11.   Sand Filter

Description
A sand filter is a surface or subsurface device that percolates stormwater down through a sand media where pollutants are filtered out. Sand filter effluent is either infiltrated or discharged.

Regulatory Credits
Pollutant Removal

85%	Total Suspended Solids
35%	Total Nitrogen
45%	Total Phosphorus

Water Quantity

Possible	Peak Attenuation
Possible	Volume Capture

Feasibility Considerations

Med	Land Requirement
High	Cost of Construction
High	Maintenance Burden
Small	Treatable Basin Size
Med	Possible Site Constraints
Med	Community Acceptance

Advantages
– Highly effective at removing TSS, BOD and fecal coliform.
– Require less space than other BMPs and can be placed underground where space is limited.
– Perimeter sand filters useful for small sites with flat terrain or high water table.

Disadvantages
– If anoxic conditions develop in the sand filter due to poor drainage, phosphorus levels can increase as water passes through the sand filter.
– May not be effective in controlling peak discharges.
– Large sand filters without vegetation may not be attractive in residential areas.
– Expensive.

Major Design Elements

Required by the NC Administrative Rules of the Environmental Management Commission. Other specifications may be necessary to meet the stated pollutant removal requirements.	
1	Sizing shall take into account all runoff at ultimate build-out including off-site drainage.
2	Vegetated side slopes shall be no steeper than 3:1.
3	BMP shall be located in a recorded drainage easement with a recorded access easement to a public ROW.
4	Seasonally high groundwater table must be at least 2 feet below the bottom of the filter for open-bottom designs.
5	A diversion or bypass structure is an acceptable means for accommodating storm flows in excess of the design flow for sand filters.
6	A vegetated filter strip is not required for overflows, bypass flows, or discharges from a sand filter (except for within ½ mile of and draining to SA waters or unnamed tributaries of to SA waters). For SA waters in Phase II areas, criteria in S.L. 2006-246 Section 9(h) must still be met.
7	The design shall be located a minimum of 30 feet from surface waters, and 50 feet from Class SA waters.
8	The design shall be located a minimum of 100 feet from water supply wells, unless it is a closed desgin with underdrains installed.
Required by DWQ policy. These are based on available research, and represent what DWQ considers necessary to achieve the stated removal efficiencies.	
9	Seasonally high groundwater table must be at least 1 foot below the bottom of the filter for closed filter designs in order to prevent draining the water table and floatation. Exceptions will be made if these concerns are mitigated.
10	Maximum contributing drainage basin is 5 acres.
11	Minimum width (parallel to flow) of a sedimentation chamber or forebay shall be 1.5 feet.
12	Sand filter must completely drain within 40 hours.
13	Sand media shall be as specified below and shall be a minimum of 18" deep (minimum of 12" over the drainage pipes).
14	All sand filter designs must provide at sufficient access to both chambers to facilitate maintenance activities.

11.1. General Characteristics and Purpose

Sand filters are capable of removing a wide variety of pollutant concentrations in stormwater via settling, filtering, and adsorption processes. Sand filters have been a proven technology for drinking water treatment for many years and now have been demonstrated to be effective in removing urban stormwater pollutants including TSS, BOD, 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 only handle a small contributing drainage basin, multiple units can be dispersed throughout a large site.

Sand filters can be of open basin design, as shown in Figure 11-1a and Figure 11-1b, or of buried trench design (a closed basin), as shown in Figures 11-2a and 11-2b. 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.

Figure 11-1a
Surface Sand Filter (Open Basin Design)

