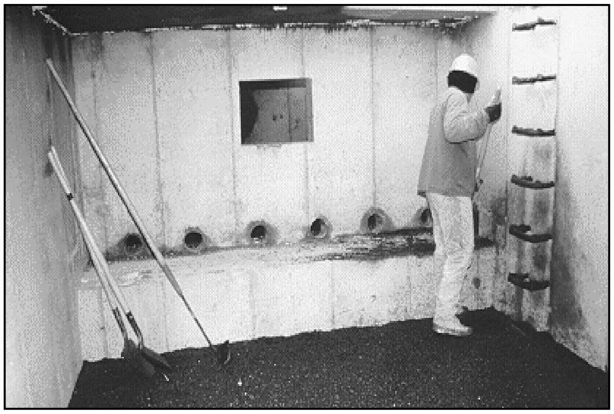
4.4.2 Underground Sand Filter

Limited Application Stormwater BMP



Description: The underground sand filter is a design variation of the surface sand filter, where the sand filter chambers and media are located in an underground vault.

KEY DESIGN CONSIDERATIONS

DESIGN GUIDELINES:

- Maximum contributing drainage area of 2 acres
- Typically requires 2 to 6 feet of head
- Precast concrete shells available, which decrease construction costs
- Underdrain required

ADVANTAGES / BENEFITS:

- High pollutant removal
- Applicable to small drainage areas
- Good for highly impervious areas
- Good retrofit capability

DISADVANTAGES / LIMITATIONS:

- High maintenance burden
- Not recommended for areas with high stormwater sediment or clay/silt runoff areas
- Possible odor problems
- Cannot be installed until site work is complete

MAINTENANCE REQUIREMENTS:

- Inspect for clogging – rake first inch of sand
- Remove sediment from forebay/chamber
- Replace sand filter media as needed

STORMWATER MANAGEMENT SUITABILITY

- ✓ **Water Quality**
- ✷ **Channel Protection**
- ☐ **Overbank Flood Protection**
- ☐ **Extreme Flood Protection**

Accepts Hotspot Runoff: *Yes (requires impermeable liner)*

✷ in certain situations

FEASIBILITY CONSIDERATIONS

L	**Land Requirement**
H	**Capital Cost**
H	**Maintenance Burden**

Residential Subdivision Use: *No*

High Density/Ultra-Urban: *Yes*

Drainage Area: *2 acres maximum*

Soils: *Not recommended for clay/silt drainage areas that are not stabilized*

L=Low **M**=Moderate **H**=High

POLLUTANT REMOVAL

H	**Total Suspended Solids**
M	**Nutrients** - Total Phosphorus / Total Nitrogen
M	**Metals** - Cadmium, Copper, Lead, and Zinc
M	**Pathogens** - Coliform, Streptococci, E.Coli

OTHER CONSIDERATIONS:

- Must be combined with other controls to provide water quantity control

4.4.2.1 General Description

The underground sand filter is a design variant of the surface sand filter. The underground sand filter is an enclosed filter system typically constructed just below grade in a vault along the edge of an impervious area such as a parking lot. The system consists of a sedimentation chamber and a sand bed filter. Runoff flows into the structure through a series of inlet grates located along the top of the control. Underground sand filters are best used for high-density land uses or ultra-urban applications where space for surface stormwater controls is limited. Figure 4-59 presents an example of an underground sand filter.

Figure 4-59. Example of an Underground Sand Filter

Multiple configurations have been developed for underground filters including the DC filter and the Delaware filter. The DC filter is intended to treat stormwater that is conveyed by a storm drain system. The Delaware filter (also known as the perimeter sand filter) is designed to collect flow directly from impervious surfaces and is well suited for installation along parking areas. Both systems operate in the same manner.

The underground sand filter is a three-chamber system. The initial chamber is a sedimentation (pretreatment) chamber that temporarily stores runoff and utilizes a wet pool to capture sediment. The sedimentation chamber is connected to the sand filter chamber by a submerged wall that protects the filter bed from oil and trash. The filter bed is 18 to 24 inches deep and may have a protective screen of gravel or permeable geotextile to limit clogging. The sand filter chamber also includes an underdrain system with inspection and clean out wells. Perforated drain pipes under the sand filter bed extend into a third chamber that collects filtered runoff. Flows beyond the filter capacity are diverted through an overflow weir.

Due to its location below the surface, underground sand filters have a high maintenance burden and should only be used where adequate inspection and maintenance can be ensured.

4.4.2.2 Stormwater Management Suitability

Underground sand filter systems are designed primarily as off-line systems for treatment of the water quality volume and will typically need to be used in conjunction with another structural BMP that can provide downstream channel protection, overbank flood protection, and extreme flood protection. However, under certain circumstances, underground sand filters can provide limited runoff quantity control, particularly for smaller storm events.

Water Quality (WQv)
In underground sand filter systems, stormwater pollutants are removed through a combination of gravitational settling, filtration and adsorption. The filtration process effectively removes suspended solids and particulates, biochemical oxygen demand (BOD), fecal coliform bacteria, and other pollutants.

Channel Protection (CPv)
For smaller sites, an underground sand filter may be designed to capture the entire channel protection volume (CPv) in either an off- or on-line configuration. Given that an underground sand filter system is typically designed to completely drain over 40 hours, the channel protection design requirement for extended detention of the 1-year, 24-hour storm runoff volume can be met. For larger sites or where only the WQv is diverted to the underground sand filter facility, another structural control must be used to provide extended detention of the CPv.

