A SunCam online continuing education course

Design of Sand Filters & Bioretention Systems

by

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Introduction:
This course presents an overview of the design features that go into providing stormwater management quality control. It discusses the most common means of providing this control and describes in detail the design procedures for two types of features: sand filters and bioretention systems.

When you complete this course you should be familiar not only with the problem of storm water quality control but with the various ways of providing for it. In addition, you will be familiar with the layout, design, and function of both sand filters and bioretention systems.

There are several references dealing with the treatment of stormwater quality. For this course, much of the information is taken from the New Jersey Department of Environmental Protection's Best Management Practices Manual and the New York State Stormwater Management Design Manual.

Statement of the Problem:
For many years various state, county, and local reviewing agencies have required that the rate and quantity of stormwater be controlled and designer engineers have used detention basins, drywells, and other means to provide this control. In the more recent past, however, there has been growing realization that the stormwater often has a pollutant loading and the quality of the stormwater must also be treated. Urban and rural stormwater can carry any and all of the following pollutants:

1. Suspended solids.
2. Nitrogen.
3. Phosphorous.
4. Hydrocarbons.
5. Heavy metals.
6. Pathogens.

Each of these pollutants can cause health issues downstream of the discharge points. In general, the stormwater control features discussed in this course are most effective in dealing with the total suspended solid load. However, sand filters and, to a greater extent, bioretetion systems can treat the other pollutants as well.

Several states have adopted stormwater pollutant control ordinances. In fact the New York Department of Environmental Conservation lists the following top ten water quality issues in the state:

1. Urban stormwater runoff.
2. Aging/Inadequate wastewater treatment infrastructure.
3. Nutrient Eutrophication.
4. Atmospheric deposition and acid rain.
5. Legacy pollutants in sediments and fish.
6. Atmospheric deposition of mercury.
7. Habitat/hydrologic modification.
8. Nuisance aquatic weed growth and invasive species.
9. Pathogen contamination of shellfish.
10. Inadequate onsite wastewater treatment.

Note that stormwater quality is right at the top of the above list. It should also be noted that stormwater runoff quality also plays a part several of the other water quality issues listed above. Nutrient eutrophication, legacy pollutants in sediments and fish, habitat/hydrologic modification, and nuisance aquatic weed growth can all be treated, to some degree, by controlling the quality of stormwater runoff.

Designers have a variety of methodologies for treating stormwater runoff. Many of these have actually been incorporated into stormwater design plans for many years. These include the following soil erosion & sediment control features:

1. Silt fence or staked hay bales.
2. Inlet filters.
3. Stone tracking pads at construction entrances.
4. Conduit outlet protection.

The inlet filters & silt fence shown above are both intended to keep sediment and other debris from travelling downstream.

However, in order to provide significant water quality control more extensive measures are required. These include sand filters, bioretention systems (basins & swales), constructed wetlands, extended detention basins, infiltration structures, manufactured treatment devices, pervious paving systems, vegetated filter strips, wet ponds, and others.

The New Jersey Department of Environmental Protection (NJDEP) requires that a stormwater system for major developments remove at least 80% of the total suspended solids (TSS). Major Development is defined by the NJDEP as a project that disturbs more than 1 acre of ground or proposed new impervious surfaces of greater than ¼ acre. The NJDEP has a hierarchy of treatment protocols for stormwater control. The table below shows the TSS removal rates for the various stormwater treatment facilities. These values are used for regulatory purposes and cannot be taken as actual values. However, they do give a good idea of the relative merits of the different types of systems.

Stormwater Quality Control Feature	**NJDEP Adopted TSS Removal Rate (%)**
Bioretention System	90
Constructed Stormwater Wetland	90
Extended Detention Basin	40 to 60 (Depending upon the detention time. To obtain 60% TSS removal rate, a minimum of 10% of the water quality storm volume must remain in the basin for 24 hours).
Infiltration Structure	80
Manufactured Treatment Device	Varies (Based on testing approved by the NJDEP)
Pervious Paving System	80 (Only if the system includes a runoff storage bed that functions as an infiltration basin. Without this, no credit is given by the NJDEP for TSS removal).
Sand Filter	80
Vegetative Filter	60 to 80 (Based on the length and slope of the filter and the vegetative characteristics. The NJDEP will only credit indigenous woods with 80% TSS removal).
Wet Pond	50 to 90 (Based upon pool volume and detention time).

The design engineer has to take several factors into account when deciding which of the above features to employ on a specific project. Some of these factors include:

1. Soil characteristics. (e.g. Constructed wetlands would require that the area does not dry out for extended periods and bioretention basins can only be used in areas where there is no high groundwater).
2. Area available for the stormwater control feature.
3. Installation and maintenance costs.

Because not all of the features listed above attain the required 80% TSS removal rate, it is sometimes required to use two stormwater quality control features in series. If this done, the NJDEP suggests that one of the following methodologies be employed:

1. Arrange the features from upstream to downstream in order of increasing TSS removal rate.
2. Arrange the features from upstream to downstream in order of increasing nutrient removal rate.

3. Arrange the features from upstream to downstream by their relative ease of sediment and debris removal.

In practice, however, when stormwater quality control features are placed in series it is often more pragmatic considerations that govern their relative positions. For instance, porous paving must necessarily be placed upstream of a sand filter or, alternatively a sand filter should be placed upstream of an extended detention basin.

The NJDEP also requires that the TSS removal from a series of stormwater control features be calculated by the following equation:

$R = A + B - ((AXB)/100)$, where
R = Total TSS removal rate
A = TSS removal rate for the upstream feature
B = TSS removal rate for the downstream feature

For example suppose that a designer engineer decides to use a vegetative filter strip (with an assigned TSS removal rate of 60) upstream of a sand filter. Referring to the chart and the equation above, the total TSS removal rate for this system can be calculated as follows:

A = TSS removal rate for vegetative filter = 60%
B = TSS removal rate for sand filters = 80%
$R = 60 + 80 - ((60X80)/100) = 92\%$

The NJDEP also lists the following typical phosphorous and nitrogen removal rates for various Stormwater quality control features:

Stormwater Quality Control Feature	**Total Phosphorous Removal Rate (%)**	**Total Nitrogen Removal Rate (%)**
Bioretention Basin	60	30
Constructed Stormwater Wetland	50	30
Extended Detention Basin	20	20
Infiltration Basin	60	50
Manufactured Treatment Device	Varies (Based on testing approved by the NJDEP)	Varies (Based on testing approved by the NJDEP)
Pervious Paving	60	50
Sand Filter	50	35
Vegetative Filter	30	30
Wet Pond	50	30

It can be seen from a comparison of the two tables shown above, that most of these features are more efficient at removing total suspended solids than they are at either phosphorous or nitrogen removal. The NJDEP does not credit dry wells with any stormwater quality control benefit for either TSS or nitrogen/phosphorous removal. However, if properly designed and installed a drywell can approximate an infiltration basin in function and shoud be considered of some benefit in the control of stormwater quality.