11.2. Meeting Regulatory Requirements

A listing of the major design elements is provided on the first page of this chapter. At a minimum, any sand filter must meet the major design elements indicated as being from the North Carolina Administrative Code. To receive the pollutant removal rates listed in the front of this Chapter, the sand filter must meet all of the major design elements listed in the beginning of this Chapter.
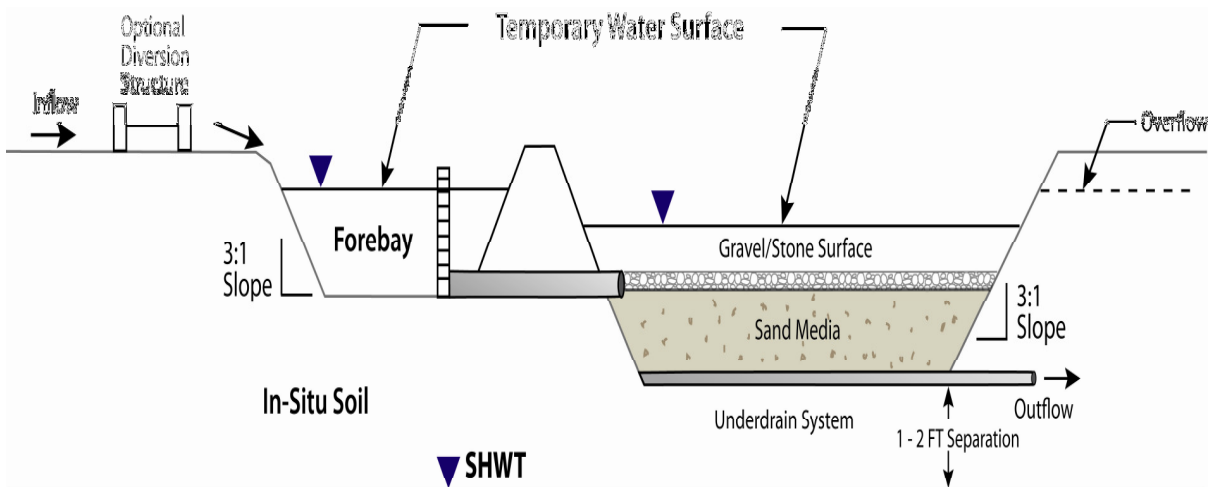
Pollutant Removal Calculations
The pollutant removal calculations for sand filters are as described in Section 3.4, and use the pollutant removal rates shown at the beginning of this chapter. Construction of an open basin sand filter also passively lowers nutrient loading since it is counted as pervious surface when calculating nutrient loading. Buried trench sand filters receive whatever runoff values the surface above them is assigned.
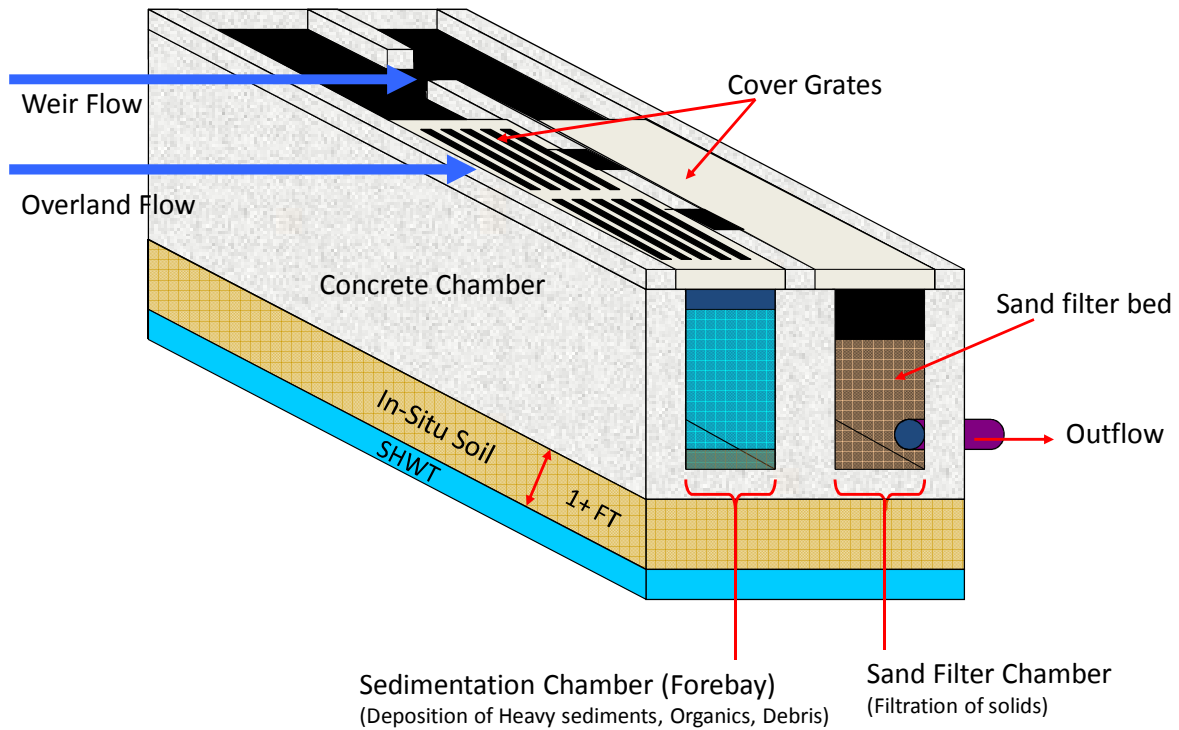
Volume Control Calculations
A sand filter can be designed with enough storage to provide active volume capture (calculations for which are provided in Section 3.4); however, special provisions must typically be made to the outlet to provide peak flow attenuation. An open basin sand filter provides some passive volume control capabilities by providing pervious surface and therefore reducing the total runoff volume to be controlled, however, buried trench sand filters may not.

