Sand and Organic Filters

Practice Description

Sand filters are usually designed as two-chambered stormwater practices: the first is a settling chamber, and the second is a filter bed filled with sand or another filtering media. As stormwater flows into the first chamber, large particles settle out, and then finer particles and other pollutants are removed as stormwater flows through the filtering medium. There are several modifications of the basic sand filter design, including the surface sand filter, underground sand filter, perimeter sand filter, organic media filter, and multi-chamber treatment train. All of these filtering practices operate on the same basic principle. Modifications to the traditional surface sand filter were made primarily to fit sand filters into more challenging design sites (e.g., underground and perimeter filters) or to improve pollutant removal (e.g., organic media filter).

Planning Considerations

Sand filters have been a proven technology for drinking water treatment for many years and more recently have been demonstrated to be effective in removing urban stormwater pollutants including total suspended solids, biological oxygen demand, fecal coliform, hydrocarbons, and metals. Since sand filters can be located underground, they can also be used in areas with limited surface space.

Sand filters are designed primarily for water quality enhancement; flow volume control is typically a secondary consideration. They are generally applied to land uses with a large fraction of impervious surfaces. Although an individual sand filter can handle only a small contributing drainage basin, multiple units can be dispersed throughout a large site. Sand filters can be of open basin design or of buried trench design (a closed basin). Sand filters typically employ underdrain systems to collect and discharge treated stormwater but can also be designed as infiltration type systems when located in soils with sufficient permeability or infiltration rates.

Sand filters are a good option to achieve water quality goals in retrofit studies where space is limited, because they consume very little surface space and have few site restrictions. It is important to note, however, that sand filters cannot treat a very large drainage area. Using small-site BMPs in a retrofit may be the only option for a retrofit study in a highly urbanized area, but it is expensive to treat the drainage area of an entire watershed using many small-site practices, as opposed to one larger facility such as a pond.

Design Criteria

Converting Erosion- and Sediment-Control Devices

A basin used for construction erosion and sediment control can be converted into an open basin-type sand filter if all sediment is removed from the basin prior to construction of the sand filter and proper sand filter design is followed. Buried trench-type sand filters are typically newly constructed after site construction and not placed in modified site construction sediment- and erosion-control basins. Sand filters are not to be brought on-line until site construction activities are completed and groundcover is fully stabilized.

Drainage Area

The maximum contributing drainage area to an individual sand filter shall be less than 5 acres; however, 1 acre or less is recommended. Multiple sand filters can be used throughout a development to provide treatment for larger sites.

Slope

Sand filters can be used on sites with slopes up to about 6 percent. It is challenging to use most sand filters in very flat terrain because they require a significant amount of elevation drop, or head (about 5 to 8 feet), to allow flow through the system. One exception is the perimeter sand filter, which can be applied with as little as 2 feet of head.

Soils/Topography

When sand filters are designed as a stand-alone practice, they can be used on almost any soil because they can be designed so that stormwater never infiltrates into the soil or interacts with the groundwater. Alternatively, sand filters can be designed as pretreatment for an infiltration practice, where soils do play a role.

Groundwater

Designers should provide at least 2 feet of separation between the bottom of the filter and the seasonally high groundwater table. This design feature prevents both structural damage to the filter and possibly, though unlikely, groundwater contamination.

Pretreatment

Erosive velocities and high sediment loads are a concern with sand filters. Sediment can quickly blind a sand filter and cause premature failure of the BMP. Two devices that reduce the impact of these factors on the sand filter are flow splitter devices and forebays.

Flow beyond the design flow can overload the hydraulic capacity of a sand filter (usually resulting in an overflow), cause erosion in open basin sand filters, and deliver more sediment to the sand filter than is necessary. Because of these issues, sand filters are required to be designed "off-line," meaning only the design volume of the stormwater flow is sent from the conveyance system into the treatment unit, and the excess is diverted.