A traditional detention basin, such as the one shown below, will control the peak rate of runoff but provides little or no stormwater quality treatment.

In order to provide appropriate stormwater quality treatment for the basin shown above, either one of the features listed above would need to be placed upstream of the basin or else the basin itself would need to be retrofitted for stormwater control.

When choosing specific stormwater quality control features there are a few miscellaneous considerations to keep in mind:

1. Rooftop runoff is generally considered “clean” and does not have to be treated. However, in areas with heavy woods, the rooftop runoff can carry a significant load of leaves and other organic matter. This load should be filtered prior to be recharged into the ground or conveyed downstream.

2. There are non-structural ways to treat stormwatwer. For instance minimizing the amount of lawn on a site can reduce the amount of fertilizer and pesticide used and, consequently, reduce the pollutant load in runoff. Reducing the amount of lawn is an especially effective way to reduce the nitrogen load downstream.
3. Sites that have multiple discharge points require special considerations. The runoff from each of the discharges must be treated to acceptable levels.
4. All of the stormwater control features listed above will need some type of maintenance. This may vary from fairly simple lawn mowing and related activities in the case of sand filters to changing cartridges in the case of some manufactured treatment devices. The design engineer should be aware of the entity that will ultimately be responsible for the maintenance and ensure that competent personnel will be involved in the upkeep of the features employed.
5. The design engineer should always check with the applicable reviewing agency to avoid designing a stormwater control feature that will not be approved.

We will now turn to the design of two of the stormwater control features listed above: sand filters and bioretention systems.

Design of Sand Filters:

A sand filter is a treatment facility that consists of a forebay and an undrained sand bed. The sand filter is configured such that runoff first enters the forebay, where trash, debris, and coarse sediments are removed prior to entering the sand bed. The sand filter can be either an above ground or a subsurface facility. Sand filters are useful as runoff treatment units and are often employed upstream of stormwater retention facilities such as detention basins or drywells.

Sand filters are useful in highly impervious areas such as roadsides or along parking lots. They are generally not recommended in areas where the runoff will carry a high volume of sediment, debris, and organic matter, such as leaves. If sand filters are used in these areas, then it is highly recommended that some form of pre-treatment is provided. A well-designed sand filter is useful for filtering out TSS, heavy metal, and hydrocarbons. They are not considered to be as effective in removing nutrients or bacteria from stormwater runoff. A bioretention system is more capable of removing these pollutants.

A sand filter has four main components:

1. A forebay zone.
2. A sand filter zone.
3. An underdrain within the sand filter zone.

4. An overflow.

The photograph below shows many of the elements of a sand filter. The inlet pipe flows into the headwall on the extreme left of the photo. The forebay is immediately to the right of this headwall. An intermediate berm with an overflow box from the forebay separates the forebay from the sand filter to the right. The sand filter has its own overflow box which drains into an above-ground detention basin. Note that the inlet to the forebay is protected by riprap because the velocity in this area is often erosive. However, no riprap is required downstream of the headwall within the sand bed itself because the very flat slope of the inlet pipe will not cause erosion or scour. This can be seen by the fact that there is no visible erosion downstream of this headwall although the sand filter has been functioning for more than one year.

The photograph below shows the same sand filter looking upstream from the sand filter berm. Note that the sand filter area appears to be draining properly and there is no standing water within it. There will be no outlet from the sand filter into the detention basin until the overflow box (shown in the foreground) is overtopped.

The following table regarding the sand filter design features is taken from the NJDEP Best Management Practices Manual:

Description	Surface Filter
Total Temporary Volume in Forebay and Sand Bed Volumes (V_{QS})	Stormwater Quality Design Storm Runoff Volume
Approximate Temporary Sand Bed Volume (V_{ST})	$(0.5)(V_{QS})$
Minimum Sand Bed Thickness (TH_S)	18 inches
Sand Bed Design Porosity (n)	0.3
Sand Bed Design Drain Time (T_D)	1.5 days
Minimum Sand Bed Surface Area (A_S)	See Equation 1, below
Approximate Temporary Forebay Volume (V_{FT})	$(0.5)(V_{QS})$
Minimum Forebay Surface Area (A_F)	$(0.05)(V_{QS})$
Minimum Temporary Forebay Depth (D_{FT})	2 feet
Minimum Permanent Frebay Depth (D_{FP})	N/A
Overall Minimum Length to Width Ratio (L/W)	2

Equation 1: $A_S = (V_{QS})(TH_S)/((K)(D_{ST}/2 + TH_S)(T_D))$

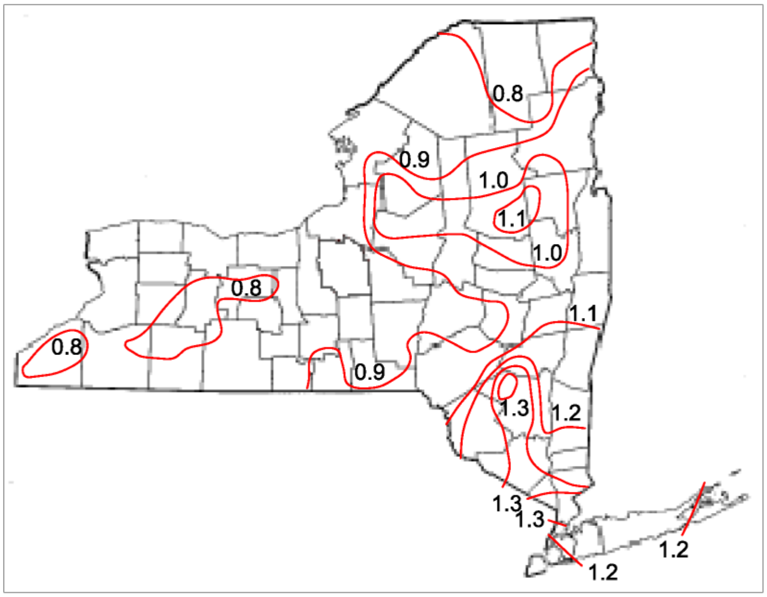
Where k = sand bed design permeability in feet per day. (A value of 4 is typically used.)
In order to properly size the drywell is important to choose the volume of runoff generated by the design storm. It is widely accepted that smaller, run-of-the-mill storms are the ones that flush most of the pollutants downstream. These storms are variously known as “first flush” or “water quality” storms and are generally frequently occurring storms of low intensity. There are several ways of representing this storm and the design engineer must be aware of the particular state’s requirements.

