Sand Filters

Description: Multi-chamber structure designed to treat stormwater runoff through filtration, using a sediment forebay, a sand bed as its primary filter media and an underdrain collection system (typically).

Variations: Underground Sand Filter (see PTP-10), Perimeter Sand Filter (see PTP-11), and Organic Filter (PTP-12)

Components:
- Forebay (or sedimentation chamber)—settles coarse particles and trash
- Sand bed (or Filtration) chamber—provides water quality treatment by filtering other pollutants
- Spillway system(s)— provide discharge control

Advantages/Benefits:
- Applicable to small drainage areas
- Good for highly impervious areas
- Good for water quality retrofits to existing developments

Disadvantages/Limitations:
- High maintenance burden
- Not recommended for areas with high sediment content in stormwater or clay/silt runoff areas
- Relatively costly
- Possible odor problems
- Typically needs to be combined with other controls to provide water quantity control

Design considerations:
- Typically requires 2 to 6 feet of head
- Maximum contributing drainage area of 10 acres
- In karst areas use polyliner or impermeable membrane to seal bottom of earthen surface sand filter or use watertight structure

Selection Criteria:

- [x] **Water Quality 80 % TSS Removal**
- [x] **Accepts Hotspot Runoff**
- [ ] **Residential Subdivision**
- [x] **High Density / Ultra Urban Use**

Maintenance:
- Inspect for clogging—rake first inch of sand
- Remove sediment from forebay-chamber
- Replace sand filter media as needed
- Clean spillway system(s)

H — **Maintenance Burden**

L = Low M = Moderate H = High

General Description

Sand filters (also referred to as *filtration basins*) are structural stormwater controls that capture and temporarily store stormwater runoff and treat it by filtering it through a bed of sand. The surface sand filter is a ground-level open air structure that consists of a pretreatment sediment forebay and a sand bed chamber. This system can treat drainage areas up to 10 acres in size and is an off-line device in which flows larger than the water quality volume by-pass the system. Surface sand filters can be designed as an excavation with earthen embankments or as a concrete or block structure. The filtered runoff is collected and returned to the conveyance system, or it can also be partially or fully exfiltrated into the surrounding soil in areas with porous soils. A schematic of a surface sand filter is shown in Figure 4.1.

Because they have few site constraints beside head requirements, sand filters can be used on development sites where the use of other structural controls may be precluded. However, sand filter systems can be relatively expensive to construct and install and they have high maintenance requirements.

A design variant, the *underground sand filter*, is intended primarily for extremely space limited and high density areas and is thus considered a limited application structural control. See PTP-10 for more details. Another design variant is the *perimeter sand filter*, which 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. See PTP-16 for information on the perimeter sand filter.

In surface sand filter systems, stormwater pollutants are removed through a combination of gravitational settling, filtration, and adsorption. The filtration process effectively traps suspended solids and particulates. As solids are trapped in the sand bed, some reduction of associated pollutants such as biochemical oxygen demand (BOD), fecal coliform bacteria, and other pollutants may be achieved.

Site and Design Considerations

Location and Siting

1. Surface sand filters should have a contributing drainage area of 10 acres or less.
2. Surface sand filter systems are generally applied to land uses with a high percentage of impervious surfaces. Sites with less than 50% imperviousness or with high clay/silt sediment loads must not use sand filters without adequate pretreatment because the sediment causes clogging and failure of the filter bed. Any disturbed areas within the sand filter facility drainage area should be identified and stabilized. Filtration controls should only be constructed after the construction site is stabilized.

Site and Design Considerations (Continued)

3. Surface sand filters are used in an off-line configuration where the water quality volume (WQ_v) is diverted to the filter facility. Stormwater flows greater than the WQ_v are diverted to other controls or downstream using a diversion structure or flow splitter.
4. Sand filter systems are designed for intermittent flow and must be allowed to drain and aerate between rainfall events. They should not be used on sites with a continuous flow from groundwater, sump pumps, or other sources.

General Design

5. A surface sand filter facility consists of a two-chamber open-air structure, which is located at ground-level. The first chamber is the sediment forebay (sedimentation chamber) while the second chamber houses the sand filter bed. Flow enters the forebay chamber where settling of larger sediment particles occurs. Discharge from the forebay chamber flows through a perforated standpipe into the sand bed chamber. The flow is then uniformly distributed across the sand bed chamber via distribution vault or weir. After passing though the filter bed, runoff is collected by a perforated pipe and gravel underdrain system. Figure 4.1 provides plan view and profile schematics of a surface sand filter.