**Figure 11-1b**
Open Basin Profile View

Figure 11-2a
Buried Trench (Closed-Basin) Sand Filter, 3-D View*
Derived from Shaver, 1992

Weir Flow

Overland Flow

Cover Grates

Concrete Chamber

Sand filter bed

In-Situ Soil
SHWT
1+ FT

Outflow

Sedimentation Chamber (Forebay)
(Deposition of Heavy sediments, Organics, Debris)

Sand Filter Chamber
(Filtration of solids)

*Exceptions to the 1ft SHWT separation will be made if the sand filter does not drain the water table and it does not float. Special care should be used when proposing structures such as concrete because joints may break down over time, causing the water table to leak into the sand filter.

Figure 11-2b
Buried Trench (Closed Basin) Sand Filter
Derived from Shaver, 1992
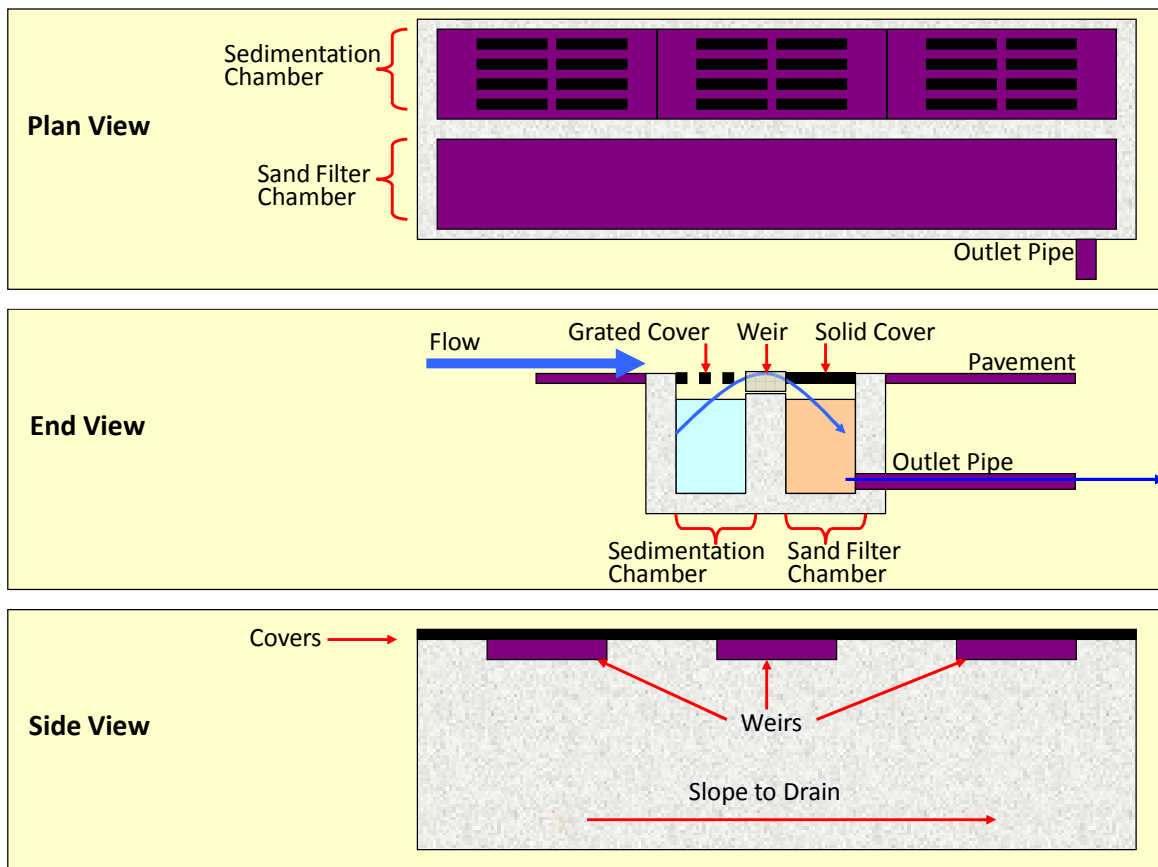
11.3. Design