New York State uses the following equation to calculate the runoff from a water quality storm:

$WQ_V = ((P)(R_V)(A))/12$, where:

WQ_V is the water quality storm volume
$Rv = 0.05 + 0.009(I)$
I= Impervious coverage in the watershed in percent
The minimum Rv is set at 0.2
P= 90% Rainfall Event (see the map below), and
A= watershed area

90% Rainfall in NY State



For example, suppose that you need to determine the water quality storm value for 10 acre site with 4 acres of proposed impervious surfaces located on the extreme eastern tip of Long Island. In this case, the water quality storm volume is calculated as follows:

I = 40%

$Rv = 0.05 + 0.009(40) = 0.41$

The eastern tip of Long Island is located at the lower right hand corner of the map of New York shown above. The 90% Rainfall in this area is shown to be 1.2.

A=10 acres

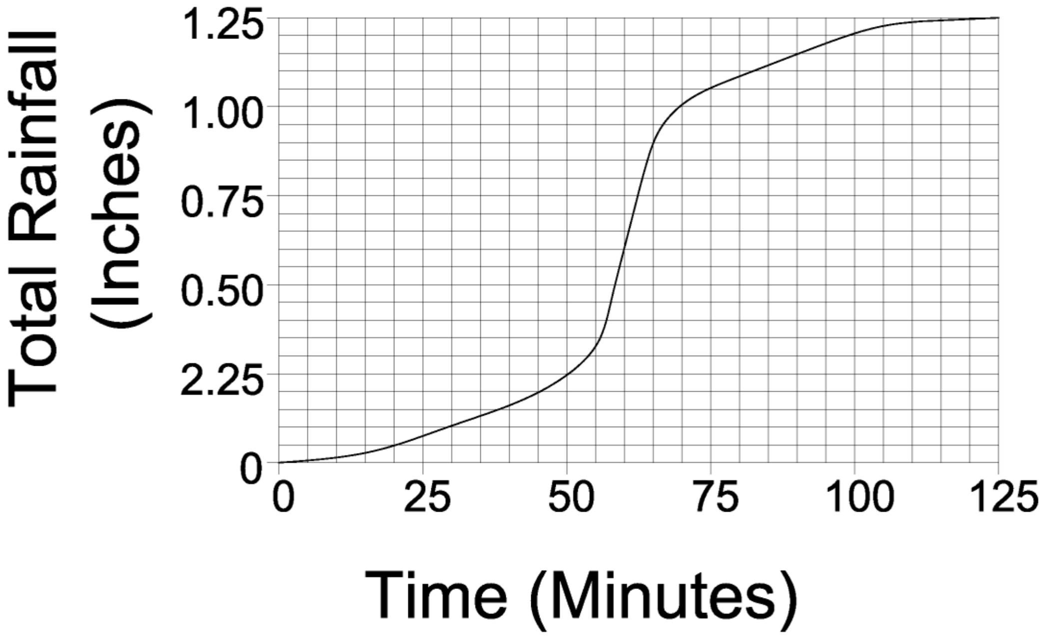
Using the equation above, calculate the water quality volume:

$WQV = ((1.2)(0.41)(10))/12 = 0.41ac - ft = 17{,}860CF$

Conversely, the New Jersey Department of Environmental Protection (NJDEP) has a completely different way of calculating the water quality storm. The NJDEP designates a 2 hour, 1.25" rainfall event as a water quality storm. This storm has a specific rainfall distribution as shown below:

Time (Minutes)	Cumulative Rainfall (inches)	Incremental rainfall (inches)
0	0.0000	0.000
5	0.0083	0.0083
10	0.0166	0.083
15	0.025	0.084
20	0.0500	0.0250
25	0.0750	0.0250
30	0.1000	0.0250
35	0.1330	0.0330
40	0.1660	0.0330
45	0.2000	0.0340
50	0.2583	0.0583
55	0.3583	0.1000
60	0.6250	0.2667
65	0.8917	0.2667
70	0.9917	0.1000
75	1.0500	0.0583
80	1.0840	0.0340
85	1.1170	0.0330
90	1.1500	0.0330
95	1.1750	0.0250
100	1.2000	0.0250
105	1.2250	0.0250
110	1.2334	0.0084
115	1.2417	0.0083
120	1.2500	0.0083

This storm can be input into a standard hydrograph-generating program to determine the water quality runoff volume in New Jersey. The duration-intensity curve of this storm is shown graphically below:

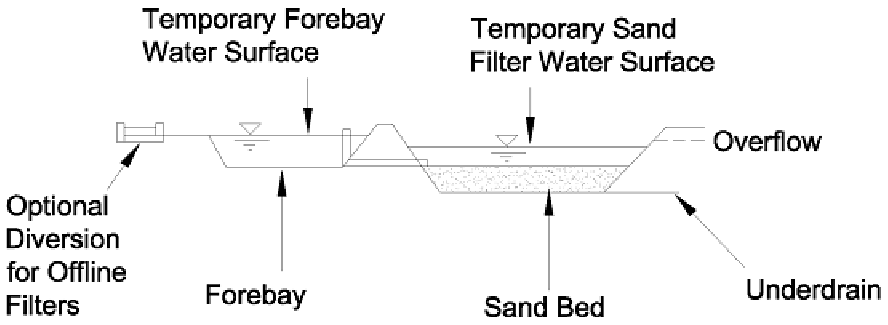


It can be seen that the duration-intensity relationship of this storm is strongly non-linear. In fact, 60% of the total precipitation occurs during the 20 minute period from 50 minutes to 70 minutes after the start of the storm. This type of rainfall distribution is representative of typical small scale storms on the east coast of the United States.

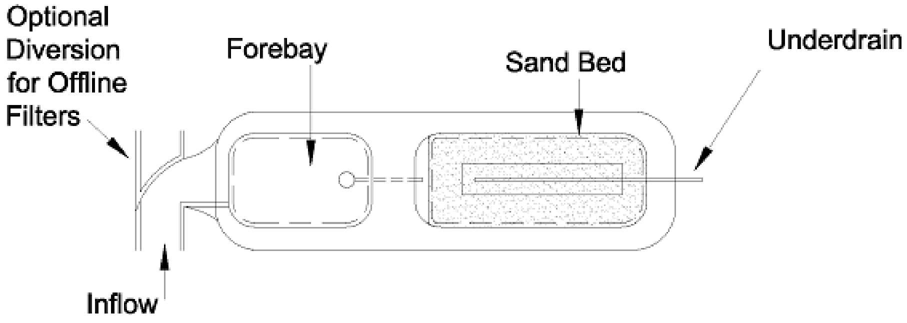
The sand filter shown below was designed as a pre-treatment facility for stormwater entering the detention basin which is to the left of the gabion wall. However, this sand filter does not appear to have been constructed correctly as there is no forebay visible.

