Volume/Peak Rate Reduction by Infiltration BMPs

BMP 6.7: Constructed Filter

Filters are structures or excavated areas containing a layer of sand, compost, organic material, peat, or other filter media that reduce pollutant levels in stormwater runoff by filtering sediments, metals, hydrocarbons, and other pollutants.

Key Design Elements

- Drain down – should empty within 72 hrs
- Minimum permeability of filtration medium required
- Minimum depth of filtering medium = 18"
- Perforated pipes (4" min) in stone
- May be designed to collect and convey filtered runoff down-gradient
- May be designed to infiltrate
- Pretreatment for debris and sediment may be needed
- Must be sized for drainage area
- Regular inspection and maintenance required for continued functioning
- Positive overflow is required

Potential Applications

Residential:	**LIMITED**
Commercial:	**YES**
Ultra Urban:	**YES**
Industrial:	**YES**
Retrofit:	**YES**
Highway/Road:	**YES**

Stormwater Functions

Volume Reduction:	**Low-Med***
Recharge:	**Low-Med***
Peak Rate Control:	**Low/High**
Water Quality:	**High**

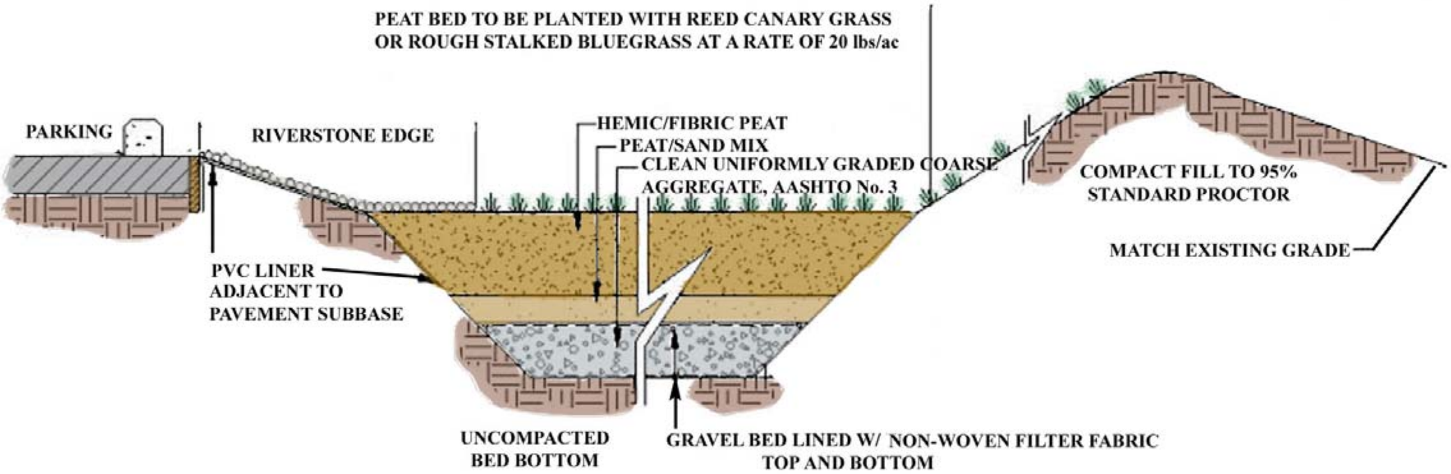
**If Infiltration Used*

Pollutant Removal

TSS:	**85%**
TP:	**85%**
NO_3:	**30%**

Other Considerations

- Certain applications may warrant spill containment
- **Infiltration Systems Guidelines** and **Soil Investigation Guidelines** should be followed, see Section 6.8.



PARKING LOT VEGETATED PEAT FILTER EXAMPLE (CA)

Description

A stormwater filter is a structure or excavation filled with material and designed to filter stormwater runoff to improve water quality. The filter media may be comprised of materials such as sand, peat, compost, granular activated carbon (GAC), perlite, or other material. In some applications the stormwater runoff flows through an open air, "pretreatment" chamber to allow the large particles and debris to settle out (sedimentation). Surface vegetation is another good option for pretreatment. The runoff then passes through the filter media where smaller pollutants are filtered out, and is collected in an under-drain and returned to the conveyance system, receiving waters or infiltrated into the soil mantle.

Variations

There are a wide variety of Filter Applications, including surface and subsurface, vegetated, perimeter, infiltration, and others. There are also a variety of filter products that may be purchased. Examples of these variations include:

Surface Non-vegetated Filter

A Surface Non-vegetated Filter is constructed by excavation or by use of a structural container. The surface may be covered in sand, peat, gravel, river stone, or similar material.

Figure 6.7-1. Surface Sand and Peat Filters (U of MN, NERC)

Vegetated

A layer of vegetation is planted on top of the filtering medium. Composted amended soil may serve as a filter media. For filters composed of filtering media such as sand (where topsoil is required for vegetation) a layer of nonwoven, permeable geotextile should separate the topsoil and vegetation from the filter media.

Figure 6.7-2. Vegetated Peat Filter, Carlisle, PA

Infiltration

Filters may be designed to allow some portion of the treated water to infiltrate. Infiltration Design Criteria apply for all Filters designed with infiltration. In all cases, a positive overflow system is recommended.

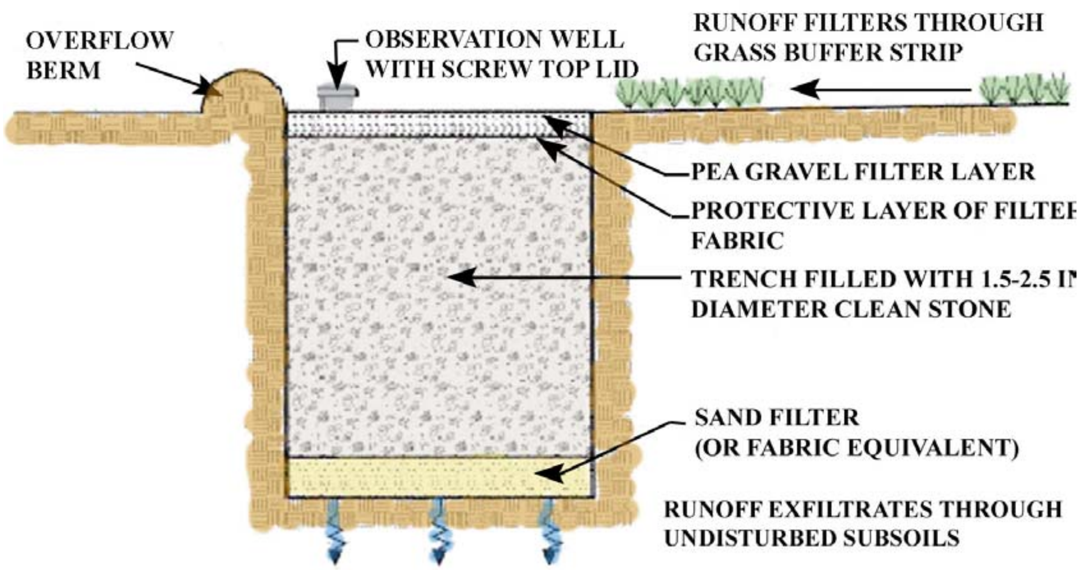


Figure 6.7-3. Combination Filter and infiltration (CA – Lehigh example)

Contained

In contained Filters, infiltration is not incorporated into the design. Contained Filters may consist of a physical structure, such as a precast concrete box. For excavated filters, an impermeable liner is added to the bottom of the excavation to convey the filtered runoff downstream.

Figure 6.7-4. Contained Filter, (Portland, OR BMP manual)

Linear "Perimeter" Filters

Perimeter Filters may consist of enclosed chambers (such as trench drains) that run along the perimeter of an impervious surface. Perimeter Filters may also be constructed by excavation and vegetated. All perimeter filters must be designed with the necessary filter medium and sized in accordance with the drainage area.

Figure 6.7-5. Perimeter filter (GA manual)

Small Subsurface

A Small Subsurface filter is an inlet designed to treat runoff at the collection source by filtration. Small Subsurface filters are useful for Hotspot Pretreatment and similar in function to Water Quality Inserts. Small Subsurface filters must be carefully designed and maintained so that runoff is directed through the filter media.