11.3.1. Converting Sediment and Erosion Control Devices

A basin used for construction sediment and erosion 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 online until site construction activities are completed and groundcover is fully stabilized.

11.3.2. Siting Issues

Sand filters shall *not* be used in areas with the following characteristics:

- The seasonal high water table (SHWT) is less than 2 feet below the proposed bottom of the facility for an open basin design. If a concrete bottom is used, then the separation can be reduced to a minimum of 1 foot.
- If site restrictions such as bedrock or hydraulics prevent the facility from being constructed to a depth that will allow for the required media thickness, ponding depth, and other appurtenances.

11.3.3. Contributing Drainage Basin

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.

11.3.4. Pretreatment and Inflow

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. Please see Section 5.3 for more information on the design and regulatory compliance issues related to flow splitters/diversion structures and designing systems off-line.

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). See Section 5.5 for design information on forebays. 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. Besides the minimum requirements from Section 5.5, 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 is 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 even 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 open basin and buried trench type, is through the use of a pipe distribution or weir system. Design of the pipe distribution system could mimic the design of the underdrain system as presented in Section 5.7.

11.3.5. Length, Width and Geometry

The area required for a sand filter device is calculated similar to many other BMP types. The applicable regulation will determine whether the Runoff Capture Design Storm or the Runoff Peak Attenuation Design Storm will be used to calculate the design volume of the unit (see Chapters 2 and 3). 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. No credit is given for storage within the media since the influent can come at such a rate that all of the volume would need to be stored above the media since essentially no infiltration will have taken place yet.

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 (Center for Watershed Protection, 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 (ft³). This is used to size the surface areas of the sedimentation chamber and the sand filter.
- WQV$_{Adj}$: Adjusted Water Quality Volume (ft³). 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 (ft²)

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

- 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:

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

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

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

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

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

- Q_o: Average rate of outflow from the sedimentation chamber (ft^3/sec). (Center for Watershed Protection, 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. (Center for Watershed Protection, 1996).

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). (Center for Watershed Protection, 1996.)
- 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 (Center for Watershed Protection, 1996).

Step 3: Ensure that the Water Quality Volume is Contained:
- Ensure that this combination of variables will contain the required volume (WQV$_{Adj}$ (ft³)):
    - $\left[A_f(ft^2) + A_s(ft^2)\right] x \left[h_{MaxFilter}(ft)\right] \geq WQV_{Adj}(ft^3)$

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 ft² of space available for this underground project.