Physical Specifications/Geometry

6. The entire treatment system (including the forebay) must temporarily hold the WQ_v prior to filtration. Table 4.1 presents the design parameters and values for the perimeter sand filter. Figure 4.2 illustrates these design parameters.
7. The forebay chamber must be sized to at least 50% of the computed $WQ_{v,}$ hold this volume for 24 hours, and have a length-to-width ratio of at least 2:1. Inlet and outlet structures should be located at opposite ends of the chamber.
8. The filter area is sized based on the principles of Darcy's Law. A coefficient of permeability (k) of 3.5 ft/day for sand should be used. The filter bed is typically designed to completely drain in 24 hours or fewer.
9. The filter media consists of an 18 to 24 inch layer of clean washed medium sand (meeting ASTM C-33 concrete sand) on top of the underdrain system. Permeable filter fabric is placed both above and below the sand bed to prevent clogging of the sand filter and the underdrain system. Figure 4.3 illustrates a typical media cross section.
10. The filter bed is equipped with a 6-inch perforated pipe (ASTM Schedule 40) underdrain in a gravel layer. The underdrain must have a minimum grade of 1/8-inch per foot (1% slope). Holes should be 3/8-inch diameter and spaced approximately 6 inches on center. Gravel should be clean washed aggregate with a maximum diameter of 3.5

Site and Design Considerations (Continued)

inches and a minimum diameter of 1.5 inches with a void space of about 30%. Do not use aggregate contaminated with soil.

11. The structure of the surface sand filter may be constructed of impermeable media such as concrete, or through the use of excavations and earthen embankments. When constructed with earthen walls/embankments, filter fabric should be used to line the bottom and side slopes of the structures before installation of the underdrain system and filter media. The structure should include an access ramp at 4:1 (H:V) or less for maintenance.

Table 4.1 Surface Sand Filter Design Parameters

Parameter Description	Parameter	Parameter Value
Total Temporary Volume in Forebay and Sand Bed Chamber	WQ_v	WQ_v; See Design Step #1
Approximate Temporary Sand Bed Volume[1]	V_{ST}	(0.5) WQ_v
Minimum Sand Bed Thickness	T_S	18 inches
Sand Bed Design Porosity	n	0.3
Sand Bed Design Permeability	k	3.5 feet/day
Sand Bed Design Drain Time	t_d	1.5 days, 36 hours max
Minimum Sand Bed Chamber Area	A_S	See Design Step #6
Approximate Temporary Forebay Volume[2]	V_{FT}	(0.5) WQ_v
Minimum Forebay Surface Area	A_F	(0.05) WQ_v
Maximum Temporary Sand Bed Depth[3]	D_{ST}	See Design Step #3
Minimum Temporary Forebay Depth	D_{FT}	2 feet
Overall Minimum Length to Width Ratio	L/W	2

1. Includes temporary storage volume in sand.
2. Includes temporary storage volume in sand.
3. Excludes storage volume in forebay permanent pool.
4. Measured from top of sand bed.

(Adapted from the New Jersey Stormwater Best Management Practices Manual)

Site and Design Considerations (Continued)

Pretreatment/Inlets

12. Pretreatment of runoff in a sand filter system is provided by the forebay chamber.
13. Inlets to surface sand filters are to be provided with energy dissipaters. Exit velocities from the forebay chamber must be nonerosive.
14. Figure 4.4 shows a typical inlet pipe from the forebay to the sand bed chamber where the flow is then evenly distributed across the filtration area.

Outlet Structures

Outlet pipe is to 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).

Emergency Spillway

Surface sand filters are off-line devices and the emergency spillway is provided in case diversion structure fails. The spillway prevents filter water levels from overtopping the embankment and causing structural damage. The emergency spillway should be located so that downstream buildings and structures will not be impacted by spillway discharges.

Maintenance Access

Adequate access through maintenance easements must be provided for all sand filter systems for inspection and maintenance, including the appropriate equipment and vehicles. Facility designs must enable maintenance personnel to easily replace the upper layers of the filter media. Maintenance access ramps at a 4:1 slope or flatter must be provided.