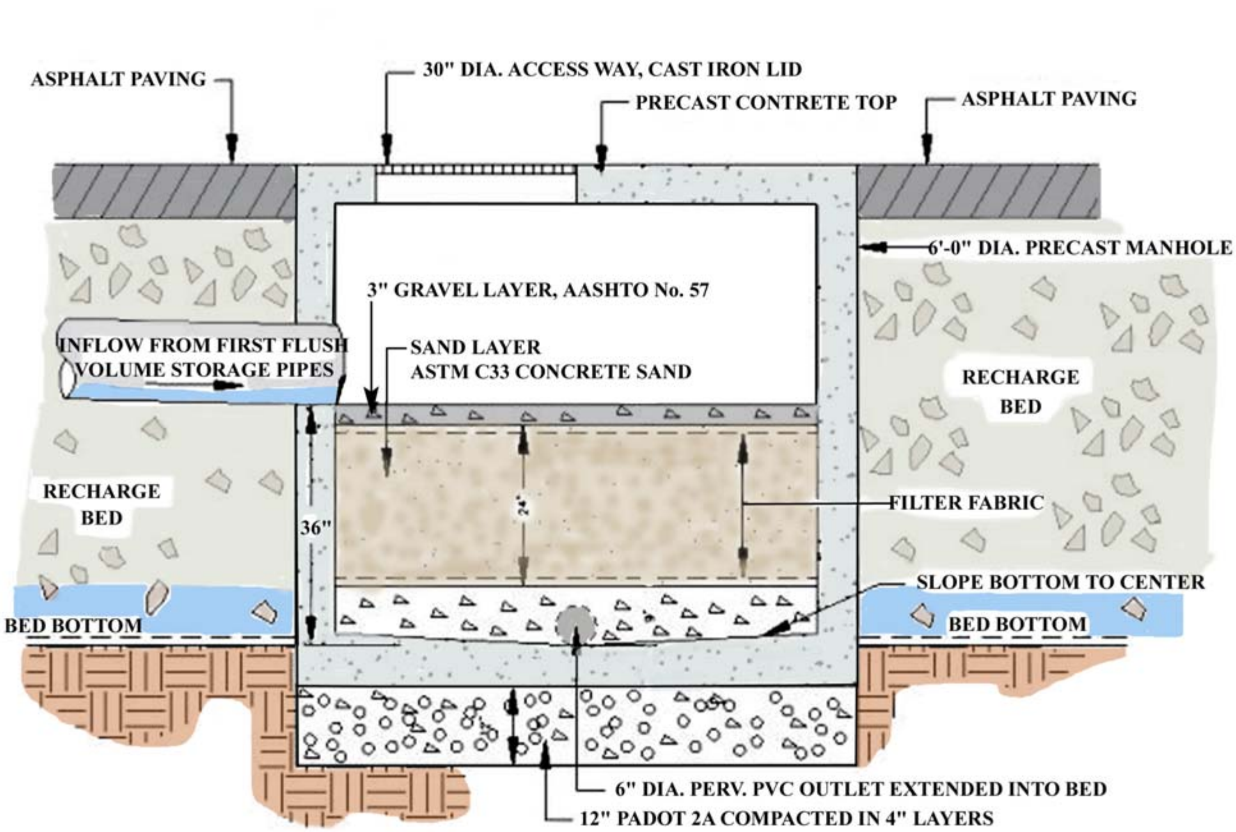


Figure 6.7-6. Small Subsurface filter (CA)

Large Subsurface

Large Subsurface Filters receive relatively large amounts of flow directed into an underground box that has separate chambers, one to settle large particles, and one to filter small particles. The water discharges through an outlet pipe and into the stormwater system.

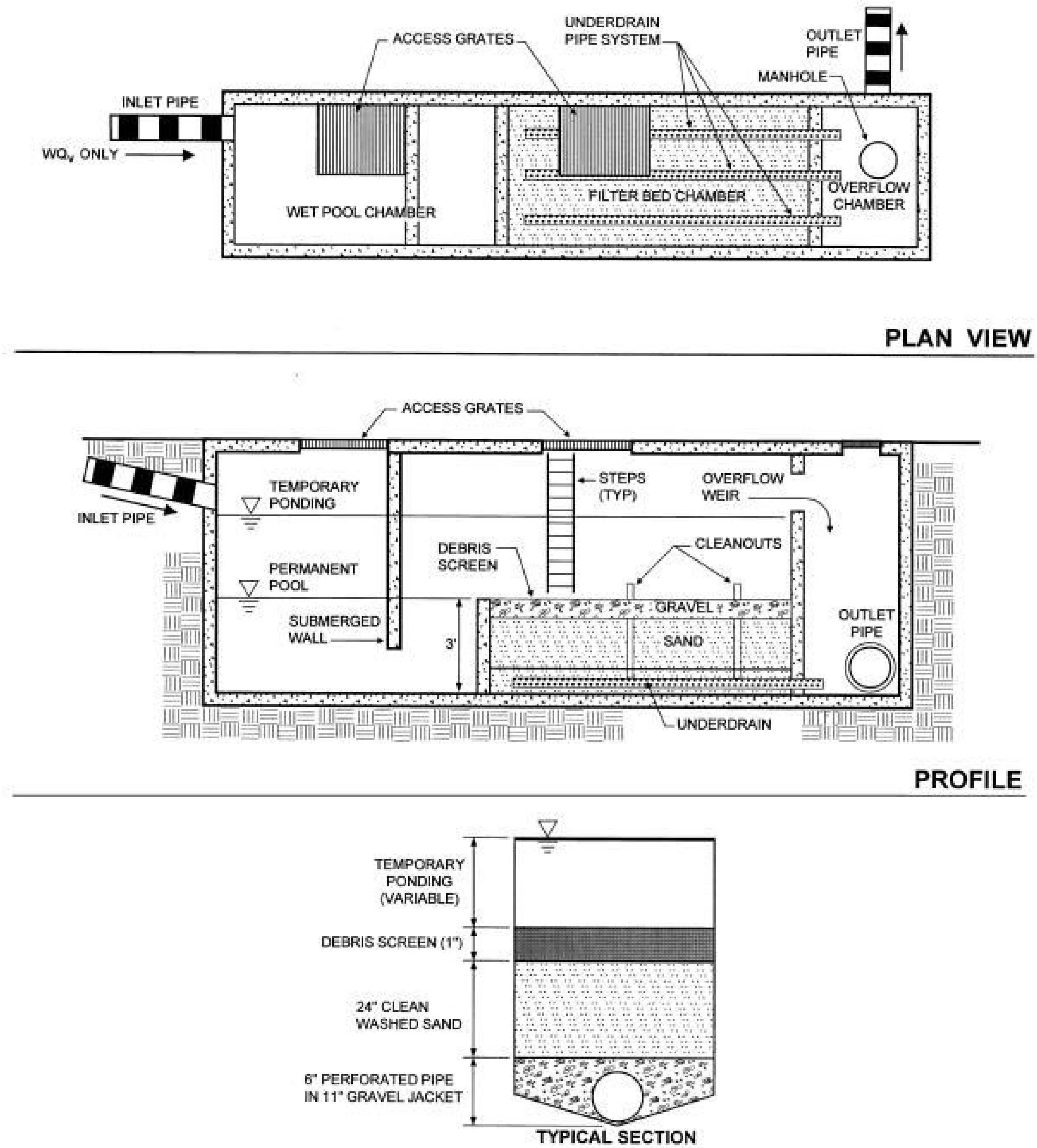


Figure 6.7-7. Large Underground Filter (NY BMP manual)

Manufactured Filtration Systems

There are a considerable number of manufactured filtration systems available, some of which also incorporate oil/water separators, vortex systems, etc. The Designer should obtain product specific information directly from the manufacturer.

Applications

Filters are applicable in urbanized areas of high pollutant loads and are especially applicable where there is limited area for construction of other BMPs. Filters may be used as a pretreatment BMP before other BMPs such as Wet Ponds or Infiltration systems. Filters may be used in Hot Spot areas for water quality treatment, and spill containment capabilities may be incorporated into a filter. Examples of typical areas that benefit from the use of a Filter BMP include:

- Parking lots
- Roadways and Highways
- Light Industrial sites
- Marina areas
- Transportation facilities
- Fast food and shopping areas
- Waste Transfer Stations
- Urban Streetscapes

Design Considerations

1. Filters should be sized as per the Control Guideline that applies. All filters must be designed so that **larger storms may safely overflow or bypass the filter**. Flow splitters, multistage chambers, and other devices may be used. A flow splitter may be necessary to allow only a portion of the runoff to enter the filter. This would create an "off-line" filter, where the volume and velocity of runoff entering the filter is controlled. If the filter is "on-line", excess flow should be designed to bypass filter and continue to another quality BMP.

2. **Entering velocity must be controlled**. A level spreader may be used to spread flow evenly across the filter surface during all storms without eroding the filter material. Parking lots may be designed to sheet flow to filters. Small riprap or riverstone edges may be used to reduce velocity and distribute flow.

3. **Pretreatment** may be necessary in areas with especially high levels of debris, large sediment, etc. Pretreatment may include oil/grit separators, vegetated filter strips, or grass swales. These measures will settle out the large particles and reduce velocity of the runoff before it enters the filter.

4. The **Filter Media** may be a variety of materials and in most cases should have a minimum depth of 18 inches and a maximum depth of 30 inches, although variations on these guidelines are acceptable if justified by the designer. Coarser materials allow for more hydraulic conductivity, but finer media filter particles of a smaller size. Sand has been

found to be a good balance between these two criteria (Urbonas), but different types of media remove different pollutants. While sand is a reliable material to remove TSS, (Debusk and Langston, 1997) peat removes slightly more TP, Cu, Cd, and Ni than sand. The Filter Media should have a minimum hydraulic conductivity (k) as follows:

- Sand 3.5 ft/day
- Peat 2.5 ft/day
- Leaf compost 8.7 ft/day

5. A **Gravel Layer** at least 6” deep is recommended beneath the Filter Media.

6. **Under drain piping** should be 4” minimum (diameter) perforated pipes, with a lateral spacing of no more than 10’. A collector pipe can be used, (running perpendicular to laterals) with a slope of 1%. All underground pipes should have clean-outs accessible from the surface.