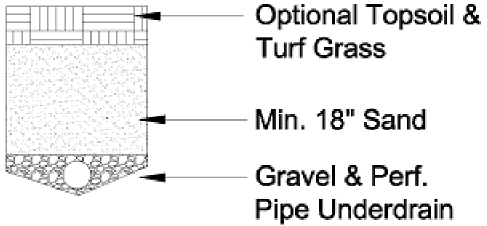
Several detail of typical sand filters are shown below. Note that all of them have the same general scheme in that they include a forebay to catch coarse sediment, the sand filter itself, where the majority of the stormwater treatment occurs, and an overflow to safely pass the larger storms.

The figures below shows a typical surface sand filter in profile, plan view, and cross section. All of the photographs of sand filters included in this course are surface sand filters.



Profile

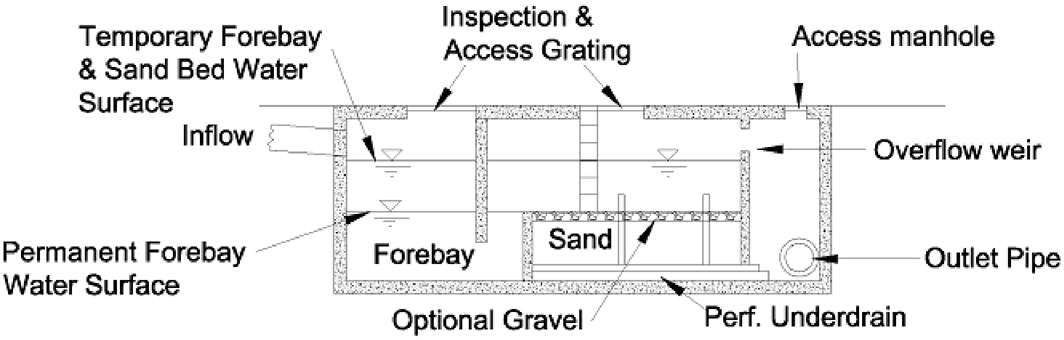




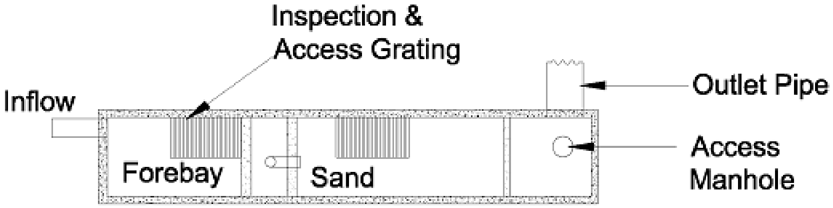
Bed Section

Surface Sand Filter Details

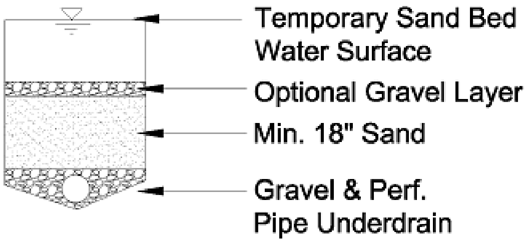
The details below show the corresponding views of a subsurface sand filter.



Profile



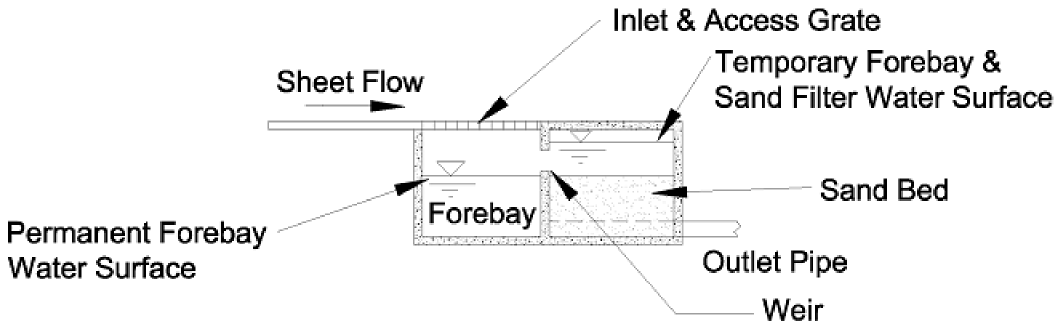
Plan View



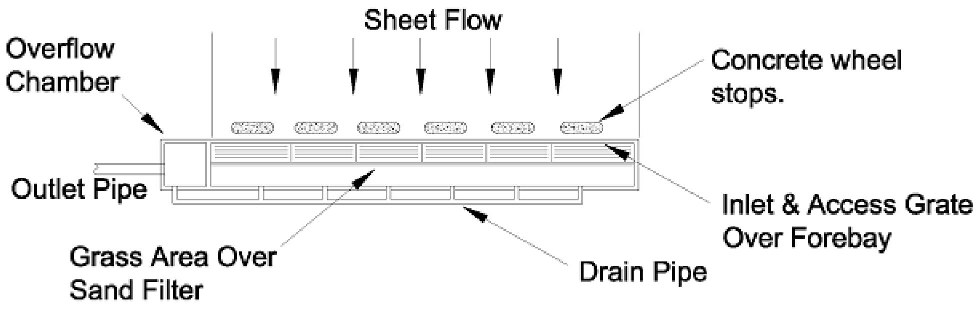
Bed Section

Underground Sand Filter Details

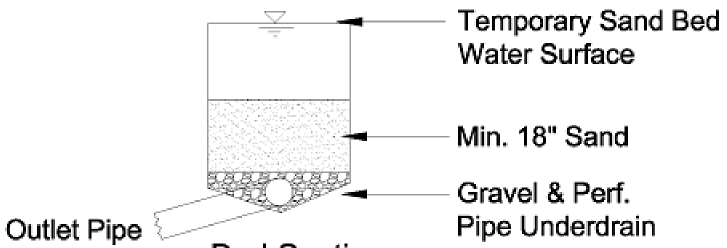
The details below show a typical perimeter sand filter. This filter is a subsurface filter that is being placed adjacent to a paved parking lot.