Safety Features

Surface sand filter facilities can be fenced to prevent unauthorized access.

Design Procedures

Step 1. Compute the Water Quality Volume.

Calculate the Water Quality Volume (WQ_v), which must be temporarily stored within the perimeter sand filter's entire treatment system.

$$WQ_v = P \times Rv \times A/12$$

Where:
WQ_v = water quality treatment volume, ac-ft
P = rainfall for the 85% storm event (1.1 in)
Rv = runoff coefficient (see below)
A = site area, acres

$$Rv = 0.015 + 0.0092*I$$

Where:
I = site impervious cover, % (for example 50% equals 50)

Step 2. Determine approximate required volumes of the forebay and sand bed.

Each should be equal to approximately 0.5 WQ_v, as shown in Table 4.1.

Step 3. Determine approximate temporary depths in sand bed (D_{ST}) and forebay (D_{FT}) for the WQ_v.

The estimate will depend on and be based on analysis of site conditions including the difference between the invert elevation of the downstream conveyance system and the maximum ground elevation at filter facility. Make sure to include the minimum sand bed thickness (T_{HS}) into the consideration for these temporary depths. Note that the maximum temporary depth in the sand bed zone (D_{ST}) is measured from the top of the sand bed, while the maximum temporary forebay depth (D_{FT}) is measured the bottom of the forebay.

Step 4. Compute minimum forebay surface area (A_F).

The minimum surface area is

$$A_F = 0.05\ (WQ_v)$$

Where:
A_F = forebay area
0.05 = a multiplier in units per area of volume (L^2/L^3)

Design Procedures Continued

Step 5. Compute total temporary storage volume in the forebay (V_{FT}).

From the maximum temporary depth in the forebay (D_{FT}) from Step 3 and the minimum forebay area (A_F) from Step 4, compute the total temporary storage volume in the forebay (V_{FT}). *Compare* this volume with the approximate required forebay volume computed in Step 2. *Adjust* the maximum temporary forebay depth (D_{FT}) and/or forebay area (A_F) as necessary to achieve a total temporary forebay storage volume (V_{FT}) as close as practical to the required forebay volume from Step 2. While adjusting the forebay surface area (A_F) by varying its length and width, remember that the forebay will be located immediately adjacent to the sand bed zone and that the minimum overall length to width ratio of the combined zone is two to one.

Step 6. Compute **sand bed** chamber area (A_S).

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

$$\mathbf{A_S = (WQ_v)\ (T_S / [(k)\ (D_{ST}/2 + T_S)\ (T_D)]}$$

Where:

A_S = Sand Bed Surface Area (in square feet)
T_S = Thickness of Sand in Sand Bed (typically 18 inches, no more than 24 inches)
k = Coefficient of permeability of filter media (ft/day) (use 3.5 ft/day for sand)
D_{ST} = Maximum Temporary Sand Bed Depth (ft)
t_d = Sand Bed Design Drain Time (1.5 days or 36 hours is recommended maximum)

See the Physical Specifications/Geometry section of the *Site and Design Considerations* for filter media specifications.

Step 7. Compute total temporary storage volume in sand bed.

$$\mathbf{V_{ST} = (A_S)(D_{ST}) + (A_S)(T_S)(n)}$$

Where:
V_{ST} = Temporary Sand Bed Storage Volume (in cubic feet)
A_S = Sand Bed Surface Area (in square feet)
D_{ST} = Maximum Temporary Sand Bed Depth (ft)
T_S = Thickness of Sand in Sand Bed, recommended 18 inches (in feet)
n = Sand Bed Design Porosity, recommended 0.3

Design Procedures (Continued)

Step 8. Compare and adjust areas and volumes to achieve storage of WQ_v within the entire facility.

Compare the total temporary sand bed storage volume (V_{ST}) with the approximate required sand bed zone volume computed in Step 2. As shown on Table 16.1, this temporary sand bed storage volume should be approximately one half of the stormwater quality design storm runoff volume (WQ_v). In addition, add the total temporary sand bed volume (V_{ST}) to the total temporary forebay storage volume (V_{FT}) to determine the total temporary storage volume in the sand filter. As shown in Table 16.1, this total temporary storage volume must equal the stormwater quality design storm runoff volume (WQ_v). Adjust the maximum temporary sand bed depth (D_{ST}) and/or sand bed area (A_S) as necessary to achieve a total temporary sand bed storage volume (V_{ST}) as close as practical to the required sand bed volume from Step 2 and a total filter volume equal to WQ_v. Remember, while adjusting width and length that forebay will be located immediately adjacent to the sand bed zone and that the minimum overall length to width ratio of the combined zone is two to one.