7. A **Drawdown Time** of not more than 72 hours is recommended for Filters.

8. The **Size** of a Filter is determined by the Volume to be treated:

$$A = V \times d / (k \times t(h+d))$$

A = Surface area of Filter (square feet)
V = Water volume (cubic feet)
d = Depth of Filter Media (min 1.5 ft; max 2.5 ft)
t = Drawdown time (days), not to exceed 72 hours
h = Head (average in feet)
k = Hydraulic conductivity (ft/day)

9. When a Filter has accumulated sediment in its pore space, its hydraulic conductivity is reduced, and so it its ability to removal pollutants. **Maintenance and Inspection** are essential for continued performance of a Filter. Based upon inspection, some or all portions of the filter media may require replacement.

10. Filters must be designed with **sufficient maintenance access** (clean-outs, room for surface cleaning, etc.). Filters that are visible and simple in design are more likely to be maintained correctly.

Detailed Stormwater Functions

Volume Reduction Calculations
If a Filter is designed to include infiltration, the Volume Reduction is a function of the Area of the Filter and infiltration rate. There is minimal volume reduction for Filters that are not designed to infiltrate.

Volume = Infiltration Volume* + Filter Volume

Infiltration Volume = Bottom Area (sf) x Infil. Rate (in/hr) x Drawdown time** (hr)

Filter Volume = Area of filter (sf) x Depth (ft) x 20%***

*For filters with infiltration only
** Not to exceed 72 hours
***For sand, amended soil, compost, peat; Use 20% unless more specific data is available

Peak Rate Mitigation Calculations

See Section 9 for Peak Rate Mitigation methodology which addresses link between volume reduction and peak rate control.

Water Quality Improvement
See Section 9 for Water Quality Improvement methodology, which addresses pollutant removal effectiveness of this BMP.

Figure 6.7-8. Laying pipes in a filter. (U of MN, NERC)

Construction Sequence

1. Permanent Filters should not be installed until the site is stabilized. Excessive sediment generated during construction can clog the Filter and prevent or reduce the anticipated post-construction water quality benefits. Stabilize all contributing areas before runoff enters filters.
2. Structures such as inlet boxes, reinforced concrete boxes, etc. should be installed in

accordance with the manufacturers' or design engineers guidance.

3. Excavated filters that infiltrate or structural filters that infiltrate should be excavated in such a manner as to avoid compaction of the subbase. Structures may be set on a layer of clean, lightly compacted gravel (such as AASHTO #57).
4. Infiltration Filters should be underlain by a layer of permeable non-woven-geotextile.
5. Place underlying gravel/stone in minimum 6 inch lifts and lightly compact. Place underdrain pipes in gravel during placement.
6. Wrap and secure nonwoven geotextile to prevent gravel/stone from clogging with sediments.
7. Lay filtering material. Do not compact.
8. Saturate filter media and allow media to drain to properly settle and distribute.
9. For vegetated filters, a layer of nonwoven geotextile between non-organic filter media and planting media is recommended.
10. There should be sufficient space (head) between the top of the filtering bed and the overflow of the Filter to allow for the maximum head designed to be stored before filtration.

Figure 6.7-9. Example of sand bed "film" on top (CA manual)

Maintenance and Inspection

Filters require a consistent inspection and maintenance program in order to maintain the integrity of the filtering system and pollutant removal mechanisms. Studies have shown that filters are very effective upon installation, but quickly decrease in efficiency as sediment accumulates in the filter. (Urbonas, Urban Drainage and Flood Control District, CO) Odor is also a concern for filters that are not maintained. Inspection of the filter is recommended at least **four times a year**.

During inspection the following conditions should be considered:

- **Standing water** – any water left in a surface filter after the design drain down time indicates the filter is not optimally functioning.
- **Film or discoloration** of any surface filter material – this indicates organics or debris have clogged the filter surface.

Filter Maintenance

- Remove trash and debris as necessary
- Scrape silt with rakes
- Till and aerate filter area
- Replace filtering medium if scraping/removal has reduced depth of filtering media

In areas where the potential exists for the discharge and accumulation of toxic pollutants (such as metals), filter media removed from filters must be handled and disposed of in accordance with all state and federal regulations.

Winter concerns

Pennsylvania's winter temperatures go below freezing about four months out of every year, and surface filtration may not take place as well in the winter. Peat and compost may hold water, freeze, and become impervious on the surface. Design options that allow directly for subsurface discharge into the filter media during cold weather may overcome this condition.

Cost Issues

Filter costs vary according to the filtering medial (sand, peat, compost), land clearing, excavation, grading, inlet and outlet structures, perforated pipes, encasing structure (if used), and maintenance cost. Underground structures may contribute significantly to the cost of a Filter.

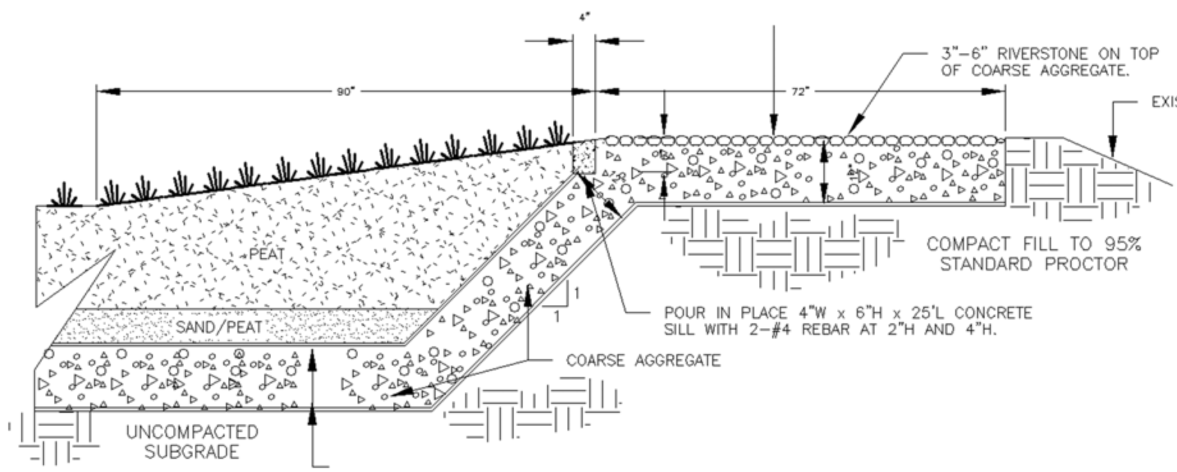


Figure 6.7-10. Peat Surface Filter

Specifications

1. **Stone/Gravel** shall be uniformly graded coarse aggregate, 1 inch to ¾ inch with a wash loss of no more than 0.5%, AASHTO size number 57 per AASHTO Specifications, Part I, 19th Ed., 1998, or later and shall have voids 40% as measured by ASTM-C29.

2. **Peat** shall have ash content <15%, pH range 3.3-5.2, loose bulk density range 0.12-0.14 g/cc.

3. **Sand** shall be ASTM-C-33 (or AASHTO M-6) size (0.02” – 0.04”), concrete sand, clean, medium to fine sand, no organic material.

4. **Non-Woven Geotextile** shall consist of needled nonwoven polypropylene fibers and meet the following properties:
   a. Grab Tensile Strength (ASTM-D4632) ³ 120 lbs
   b. Mullen Burst Strength (ASTM-D3786) ³ 225 psi
   c. Flow Rate (ASTM-D4491) ³ 95 gal/min/ft^2
   d. UV Resistance after 500 hrs (ASTM-D4355) ³ 70%
   e. Heat-set or heat-calendared fabrics are not permitted

   Acceptable types include Mirafi 140N, Amoco 4547, Geotex 451, or approved others.

5. **Topsoil** See Appendix C

6. **Pipe** shall be continuously perforated, smooth interior, with a minimum inside diameter of 8-inches. High-density polyethylene (HDPE) pipe shall meet AASHTO M252, Type S or AASHTO M294, Type S.

References

Georgia BMP Manual

University of Minnesota Extension Service, Northeast Regional Correction Center (NERCC)

"Field Evaluation of a Stormwater Sand Filter" Ben R. Urbonas, John T. Doerfer and L. Scott Tucker www.udfcd.org/fhn96/flood1.html

"An Evaluation of Filter Media For Treating Stormwater Runoff" Thomas A DeBustk and Michael A. Langston, Benefict Schwegler, Scott Davidson, Fifth Biennial Stormwater Research Conference, November, 1997

"A Denitrification System For Septic Tank Effluent Using Sphagnum Peat Moss" E. S. Winkler, and P. L. M. Veneman

"Stormwater Sand Filter Sizing and Design – A Unit Operations Approach" Urbonas

New York BMP Manual

California BMP Manual

Volume/Peak Rate Reduction by Infiltration BMPs
BMP 6.8: Vegetated Swale

A Vegetated Swale is a broad, shallow, trapezoidal or parabolic channel, densely planted with a variety of trees, shrubs, and/or grasses. It is designed to attenuate and in some cases infiltrate runoff volume from adjacent impervious surfaces, allowing some pollutants to settle out in the process. In steeper slope situations, check dams are used to further enhance attenuation and infiltration opportunities.