A forebay or sedimentation chamber is required on all sand filters, to protect the sand filter from clogging due to sediment and to reduce the energy of the influent flow. The forebay can be in the form of an open basin (typical with an open basin sand filter design), or a subsurface concrete chamber (typical with a buried trench design). The forebay must contain ponded water (not be drained down with the sand filter). If a subsurface concrete chamber is provided, appropriate means of removing accumulated sediment must be demonstrated. Since individual sand filters treat relatively small volumes of stormwater and the design of the forebay is a percent of the total design volume, the forebay can also be very small. The minimum width (measurement parallel to flow direction) of the sedimentation chamber or forebay shall be 1.5 feet.

Following the sedimentation chamber or forebay, stormwater flow may be distributed over the surface of the sand filter in a variety of ways. In an open design, it could flow onto the sand filter as sheet flow via a level spreader. Depending on the geometry of the sand filter, however, that may not provide enough flow distribution to prevent overloading and clogging of the leading edge of the sand filter. One common method of distributing flow onto sand filters, both the open basin and buried trench types, is through the use of a pipe distribution or weir system.

Length, Width and Geometry

The area required for a sand filter device is calculated similar to many other BMP types. Since a sand filter must be completely drained within 40 hours, the ponding depth is a function of the media's infiltration rate. Once the ponding depth is known, the surface area can be calculated based on the design volume.

A sand filter consists of two parts, the sedimentation basin (which serves as a sort of forebay) and the sand filter itself. These two parts are collectively referred to as the "sand filter." An open basin type sand filter can be rectangular, square, circular, or irregular. Buried trench systems (closed basin systems) are often very rectangular, approaching linear. The important factor is that incoming stormwater is distributed relatively evenly over the surface of the sand filter. The following series of steps are used to determine the appropriate sand filter size.

Step 1: Compute the water quality volume (WQV) using Schueler's Simple Method, as described in Chapter 3 and summarized below, and the adjusted water quality volume (WQV_{Adj}) as defined below (CWP, 1996).

$$WQV(ft^3) = \frac{R_v(unitless)}{1} x \frac{A_D(acres)}{1} x \frac{43{,}560\,ft^2}{1Acre} x \frac{R_D inchRain}{1} x \frac{ft}{12in}$$

$$WQV_{Adj}(ft^3) = (0.75)WQV$$

- WQV: Water Quality Volume (ft^3). This is used to size the surface areas of the sedimentation chamber and the sand filter.

- WQV_{Adj}: Adjusted Water Quality Volume (ft^3). This is used as the volume that must be contained between the sedimentation chamber and the sand filter (above the sand).
- A_D: Drainage area to the sand filter (acres)
- R_v: Volumetric runoff coefficient (unitless) = 0.05 + 0.009(%Imp)
  - %Imp: Percent of impervious of land draining to the sand filter

Step 2: Determine the maximum and average head on the sand filter, and determine the surface areas of the sand filter and the sedimentation chamber.

Maximum Head on the Sand Filter

- $h_{MaxFilter}$(ft): Maximum head on the sand filter (ft). This head is typically measured from the top of the overflow weir, which separates the sediment chamber from the sand chamber, to the top of the sand and should be no more than 6 feet. Choose the maximum head so that the following equation is true:

$$h_{MaxFilter}\,(ft) = \frac{WQV_{Adj}\,(ft^3)}{A_S\,(ft^2) + A_f\,(ft^2)}$$

- A_s: Surface area of the sedimentation basin (ft^2)
- A_f: Surface area of the sand filter bed (ft^2)

$$h_A(ft) = \frac{h_{MaxFilter}(ft)}{2}$$

- h_A = Average head (ft). The average head on the sand filter is approximately equal to the average head on the sedimentation basin.

Sedimentation Basin Surface Area:

The minimum surface area for the sedimentation basin is determined by the Camp Hazen Equation:

$$A_s\,(ft^2) = -\frac{Q_o\left(\frac{ft^3}{\sec}\right)}{w\left(\frac{ft}{\sec}\right)}\,x\ln(1-E)$$

$$A_S\,(ft^2) = -\frac{\left(\frac{WQV(ft^3)}{24hr}\right)x\left(\frac{1hr}{3600\sec}\right)}{0.0004\left(\frac{ft}{\sec}\right)}\,x\ln(1-0.9)$$

$$A_S\,(ft^2) = 0.066WQV\,(ft^2)$$

$$A_S\,(ft^2) = 0.066\left[\frac{R_v\,(unitless)}{1}\,x\,\frac{A_D\,(Acres)}{1}\,x\,\frac{43{,}560(ft^2)}{(Acre)}\,x\,\frac{R_D\,(in)}{1}\,x\,\frac{1(ft)}{12(in)}\right](ft^2)$$

$$A_S\,(ft^2) = \left[240 * R_v\,(unitless) * A_D\,(acres)\right] * R_D\left(ft^2\right)$$