Step 9. Design flow diversion structure.

A flow regulator (or flow splitter diversion structure) should be supplied to divert the WQ_v to the sand filter.

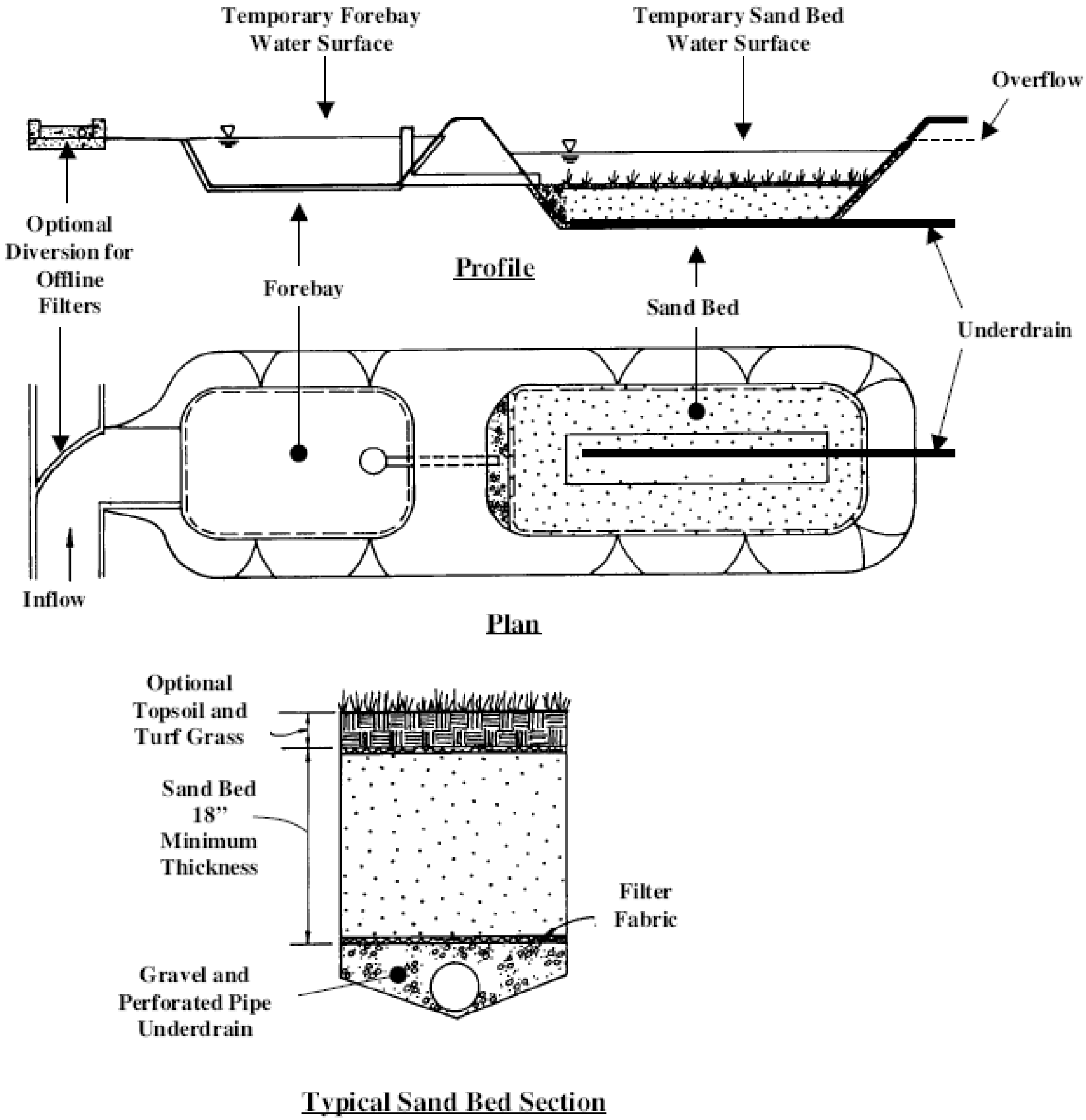
Size low flow orifice, weir, or other device to bypass the 100-year flood.