Key Design Elements

- Plant dense, low-growing native vegetation that is water-resistant, drought and salt tolerant, providing substantial pollutant removal capabilities
- Longitudinal slopes range from 2 to 6%
- Side slopes range from 3:1 to 4:1
- Bottom width of 2 to 8 feet
- Check-dams can provide limited detention storage, as well as enhanced volume control through infiltration
- Convey the 10-year storm event with a minimum of 6 inches of freeboard
- Designed for non-erosive velocities up to the 2-year storm event
- Design to aesthetically fit into the landscape, where possible
- Significantly slows the rate of runoff conveyance

Potential Applications

Residential:	YES
Commercial:	YES
Ultra Urban:	NO
Industrial:	YES
Retrofit:	YES*
Highway/Road:	YES

Applicable with specific considerations to design

Stormwater Functions

Volume Reduction:	Low/Med.
Recharge:	Low/Med.
Peak Rate Control:	Med./High
Water Quality:	Med./High

Pollutant Removal

TSS:	50%
TP:	50%
NO_3:	20%

Other Considerations

- **Soil Investigation Guidelines** required if infiltration considered, see Section 6.8.

Description

Vegetated swales are broad, shallow, earthen channels designed to slow runoff, promote infiltration, and filter pollutants and sediments in the process of conveying runoff. Vegetated Swales provide an environmentally superior alternative to conventional curb and gutter conveyance systems, while providing partially treated (pretreatment) and partially distributed stormwater flows to subsequent BMP's. Swales are often heavily vegetated with a dense and diverse selection of native, close-growing, water-resistant plants with high pollutant removal potential. The various pollutant removal mechanisms of a swale include: filtering by the swale vegetation (both on side slopes and on bottom), filtering through a subsoil matrix, and/or infiltration into the underlying soils with the full array of infiltration-oriented pollutant removal mechanisms.

A Vegetated Swale typically consists of a band of dense vegetation, underlain by at least 30 inches of permeable soil. Swales constructed with an underlying 12 to 24 inch aggregate layer provide significant volume reduction and reduce the stormwater conveyance rate. The permeable soil media should have a minimum infiltration rate of 0.5 inch per hour and contain a high level of organic material to enhance pollutant removal. A nonwoven geotextile shall completely wrap the aggregate trench (See BMP 6.4 Infiltration Trench for further design guidelines).

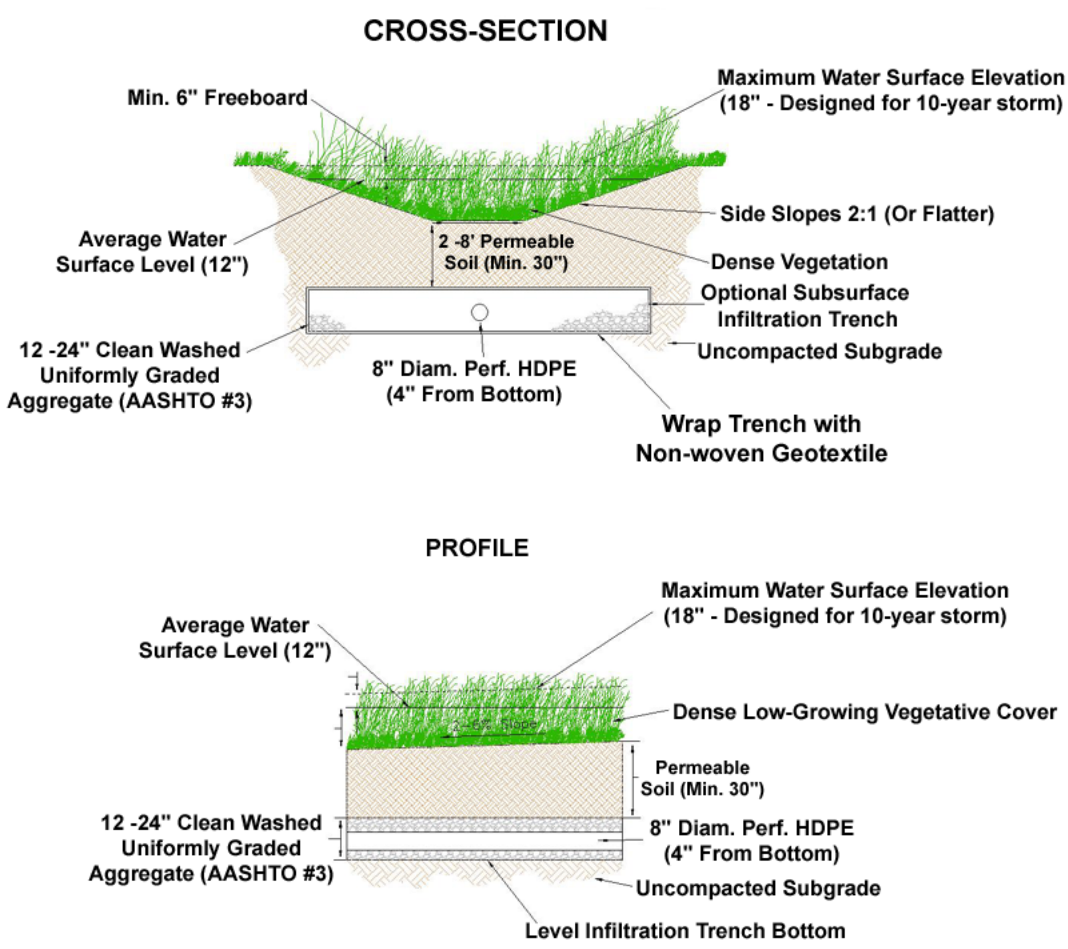


Figure 6.8-1. Detail showing vegetated swale

A major concern when designing Vegetated Swales is to make certain that excessive stormwater flows, slope, and other factors do not combine to produce erosive flows, which exceed Vegetated Swale capabilities. Use of check dams can enhanced swale performance in such situations.

A key feature of vegetated swale design is that swales can be well integrated into the landscape character of the surrounding area. A vegetated swale can often enhance the aesthetic value of a site through the selection of appropriate native vegetation. Swales may also discreetly blend in with landscaping features, especially when adjacent to roads.

Figure 6.8-2. Vegetated swale along parking area

Variations

Vegetated Swale with Infiltration Trench

This option includes a 12 to 24 inch aggregate bed or trench, wrapped in a nonwoven geotextile (See BMP 6.4 Infiltration Trench for further design guidelines). This addition of an aggregate bed or trench substantially increases volume control and water quality performance although costs also are increased. Soil Testing and Infiltration Protocols in Section 6.8 should be followed.

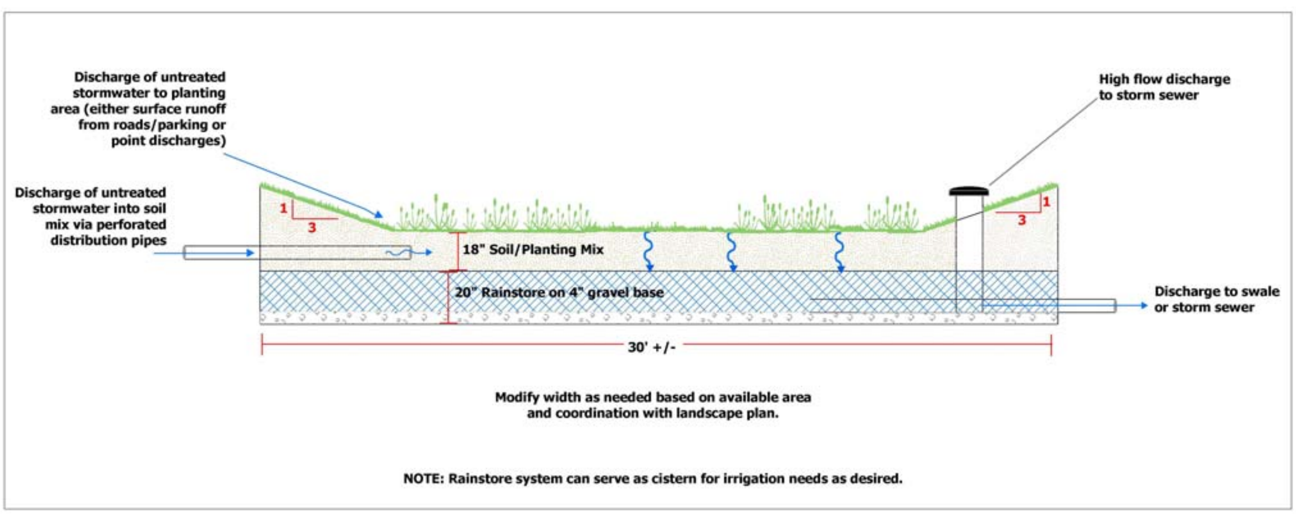


Figure 6.8-3. Example of vegetated swale with infiltration trench (CA, 2003)

Vegetated Swales with Infiltration Trenches are best fitted for milder sloped swales where the addition of the aggregated bed system is recommended to make sure that the maximum allowable ponding time of 72 hours is not exceeded. This aggregated bed system shall consist of at least 12 inches of uniformly graded aggregate. Ideally, the underdrain system shall be designed like an infiltration trench. The subsurface trench should be comprised of terraced levels, though sloping trench bottoms may also be acceptable. The storage capacity of the infiltration trench may be added to the surface storage volume to achieve the required storage of the 1-inch storm event.