Overbank Flood Protection (up to Qp_{25}) and Extreme Flood Protection (Qp_{100})
Underground sand filters are not useful for flood protection. Another structural control, such as a conventional detention pond, must be used in conjunction with an underground sand filter system to control stormwater peak discharges. Further, underground sand filter facilities utilized on-line must provide flow diversion and/or be designed to safely pass extreme storm flows and protect the filter bed and facility.

4.4.2.3 Pollutant Removal Capabilities

Underground sand filters are presumed to be able to remove 80% of the total suspended solids (TSS) load in typical urban post-development runoff when sized, designed, constructed and maintained in accordance with the recommended specifications. Undersized or poorly designed underground sand filters can reduce TSS removal performance.

Additionally, research has shown that use of underground sand filters will have benefits beyond the removal of TSS, such as the removal of other pollutants (i.e. phosphorous, nitrogen, fecal coliform and heavy metals), as well, which is useful information should the pollutant removal criteria change in the future. The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from sampling data.

- Total Suspended Solids – 80%
- Total Phosphorus – 50%
- Total Nitrogen – 30%
- Heavy Metals – 50%
- Pathogens – 40%

For additional information and data on pollutant removal capabilities for underground sand filters, see the National Pollutant Removal Performance Database (2nd Edition) available at www.cwp.org and the International Stormwater Best Management Practices (BMP) Database at www.bmpdatabase.org.

4.4.2.4 Application and Site Feasibility Criteria

Underground sand filter systems are well-suited for highly impervious areas where land available for structural BMPs is limited. Underground sand filters should primarily be considered for new construction or retrofit opportunities for commercial, industrial, and institutional areas where the sediment load is relatively low, such as: parking lots, driveways, loading docks, gas stations, garages, airport runways/taxiways, and storage yards.

To avoid rapid clogging and failure of the filter media, the use of underground sand filters should be avoided in areas with less than 50% impervious cover, or high sediment yield sites with clay/silt soils.

The following basic criteria should be evaluated to ensure the suitability of an underground sand filter facility for meeting stormwater management objectives on a site or development.

General Feasibility

- Not suitable for use in a residential subdivision
- Suitable for use in high density/ultra-urban areas
- Not suitable for use as a regional stormwater control. On-site applications are typically most feasible.

Physical Feasibility - Physical Constraints at Project Site

- Drainage Area – 2 acres maximum for an underground sand filter
- Space Required – Function of available head at site
- Minimum Head – The surface slope across the filter location should be no greater than 6%. The elevation difference needed at a site from the inflow to the outflow is 2-6 feet.
- Minimum Depth to Water Table – If used on a site with an underlying water supply aquifer, a separation distance of 2 feet is required between the bottom of the sand filter and the elevation of the seasonally high water table to prevent groundwater contamination.
- Soils – Not recommended for clay/silt drainage areas that are not stabilized.

Other Constraints / Considerations

- Aquifer Protection – Do not allow infiltration of filtered hotspot runoff into groundwater

4.4.2.5 Planning and Design Standards

The following standards shall be considered **minimum** design standards for the design of underground sand filters. Underground sand filters that are not designed to these standards will not be approved. The Director of Engineering and Public Works (the Director) shall have the authority to require additional design conditions if deemed necessary.

A. CONSTRUCTION SEQUENCING

- Care shall be taken during construction to minimize the risk of premature failure of the underground sand filter due to deposition of sediments from disturbed, unstabilized areas. This can be minimized or avoided by proper construction sequencing.
- Ideally, the construction of an underground filter shall take place **after** the construction site has been stabilized. In the event that the underground sand filter is not constructed after site stabilization, diversion of site runoff around the sand filter and installation and maintenance of appropriate erosion prevention and sediment controls prior to site stabilization is required.
- Diversion berms shall be maintained around an underground sand filter during all phases of construction. No runoff shall enter the sand filter area prior to completion of construction and the complete stabilization of construction areas. Erosion prevention and sediment controls shall be maintained around the filter to prevent runoff and sediment from entering the sand filter during construction.
- Underground sand filters shall not be used as a temporary sediment trap for construction activities.
- During and after excavation of the underground sand filter area, all excavated materials shall be placed downstream, away from the sand filter, to prevent redeposit of the material during runoff events.

B. LOCATION AND SITING

- Underground sand filters shall have a contributing drainage area of 2 acres or less.
- Underground sand filter systems are generally applied to land uses with a high percentage of impervious surfaces. Sand filters shall not be utilized for sites that have less than 50% impervious cover. Any disturbed or denuded areas located within the area draining to and treated by the underground sand filter shall be stabilized prior to construction and use of the sand filter.
- Delaware underground sand filters are typically sited along the edge, or perimeter, of an impervious area such as a parking lot.
- DC underground sand filters are installed within the storm drain system.
- Underground sand filter systems shall be designed for intermittent flow and must be allowed to drain and re-aerate between rainfall events. They shall not be used on sites with a continuous flow from groundwater, sump pumps, or other sources.