- $Q_{o:}$ Average rate of outflow from the sedimentation chamber (ft^3/sec). (CWP, 1996)
- E: Trap efficiency of the chamber = 0.9 (unitless)
- w: Settling velocity of particle. Assume that the particles collected by the filter are 20 microns in diameter. For 20 microns, w = 0.0004 (ft/sec). This varies depending on the imperviousness of the land draining to the sand filter, but the value presented here is representative of most situations.

Sand Filter Bed Surface Area:
The minimum surface area for the sand filter bed is determined by Darcy's Law:

$$A_f\,(ft^2) = \frac{(WQV)(d_F)}{(k)(t)(h_A + d_F)}$$

- d_F: Depth of the sand filter bed, (ft). This should be a minimum of 1.5 ft.
- k: Coefficient of permeability for the sand filter bed = 3.5 (ft/day).
- t: Time required to drain the WQV through the sand filter bed (day). This time should be 40 hours (1.66 days).**Error! Bookmark not defined.**
- h_A: Average head (ft).
  - Determine the average head of water above the sand filter. The average head above the sand filter is half of the maximum head on the filter.

Step 3: Ensure that the water quality volume is contained:

- Ensure that this combination of variables will contain the required volume (WQV_{Adj} (ft^3)):
  - $\left[A_f\,(ft^2) + A_s\,(ft^2)\right] x \left[h_{MaxFilter}(ft)\right] \geq WQV_{Adj}\,(ft^3)$

Step 4: Additional design requirements:
For underground sand filters, provide at least 5 feet of clearance between the surface of the sand filter and the bottom of the roof of the underground structure to facilitate cleaning and maintenance.

Example Calculation

Design a sand filter to treat the first inch of water from a 1-acre site that is 100% impervious. There is 720 ft^2 of space available for this underground project.

Step 1 – Compute water quality volume

- Rv = 0.05 + 0.9(%Imp) = 0.05 + 0.009(100) = 0.95
- $WQV(ft^3) = \frac{0.95(unitless)}{1} x \frac{1(acres)}{1} x \frac{43{,}560\,ft^2}{1Acre} x \frac{1inchRain}{1} x \frac{ft}{12in} = 3{,}449\,ft^3$

  $WQV_{Adj}(ft^3) = (0.75)(3{,}449) = 2{,}587(ft^3)$

Step 2 – Determine filter bed and sedimentation basin surface areas with respect to water quality volume and maximum head

- $h_{MaxFilter}(ft) = \dfrac{2{,}586(ft^3)}{A_S(ft^2) + A_f(ft^2)}$, for maximum heads between 0.5 foot and 6 feet, the following combinations of variables will work:

$H_{MaxFilter}$ **(ft)**	**WQV_{adj}** **(cu ft)**	**$A_s + A_f$** **(sq ft)**
0.5	2,586	5,172
1.0	2,586	2,586
1.5	2,586	1,724
2.0	2,586	1,293
3.0	2,586	862
4.0	2,586	647
5.0	2,586	517
6.0	2,586	431

- $A_s(ft^2)$ = 240*0.95*1 = 228 (ft^2) – This is the minimum value for the area of the sedimentation basin. Larger basins are acceptable.

- Choose a combination of A_f and h_A to meet the available space on-site. Typically, the sedimentation chamber and the sand filter bed should be approximately the same size. If 720 ft^2 of space is available, then A_s and A_f can both be 360 ft^2, and the maximum head on the sand filter is interpolated to be 3.6 ft. The average head is half of the maximum head, 1.8 ft. Check to ensure that the minimum area for the sand filter is attained:

  - $A_f(ft^2) = \dfrac{(3{,}449(ft^2))(1.5(ft))}{(3.5(ft/day))(1.66(day))(1.8(ft)+1.5(ft))} = 270\ ft^2$.