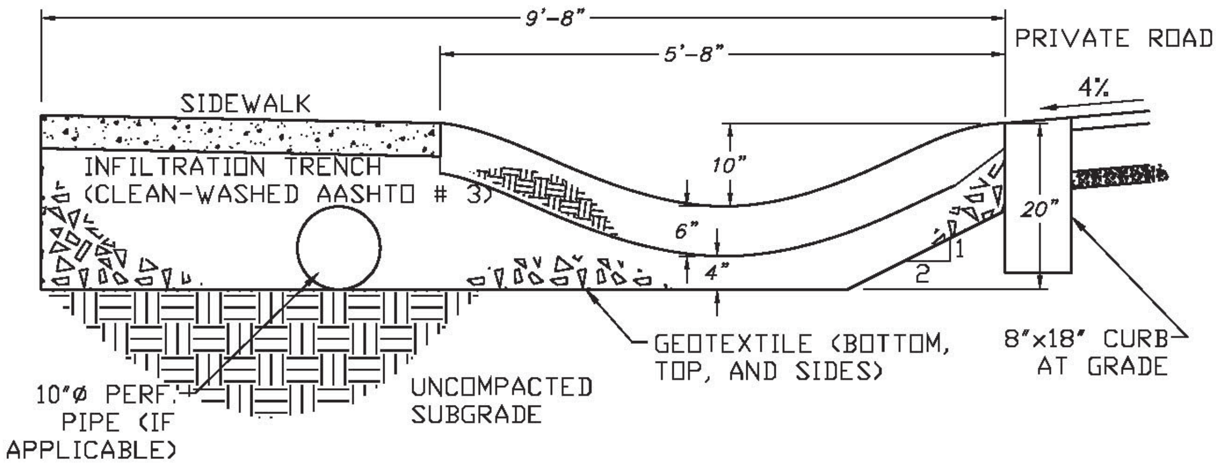


Figure 6.8-4. Example of Vegetated Swale with Infiltration Trench along road.

Grass Swale

Grass swales are essentially conventional drainage ditches. They typically have milder side and longitudinal slopes than their vegetated counterparts. Grass swales are usually less expensive than vegetated swales. However, they provide far less infiltration and pollutant removal opportunities. Grass swales are to be used only as pretreatment for other structural BMPs. Design of grass swales is often rate-based. Grassed swales, where appropriate, are preferred over catch basins and pipes because of their ability to reduce the rate of flow across a site.

Figure 6.8-5. Vegetated swale along residential area (Virginia Stormwater Management Handbook)

Wet Swales

Wet swales are essentially linear wetland cells. Their design often incorporates shallow, permanent pools or marshy conditions that can sustain wetland vegetation, which in turn provides potentially high pollutant removal. A high water table or poorly drained soils are a prerequisite for wet swales. The drawback with wet swales, at least in residential or commercial settings, is that they may promote mosquito breeding in the shallow standing water. Infiltration is minimal if water remains for extended periods.

Figure 6.8-6. Vegetated swale along road (Georgia BMP Manual)

Applications

- **Parking**

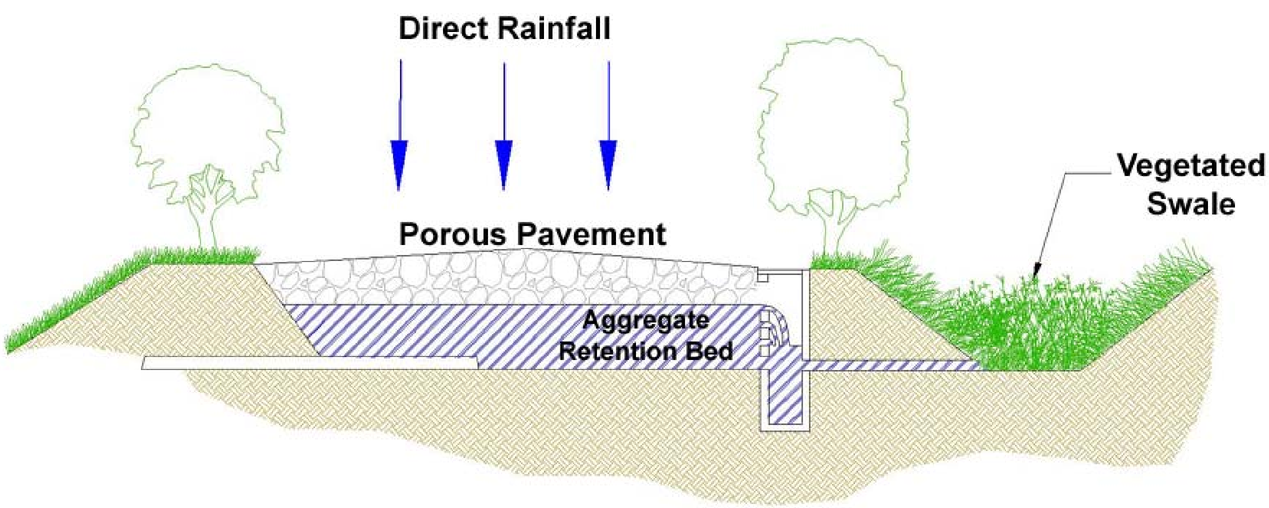


Figure 6.8-7. Schematic showing vegetated swale along parking area (CA, 2004)

- **Commercial and light industrial facilities**
- **Roads and highways**
- **Residential developments**
- **Pretreatment for volume-based BMPs**
- **Alternative to curb/gutter and storm sewer**

Design Considerations

1. Vegetated Swales are sized to temporarily store and infiltrate the 1 inch storm event, while providing conveyance for up to the 10-year storm with freeboard; flows for up to the 2-year storm are to be accommodated without causing erosion. Swales shall maintain a maximum ponding depth of 18 inches at the end point of the channel, with a 12-inch average maintained throughout. Six inches of freeboard is recommended for the 10-year storm. Residence times between 5 and 9 minutes are acceptable for swales without check-dams. The maximum ponding time is 48 hours, though 24 hours is more desirable (minimum of 30 minutes). Swales shall generally be designed for non-erosive velocities up to the 2-year design storm. Studies have shown that the maximum amount of swale filtering occurs for water depths below 6 inches. It is critical that swale vegetation not be submerged, as it could cause the vegetation to bend over with the flow. This would naturally lead to reduced roughness of the swale, higher flow velocities, and reduced contact filtering opportunities.

2. Longitudinal slopes between 2% and 3% are generally recommended for swales. If the topography necessitates steeper slopes, check dams are suggested to reduce the energy gradient.

Figure 6.8-8. Check Dam (Georgia BMP Manual)

Figure 6.8-9. Check dams along a vegetated swale (Virginia Stormwater Management Handbook)

3. Check dams are recommended for vegetated swales with longitudinal slopes greater than 3%. They are often employed to enhance infiltration capacity, decrease runoff volume, rate, and velocity, and promote additional filtering and settling of nutrients and other pollutants. In effect, check-dams create a series of small, temporary pools along the length of the swale, which shall drain down within a maximum of 72 hours. Swales with check-dams are much more effective at mitigating runoff quantity and quality than those without. The frequency and design of check-dams in a swale will depend on the swale length and slope, as well as the desired amount of storage/treatment volume.

   Check-dams shall be constructed to a height of 6 to 12 in and be regularly spaced. The following materials have been employed for check-dams: natural wood, concrete, stone, and earth. Earthen check-dams however, are typically not recommended due to their potential to erode. A weep hole(s) may be added to a check-dam to allow the retained volume to slowly drain out. Care should be taken to ensure that the weep hole(s) is not subject to clogging. In the case of a stone check-dam, a better approach might be to allow low flows (2-year storm) to drain through the stone, while allowing higher flows (10-year storm) drain through a weir in the center of the dam. Flows through a stone check-dam are a function of stone size, flow depth, flow width, and flow path length through the dam. The following equation can be used to determine the flow through a stone check dam up to 6 feet long:

$$q = h^{1.5} / (L/D + 2.5 + L^2)^{0.5}$$

   where:

   q = flow rate exiting check dam (cfs/ft)
   h = flow depth (ft)
   L = length of flow (ft)
   D = average stone diameter (ft) (more uniform gradations are preferred)

For low flows, check-dam geometry and swale width are actually more influential on flow than stone size. The average flow length through a check-dam as a function of flow depth can be determined by the following equation:

$$L = (ss) \times (2d - h)$$

where:
ss = check dam side slope (maximum 2:1)
d = height of dam (ft)
h = flow depth (ft)

When swale flows overwhelm the flow-through capacity of a stone check-dam, the top of the dam shall act as a standard weir (use standard weir equation). (Though a principal spillway, 6 inches below the height of the dam, may also be required depending on flow conditions.) If the check-dam is designed to be overtopped, appropriate selection of aggregate will ensure stability during flooding events. In general, one stone size for a dam is recommended for ease of construction. However, two or more stone sizes may be used, provided a larger stone (e.g. R-4) is placed on the downstream side, since flows are concentrated at the exit channel of the weir. Several feet of smaller stone (e.g. AASHTO #57) can then be placed on the upstream side. Smaller stone may also be more appropriate at the base of the dam for constructability purposes.