Profile



Plan View



Bed Section

Perimeter Sand Filter Details

The sand filter shown below treats runoff collected from a parking lot and discharges it into a detention basin. In this view the forebay is in the foreground and the sand filter is to the rear. Once again, note the riprap in the forebay to stabilize this area and to prevent erosion and scour.

The sand filter shown in the picture above looks as though it could have been designed as a perimeter sand filter since it adjacent to a parking lot. However, the arrangement of the forebay in relation to the sand bed itself worked better as a typical surface sand filter.

Example 1:
A bank building and associated parking lot is proposed for a one acre site in Hunterdon County, New Jersey. In order to provide water quality control a sand filter will be provided upstream of a conventional detention basin. Using the New Jersey Department of Environmntal Protection's water quality control storm, the runoff volume has been calculated as 1500 CF. There is an area of approximately 40 feet 80 feet by feet available upstream of the basin for the sand filter. The design of this sand filter is shown in the detail and the table below. The table compares the NJDEP required values with the values provided in the design.

Solution:
A 40 foot X 16' inside dimension will be used for the interior of the sand filter and forebay. The table below will summarize the calculations:

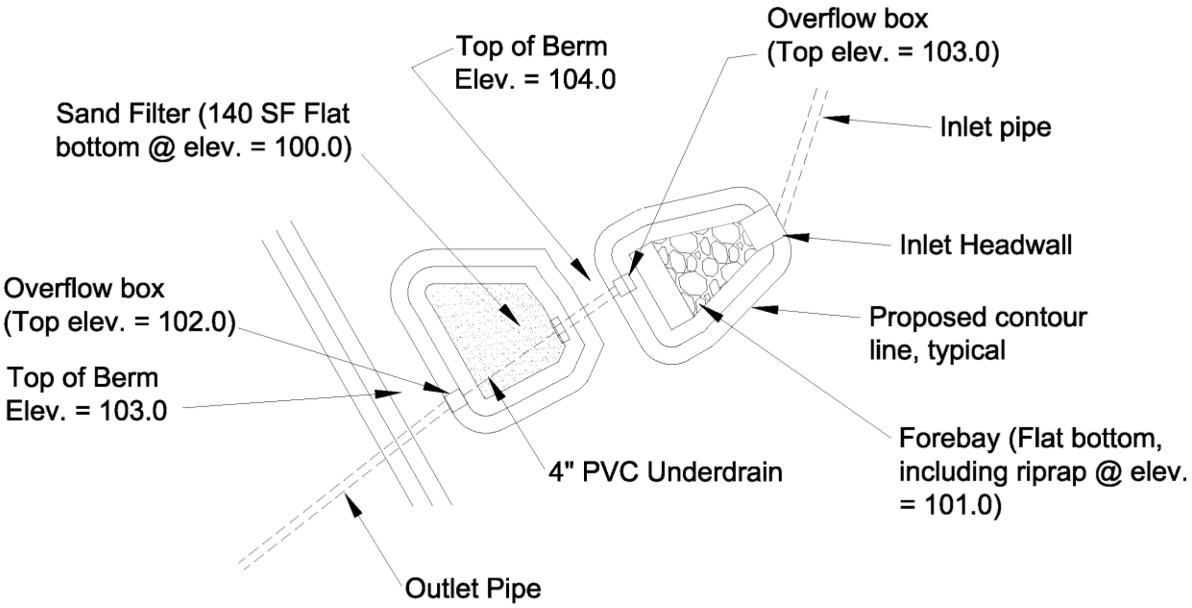
Description	Required	Provided
Total Temporary Volume in Forebay and Sand Bed Volumes (V_{QS})	600 CF	736 CF
Approximate Temporary Sand Bed Volume (V_{ST})	$(0.5)(600) = 300CF$	456 CF
Minimum Sand Bed Thickness (TH_S)	18 inches	18 inches
Sand Bed Design Porosity (n)	0.3	0.3
Sand Bed Design Drain Time (T_D)	1.5 days	1.5 days
Minimum Sand Bed Surface Area (A_S)	See Equation 1, below	138 SF
Approximate Temporary Forebay Volume (VFT)	$(0.5)(600) = 300CF$	280 CF
Minimum Forebay Surface Area (A_F)	(0.05)(600)=75SF	30 SF
Minimum Temporary Forebay Depth (D_{FT})	2 feet	2.0 FT
Minimum Permanent Forebay Depth (D_{FP})	N/A	None
Overall Minimum Length to Width Ratio (L/W)	2	$40'/16' = 2.5$

Equation 1: $A_S = (V_{QS})(TH_S)/((K)(D_{ST}/2 + TH_S)(T_D))$

In this case: V_{QS} =1500 CF (Given)
TH_S =1.5 FT
K=4 FT/Day
D_{st} = 2 FT
T_D = 1.5 Days

Equation 1: $A_S = (1500)(1.4)/((4)(D_{ST}/2+1.5)(T_D))$

A detail of the resulting sand filter is shown below. Photographs of this sand filter are included on pages 10 and 11 of this course booklet.
The detail shows that both the forebay and the sand filter have a working depth of 2 feet (from the flat bottom to the top of the overflow box). The berm elevations are set at least one foot above the tops of the overflow boxes to allow the runoff to safely pass downstream without overtopping the berms.



Hunterdon County, NJ Sand Filter Plan

How Does it Work:
One of the great things about a sand filter is that it is really such a simple system. In this way is preferable to some of the more complicated stormwater control measures, such as manufactured treatment devices. The forebay acts as a settling basin and functions to remove suspended solids from the runoff. Only a small part of the TSS load of most storms will actually pass over the overflow box and enter the sand filter. The process is repeated in the sand bed, itself, and even

more solids are removed. In addition, most of the runoff from a water quality storm will never overflow the sand filter overflow box and will, instead, be absorbed through the sand layer. This filtering through the sand layer increases the system's ability to remove pollutants from the runoff.

Maintenance of Sand Filters:

In order for a sand filter to function properly over a number of years, routine maintenance is required. Most of the maintenance is aimed at keeping the sediment load in the sand filter to a minimum. Excessive siltation will cause the sand layer to lose its porosity and will negatively affect the performance of the filter. While the maintenance of a specific sand filter will vary depending on the climate, characteristics of the contributing drainage area, and the actual use of the sand filter, the schedule below is a good general guideline for sand filter maintenance:

1. A sand filter should be inspected several times annually and after every major storm event for evidence of excess siltation.
2. The inspection should cover any area that might be susceptible to excessive siltation including the inlet channel or pipe, the forebay, the overflow structure, and the sand filter, itself.
3. Excess sediment should be removed after the sand filter has completely dried. If the forebay has a permanent pool, it should be pumped dry prior to removing the sediment.
4. In sand filters with turf grass bottoms, the grass should be mowed at least once a month during the growing season.
5. The grass should also be inspected for damage. If the turf grass suffers a loss of more than 50%, it shall be replanted.
6. When doing any maintenance on the sand filter every effort should be made to avoid compacting the sand layer or the forebay. If the sand layer becomes compacted it may need to be replaced to ensure that it continues to function properly.
7. Subsurface sand filters should generally be inspected more often than surface sand filters. This is because the forebay and sand layer are not visible (without opening the access grates) and they can become clogged without it being apparent. In particular, the forebay of a subsurface sand filter is an obvious place for debris to collect.