Step 10. Design inlets, underdrain system, overflow weirs, and outlet structures.

See *Site and Design Considerations* for more information on underdrain specifications and outlet structures. PTP-01 provides more information on sizing orifices, weirs, and outlets.

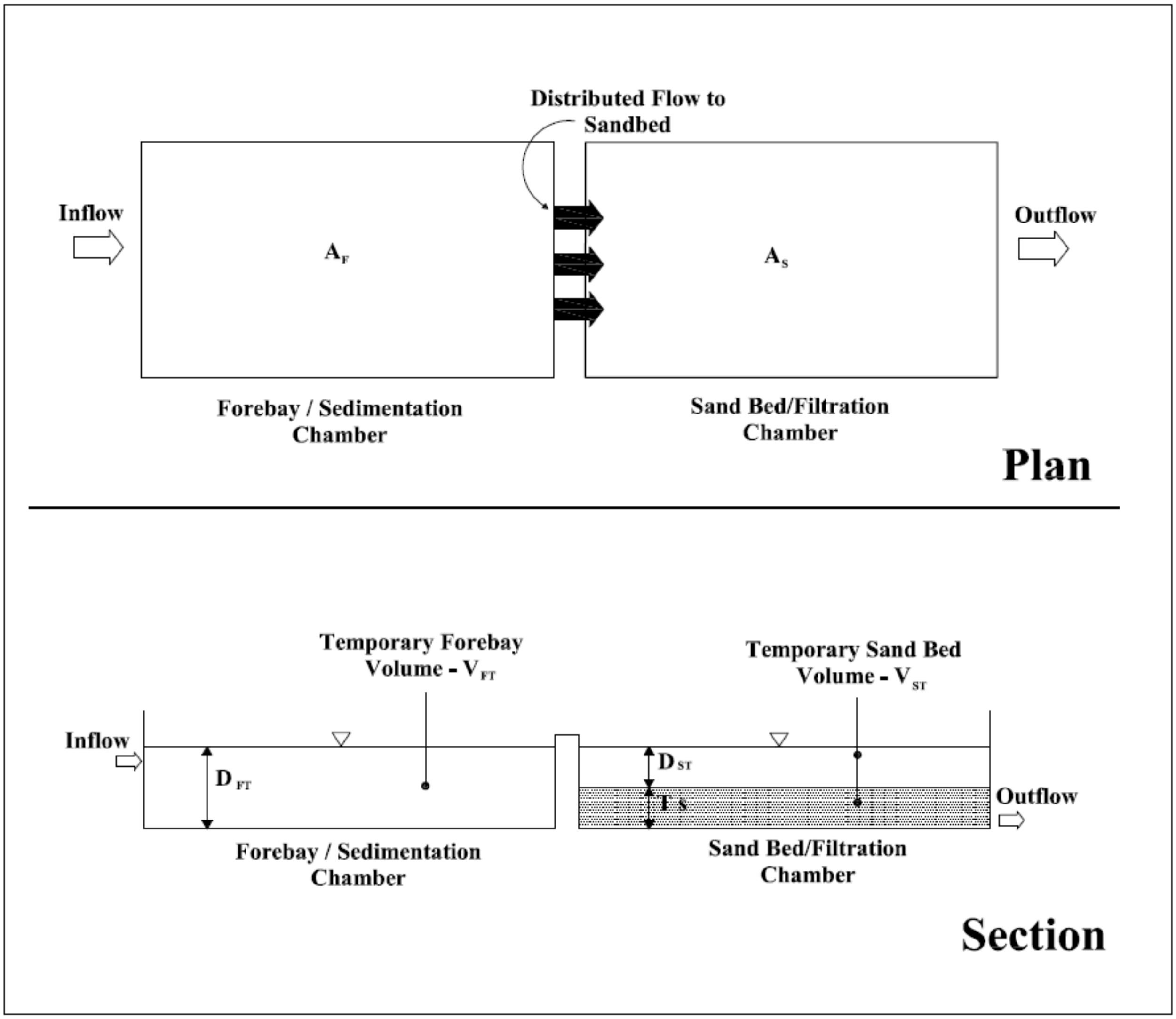
Step 11. Design emergency overflow.