C. PHYSICAL SPECIFICATIONS / GEOMETRY

- The entire treatment system (including the sedimentation chamber) must temporarily hold at least 75% of the WQv prior to filtration. Figures 4-60 and 4-61 illustrate the distribution of the treatment volume (0.75 WQv) among the various components of the underground sand filters, including:
  - V_w – wet pool volume within the sedimentation basin
  - V_f – volume within the voids in the filter bed
  - V_{temp} – temporary volume stored above the filter bed
  - A_s – the surface area of the sedimentation basin
  - A_f – surface area of the filter media
  - h_f – average height of water above the filter media (1/2 h_{temp})
  - d_f – depth of filter media
- The sedimentation chamber shall be sized to at least 50% of the computed WQv.
- The filter area shall be sized based on the principles of Darcy's Law. A coefficient of permeability (k) of 3.5 ft/day for sand shall be used. The filter bed shall be designed to completely drain in 40 hours or less.
- The filter media shall consist of an 18-inch to 24-inch layer of clean washed medium aggregate concrete sand (ASTM C-33) on top of the underdrain system. Figure 4-62 illustrates a typical media cross section.
- The filter bed shall be equipped with a 6-inch perforated pipe underdrain (PVC AASHTO M 252, HDPE, or other suitable pipe material) in a gravel layer. The underdrain shall have a minimum grade of 1/8-inch per foot (1% slope). Holes shall be 3/8-inch diameter and spaced approximately 6 inches on center. Gravel shall be clean-washed aggregate with a maximum diameter of 3.5 inches and a minimum diameter of 1.5 inches with a void space of about 40%. Aggregate contaminated with soil shall not be used.

Figure 4-60. Underground (DC) Sand Filter Volumes

(Source: Center for Watershed Protection)

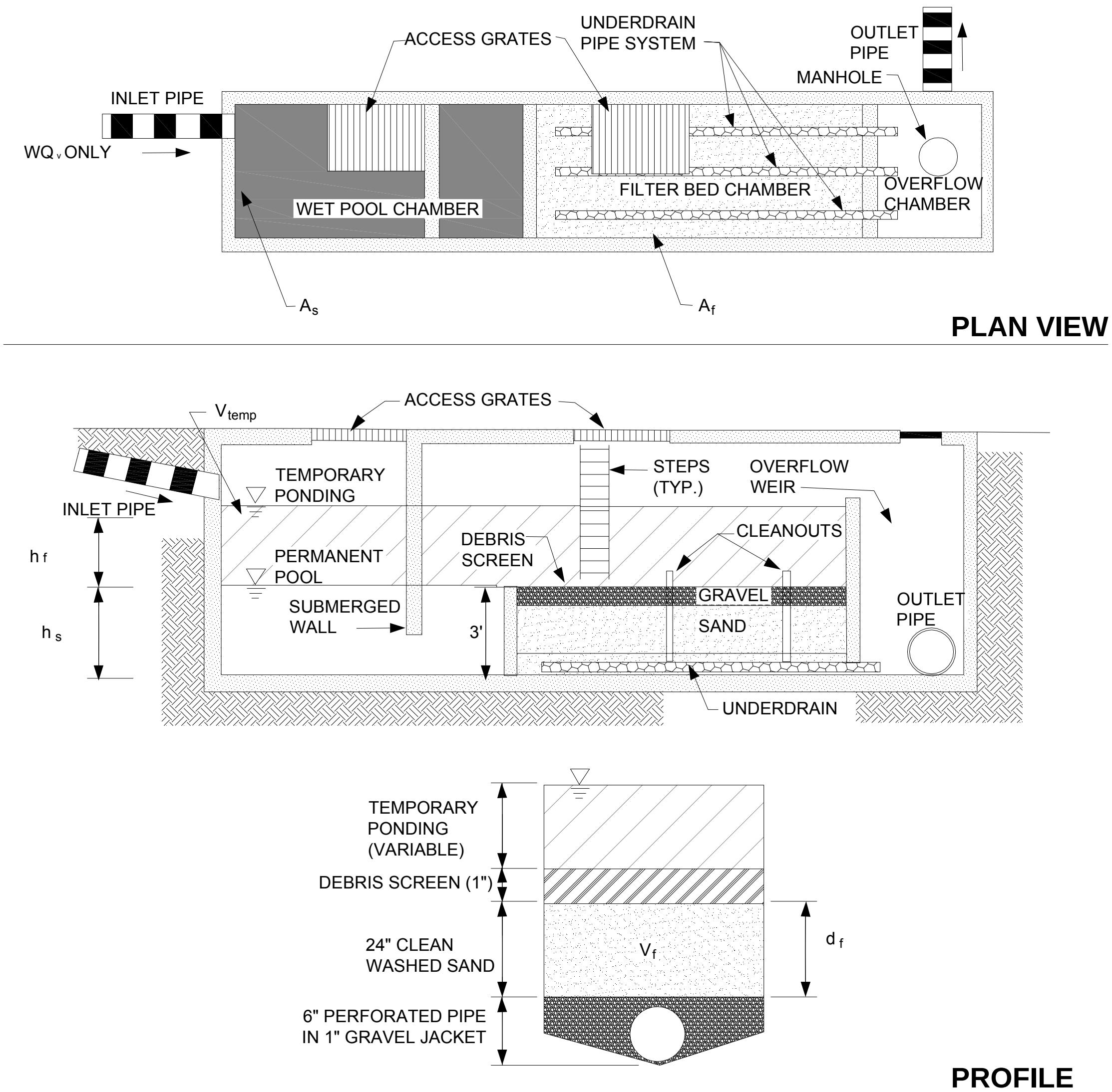


Figure 4-61. Perimeter Sand Filter Volumes
(Source: Claytor and Schueler, 1996)

