with sufficient dimensions may be modified to contain sand filter systems employing D.C. concepts. Figure 13 portrays two views of an adaptation of a standard precast drop inlet to contain an inlet filter concept developed by the City of Alexandria's engineering staff. A built-in flow splitter is provided. The sedimentation chamber is made long and narrow, requiring a 180-degree "switch-back" in flow of the runoff, which increases energy dissipation and particle settlement. The filter illustrated fits inside a standard 8 ft. by 8 ft. by 20 ft. precast concrete drop inlet shell and will capture and treat the WQV from 1/3 acre of new impervious cover, such as highway pavement. The filter may also be fed by a separate or integral grated inlet.

F) Maintenance and Construction Requirements

The developer/owner must check with the individual jurisdiction in which the facility is being constructed for their specific requirements. In Fairfax County, for example, a Maintenance Agreement with the County concerning the site stormwater quantity/quality management facilities must be executed by the developer/owner before the Final Site Plan for the construction will be approved.



SEDIMENTATION CHAMBER CUTAWAY



FILTER CHAMBER CUTAWAY

Figure 13: "Switch-Back" Sand Filter in Precast Drop Inlet Shell

V. Delaware Surface Sand Filter (DSF) Systems

A) Facility Description

The Delaware Department of Natural Resources and Environmental Control has developed a surface sand filter system for use in the State of Delaware. As originally conceived, the Delaware Sand Filter is an on-line facility processing all stormwater exiting the treated site up to the point that its overflow limit is reached (Delaware provides for treating the first one inch of runoff). Northern Virginia jurisdictions require that an integral flow-splitter be used to isolate and treat the Water Quality Volume.

Figure 14 presents a schematic drawing of the original Delaware Sand Filter. The system consists of two parallel concrete trenches connected by close-spaced wide notches in the top of the wall dividing the trenches. The trench adjacent to the site being served is the sedimentation chamber. When accepting sheet flow, it is fitted with a grated cover. Concentrated stormwater may also be conveyed to the chamber in enclosed storm drain pipes. The second chamber, which contains the sand filter, is always fitted with a solid cover.

Storm flows enter the sedimentation chamber through the grates, causing the sedimentation pool to rise and overflow into the filter chamber through the weir notches at the top of the dividing wall, assuring that the water to be treated arrives at the filter as sheet flow. This is essential to prevent scouring out of the sand. The permanent pool in the sedimentation chamber is dead storage, which inhibits resuspension of particles that were deposited in earlier storms and prevents the heavier sediments from being washed into the filter chamber. Floatable materials and hydrocarbon films, however, may reach the filter media through the surface outflow.

The second trench contains the top 2 inches stone filter layer, the middle 18 inches of sand, and the bottom 16 inch stone layer. Six inch diameter PVC underdrains are to be provided in this stone layer.