4. The effectiveness of a vegetated swale is directly related to the contributing land use, the size of the drainage area, the soil type, slope, drainage area imperviousness, proposed vegetation, and the swale dimensions. Use of natural low points in the topography may be suited for swale location, as are natural drainage courses although infiltration capability may also be reduced in these situations. The topography of a site shall allow for the design of a swale with sufficiently mild slope and flow capacity. Swales are impractical in areas of extreme (very flat or steep) slopes. Of course, adequate space is required for vegetated swales. Swales are ideal as an alternative to curbs and gutters along parking lots and along small roads in gently sloping terrain.

   Siting of vegetated swales should take into account the location and function of other site features (buffers, undisturbed natural areas, etc.). Siting should also attempt to aesthetically fit the swale into the landscape as much as possible. Sharp bends in swales should be avoided.

   Implementing vegetated swales is challenging when development density exceeds four dwelling units per acre, in which case the number of driveway culverts often increases to the point where swales essentially become broken-pipe systems.

   Where possible, construct swales in areas of uncompacted cut. Avoid constructing side slopes in fill material. Fill slopes can be prone to erosion and/or structural damage by burrowing animals.

5. Soil Investigation and Percolation Testing Required when infiltration is planned (see Section 6.8).

6. Guidelines for Infiltration Systems must be met (see Section 6.8).

7. Swales are typically most effective, when treating an area of 1 to 2 acres although vegetated swales can be used to treat and convey runoff from an area of 5 to 10 acres in size. Swales serving greater than 10-acre drainage areas will still provide a lesser degree water quality treatment, unless special provisions are made to manage the increased flows.

8. Runoff can be directed into Vegetated Swales either as concentrated flows or as lateral sheet flow drainage. Both are acceptable provided sufficient stabilization or energy dissipation is included (see #6). If flow is to be directed into a swale via curb cuts, provide a 2 to 3 inch drop at the interface of pavement and swale. Curb cuts should be at least 12 inches wide to prevent clogging and should be spaced appropriately.

9. Vegetated swales are sometimes used as pretreatment devices for other structural BMP's, especially roadway runoff. However, when swales themselves are intended to effectively treat runoff from highly impervious surfaces, pretreatment measures are recommended to enhance swale performance. Pretreatment can dramatically extend the functional life of any BMP, as well as increase its pollutant removal efficiency by settling out some of the heavier sediments. This treatment volume is typically obtained by installing check dams at pipe inlets and/or driveway crossings. Other pretreatment options include a vegetated filter strip, a sediment forebay (or plunge pool) for concentrated flows, or a pea gravel diaphragm (or alternative) with a 6-inch drop where parking lot sheet flow is directed into a swale.

10. The soil base for a vegetated swale must provide stability and adequate support for proposed vegetation. When the existing site soil is deemed unsuitable (clayey, rocky, coarse sands, etc.) to support dense vegetation, replacing with approximately 12 inches of loamy or sandy soils is recommended. In general, alkaline soils should be used to further reduce and retain metals. Swale soils shall also be well-drained. If the infiltration capacity is compromised during construction, the first several feet shall be removed and replaced with a blend of topsoil and sand to promote infiltration and biological growth.

11. Swales are most efficient when their cross-sections are parabolic or trapezoidal in nature. Swale side slopes are best within a range of 3:1 to 4:1 and shall never be greater than 2:1 for ease of maintenance and side inflow from sheet flow.

12. To ensure the filtration capacity and proper performance of swales, the bottom widths typically range from 2 to 8 feet. Wider channels are feasible only when obstructions such as berms or walls are employed to prohibit braiding or uncontrolled sub-channel formation. The maximum bottom width to depth ratio for a trapezoidal swale should be 12:1.

13. Ideal swale vegetation shall consist of a dense and diverse selection of close-growing, water-resistant plants whose growing season preferably corresponds to the wet season. For swales that are not part of a regularly irrigated landscaped area, drought tolerant vegetation should be considered as well. Vegetation shall be selected at an early stage in the design process, with well-defined pollution control goals in mind. Selected vegetation must be able to thrive at the specific site and therefore should be chosen carefully (See Appendix B). Use of native plant species is strongly advised, as is avoidance of invasive plant species. Swale vegetation must also be salt tolerant, if winter road maintenance activities are expected to contribute salt/chlorides.

Table: 6.8-1. Commonly used vegetation in swales (New Jersey BMP Manual, 2004)

Common Name	Scientific Name	Notes
Alkai saltgrass	Puccinellia distans	Cool, good for wet, saline swales
Fowl bluegrass	Poa palustris	Cool, good for wet swales
Canada bluejoint	Calamagrostis canadensis	Cool, good for wet swales
Creeping bentgrass	Agrostis palustris	Cool, good for wet swales, salt tolerant
Red fescue	Festuca rubra	Cool, not for wet swales
Redtop	Agrostis gigantea	Cool, good for wet swales
Rough bluegrass	Poa trivialis	Cool, good for wet, shady swales
Switchgrass	Panicum virgatum	Warm, good for wet swales, some salt tolerance
Wildrye	Elymus virginicus/rigarius	Cool, good for shady, wet swales
Notes: These grasses are sod forming and can withstand frequent inundation, and are ideal for the swale or grass channel environment. A few are also salt-tolerant. Cool refers to cool season grasses that grow during the cooler temperatures of spring and fall. Warm refers to warm season grasses that grow most vigorously during the hot, mid-summer months.		

By landscaping with trees along side slopes, swales can be easily and aesthetically integrated into the overall site design without unnecessary loss of usable space. An important consideration however, is that tree plantings allow enough light to pass and sustain a dense ground cover. When the trees have reached maturity, they should provide enough shade to markedly reduce high temperatures in swale runoff.

14. Check the temporary and permanent stability of the swale using the standards outlined in the Pennsylvania Erosion and Sediment Pollution Control Program Manual. Swales shall convey either 2.75 cfs/acre or the calculated peak discharge from a 10-year storm event. In most cases, the permissible velocity design method may be used for channel linings. The allowable shear method is also acceptable. Flow capacity, velocity, and design depth in swales are generally calculated by Manning's equation.

    Prior to establishment of vegetation, a swale is particularly vulnerable to scour and erosion and therefore its seed bed must be protected with temporary erosion control, such as straw matting, compost blankets, or fiberglass roving. Most vendors will provide information about the Manning's 'n' value and will specify the maximum permissible velocity or allowable unit tractive force for the lining material.

    The post-vegetation establishment capacity of the swale shall also be confirmed. Permanent turf reinforcement may supersede temporary reinforcement on sites where not exceeding the maximum permissible velocity is problematic. If driveways or roads cross a swale, culvert capacity may supersede Manning's equation for determination of design flow depth. In these cases, the culvert should be checked to establish that the backwater elevation would not exceed the banks of the swale. If the culverts are to discharge to a minimum tailwater condition, the exit velocity for the culvert should be evaluated for design conditions. If the maximum permissible velocity is exceeded at the culvert outlet, energy

Table 6.8-2. Maximum Permissible Shear Stresses for Various Channel Liners (PA E&S Manual)

Lining Category	Lining Type	lb/ft^2
Unlined - Erodible Soils*	Silts, Fine -Medium Sands	0.03
	Coarse Sands	0.04
	Very Coarse Sands	0.05
	Fine Gravel	0.10
Erosion Resistant Soils**	Clay loam	0.25
	Silty Clay loam	0.18
	Sandy Clay Loam	0.10
	Loam	0.07
	Silt Loam	0.12
	Sandy Loam	0.02
	Gravely, Stony, Channery Loam	0.05
	Stony or Channery Silt Loam	0.07
Temporary Liners	Jute	0.45
	Straw with Net	1.45
	Coir - Double Net	2.25
	Coconut Fiber -Double Net	2.25
	Curled Wood Mat	1.55
	Curled Wood-Double Net	1.75
	Curled Wood - Hi Velocity	2.00
	Synthetic Mat	2.00
Vegetative Liners	Class B	2.10
	Class C	1.00
	Class D	0.60
Riprap***	R-1	0.25
	R-2	0.50
	R-3	1.00
	R-4	2.00
	R-5	3.00
	R-6	4.00
	R-7	5.00
	R-8	8.00

* Soils having an erodibility “K” factor greater than 0.37.
** Soils having an erodibility “K” factor less than or equal to 0.37
*** Permissible shear stresses based on rock at 165 lb/cuft. Adjust velocities for other rock weights used. See Table 12.