1. **Step 1 – Compute water quality volume**
    - Rv=0.05+0.9(%Imp)=0.05+0.009(100)=0.95
    - $WQV(ft^3) = \frac{0.95(unitless)}{1} x \frac{1(acres)}{1} x \frac{43,560 ft^2}{1 Acre} x \frac{1 inch Rain}{1} x \frac{ft}{12 in} = 3,449 ft^3$
    - $WQV_{Adj}(ft^3) = (0.75)(3,449) = 2,587(ft^3)$

2. **Step 2 – Determine filter bed and sedimentation basin surface areas with respect to water quality volume and maximum head**
    - $h_{MaxFilter}(ft) = \frac{2,586(ft^3)}{A_S(ft^2) + A_f(ft^2)}$, for maximum heads between 0.5

    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(ft²)=240*0.95*1=228 (ft²), 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 onsite. Typically, the sedimentation chamber and the sand filter bed should be approximately the same size. If there is 720 ft² of space available, then A_s and A_f can both be 360 ft², 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(ft²)= $\dfrac{(3,449(ft^2))(1.5(ft))}{(3.5(ft/day))(1.66(day))(1.8(ft)+1.5(ft))} = 270$ ft².
    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=360ft²
  - A_s=360ft²
  - $h_{MaxFilter}$=3.6 ft
  - h_A=1.8ft

3. **Step 3 – Verify volumes**
   - $2,592(ft^3) = [360(ft^2)+360(ft^2)]x[3.6(ft)] \Rightarrow \geq 2,586(ft^3)$

4. **Step 4 – Check additional design criteria**
   - Because this is an underground project, sufficient access must be provided to facilitate cleaning and maintenance.

11.3.6. 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).

11.3.7. Media Requirements

The media in the sand filter shall be cleaned, washed, course 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.

11.3.8. Outlet Design

If the sand filter is designed as an infiltration type system, please refer to the in-situ soil requirements and other applicable design and construction recommendations of Chapter 16 Infiltration Devices. In general, sand filters constructed in the coastal areas will have in-situ permeabilities that allow construction of infiltration type sand filters. Note that infiltration type sand filters must be located at least 100 feet from a water supply well.

In general, sand filter BMPs in the Mountain and Piedmont regions of North Carolina will require underdrains unless located in areas with good soil permeability rates. The underdrain system shall be designed as shown in Section 5.7. The underdrain system may connect to another BMP or to the conveyance system.

Observation wells and/or clean-out pipes must be provided at a minimum one per 1,000 square feet of surface area. Observation wells, as well as the ends of underdrain pipes that do not terminate in an observation well, must be capped.

11.4. Maintenance

The following section contains information on maintenance issues common to sand filters and a sample O&M agreement required by DWQ for installation of a sand filter BMP.

11.4.1   Common Maintenance Issues

Sand filters should be inspected at least once per month, and after any large storm events to check for damage. They must be maintained as needed to remove visible surface sediment accumulation, trash, debris, and leaf litter to prevent the filter from clogging prematurely. Sediment should be cleaned out of the forebay/sedimentation chamber when it accumulates to a depth of more than 6 inches. Any structures (outlets,

flow diversions, embankments, etc.) should be checked at least annually for damage or degradation. Figures 11-3a and 11.3b show an example of a sand filter that is overdue for maintenance.

Figure 11-3a
Sedimentation Chamber Overdue for Maintenance

Figure 11-3b
Sand Filter Chamber Overdue for Maintenance

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 cleanouts 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.

11.4.2. Sample Operation and Maintenance Provisions

Important maintenance procedures:
– The drainage area will be carefully managed to reduce the sediment load to the sand filter.
– The sedimentation chamber or forebay will be cleaned out whenever sediment depth exceeds six inches.
– Once a year, sand media will be skimmed.
– The sand filter media will be replaced whenever it fails to function properly after maintenance.

The sand filter will be inspected **quarterly and within 24 hours after every storm event greater than 1.0 inches (or 1.5 inches if in a Coastal County)**. Records of operation and maintenance will be kept in a known set location and will be available upon request.

Inspection activities shall be performed as follows. Any problems that are found shall be repaired immediately.