B) Design Considerations

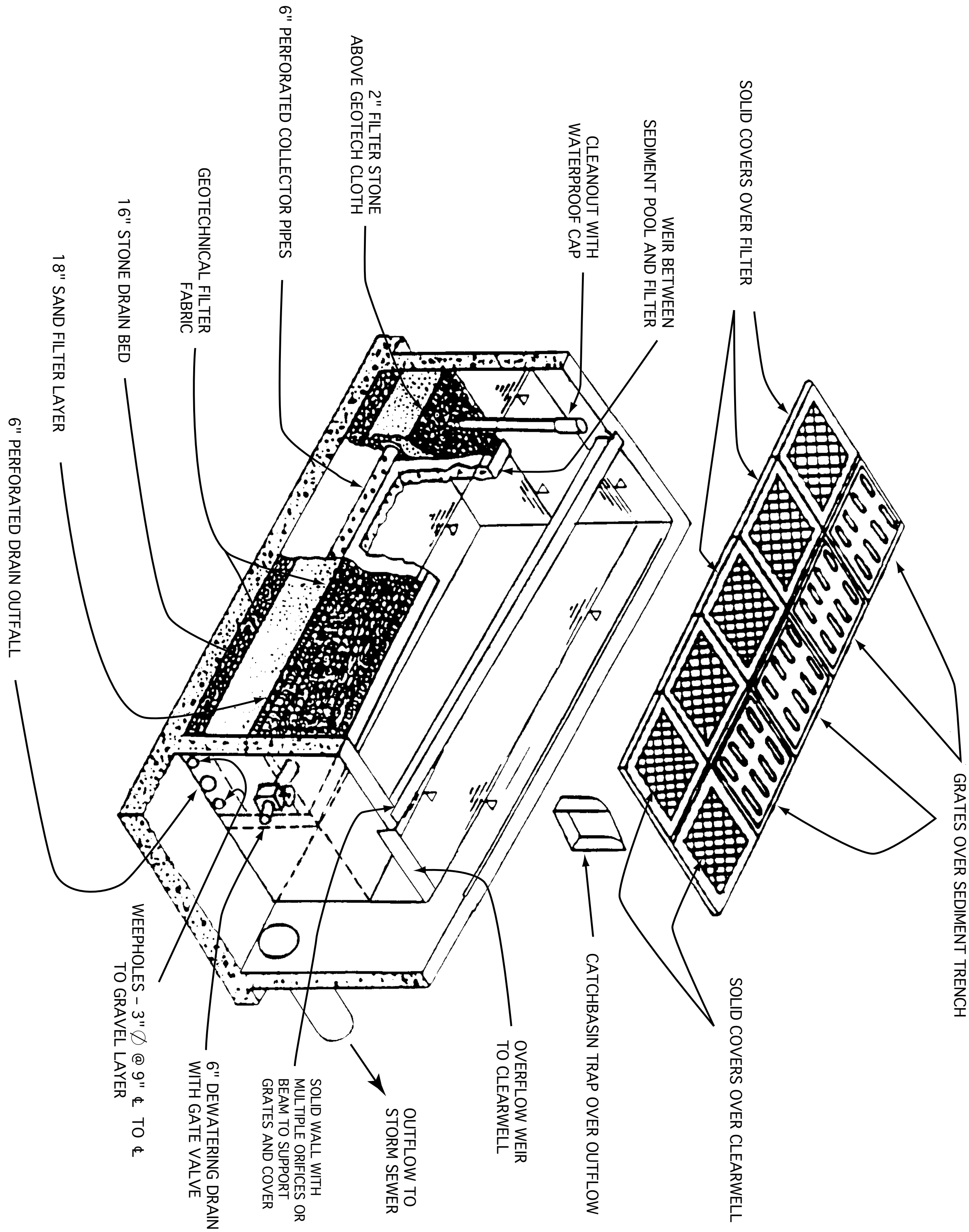
1) Applicability

A major advantage of the Delaware Sand Filter is that it can be installed in shallow configurations, which is especially critical in flatter regions where high water tables exist. The simplicity of the system and the ready accessibility of the chambers for periodic maintenance also prove attractive.

An obvious difference from the D.C. system is that the Delaware Sand Filter design has no provision for excluding floatable debris smaller than the grate openings and petroleum sheens from reaching the filter media. Earlier clogging of the sand filter might therefore be expected, and care would have to be exercised in disposing of clogged sand materials removed during maintenance because of their likely petroleum hydrocarbon content.

The original DSF, which was constructed in Maryland in 1986, cost approximately $10,000 and serves a one-acre watershed. A large slotted curb filter constructed in the City of Alexandria cost approximately $40,000 to serve a watershed of 1.7 impervious acres. Two small custom-built systems which have been constructed to serve smaller areas cost in the $4,000-$7,000 range.

Figure 14: Original Delaware Sand Filter



2) Practicality

A similar sand filter system constructed in Maryland has been in service for approximately six years. It serves a parking lot that is heavily used by patrons of a courthouse. The Delaware Department of Natural Resources and Environmental Control has visited the Maryland facility on a regular basis over the six-year period. Maintenance personnel have reported that there have been no instances where the sand filter has overflowed. Only recently has the system appeared to be clogging to the point that the operation of the system may be impaired. Oil, grease, and finer sediments have migrated into the sand to a depth of only two (2) to three (3) inches.

Disposal of petroleum contaminated sand would appear to be the only potential problem with the use of this filter system. Owners of relatively lightly used parking facilities, such as church parking lots, might not have as severe a problem in this respect as might commercial establishments with high usage.

C) Design Procedures

Figure 15 shows dimensional relationships for the Delaware Sand Filter as adopted for use in Northern Virginia.

1) Calculate the Required Surface Areas of the Chambers

Considering critical site constraints (storm sewer invert at proposed connection point, minimum BMP invert to achieve drainage to connection point, site surface elevation at BMP location, required height of overflow weir to convey 10-year storm, etc.), select maximum ponding depth over filter. If an integral flow separator is to be built into the DSF shell, size the overflow weir, orifice, or pipe using the procedures outlined previously.