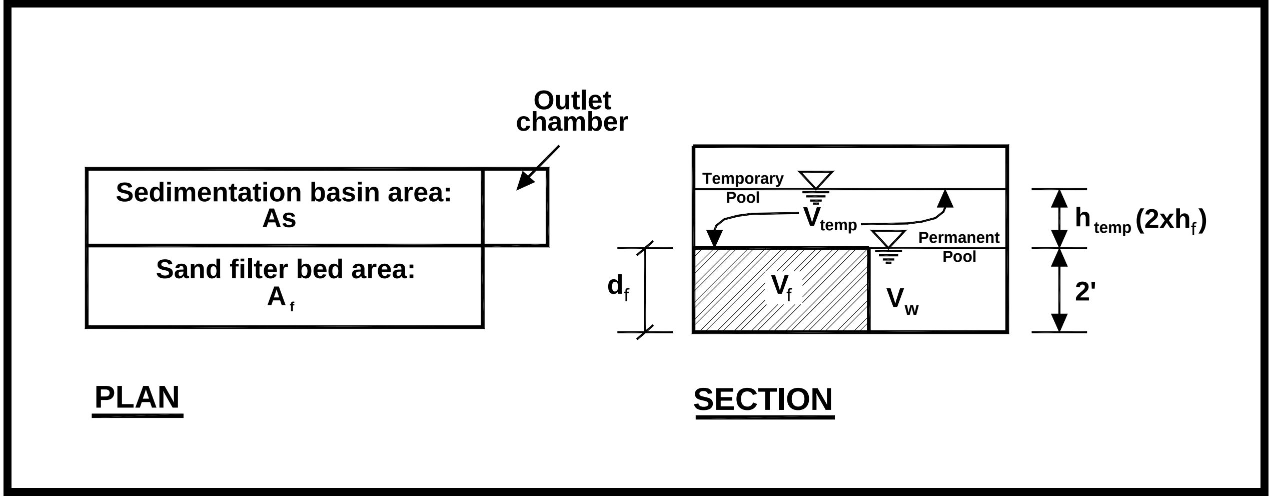
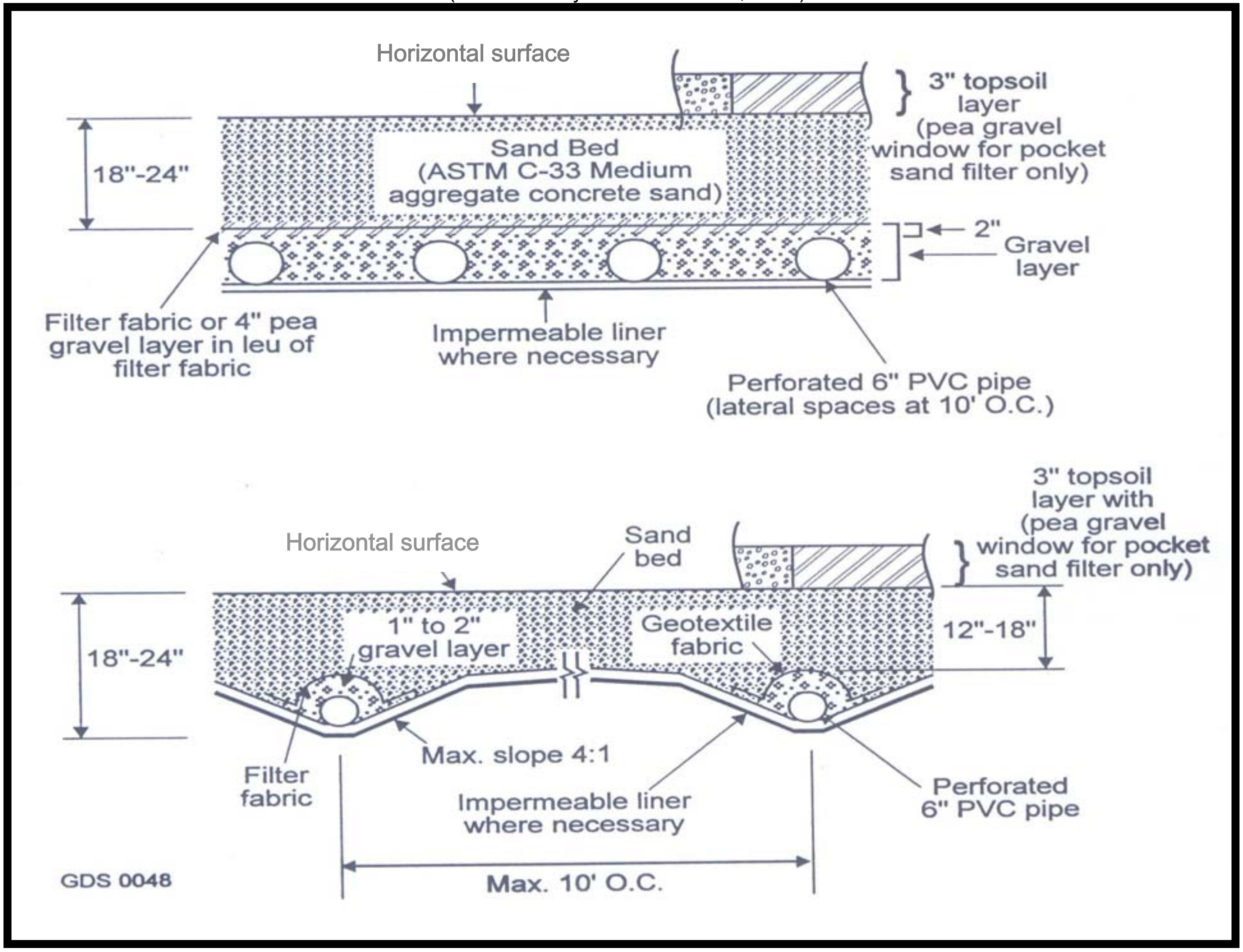