Table 11-1
Sample Operation and Maintenance Provisions for Sand Filters

BMP element:	Potential problems:	How to remediate the problem:
Entire BMP	Trash/debris is present.	Remove the trash/debris.
Adjacent pavement (if applicable)	Sediment is present on the pavement surface.	Sweep or vacuum the sediment as soon as possible.
Perimeter of sand filter	Areas of bare soil and/or erosive gullies have formed.	Regrade soil if necessary to remove the gully, and then plant a ground cover and water until it is established. Provide lime and a one-time fertilizer application.
	Vegetation is too short or too long.	Maintain vegetation at an appropriate height.
Flow diversion structure	The structure is clogged.	Unclog the conveyance and dispose of any sediment offsite.
	The structure is damaged.	Make any necessary repairs or replace if damage is too large for repair.
Forebay or pretreatment area	Sediment has accumulated to a depth of greater than six inches.	Search for the source of the sediment and remedy the problem if possible. Remove the sediment and stabilize or dispose of it in a location where it will not cause impacts to streams or the BMP.
	Erosion has occurred.	Provide additional erosion protection such as reinforced turf matting or riprap if needed to prevent future erosion problems.
	Weeds are present.	Remove the weeds, preferably by hand. If a pesticide is used, wipe it on the plants rather than spraying.
Filter bed and underdrain collection system	Water is ponding on the surface for more than 24 hours after a storm.	Check to see if the collector system is clogged and flush if necessary. If water still ponds, remove the top few inches of filter bed media and replace. If water still ponds, then consult an expert.
Outlet device	Clogging has occurred.	Clean out the outlet device. Dispose of the sediment offsite.
	The outlet device is damaged	Repair or replace the outlet device.
Receiving water	Erosion or other signs of damage have occurred at the outlet.	Contact the NC Division of Water Quality 401 Oversight Unit at 919-733-1786.

September 28, 2007 Changes:
1. Major Design Elements:
    i. Reformatted to include numbered requirements.
    ii. Separated the following requirement into two requirements, "Seasonally high groundwater table must be at least 2 feet below the bottom of the filter for open-bottom designs, and at least 1 foot below the bottom of the filter for pre-cast designs." It now reads,
        1. "Seasonally high groundwater table must be at least 2 feet below the bottom of the filter for open-bottom designs," which is specified as an Administrative Code requirement per 15A NCAC 02H .1008(d)(3),
        2. "Seasonally high groundwater table must be at least 1 foot below the bottom of the filter for closed filter designs in order to prevent draining the water table and floatation. Exceptions will be made if these concerns are mitigated," which is specified as based on NC DWQ policy. The clause regarding the exception has been added.
    iii. Added a requirement that the design shall be located a minimum of 30 feet from surface waters, and 50 feet from Class SA waters per 15A NCAC 02H .1008(d)(1).
    iv. Added a requirement that the design shall be located a minimum of 100 feet from water supply wells per 15A NCAC 02H .1008(d)(2).
    v. Added a requirement that the volume in excess of the design volume, as determined from the design storm, shall bypass the cell per 15A NCAC 02H .1008(d)(4).
    vi. Added a requirement that the volume in excess of the design volume shall be evenly distributed across a minimum 30 feet long vegetative filter strip. (A 50-ft filter is required in some locations.) If this can not be attained, alternate designs will be considered on a case by case basis. This requirement is per 15A NCAC 02H .1008(c)(4) and 15A NCAC 02H .1005(b)(iii).
2. 11.3.5: Three equations referred to a 1.0" depth. Because this depth varies by location, this equation has been updated to reference "R_D", the design storm depth used in the Simple Method calculation. *(Note: These changes are not visible in Track Changes.)*
3. 11.3.5: Corrected a typo in one equation, "0.09" has been replaced by "0.9".
4. Figure 11-2a: Altered for clarification.

September 20, 2009 Changes:
1. Various changes throughout the chapter to layout, terminology, wording, photos, illustrations, and order of topics.
2. Inserted Figure 11-1a and revised Figure 11-1b.
3. Revised Figure 11-2a and Figure 11-2b.
4. Updated sample O&M agreement.
5. Increased total phosphorus removal credit to 40%.
6. Clarified surface area and depth design procedures and example calculation.
7. Clarified how to determine maximum head.
8. Revised requirement regarding minimum distance to water supply wells.
9. Emphasized use of forebay as pretreatment device.
10. Removed requirement of five (5) feet of clearance between top of sand bed and roof of underground sand filter.
11. Revised requirement of 2-6 feet maximum head to allow up to six (6) feet max head.