Because of the shallow configuration of this BMP, resulting in low levels of hydraulic head above the filter, application of the usual partial sedimentation filter formula may not create enough storage volume to contain the WQV. With the dimensional relationships shown in Figure 15 and k = 2.0 ft./day, the required DSF filter area to contain the WQV may be written as follows:

$$A_f = \frac{1816 I_a}{4.1h + 0.9} = \frac{WQV}{4.1h + 0.9} \qquad (25)$$

where:

A_f = the area of the filter in square feet,
I_a = the impervious area on the watershed in acres, and
h = 1/2 the maximum ponding depth over the filter in feet.

If the maximum ponding depth above the filter (2h) is less than 2.67 feet (2'-8"), the WQV storage requirement governs, and the above formula must be used to size the filter. If the maximum ponding depth above the filter (2h) is 2.67 feet or greater, use the partial sedimentation filter formula (equation 8).

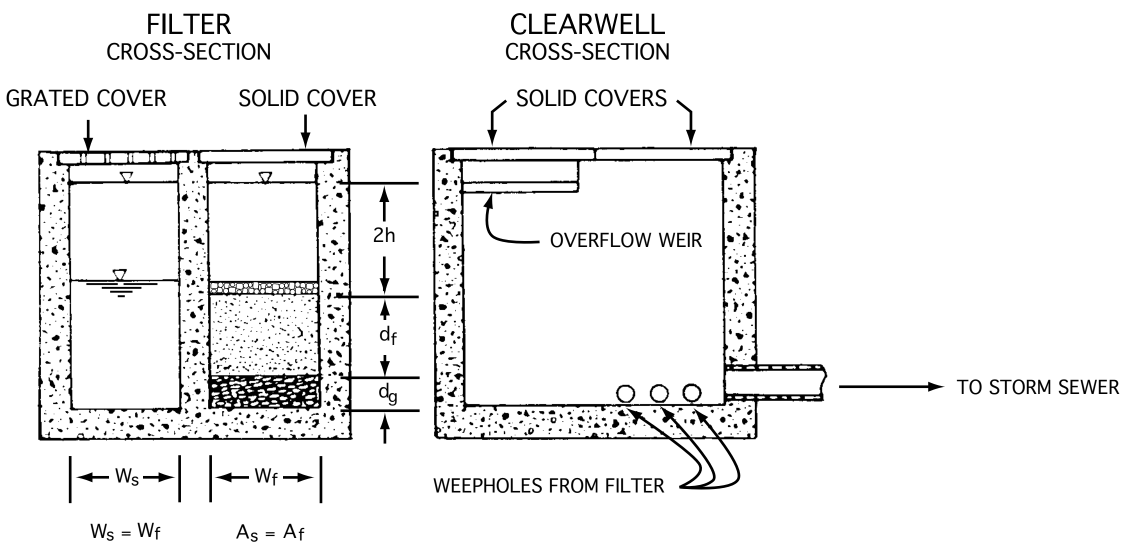


Figure 15: Dimensional Relationships for Delaware Sand Filters

$$A_f = \frac{545 I_a d_f}{(h + d_f)} \qquad (26)$$

where:

d_f = depth of the filter media in ft. (1.5-2.0)

2) Establish Dimensions of the Facility

Site considerations usually dictate the final dimensions of the facility. Sediment trenches and filter trenches will normally be 18-30 inches wide. Use of standard grates requires a trench width of 26".

3) Sand Filter Chamber

The top layer should be 2" of VDOT #57 stone over a middle layer of 18 inches of ASTM C33 Concrete Sand or VDOT Section 202 Grade A Fine Aggregate Sand. The top surface of the sand filter must be level (no grade). Under the sand there should be a 16" thick layer of 1/2 to two (2) inch diameter stone (e.g. VDOT #57 stone) which provides a minimum of two inches of cover over six (6) inch diameter PVC underdrain piping. The sand and stone must be separated by a layer of geotechnical fabric meeting the following specifications:

Property	Test Method	Unit	Specification
Material	Nonwoven geotextile fabric		
Unit Weight		Oz./sq.yd.	8 (min.)
Filtration Rate		In./Sec.	0.08 (min.)
Puncture Strength	ASTM D-751 (Modified)	Lb.	125 (min.)
Mullen Burst Strength	ASTM D-751	PSI	400 (min.)
Tensile Strength	ASTM D-1682	Lb.	300 (min.)
Equiv. Opening Size	US Standard Sieve	No.	80 (min.)

4) Geotechnical Fabric Overlayment

In circumstances where frequent maintenance of the filter sand is to be expected, such as when treating runoff from service stations and other auto-related activities, a layer of plastic reinforced filter fabric, such as Enkadrain 9120, may be placed on top of the filter sand and secured with weights. The fabric may then be rolled up and disposed of as collection of pollutants dictates.