An overflow must be provided in case of a failure in the diversion structure. Non-erosive velocities need to be ensured at the outlet point.



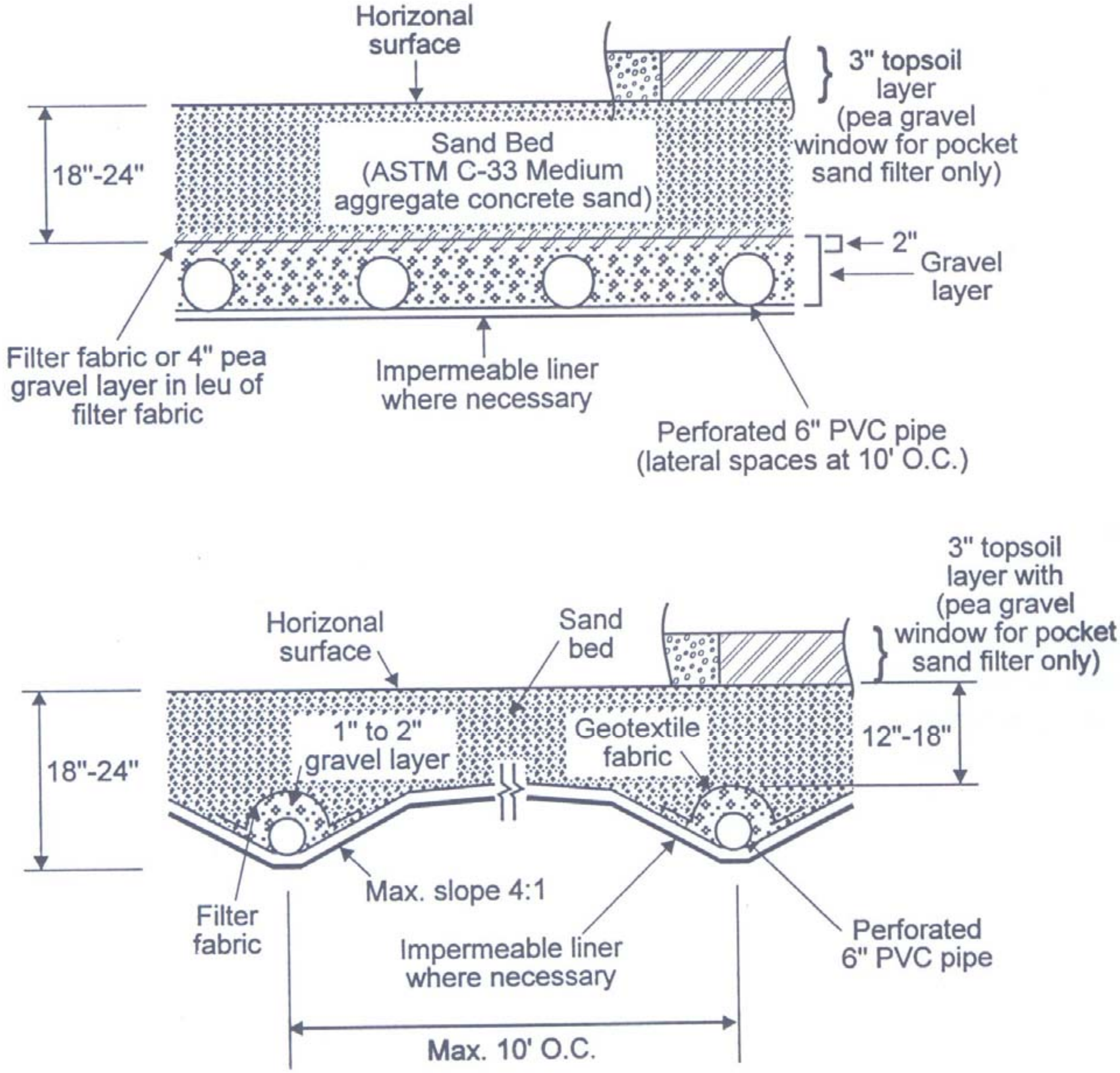
(Source: New Jersey Stormwater Best Management Practices Manual, 2003)