The photo at the left shows a well-maintained sand filter. Note that it is free of leaves & debris (although the photograph is taken in October in New Jersey) and that the grass has been mowed.

Final Considerations Regarding Sand Filters:
As can be seen by the information presented above, sand filters are very useful stormwater control devices and can be used in a variety of situations. They generally take up a fairly small amount of space and can be worked into the design of most sites. They are highly susceptible to becoming clogged with sediment, however. Therefore, every effort should be made to see that the routine maintenance listed above is performed on a regular basis. This maintenance is easier and less costly than the alternative, which is re-establishing the sand filter after it has become clogged with silt and other debris.

Finally, it should be noted that the design filter is only sized for the water quality storm. As explained above, this is a relatively high frequency, low-intensity storm that will not generate much runoff. However, the sand filter must be designed to safely pass larger storms without compromising the integrity of the berm. This can be accomplished by employing some form a “flow-splitter” upstream of the sand filter. This can take the form of a catch basin box with a lower pipe that routes smaller storms into the sand filter and a larger pipe at a higher elevation that flows directly into the detention basin downstream of the sand filter.However, the sand filter, itself, should be equipped with some kind of overflow to safely convey the runoff from these larger storms downstream.

Design of Bioretention Systems:

A bioretention system consists of a soil bed planted with suitable native vegetation. It can be either in the form of a basin with a flat bottom or a swale with a slightly sloping bottom. Stormwater is directed into the system and the runoff is treated by the vegetation within the bed. The descriptions and design features described herein are taken from the New Jersey Department of Environmental Protections’s Best Management Practices Manual.

Bioretention systems are sometimes known as rain gardens. However, the term rain garden is somewhat generic and may mean different things to different people or in different regions. Therefore, we will not use the term in this course.

A bioretention system is a more complete runoff treatment system than a sand filter. It is useful in removing a variety of pollutants including suspended solids, nutrients, metals, hydrocarbons, and bacteria. The New York State Stormwater Management Design Manual indicates that a bioretention system is “good’ at removing phosphorus, nitrogen, and metals from stormwatrer runoff and “fair” at removing various pathogens, including Coliform, Streptococci, and E. Coli.

Two examples of bioretention systems are shown below. The first picture shows a very attractive bioretention system that enlivens a downtown area. The water-tolerant plantings in this basin appear to be thriving.

The photograph below shows a roadside biotretention swale. In this photograph several of the typical bioretention features are visible including:

1. The relatively flat bottom.
2. The shrub plantings within the basin.
3. The overflow box, which is barely visible behind the tall ornamental grasses in the background of the photograph.

Note in this picture that runoff sheets off the roadway into the bioretention swale and that there is no point discharge into the swale which could cause erosion. The runoff from the parking lot is directed into the swale via a concrete flume which prevents erosion within the system.

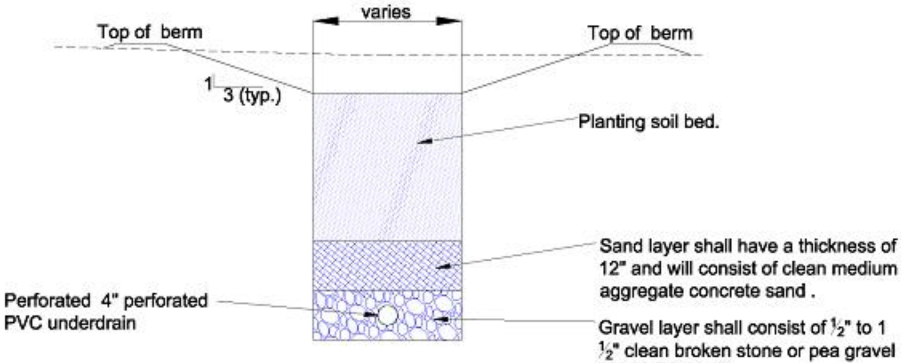
As with a conventional detention basin a bioretention system can incorporate a forebay area. This will help to trap debris and filter sediments and increase the time of concentration within the basin. The forebay should be designed to hold water for a specified period of time (e.g. 24 hours) and then let it out into the main bioretention basin. This can be accomplished either by means of an underdrain or by using a semi-porous material in the intermediate berm between the forebay and the main basin.

Design Parameters:

The main design parameters to be considered are as follows:

1. The storage volume, depth, and duration of retention.
2. The permeability rates of the material in the soil bed and the native material below it.
3. The characteristics of the soil planting bed.
4. The vegetation to be planted within the system.
5. The composition of the sand layer & underdrain material.
6. The inflow and overflow characteristics.

The detail below shows the general characteristics of the bioretention system.
The detail will be used in describing the design parameters listed above. The detail shows a system with an underdrain. However, bioretention systems can be designed without underdrains as well.



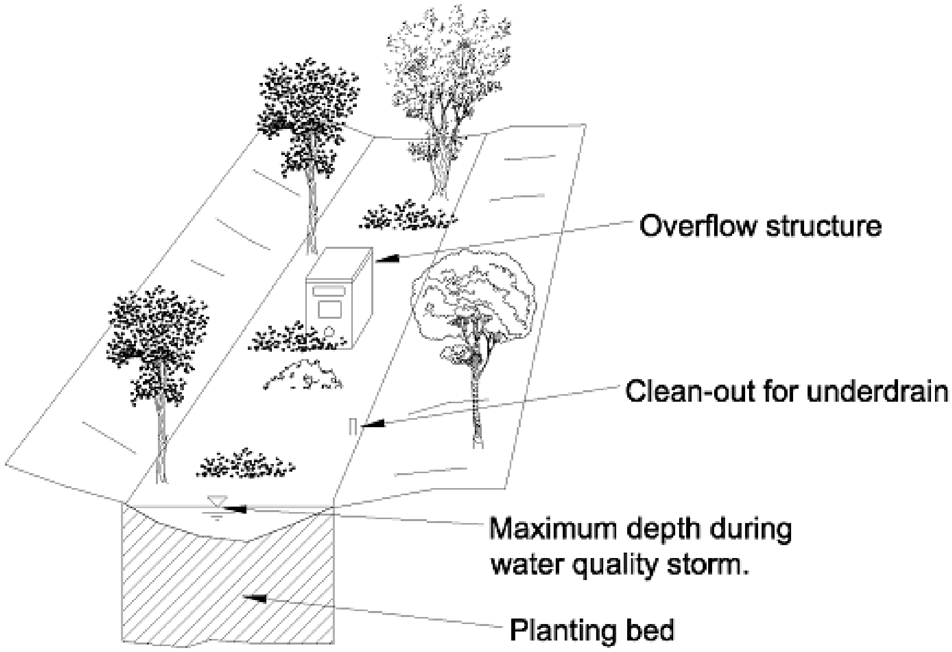
Bioretention Swale Cross Section Detail
NTS