5) Underdrain Piping or Drain Tiles

Underdrain piping should be six inches in diameter with 3/8 inch perforations, piping should be schedule 40 polyvinyl chloride or greater strength. Each row of perforations should contain at least 6 holes and the maximum spacing between rows of perforations should not exceed six (6) inches. The minimum grade of the piping should be 1/8 inch per foot (1 percent slope). A vertical cleanout/inspection well extending above the surface of the sand and equipped with a waterproof cover should be provided at the uphill end of the pipe. Drain pipes should be completely wrapped in geotechnical filter fabric meeting the specification in section 3 (above) before placement in the filter.

Shallow rectangular drain tiles may be fabricated from such materials as fiberglass structural channels, saving several inches of filter depth. Drain tiles should normally be in two-foot lengths and spaced to provide gaps 1/8-inch less than the smallest gravel sizes on all four sides. Sections of tile may be cast in the dividing wall between the filter and the clearwell to provide shallow outflow orifices.

6) Weepholes

Where gravel underdrains are used, the weepholes between the filter chamber and the shell should be three (3) inches in diameter. Minimum spacing should be nine (9) inches center to center. The openings on the filter side of the dividing wall should be covered to the width of the trench with 12-inch high plastic hardware cloth of 1/4 inch mesh or galvanized steel wire, minimum wire diameter 0.03-inch, number 4 mesh hardware cloth anchored firmly to the dividing wall structure and folded 6 inches back under the bottom stone. Weepholes conforming to these specifications may also be provided in addition to underdrain pipes to provide a backup in case of pipe clogging.

7) Grates and Covers

When grates and cast steel covers are used, design to take the same wheel loads as the adjacent pavement. Where possible, use standard grates to reduce costs. Grates and covers should be supported by a galvanized steel perimeter frame.

8) Hoods or Catch Basin Traps for Overflow Weirs

In applications where trapping of hydrocarbons and other floating pollutants is required, such as at auto-related activities, large storm overflow weirs should be equipped with a 10-gauge aluminum hood or commercially available catch basin trap. The hood or trap should extend a minimum of one foot into the permanent pool.

9) Outfall Pipe(s)

When a large storm bypass is provided, design the outfall for the 10-year storm peak flow rate. Pipe should conform to The City of Alexandria standards for storm sewer piping. Minimum pipe size should usually be ten-inch pipe, but eight-inch pipe may be used with short (20 feet or under) lengths of precast filter shells. For Fairfax County, minimum pipe size should usually be 15 inch pipe, but 12 inch pipe may be used with short (20 inch or under) lengths of precast filter shells.

D) Filter Specifications and Details

Filter specifications and details for the Delaware Sand Filter are the same as the D.C. Filter detail.

E) Maintenance and Construction Requirements

The developer/owner must check with the individual jurisdiction in which the facility is being constructed for their specific requirements. In Fairfax County, for example, a Maintenance Agreement with the County concerning the site stormwater quantity/quality management facilities must be executed by the developer/owner before the Final Site Plan for the construction will be approved.

APPENDIX

Sand Filter BMP Computation Worksheets

SAND FILTER BMP COMPUTATIONS
Worksheet 1: Computations Common to all Sand Filter BMPs

Part 1: Compute Post-Development Site Impervious Acreage (I_a):

structures = ___________________ ft^2
parking lot = ___________________ ft^2
roadway = ___________________ ft^2
sidewalk = ___________________ ft^2
other = ___________________ ft^2
= ___________________ ft^2
= ___________________ ft^2
= ___________________ ft^2

Total = _______________ ft^2/43,560 = I_a = __________ acres

Part 2: Compute Water Quality Volume to be Treated:

WQV = 1816I_a = ____________ x ____________ = __________ ft^3

Part 3: Identify Critical Site Parameters:

Storm Sewer invert at proposed connection point = ____________ ft

Length of outflow line (BMP - storm sewer) = ____________ ft

Minimum BMP outflow invert @ minimum 0.5% grade = ____________ ft

Site Plan surface elevation at BMP location = ____________ ft

Inflow invert to BMP from drainage system plan = ____________ ft

Flow splitter weir or bypass pipe invert = ____________ ft
(usually set at maximum BMP ponding depth)

BMP outflow possible by gravity _________ ;

Overflow weirs and orifices or bypass pipes shall be designed to pass the peak flow rate of the 10-year storm (5 min. T_c) using Rational Method (Q=CIA).