Figure 4-62. Typical Sand Filter Media Cross Sections
(Source: Claytor and Schueler, 1996)



D. OUTLET STRUCTURES

- An outlet pipe shall be provided from the underdrain system to the facility discharge. Due to the slow rate of filtration, outlet protection is generally unnecessary (except for emergency overflows and spillways). However, the design shall ensure that the discharges from the underdrain system occur in a non-erosive manner.

E. EMERGENCY SPILLWAY

- An emergency bypass spillway or weir must be included in the underground sand filter design to safely pass flows that exceed the WQv (and CPv if the filter is utilized for channel protection purposes

F. MAINTENANCE ACCESS

- A minimum 20' wide maintenance right-of-way or drainage easement shall be provided for an underground sand filter from a driveway, public or private road. The maintenance access easement shall have a maximum slope of no more than 15% and shall have a minimum unobstructed drive path having a width of 12 feet, appropriately stabilized to withstand maintenance equipment and vehicles. Adequate access must be provided to the grates of the filter bed. Facility designs must enable maintenance personnel to easily remove and replace upper layers of the filter media.

G. SAFETY FEATURES

- Inlets, access grates and outlets shall be designed and maintained so as not to permit access by children. Inlet and access grates to the underground sand filters may be locked.

4.4.2.6 Design Procedures

Step 1. Compute runoff control volumes

Calculate WQv, CPv in accordance with the guidance presented in Volume 2, Chapter 3.

Step 2. Determine if the development site and conditions are appropriate for the use of an underground sand filter.

Consider the Application and Site Feasibility Criteria Check with Knox County Engineering and other agencies as appropriate to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Step 3. Compute WQv peak discharge (Q_{wq})

The peak rate of discharge for water quality design storm is needed for sizing of off-line diversion structures (see Volume 2, Chapter 3 for more information on this calculation).

(a) Using WQv, compute CN

(b) Compute time of concentration using TR-55 method

(c) Determine appropriate unit peak discharge from time of concentration

(d) Compute Q_{wq} in inches from unit peak discharge, drainage area, and WQv.

Step 4. Size flow diversion structure, (if needed)

If a diversion structure is utilized, a flow regulator should be supplied to divert the WQv to the underground sand filter facility. Size low flow orifice, weir, or other device to pass Q_{wq}.

Step 5. Size filtration basin chamber

The filter area is sized using the following equation (based on Darcy's Law):

$$A_f = (WQv)\ (d_f)\ /\ [(k)\ (h_f + d_f)\ (t_f)]$$

where:

A_f = surface area of filter bed (ft^2)
WQv = water quality volume (ft^3)

d_f = filter bed depth (1.5 ft)
(at least 18 inches, no more than 24 inches)
k = coefficient of permeability of filter media (ft/day)
(use 3.5 ft/day for sand)
h_f = average height of water above filter bed (ft)
(1/2 h_{max}, which varies based on site but h_{max} is typically $\leq$ 6 feet)
t_f = design filter bed drain time (days)
(1.67 days or 40 hours is required maximum time)

Set preliminary dimensions of filtration basin chamber.

Step 6. Size sedimentation chamber

Depending on the type of underground sand filter system utilized, the sedimentation chamber shall be sized to at least 50% of the computed WQv and have a length-to-width ratio of 2:1. The Camp-Hazen equation is used to compute the required surface area:

$$A_s = -(Q_o/w) * \text{Ln}(1-E)$$

where:
A_s = sedimentation basin surface area (ft^2)
Q_o = rate of outflow = the WQv (ft^3) / 86400 seconds
w = particle settling velocity (ft/sec)
E = trap efficiency

Assuming:
- E = 90% sediment trap efficiency (0.9)
- w = particle settling velocity (ft/sec) = 0.0033 ft/sec for imperviousness $\geq$ 75%
- w = particle settling velocity (ft/sec) = 0.0004 ft/sec for imperviousness < 75%
- average of 24 hour holding period

Then:
A_s = (0.0081) (WQv) ft^2 for I $\geq$ 75%
A_s = (0.066) (WQv) ft^2 for I < 75%

Set preliminary dimensions of sedimentation chamber.