  This is the minimum value for the area of the sand filter. Larger sand filters are acceptable, and therefore the chosen combination of variables is acceptable for this design.

- There are several combinations of surface areas and depths that would be acceptable for this design. In this example:
  - A_f = 360 ft^2
  - A_s = 360 ft^2
  - $h_{MaxFilter}$ = 3.6 ft
  - h_A = 1.8 ft

Step 3 – Verify volumes

- $2{,}592(ft^3) = [360(ft^2) + 360(ft^2)]x[3.6(ft)] \Rightarrow \geq\ 2{,}586(ft^3)$

Step 4 – Check additional design criteria

- Because this is an underground project, sufficient access must be provided to facilitate cleaning and maintenance.

Treatment

Treatment design features help enhance the ability of a stormwater-management practice to remove pollutants. In filtering systems, designers should provide at least 75 percent of the water quality volume in the practice, including both the sand chamber and the sediment chamber. The filter bed should be sized using Darcy's Law, which relates the velocity of fluids to the hydraulic head and the coefficient of permeability of a medium. In sand filters, designers should select a medium-sized sand as the filtering medium.

Media Requirements

The media in the sand filter shall be cleaned, washed, coarse masonry sand such as ASTM C33. The sand particles shall be less than 2 mm average diameter. The filter bed shall have a minimum depth of 18 inches, with a minimum depth of sand above the drainage pipe of 12 inches. The medium for organic filtering can be a combination of 50% peat and 50% sand or compost-only filter, both with a minimum depth of 18 inches. The peat/sand filter should be installed over a 6-inch layer of sand.

Conveyance

Conveyance of stormwater runoff into and through the filter should be conducted safely and in a manner that minimizes erosion potential. Ideally, some stormwater treatment can be achieved during conveyance to and from the filter. Since filtering practices are usually designed as "off-line" systems, meaning that they have the smaller water quality volume diverted to them only during larger storms, using a flow splitter, which is a structure that bypasses larger flows to the storm drain system or to a stabilized channel. One exception is the perimeter filter. In this design, all flows enter the system, but larger flows overflow to an outlet chamber and are not treated by the practice. All filtering practices, with the exception of exfilter designs, are designed with an underdrain below the filtering bed. An underdrain is a perforated pipe system in a gravel bed, installed on the bottom of filtering practices and used to collect and remove filtered runoff.

Drainage Considerations

The sand filter chamber shall drain completely within 40 hours. The length of time that it takes to drain the media of a filter is controlled by the infiltration rate of the media (or possibly the infiltration rate of the in situ soil if the system is designed as an infiltration type system).

Landscaping

Landscaping can add to both the aesthetic value and the treatment ability of stormwater practices. In sand filters, little landscaping is generally used on the practice, although surface sand filters and organic media filters may be designed with a grass cover on the surface of the filter. In all filters, designers need to ensure that the contributing drainage has dense vegetation to reduce sediment loads to the practice.

Common Problems

When the filtering capacity diminishes substantially (e.g., when water ponds on the surface for more than 40 hours), remedial actions must be taken. One possible cause of this problem is that collection pipe systems have become clogged. Annual flushing of pipe clean-outs is recommended to facilitate unclogging of the pipes without disturbing the filter area. If the water still ponds above the sand filter bed for more than 40 hours, the top few inches of media should be removed and replaced with fresh media. The removed sediments should be disposed of in an acceptable manner (e.g., landfill). If the problem still persists, more extensive rebuilding is required.

Maintenance

Typical annual maintenance requirements are:

- Check to see that the filter bed is clean of sediments, and the sediment chamber is no more than one-half full of sediment; remove sediment if necessary.
- Make sure that there is no evidence of deterioration, sailing, or cracking of concrete.
- Inspect grates (if used).
- Inspect inlets, outlets, and overflow spillway to ensure good condition and no evidence of erosion.
- Repair or replace any damaged structural parts.
- Stabilize any eroded areas.
- Ensure that flow is not bypassing the facility.