1) When designing overflow weirs, size the weir by solving the following formula for H:

$$Q_{10} = 3.0LH^{1.5}$$

where:
Q_{10} = peak flow rate for the 10-year storm (cfs)
H = the depth of ponded water above the crest of the weir (ft.)
L = length of the weir (ft.)

_______ = 3.0 x _________ x $H^{1.5}$

$H^{1.5}$ = ______________ ; H = ________ ft.

2) When a hooded overflow orifice is employed, use the orifice formula to size the overflow:

$$Q_{10}=C_dA(2gh_{10})^{0.5}$$

where:
Q_{10} = the peak flow rate for the 10-year storm
g = the acceleration of gravity (32.2 ft./sec.^{2})
C_d = the coefficient of discharge (use 0.6)
A = area of the orifice in ft.^{2}
h_{10} = depth of ponded water above the centerline of the orifice

__________ = 0.6A x (64.4 x _________)$^{0.5}$

A = _________ / [(0.6 x (64.4 x ___________)$^{0.5}$] = __________ ft^2

3) When a bypass pipe is employed, use Manning's equation to size the overflow pipe:

$$V = \frac{1.49}{n} \times (R_h^{0.667})S^{0.5}$$

where:
V = velocity of flow (fps)
n = roughness coefficient (use 0.013 for concrete, DIP, and PVC pipe and 0.024 for corrugated metal)
S = slope of the pipe (energy gradient) (minimum 0.005)
R_h = the hydraulic radius in ft. = area of the pipe in ft.^{2} divided by the inside circumference of the pipe (wetted perimeter) in ft.

Selected bypass pipe material ______________________

Selected bypass pipe diameter = ____________________ in.

SAND FILTER BMP COMPUTATIONS

Worksheet 2: Computations of Austin Sand Filter

(Full Sedimentation Unless Noted)

Part 4: Considering data on Worksheet 1, select maximum ponding depth over filter:

2h = _______________ ft;
h = _______________ ft

From WORKSHEET 1;

I_a = _______________ acres
WQV = _______________ ft^3

Part 5: Compute Minimum Area of Filter (A_{fm}):

$A_{fm} = \frac{k_1 I_a d_f}{(d_f + h)}$; use k_1 = 310 (full sedimentation)
use k_1 = 545 (partial sedimentation)

A_{fm} = [(310 x _______ x ________) / (_______ + _________)]

A_{fm} = _______________ ft^2

Part 6: Considering Site Constraints, Select Filter Width (W_f) and Compute Filter Length (L_f) and Adjusted Filter Area (A_f):

W_f = _______________ ft

$L_f = A_{fm} / W_f$

L_f = _____________ / ______________

L_f = __________ , say ___________ ft

$A_f = W_f \times L_f$ = __________ x ________

A_f = _______________ ft^2

Part 7: Compute the Storage Volume on Top of the Filter (V_{tf}):

Provide elevation-storage relationship here or reference plan sheet where it may be found.

At elevation _______________

V_{tf} = _____________ ft^3 This volume must be ≥ 0.2 WQV

Part 8: Compute Storage in Filter Voids (V_v):
(assume 40% voids in filter media)

V_v = A_f x (d_f + d_g) x 0.4
V_v = __________ x (________ + _________) x 0.4
V_v = _____________ ft^3

Part 9: Compute Flow Through Filter During Filling Period (V_Q):
(assume 1-hour to fill per D.C. practice)

$V_Q = \frac{k_2 A_f (d_f + h)}{d_f}$; use k_2 = 3.5 ft/day = 0.1458 ft/hr (full sedimentation)
use k_2 = 2 ft/day = 0.0833 ft/hr (partial sedimentation)

V_Q = [0.1458 x ______ x (______ + ______)]/ ______
V_Q = _____________ ft^3

Part 10: Compute the Total Volume Available in the Sand Filter Basin (V_{sf}):

V_{sf} = V_{tf} + V_V + V_Q
V_{st} = ___________ + __________ + __________
V_{st} = _____________ ft^3

Part 11: Compute the Size of the Sedimentation Basin (V_{sb}):

Provide elevation-storage relationship here or reference plan sheet where it may be found.

At elevation _______________

V_{sb} = _____________ ft^3

Full Sedimentation Design V_{sb} must be ≥ WQV

Partial Sedimentation Design V_{sb} must be ≥ 0.2WQV

When designing the Partial Sedimentation Basin the total volume must equal or exceed the WQV.