Step 7. Compute V_{min}

$$V_{min} = 0.75 * WQv$$

Step 8. Compute storage volumes within entire facility and sedimentation chamber orifice size

Underground (D.C.) sand filter:

$$V_{min} = 0.75\ WQv = V_s + V_f + V_{f\text{-}temp}$$

(1) Compute V_f = water volume within filter bed/gravel/pipe = $A_f * d_f * n$
Where: n = porosity = 0.4 for most applications

(2) Compute $V_{f\text{-}temp}$ = temporary storage volume above the filter bed = $2 * h_f * A_f$

(3) Compute V_s = volume within sediment chamber = $V_{min} - V_f - V_{f\text{-}temp}$

(4) Compute h_s = height in sedimentation chamber = V_s/A_s

(5) Ensure h_s and h_f fit available head and other dimensions still fit – change as necessary in design iterations until all site dimensions fit.

(6) Size weir from sediment chamber to filter chamber to release V_s within 24-hours at average release rate with 0.5 h_s as average head.

(7) Design outlet structure with perforations allowing for a safety factor of safety ten (10) times the orifice capacity.

(8) Size distribution chamber to spread flow over filtration media – level spreader weir.

Underground perimeter (Delaware) sand filter:

(1) Compute V_f = water volume within filter bed/gravel/pipe = $A_f * d_f * n$
where: A_f = surface area of filter bed (ft^2)
d_f = filter bed depth (1.5 ft)
(at least 18 inches, no more than 24 inches)
n = porosity = 0.4 for most applications

(2) Compute V_w = wet pool storage volume A_s * 2 feet minimum

(3) Compute V_{temp} = temporary storage volume = $V_{min} – (V_f + V_w)$

(4) Compute h_{temp} = temporary storage height = $V_{temp} / (A_f + A_s)$

(5) Ensure $h_{temp} \geq 2 * h_f$, otherwise decrease h_f and re-compute. Ensure dimensions fit available head and area – change as necessary in design iterations until all site dimensions fit.

(6) Size distribution weirs from sediment chamber to filter chamber.

Step 9. Design inlets, underdrain system, and outlet structures

See design criteria above for more details.

Step 10. Compute overflow weir sizes

Underground (D.C.) sand filter:

$$V_{min} = 0.75\ WQv = V_s + V_f + V_{f\text{-}temp}$$

(1) Compute V_f = water volume within filter bed/gravel/pipe = $A_f * d_f * n$
where: n = porosity = 0.4 for most applications

(2) Compute $V_{f\text{-}temp}$ = temporary storage volume above the filter bed = $2 * h_f * A_f$

(3) Compute V_s = volume within sediment chamber = $V_{min} - V_f - V_{f\text{-}temp}$

(4) Compute hs = height in sedimentation chamber = Vs/As

(5) Ensure hs and hf fit available head and other dimensions still fit – change as necessary in design iterations until all site dimensions fit.

(6) Size orifice from sediment chamber to filter chamber to release Vs within 24-hours at average release rate with 0.5 hs as average head.

(7) Design outlet structure with perforations allowing for a safety factor of ten (10) times the orifice capacity.

(8) Size distribution chamber to spread flow over filtration media – level spreader weir or orifices.

Underground perimeter (Delaware) sand filter: Size overflow weir at end of sedimentation chamber to handle excess inflow, set at WQv elevation.

4.4.2.7 Maintenance Requirements and Inspection Checklist

Note: Section 4.2.2.7 must be included in the Operations and Maintenance Plan that is recorded with the deed.

Regular inspection and maintenance is critical to the effective operation of an underground sand filter as designed. It is the responsibility of the property owner to maintain all stormwater BMPs in accordance with the minimum design standards and other guidance provided in this manual. The Director has the authority to impose additional maintenance requirements where deemed necessary.

This page provides guidance on maintenance activities that are typically required for underground sand filters, along with a suggested frequency for each activity. Individual filters may have more, or less, frequent maintenance needs, depending upon a variety of factors including the occurrence of large storm events, overly wet or dry (i.e., drought) regional hydrologic conditions, and any changes or redevelopment in the upstream land use. Each property owner shall perform the activities identified below at the frequency needed to maintain the sand filter in proper operating condition at all times.

Inspection Activities	Suggested Schedule
• A record should be kept of the dewatering time (i.e., the time required to drain the filter bed completely after a storm event) for a sand filter to determine if maintenance is necessary. The filter bed should drain completely in about 40 hours after the end of the rainfall. • Check to ensure that the filter surface does not clog after storm events.	After Rain Events
• Check the contributing drainage area, facility, inlets and outlets for debris. • Check to ensure that the filter surface is not clogging.	Monthly
• Check to see that the filter bed is clean of sediment, and the sediment chamber is not more than 50% full or 6 inches, whichever is less, of sediment. Remove sediment as necessary. • Make sure that there is no evidence of deterioration, spalling, bulging, or cracking of concrete. • Inspect grates of sand filter (perimeter and Delaware). • Inspect inlets, outlets and overflow spillway to ensure good condition and no evidence of erosion. • Check to see if stormwater flow is bypassing the facility (if so designed). • Ensure that no noticeable odors are detected outside the facility.	Annually
Maintenance Activities	**Suggested Schedule**
• Mow and stabilize (prevent erosion, vegetate denuded areas) the area draining to the underground sand filter. Collect and remove grass clippings. Remove trash and debris. • Ensure that activities in the drainage area minimize oil/grease and sediment entry to the system. • If permanent water level is present (perimeter and Delaware).in sand filter, ensure that the chamber does not leak, and normal pool level is retained.	Monthly
• Check to see that the filter bed is clean of sediment, and the sediment chamber is not more than 50% full or 6 inches, whichever is less, of sediment. Remove sediment as necessary. • Repair or replace any damaged structural parts. • Stabilize any eroded areas.	Annually
• If filter bed is clogged or partially clogged, manual manipulation of the surface layer of sand may be required. Remove the top few inches of sand, roto-till or otherwise cultivate the surface, and replace media with sand meeting the design specifications. • Replace any filter fabric that has become clogged.	As needed