Determining the required storage and subsequent depth of the bioretention system is one of the most important considerations in the design. Generally, the bioretenion system should be designed to store the water quality storm (as described under the discussion of sand filters, above). However, the bioretention basin (unlike a sand filter) can double as a typical detention basin. That is, the area above the overflow can be used for temporary stormwater storage.

It is imperative that the material in the planting bed and below has the appropriate permeability rates in order for the bioretention system to function properly. The stormwater runoff from the water quality storm should drain out of the system within 72 hours. In order to achieve the correct permeabilities the materials should have the following consistency:

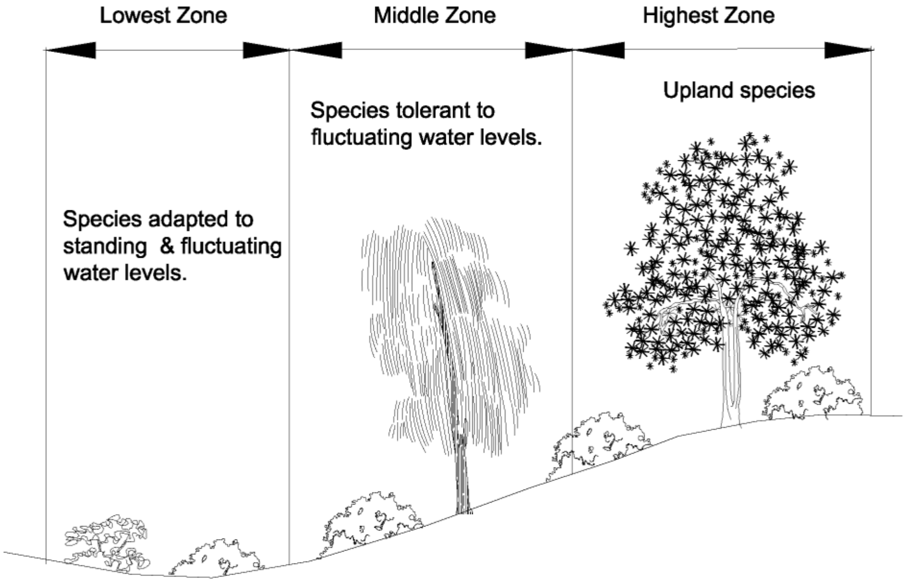
1. The planting bed should consist of 85% to 95% sand and between 2% and 5% clay. In addition the sand should be less than 50% fine sand (i.e. sand that passes a #60 or 0.25mm sieve). It should be mixed with between 3% and 7% organics. The material should have a PH of between 5.5 and 6.5. According to the NJDEP, the total depth of the planting bed should be between 18" and 24". In New York State this depth may be increased.
2. The sand bed should have a permeability at least twice that of the planting bed material.
3. The native material below the gravel layer must have sufficient permeability to ensure that the system will drain.
4. There should be at least one foot separation between the bottom of the gravel layer and the high water table. If this cannot be achieved, then the design engineer should use a different method of providing stormwater quality control.

An isometric view of a bioretention system is shown below. Generally the maximum depth during a water quality storm event should not exceed 18". The system shown in this view appears to have a significant amount of storage between the level of the maximum water quality storage depth and the top of the overflow structure. Therefore, this system could function as a detention basin to control the peak rate stormwater discharge from larger storms as well as functioning as a stomwater quality control feature.



Bioretention Basin Schematic

The vegetation in the bioretention system is a key component in the system ability to filter and treat runoff. It filters some of the nutrients and other pollutants in the runoff. Therefore every effort should be made to ensure that the vegetation becomes well established and is able to thrive in the long term. Portions of the bioretention system are expected to be frequently wet and native plants should be chosen that will be able to thrive under these conditions. A schematic bioretention system planting plan is shown below:



Schematic Bioretention Planting Plan

Generally, the plantings should be selected to approximate a native forest shrub community. On the higher slopes these plants should generally be upland species. Trees should be the dominant plants in this zone. In the wetter zones, native shrubs and herbaceous plantings should be selected that will tolerate the frequent flooding and pollutant loading of this zone.

The following basic guidelines should be considered when choosing the plantings for the bioretention system:

1. Native plantings should be used and the vegetation should be appropriate for the zone within the bioretention system.
2. The layout of species should be as natural and random as possible.
3. A canopy layer should be established with an understory of shrubs and herbaceous plantings.
4. Woody vegetation should not be placed within the area of inflows. These areas should generally be covered with turf grasses (or with riprap if the velocities are expected to be erosive).
5. Aesthetics and visual characteristics of the system should be considered.

6. Care must be taken to ensure that the proposed plantings do not conflict with traffic sight lines, existing or proposed utilities or other features.
7. Site-tolerant grasses can be used in high velocity areas (e.g. inflow channels).

A listing of suggested plantings within bioretention systems in New Jersey is shown in the table below. This table is for illustrative purposes only and, of course, different species will have to substituted for these ones in other climatological areas in the country. Note, however, that the table includes a wide variety of trees, shrubs, and herbaceous plantings and includes both upland species and species that tolerate periods of inundation. For bioretention basins in other regions, local regulations should be consulted. For example, the Fairfax County, VA Public Works and Environmental Services Department has a 22 page listing of recommended plantings within bioretention systems.