$V_{sf} + V_{sb} \geq WQV$

__________ + __________ ≥ WQV

Part 12: Size the Outlet Structure Control Orifice for the Full Sedimentation Basin:

(Do not provide extended draw-down for the partial sedimentation basin. Provide minimum 12" orifice with flow spread over the sand filter for partial sedimentation.)

WQV = _____________ ft^3

Maximum Depth (d_m) at the required WQV from the elevation storage curve for the facility.

d_m = _____________ ft

Peak outflow rate (Q_p) at the maximum head for a drawdown time of 24 hours.

Q_p = WQV / (0.5 x 3600 x 24)

= 0.0000232 x WQV = 0.0000232 x __________

= _______________ cfs

Required Orifice Area (A)

A = Q_p / (0.6 x (64.4 x $d_m)^{0.5}$) = _______________ / (0.6 x (64.4 x $d_m)^{0.5}$

= _______________ ft^2

Diameter of Circular Orifice (D)

D = 2.0 $(A/3.1415927)^{0.5}$ = 2.0 x (_____________ / $3.1415927)^{0.5}$

= _______________ ft^2; or x 12 = ____________ in

SAND FILTER BMP COMPUTATIONS
Worksheet 3: Computations for D.C. Sand Filters

Part 4: Considering data on Worksheet 1, select maximum ponding depth over filter:

2h = __________________ ft;
h = __________________ ft

From WORKSHEET 1;

I_a = __________________ acres
WQV = __________________ ft^3

Part 5: Compute Minimum Area of Filter (A_{fm}):

$$A_{fm} = \frac{545 I_a d_f}{(d_f + h)}$$

A_{fm} = [(545 x ________ x ________) / (_________ + ________)]

A_{fm} = __________________ ft^2

Part 6: Considering Site Constraints, Select Filter Width (W_f) and Compute Filter Length (L_f) and Adjusted Filter Area (A_f):

W_f = ____________ ft;

L_f = A_{fm}/W_f

L_f = ____________ / ___________

L_f = _________ , say __________ ft

A_f = W_f x L_f = __________ x ___________

A_f = ____________ ft^2

Part 7: Compute the Storage Volume on Top of the Filter (V_{tf}):

V_{tf} = A_f x 2h
V_{tf} = _________ x ________
V_{tf} = ____________ ft^3

Part 8: Compute Storage in Filter Voids (V_v):
(assume 40% voids in filter media)

V_v = A_f x (d_f + d_g) x 0.4

V_v = __________ x (________ + _________) x 0.4

V_v = _____________ ft^3

Part 9: Compute Flow Through Filter During Filling Period (V_Q):
(assume 1-hour to fill per D.C. practice)

$V_Q = \frac{kA_f(d_f + h)}{d_f}$; use k = 2 ft/day = 0.0833 ft/hr

V_Q = [0.0833 x ______ x (______ + _______)]/ _________

V_Q = _____________ ft^3

Part 10: Compute Net Flow Volume to be Stored Awaiting Filtration (V_{st}):

V_{st} = WQV - V_{tf} - V_V - V_Q

V_{st} = __________ - _________ - _________ - __________

V_{st} = _____________ ft^3

Part 11: Compute Minimum Length of Permanent Pool (L_{pm}):

$L_{pm} = \frac{V_{st}}{2h \times W_f}$

L_{pm} = ___________ / (___________ x ____________)

L_{pm} = _____________ ft

Part 12: Compute Minimum Length of Sediment Chamber (L_{sm}):

20% of WQV = 0.2WQV = 0.2 (__________) = ________ ft^3

If $V_{st} \geq 0.2WQV$, use

$$L_{sm} = \frac{V_{st}}{2h \times W_f}$$

L_{sm} = __________ / (__________ x___________)

L_{sm} = ____________

If $V_{st} \leq 0.2WQV$, use

$$L_{sm} = \frac{0.2WQV}{2h \times W_f}$$

L_{sm} = __________ / (__________ x___________)

L_{sm} = ____________

Part 13: Set Final Length of Permanent Pool (L_p)

Lsm + 2 ft = ___________ + 2 = ____________

If Lpm ≥ Lsm + 2 ft, make Lp = Lpm = ___________ ft

If Lpm < Lsm + 2 ft, make Lp = Lsm + 2 ft = ____________ ft

Part 14: Set Length of Clearwell (L_{cw}) for Adequate Maintenance Access (Minimum = 3 ft) and Compute Final Inside Length (L_{ti}):

L_{cw} = ____________;

Sum of interior partition thickness (t_{pi}) = _________ ft

$L_{ti} = L_f + L_p + L_{cw} + t_{pi}$

L_{ti} = _________ + _________ + _________ + ________

L_{ti} = ____________ ft

Part 15: Design Structural Shell to Accommodate Soil and Load Conditions at Site:

Note: It may be economical to adjust final dimensions upward to correspond with standard precast structures or to round dimensions upward to simplify layout during construction.