Knox County encourages the use of the inspection checklist that is presented on the next page to guide the property owner in the inspection and maintenance of underground sand filters. The Director can require the use of this checklist or other form(s) of maintenance documentation when and where deemed necessary in order to ensure the long-term proper operation of the underground sand filter. Questions regarding stormwater facility inspection and maintenance should be referred to the Knox County Department of Engineering and Public Works, Stormwater Management Division.

INSPECTION CHECKLIST AND MAINTENANCE GUIDANCE (continued)
UNDERGROUND SAND FILTER INSPECTION CHECKLIST

Location: ____ Owner Change since last inspection? Y N

Owner Name, Address, Phone: ____

Date: __________ Time: ____________ Site conditions:______________________________________

Inspection Items	Satisfactory (S) or Unsatisfactory (U)	Comments/Corrective Action
Underground Sand Filter Inspection List		
Complete drainage of the filter in about 40 hours after a rain event?		
Clogging of filter surface?		
Clogging of inlet/outlet structures?		
Clogging of filter fabric?		
Filter clear of debris and functional?		
Leaks or seeps in filter?		
Obstructions of spillway(s)?		
Animal burrows in filter?		
Sediment accumulation in filter bed (less than 50% is acceptable)?		
Cracking, spalling, bulging or deterioration of concrete?		
Erosion in area draining to sand filter?		
Erosion around inlets, filter bed, or outlets?		
Pipes and other structures in good condition?		
Undesirable vegetation growth?		
Other (describe)?		
Hazards		
Have there been complaints from residents?		
Public hazards noted?		

If any of the above inspection items are **UNSATISFACTORY**, list corrective actions and the corresponding completion dates below:

Corrective Action Needed	Due Date

Inspector Signature:______________________________ Inspector Name (printed)__________________________

4.4.2.8 Example Schematics

Figure 4-63. Schematic of an Underground (D.C.) Sand Filter
(Source: Center for Watershed Protection)