Figure 4.1 Surface Sand Filter Schematic



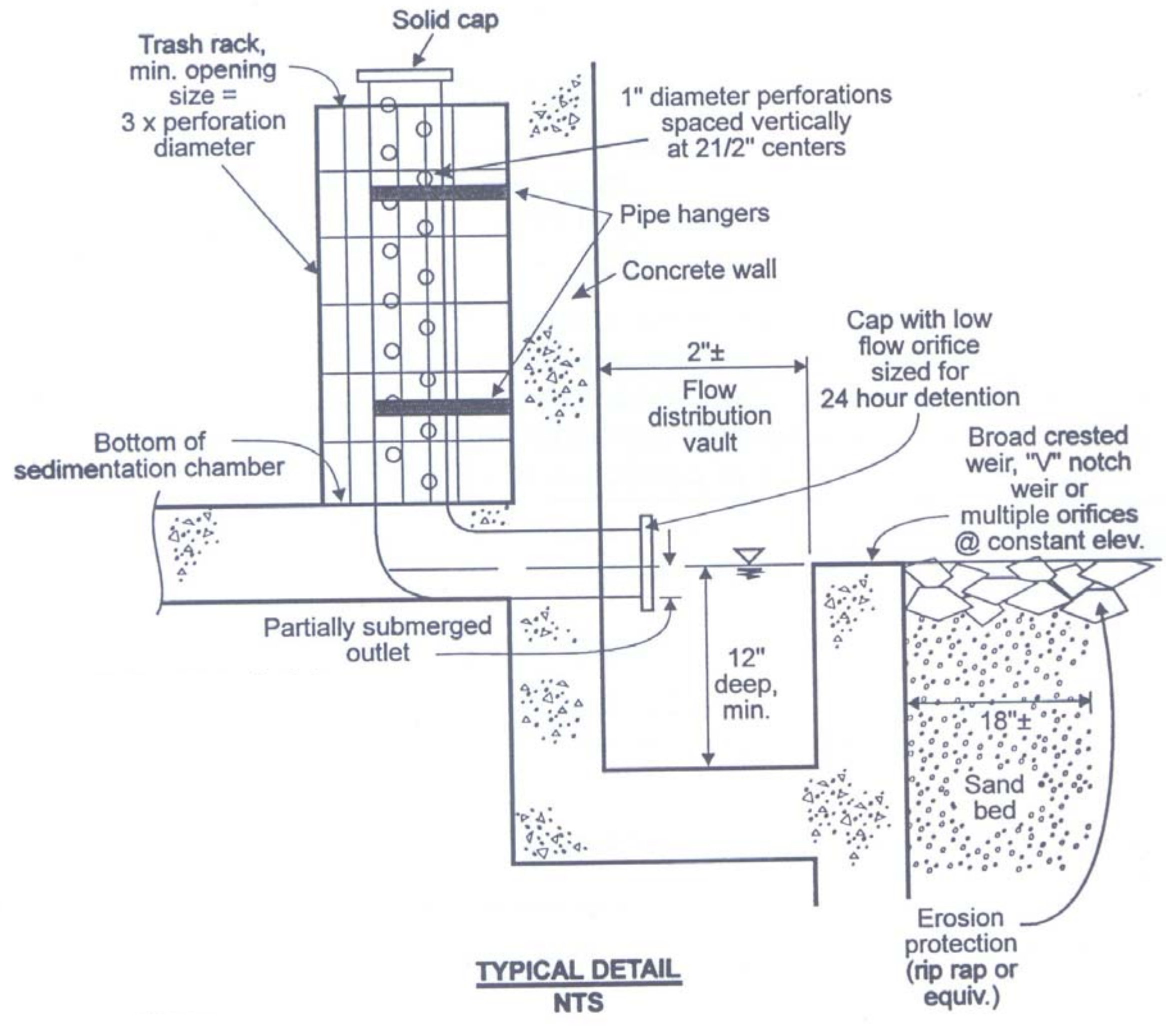
(Source: New Jersey Stormwater Best Management Practices Manual, 2003)

Figure 4.2 Schematic of Surface Sand Filter Showing Design Parameters



(Source: Claytor and Schueler, 1996)

Figure 4.3 Typical Sand Filter Media Cross Sections



(Source: Claytor and Schueler, 1996)

Figure 4.4 Surface Sand Filter Perforated Stand-Pipe

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