SAND FILTER BMP COMPUTATIONS
Worksheet 4: Computations for "Switch-Back" Sand Filters

Part 4: Considering data on Worksheet 1, select maximum ponding depth over filter:

2h = ____________ ft;

h = ____________ ft

From WORKSHEET 1;

I_a = ____________ acres

WQV = ____________ ft^3

Part 5: Compute Minimum Area of Filter (A_{fm}):

$$A_{fm} = \frac{545 I_a d_f}{(d_f + h)}$$

A_{fm} = [(545 x ________ x _______) / (_______ + _________)]

A_{fm} = ____________ ft^2

Part 6: Considering Site Constraints, Select Filter Width (W_f) and Compute Filter Length (L_f) and Adjusted Filter Area (A_f):

W_f = ____________ ft;

L_f = A_{fm}/W_f

L_f = __________ / ____________

L_f = __________ , say _________ ft

A_f = W_f x L_f = _______ x ________

A_f = ____________ ft^2

Part 7: Compute the Storage Volume on Top of the Filter (V_{tf}):

V_{tf} = A_f x 2h

V_{tf} = ___________ x __________

V_{tf} = ____________ ft^3

Part 8: Compute Storage in Filter Voids (V_v):
(assume 40% voids in filter media)

V_v = A_f x (d_f + d_g) x 0.4

V_v = _______ x (______ + ______) x 0.4

V_v = ____________ ft^3

Part 9: Compute Flow Through Filter During Filling Period (V_Q):
(assume 1-hour to fill per D.C. practice)

V_Q = $\frac{kA_f(d_f + h)}{d_f}$; use k = 2 ft/day = 0.0833 ft/hr

V_Q = [0.0833 x ______ x (______ + ________)]/ _______

V_Q = ____________ ft^3

Part 10: Select Sediment Chamber Width (Ws) and Compute the Storage Volume on Top of the 3-ft Deep Plunge Pool (V_{tpp}):

Set plunge pool length (L_{pp}) at $\geq$ 4 ft. = ____________ ft.

V_{tpp} = L_{pp} x W_s x (2h - d_p)

V_{tpp} = _________ x ________ x (_______ - ________)

V_{tpp} = ____________ ft^3

Part 11: Compute Net Flow Volume to be Stored Awaiting Filtration (V_{st}):

V_{st} = WQV - V_{tf} - V_V - V_Q - V_{tpp}

V_{st} = _________ - ________ - ________ - _________ - _________

V_{st} = ____________ ft^3

Part 12: Compute Minimum Length of Lower Pool (L_{lp}):

$$L_{lp} = \frac{V_{st}}{2h \times W_s}$$

L_{lp} = __________ / (____________ - ____________) x _________)

L_{lp} = _____________ ft

Split lower pool between sedimentation and filter chambers to make chamber lengths equal (minimum L_{lpf} - 2 ft).

$L_{lp} = L_{lps} + L_{lpf}$

L_{lps} = __________ ft; L_{lpf} = _____________ ft

Part 13: Check to Assure that Sediment Chamber Contains At Least 20% of WQV per Austin Practice:

0.2WQV = 0.2 x (__________) = __________ ft^3

If $V_{st} \geq 0.2WQV$, use

$V_{sc} = V_{tpp} + (2h \times L_{lps} \times W_s)$

V_{sc} = __________ + (________ x __________ x _________)

V_{sc} = _____________ ft^3

Part 14: Set Final Length of Sediment Chamber and Filter Chamber:

If $V_{sc} \geq WQV$, $L_s = L_{lps} + L_{pp}$

L_s = __________ + __________

L_s = _____________ ft

If $V_{sc} < WQV$, increase L_{lps} until $V_{sc} = WQV$

$$\text{New } L_{lps} = \frac{WQV - V_{tpp}}{2h \times W_s}$$

L_{lps} = [___________ - __________] / [__________ x __________]

L_{lps} = _____________ ft

New L_s = _________ + _________ = __________ ft

Make $L_f = L_s$ by increasing L_{lpf}: New L_{lpf} = ______________ ft

Part 15: Set Length of Clearwell (L_{cw}) for Adequate Maintenance Access (Minimum = 3 ft) and Compute Final Inside Length (L_{ti}) and Final Inside Width (W_t):