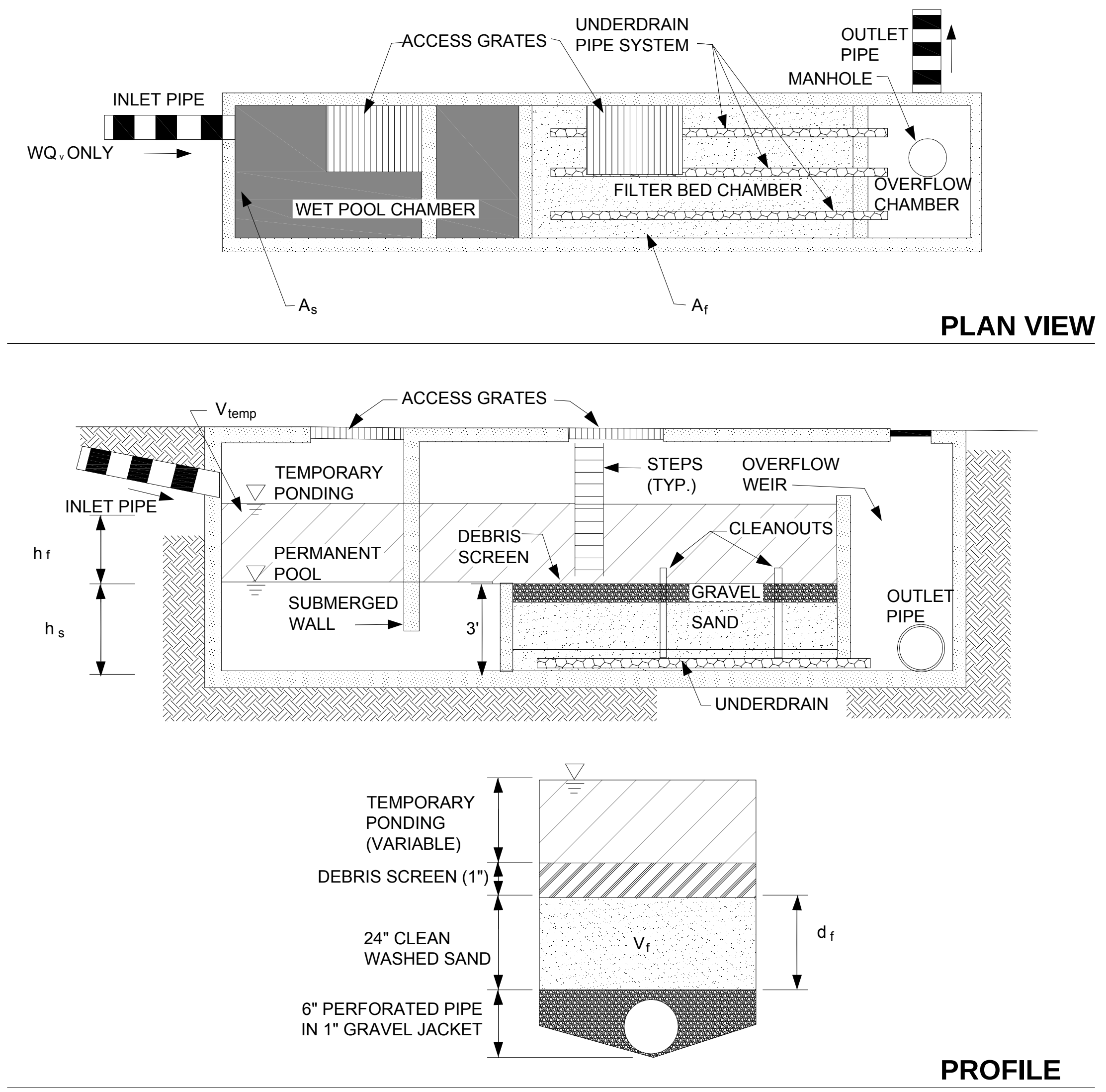
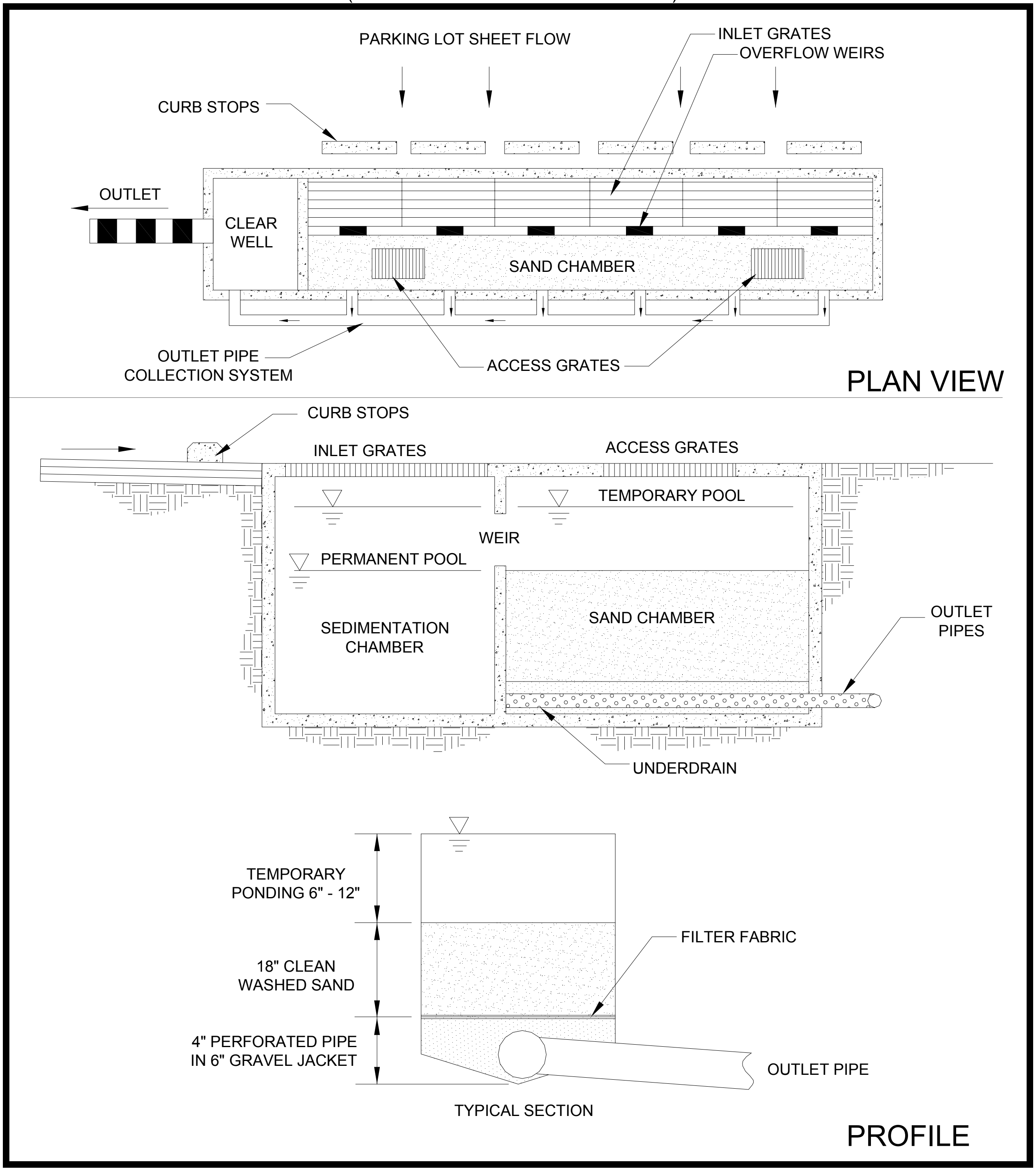


Figure 4-64. Schematic of Perimeter (Delaware) Sand Filter
(Source: Center for Watershed Protection)



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4.4.2.10 Suggested Reading

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