Trees	Shrubs	Herbaceous Plantings
Acer rubrum Red Maple	*Clethra alnifolia* Sweet Pepperbush	*Andropogon glomeratus* Lowland Broomsedge
Betula nigra River Birch	*Ilex verticallata* Winterberry	*Eupatorium purpureum* Sweet-scented Joe Pye weed
Chionanthus virginicus Fringe-tree	*Hamemelis Virginiana* Witch Hazel	*Iris versicolor* Blue flag
Juniperus virginiata Eastern red cedar	*Cephalathus occidentalis* Buttonbush	*Scripus pungens* Three square bulrush
Nyssa sylatica Black gum	*Vaccinium corymbosum* Highbush blueberry	*Lobelia cardinalis* Cardinal flower
Diospyros virginiana Persimmon	*Ilex glabra* Inkberry	*Panicum virgatum* Switchgrass
Platanus occidentalis Sycamore	*Viburnam dentatum* Arrowwood	*Rudbeckia lacniata* Cutleaf coneflower
Quercus Palustrus Pin Oak	*Lindera benzoin* Spicebush	*Scirpus cyperinus* Woolgrass
Salix Nigra Black Willow	*Morella pennsylvanica* Bayberry	*Vermonia novaboracensis* New York ironweed

In inlet channels, it is important to use sod-forming grasses that can withstand frequent inundation, such as Alkali saltgrass (puccinellia distans), Canada bluejoint (poa palustris), Switchgrass Panicum virgatum) or other similar species. It is often advisable to consult with a landscaping expert as to the exact placement of plantings (including grasses) within the bioretention system. Once again, these species are applicable to New Jersey and adjacent regions. In other areas, consult with a local expert as to the grasses to be specified. Of course, if velocities in the inlet channel are expected to be erosive the channel should be lines with riprap, concrete, or the like to stabilize the channel. It is absolutely imperative that the inlet channels to the bioretention system are free of erosion and scour.

Limits on the Use of Bioretention Systems:
There are basically two situations in which a bioretention basin cannot be used. These are as follows:

1. Areas with high water table. Remember that the bottom of the bioretention system must be at least 1 foot above the seasonal high water table for the system to function properly.
2. Areas with insufficient percolation. In these areas the bioretention system will not function properly because it will not dry within the specified 72 hours. Therefore, the species specified will not thrive due to the excessively long inundation periods.

If the area will not support a bioretention system (due to the criteria listed above), then the design engineer must choose another method of providing water quality control. If there is a high water table and sufficient drainage area, a constructed stormwater wetland may be a good option. However, the design of stormwater wetlands is beyond the scope of this course.

How Does it Work:
In many ways a bioretention system functions much like a sand filter. It too removes suspended solids by allowing the runoff from a water quality storm to settle and percolate into the ground. The soil in the planting bed is somewhat analogous to the sand layer in the sand filter in that it will filter out pollutants from the runoff. However, the bioretention system’s greater capacity for removing pollutants is due to its increased density of woody vegetation. As in a wetland area, these plants are effective in pulling out pollutants from the runoff and preventing their migration downstream.

Maintenance of Bioretention Systems:
As with any stormwater control feature, maintenance of a bioretention system is absolutely essential to its proper long-term functioning. The maintenance of a bioretention system can be broken down into the following:

General Maintenance:
All bioretention system components expected to trap sediment and debris must be inspected for clogging and for excessive sediment accumulation at least four times annually and after every major rainfall. These components include the bottom of the system, trash racks, low flow channels, outlet structures, riprap aprons and cleanouts.

Vegetated Areas:
Mowing and/or trimming of the vegetation within the bioretention system must be maintained on a regular basis. Vegetated areas should be inspected regularly for erosion and scour. In addition, the vegetated areas should be inspected annually for invasive growth which should be removed immediately.
As was stated earlier, the vegetation within the bioretention system is an integral part of the filtering system. Therefore, when establishing or restoring vegetation inspections should be made biweekly during the first growing season or until the vegetation is firmly established. After establishment, the vegetation should be inspected annually. If the vegetation has experienced greater than 50% loss or damage, then the area should be re-established in accordance with the original specifications.
The use of fertilizers and pesticides should be avoided whenever possible when establishing and/or maintaining the vegetation.

Structural Components:
All structural components shall be inspected for cracking, spalling, deterioration, erosion, and excess sedimentation on an annual basis.

A controlled outlet structure such as the one shown below is an obvious place for sediment and other debris to collect. These structures should be frequently inspected and excess material removed.

Other Maintenance Criteria: The bioretention system should be inspected after every significant rainfall event to ensure that the system is draining properly. If it fails to drain within 72 hours, remedial measures should be taken. This may include the need to replace some or all of the planting bed material (and, consequently, re-establishing the vegetative cover).

Final Considerations Regarding Bioretention Systems:
As with sand filters, there are a few miscellaneous considerations that the design engineer should keep in mind when designing any type of bioretention system. For one thing, stormwater should not be directed into the bioretention system until the contributing drainage area has been stabilized. Otherwise, the sediment load is likely to overwhelm the system before the plantings can become established and the system can be destroyed before it begins to function.

In addition, bioretention systems should not be used in areas where the mature trees will have to be removed. Finally, they should not be located within karst topography so as to avoid the possibility of subsidence or the appearance of sinkholes.

Comparison of Sand Filters and Bioretention Systems:
Based on the information given in this course, a few comparisons can be made between sand filters and bioretention systems.

1. Bioretention systems can provide some visual benefit due to the mixture of woody plantings. Conversely, sand filters generally lack anything in the way of pleasing aesthetics. This should be kept in mind in projects where visual impact is important.
2. Both systems require routine maintenance. However, the maintenance required for above-ground sand filters may be somewhat simpler due to the lack of woody plantings which can hinder the removal of sediments and other debris. Generally (as shown in some of the photos included in this course) maintenance of sand filters can be as simple as mowing the lawn and removing sediment from around the overflow boxes. Because of the mixture of trees and shrubs included in bioretention systems there may be more places for sediment to accumulate making it more difficult to locate and remove the sediments.
3. While both systems are good at TSS removal, bioretention systems are generally more effective at this than sand filters. Because of the mixture of plantings, bioretention systems are also considered more versatile in that they remove a greater variety of pollutants than do sand filters.
4. Sand filters can be placed underground if space is at a premium. Of course, all bioretention systems are surface features.
5. Sand filters can only provide water quality control. However, a bioretention basin can serve a dual role in that it can also provide attenuation of the peak rate of stormwater. In order to accomplish this dual purpose, the engineer should design the bioretention basin two-zone system. The lower zone will act as the water quality control unit and can be designed as explained above. Then the controlled outlet can be configured so that the outflow from the larger storms will be controlled. In this case, special care should be taken to determine the expected frequency and duration of the inundation of the various zones so that appropriate plantings can be provided throughout the basin.

The bioretention system in New Jersey, shown above, illustrates how these systems can add a visually pleasing dimension to the landscape. In this photo, a new bioretention system is set in a residential neighborhood and will enhance the aesthetics of the properties. This photograph shows some standing water in the bottom of the basin. As explained in this course remedial measures may need to be taken in this basin to ensure that the system will drain within 72 hours of rainfall and will actually function properly.