Manufacturer’s shear stress values based on independent tests may be used.

Table 6.8-3. Maximum Permissible Velocities for Channels Lined with Vegetation (PA E&S Manual)

Cover	Slope Range Percent	Erosion resistant Soil[1]	Easily Eroded Soil [2]
Kentucky Bluegrass Tall Fescue	<5 5-10 >10	7 [3] 6 [3] 5	5 4 3
Grass Mixture Reed Canarygrass	<5 5-10	5 4	4 3
Serecea Lespedeza Weeping Lovegrass Redtop Red Fescue	<5	3.5	2.5
Annuals Temporary cover only Sudangrass	<5	3.5	2.5

[1]Cohesive (clayey) fine grain soils and coarse grain soils with a plasticity index OF 10 TO 40 (CL,CH,SC and GC). Soils with K values less than 0.37.

[2]Soils with K values greater than 0.37.

[3]Use velocities exceeding 5 ft/sec only where good cover and proper maintenance can be obtained.

dissipation measures must be implemented. The following tables list the maximum permissible shear stresses (for various channel liners) and velocities (for channels lined with vegetation) from the Pennsylvania Erosion and Sediment Pollution Control Program Manual.

15. Manning's roughness coefficient, or 'n' value, varies with type of vegetative cover and design flow depth. As a conservative approach, the lower value between that based on design depth (see graph) below and that based on vegetative cover (as defined in the Pennsylvania Erosion and Sediment Pollution Control Program Manual) shall be used in design.

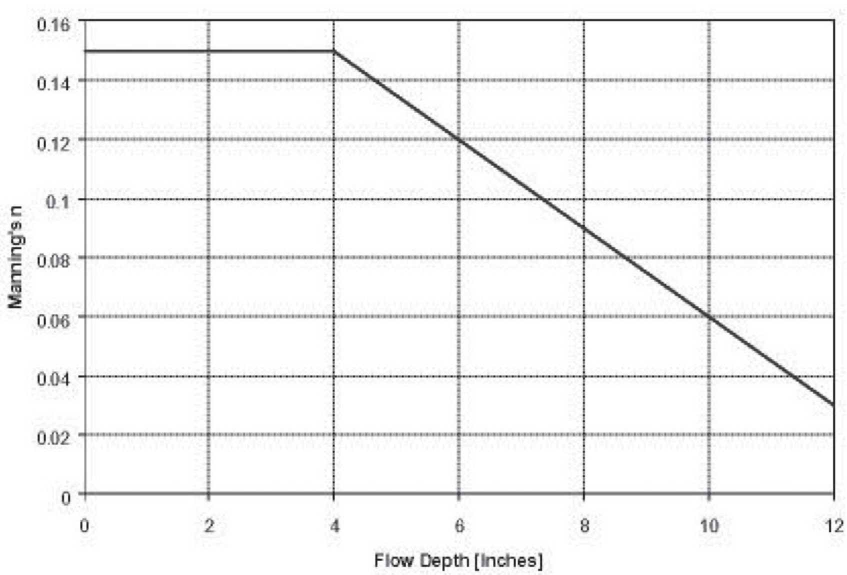


Figure 6.8-10. Manning's n Value with Varying Flow depth (Design of Stormwater Filtering Systems)

16. If swales are designed according to the guidelines discussed in this section, high levels of pollutant reduction can be expected through filtration and infiltration. In a particular swale reach, runoff should be well filtered by the time it flows over a check-dam. Thus, the stabilizing stone apron on the downhill side of the check-dam may be designed as an extension of an infiltration trench. In this way, only filtered runoff will enter a subsurface infiltration trench, thereby reducing the threat of groundwater contamination by metals.

17. Culverts (sometime elevated) are typically used in a vegetated swale at driveway or road crossings. By oversizing culverts and their flow capacity, cold weather concerns (e.g. clogging with snow) are minimized.

18. Where grades limit swale slope and culvert size, trench drains may be used to cross driveways.

19. Swales shall discharge to another structural BMP (bioretention, infiltration basin, constructed wetlands, etc.), existing stormwater infrastructure, or a stable outfall.

Detailed Stormwater Functions

Infiltration Area (if needed)

Volume Reduction Calculations

The volume retained behind each check-dam can be approximated from the following equation:

Storage Volume = 0.5 x Length of Swale Impoundment Area Per Check Dam x Depth of Check Dam x (Top Width of Check Dam + Bottom Width of Check Dam) / 2

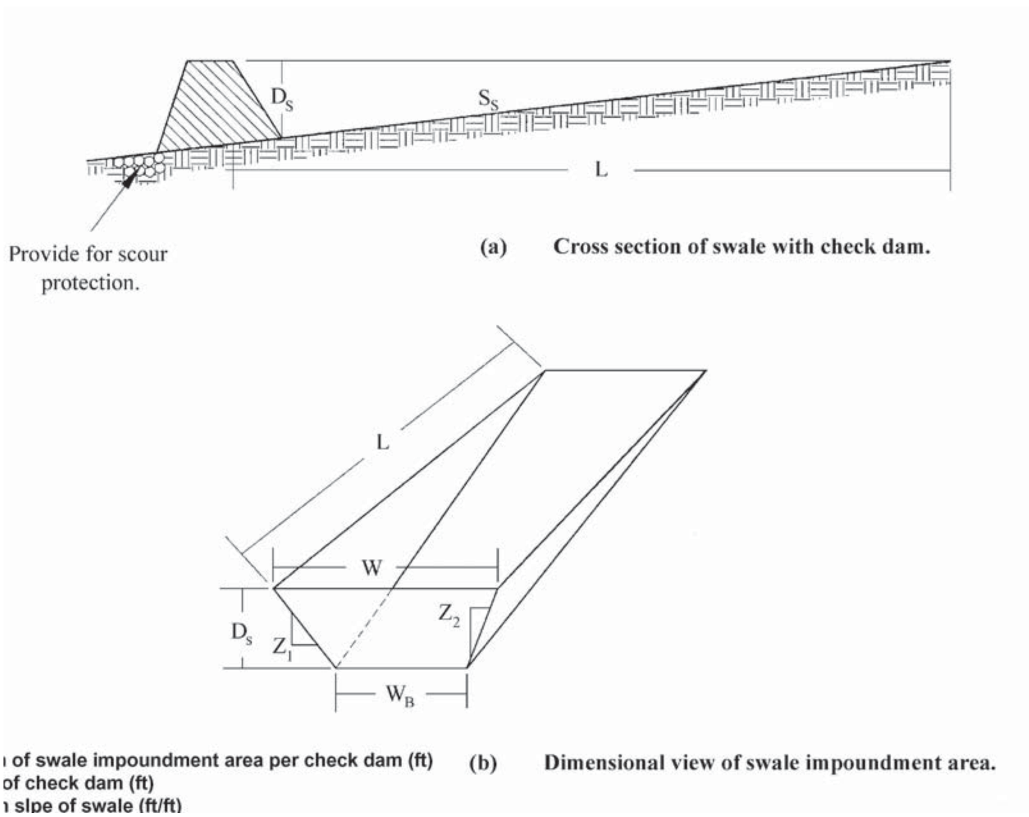


Figure 6.8-11. Cross section of vegetated swale

Peak Rate Mitigation

See Section 9 for Peak Rate Mitigation methodology, which addresses link between volume reduction and peak rate control.

Water Quality Improvement

See Section 9 for Water Quality Improvement methodology, which addresses pollutant removal effectiveness of this BMP.

Construction Sequence

1. Begin vegetated swale construction only when the upgradient site has been sufficiently stabilized and temporary erosion and sediment control measures are in place. Vegetated swales should be constructed and stabilized very early in the construction schedule, preferably before mass earthwork and paving increase the rate and volume of runoff. (Erosion and sediment control methods shall adhere to the Pennsylvania Department of Environmental Protection's *Erosion and Sediment Pollution Control Program Manual,* March 2000 or latest edition.)

2. Rough grade the vegetated swale. Equipment shall avoid excessive compaction and/or land disturbance. Excavating equipment should operate from the side of the swale and never on the bottom. If excavation leads to substantial compaction of the subgrade (where an infiltration trench is not proposed), 18 inches shall be removed and replaced with a blend of topsoil and sand to promote infiltration and biological growth. At the very least, topsoil shall be thoroughly deep plowed into the subgrade in order to penetrate the compacted zone and promote aeration and the formation of macropores. Following this, the area should be disked prior to final grading of topsoil.

3. Construct check dams, if required.

4. Fine grade the vegetated swale. Accurate grading is crucial for swales. Even the smallest non-conformities may compromise flow conditions.

5. Seed and vegetate according to final planting list. Plant the swale at a time of the year when successful establishment without irrigation is most likely. However, temporary irrigation may be needed in periods of little rain or drought. Vegetation should be established as soon as possible to prevent erosion and scour.