L_{cw} = _____________ ft;

Sum of cross full partition thickness (t_{pi}) = __________________ ft

$L_{ti} = L_f + L_{lpf} + t_{pi} + L_{cw}$

L_{ti} = __________ + _________ + ________ + _________

L_{ti} = _____________ ft

Sum of lengthwise full partition thickness (W_{pi}) = ____________ ft

$W_{ti} = W_s + W_f + W_{pi}$

W_{ti} = _________ + _________ + _________

W_{ti} = ____________ ft

Part 16: Design Structural Shell to Accommodate Soil and Load Conditions at Site:

Note: It may be economical to adjust final dimensions upward to correspond with standard precast structures or to round dimensions upward to simplify layout during construction.

SAND FILTER BMP COMPUTATIONS
Worksheet 5: Computations for Delaware Sand Filter

Part 4: Considering data on Worksheet 1, select maximum ponding depth over filter:

2h = _____________ ft;

h = _____________ ft

From WORKSHEET 1;

I_a = _____________ acres

WQV = ____________ ft^3

Part 5: Compute Minimum Area of Filter (A_{fm}) and Sediment Pool (A_{sm}):

a) If 2h ≥ 2.67 ft., use the formula:

$$A_{sm} = A_{fm} = \frac{545\ I_a d_f}{(d_f + h)}$$

= [545 x _________ x __________] / [________ + __________]

= _____________ ft^2

b) If 2h ≤ 2.67 ft., use the formula:

$$A_{sm} = A_{fm} = \frac{1816\ I_a}{(4.1h + 0.9)} = \frac{WQV}{(4.1h + 0.9)}$$

= __________ / [(4.1 x __________) + 0.9]

= _____________ ft^2

Part 6: Considering Site Constraints, Select Filter Width (W_f) and Sediment Pool Width (W_s) and Compute Filter Length (L_f) and Adjusted Filter Area (A_f) and Sediment Chamber Area (A_s):

W_s = W_f ____________ ft;

L_s = $L_f = A_{fm}/W_f$

= _____________ / ____________

= _____________ , say _________ ft

A_s = $A_f = W_f \times L_f$ = ___________ x ___________

= _____________ ft^2

Part 7: Compute Storage in Filter Voids (V_v):
(assume 40% voids in filter media)

V_v = $A_f \times d_f \times 0.4$

V_v = __________ x _________ x 0.4

V_v = _____________ ft^3

Part 8: Compute Flow Through Filter During Filling Period (V_Q):
(assume 1-hour to fill per D.C. practice)

V_Q = $\frac{kA_f(d_f + h)}{d_f}$; use k = 2 ft/day = 0.0833 ft/hr

V_Q = [0.0833 x ______ x (______ + _____)]/ _______

V_Q = _____________ ft^3

Part 9: Compute Net Flow Volume to be Stored Awaiting Filtration (V_{st}):

V_{st} = WQV - V_v - V_Q

V_{st} = __________ - __________ - __________

Vst = _____________ ft

Part 10: Compute Storage Above Filter and Sediment Pool (V_{fs}):

V_{fs} = $2h(A_f + A_s)$

V_{fs} =_________ (__________ + ___________)

V_{fs} =____________ ft

Part 11: Compute Storage Deficit (V_d):

V_d = $V_{st} - V_{fs}$

V_d =__________ - ____________

V_d =____________ ft^3

If $V_d \leq 0$, skip to Part 13. If $V_d \geq 0$, adjust design to provide additional storage.

Part 12: Select and Compute Design Adjustment:

____ a. Increase maximum ponding depth ($2h_j$):

$2h_j = V_S/A_f$ =___________ / __________

$2h_j$ = ___________ ft

____ b. Increase system length (L_i):

(1) Increase storage per lineal foot above filter and sediment pool ($V_{fs/ft}$):

$V_{fs/ft} = V_{fs}/L_f$ = ___________ / __________

=_____________ ft3/ft

(2) Compute increased system length to eliminate storage deficit (L_i):

$L_i = V_{st}/V_{st/ft}$ = ___________ / __________

= _______________ ft

____ c. Provide additional storage outside of filter shell (provide description and calculations):

____ d. Other (provide description and calculations):

Part 13: Design Structural Shell to Accommodate Soil and Load Conditions at Site:

Note: It may be economical to adjust final dimensions upward to correspond with standard precast structures or to round dimensions upward to simplify layout during construction.