6. Concurrent with #7, stabilize freshly seeded swales with appropriate temporary or permanent soil stabilization methods, such as erosion control matting or blankets. Erosion control for seeded swales shall be required for at least the first 75 days following the first storm event of the season. If runoff velocities are high, consider sodding the swale or diverting runoff until vegetation is fully established. (Erosion and sediment control methods shall adhere to the Pennsylvania Department of Environmental Protection's *Erosion and Sediment Pollution Control Program Manual*, March 2000 or latest edition.)

7. Once the swale is sufficiently stabilized, remove temporary erosion and sediment controls. It is very important that the swale be stabilized before receiving upland stormwater flow.

8. Follow maintenance guidelines, as discussed below.

   Note: If a vegetated swale is used for runoff conveyance during construction, it must be regraded and reseeded immediately after construction and stabilization has occurred. Any damaged areas must be fully restored to ensure future functionality of the swale.

Maintenance Issues

Compared to other stormwater management measures, the required upkeep of vegetated swales is relatively low. In general, maintenance strategies for swales focus on sustaining both the hydraulic and pollutant removal efficiency of the channel, as well as maintaining a dense vegetative cover. Experience has proven that proper maintenance activities ensure the functionality of vegetated swales for many years. The following schedule of inspection and maintenance activities is recommended:

Maintenance activities to be done annually or 48 hours after every major storm event (semiannually for the first year):

- Inspect and correct erosion problems, damage to vegetation, and sediment and debris accumulation (when > 3 in at any spot or covers vegetation)
- Inspect vegetation on side slopes for erosion and formation of rills or gullies, correct as needed
- Inspect for pools of standing water; dewater and discharge to a sanitary sewer at an approved location
- Mow and trim vegetation to ensure safety, aesthetics, proper swale operation, or to suppress weeds and invasive vegetation; dispose of cuttings in a local composting facility; mow only when swale is dry to avoid rutting
- Inspect for litter; remove prior to mowing
- Inspect for uniformity in cross-section and longitudinal slope, correct as needed
- Inspect swale inlet (curb cuts, pipes, etc.) and outlet for signs of erosion or blockage, correct as needed

Maintenance activities to be done as needed:

- Plant alternative grass species in the event of unsuccessful establishment
- Reseed bare areas; install appropriate erosion control measures when native soil is exposed or erosion channels are forming
- Rototill and replant swale if draw down time is less than 48 hours
- Inspect and correct check dams when signs of altered water flow (channelization, obstructions, etc.) is identified
- Water during dry periods, fertilize, and apply pesticide **only when absolutely necessary**

Most of the above maintenance activities are reasonably within the ability of individual homeowners. More intensive swales (i.e. more substantial vegetation, check dams, etc.) may warrant more intensive maintenance duties and should be vested with a responsible agency. A legally binding and enforceable maintenance agreement between the facility owner and the local review authority might be warranted to ensure sustained maintenance execution. Winter conditions also necessitate additional maintenance concerns, which include the following:

- Inspect swale immediately after the spring melt, remove residuals (e.g. sand) and replace damaged vegetation without disturbing remaining vegetation.
- If roadside or parking lot runoff is directed to the swale, mulching and/or soil aeration/ manipulation may be required in the spring to restore soil structure and moisture capacity and to reduce the impacts of deicing agents.
- Use nontoxic, organic deicing agents, applied either as blended, magnesium chloride-based liquid products or as pretreated salt.
- Use salt-tolerant vegetation in swales.

Cost Issues

As with all other BMPs, the cost of installing and maintaining Vegetated Swales varies widely with design variability, local labor/material rates, real estate value, and contingencies. In general, Vegetated Swales are considered relatively low cost control measures. Moreover, experience has shown that Vegetated Swales provide a cost-effective alternative to traditional curbs and gutters, including associated underground storm sewers. The following table compares the cost of a typical vegetated swale (15 ft top width) with the cost of traditional conveyance elements.

Table 6.8-4 Cost Comparison showing vegetated swale to pipe, curb, and gutter (Source: Bay Area Stormwater Management Agencies Association, June 1997).

	Swale	**Underground Pipe**	**Curb & Gutter**
Construction Cost (per linear foot)	\$4.50 - \$8.50 (from seed) \$15 – 20 (from sod)	\$2 per foot per inch of diameter (e.g. a 12” pipe would cost \$24 per linear foot)	\$13 – 15
Annual O&M cost (per linear foot)	\$0.75	No data	No data
Total annual cost (per linear foot)	\$1 (from seed) \$2 (from sod)	No data	No data
Lifetime (years)	50		20

It is important to note that the costs listed above are strictly estimates and shall be used for design purposes only. Also, these costs do not include the cost of activities such as clearing, grubbing, leveling, filling, and sodding (if required). The Southeastern Wisconsin Regional Planning Commission (SEWRPC, 1991) reported that actual costs, which do include these activities, may range from \$8.50

to $50.00 per linear foot depending on swale depth and bottom width. When all pertinent construction activities are considered, it is still likely that the cost of vegetated swale installation is less than that of traditional conveyance elements. When annual operation and maintenance costs are considered however, swales may prove the more expensive option, though they typically have a much longer lifespan.

Specifications

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. **Swale Soil** shall be USCS class ML (Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity), SM (Silty sands, poorly graded sand-silt mixtures), SW (Well-graded sands, gravelly sands, little or no fines) or SC (Clayey sands, poorly graded sand-clay mixtures). The first three of these designations are preferred for swales in cold climates. In general, soil with a higher percent organic content is preferred.

2. **Swale Sand** shall be ASTM C-33 fine aggregate concrete sand (0.02 in to 0.04 in).

3. **Check dams** constructed of natural wood shall be 6 in to 12 in diameter and notched as necessary. The following species are acceptable: Black Locust, Red Mulberry, Cedars, Catalpa, White Oak, Chestnut Oak, Black Walnut. The following species are not acceptable, as they can rot over time: Ash, Beech, Birch, Elm, Hackberry, hemlock, Hickories, Maples, Red and Black Oak, Pines, Poplar, Spruce, Sweetgum, and Willow. An earthen **check dam** shall be constructed of sand, gravel, and sandy loam to encourage grass cover (Sand: ASTM C-33 fine aggregate concrete sand 0.02 in to 0.04 in, Gravel: AASHTO M-43 0.5 in to 1.0 in). A stone **check dam** shall be constructed of R-4 rip rap, or equivalent.

4. Develop a native **planting mix**. (see Appendix B)

5. **Topsoil** amended with compost (see Appendix C)

6. If infiltration trench is proposed, see BMP 6.4 Infiltration Trench for specifications.

References

Alameda Countywide Clean Water Program (ACCWP). “Grassy Swales.” *Catalog of Control Measures*. <http://www.oaklandpw.com/creeks/pdf/Grassy_Swales.pdf>

AMEC Earth and Environmental Center for Watershed Protection et al. *Georgia Stormwater Management Manual*. 2001.

California Stormwater Quality Association. *California Stormwater Best Management Practices Handbook: New Development and Redevelopment*. 2003.

Caraco and Claytor. *Stormwater BMP Design Supplement for Cold Climates*. 1997.

City of Portland Environmental Services. *City of Portland Stormwater Management Manual: Revision #2*. 2002.

Center for Watershed Protection and Maryland Department of the Environment. *2000 Maryland Stormwater Design Manual*. Baltimore, MD: 2000.

Claytor, R.A. and T.R. Schuler. *Design of Stormwater Filtering Systems. Center for Watershed Protection*. Silver Spring, MD: 1996.

Colwell, S. R. et al. *Characterization of Performance Predictors and Evaluation of Mowing Practices in Biofiltration Swales*. 2000.

DURMM Manual 2002

Fletcher, T., Wong, T., and Breen, P. “Chapter 9 – Buffer Strips, Vegetated Swales and Bioretention Systems.” *Australian Runoff Quality (Draft)*. University of New Castle – Australia.

Lichten, K. “Grassy Swales.” BMP Fact Sheets. Bay Area Stormwater Management Agencies Association (BASMAA). 1997.

Maine Department of Transportation. *Maine Department of Transportation BMP Manual for Erosion and Sedimentation Control*. 1992.

North Central Texas Council of Governments. *Stormwater Best Management Practices: A Menu of Management Plan Options for Small MS4s in North Central Texas*. 2002.

Schueler, T. et al. *A Current Assessment of Urban Best Management Practices: Techniques for Reducing Nonpoint Source Pollution in the Coastal Zone*. 1992.

United States Environmental Protection Agency (USEPA). “Post-Construction Storm Water Management in New Development & Redevelopment.” *National Pollutant Discharge Elimination System (NPDES).* <http://cfpub1.epa.gov/npdes/stormwater/menuofbmps/post_8.cfm>

United States Environmental Protection Agency (USEPA). *Storm Water Technology Fact Sheet: Vegetated Swales* (EPA 832-F-99-006). 1999.

Vermont Agency of Natural Resources. *The Vermont Stormwater Management Manual*. 2002.

Virginia Stormwater Management Handbook, Volumes 1 and 2, First Edition, 1999

Volume/Peak Rate Reduction by Infiltration BMPs
BMP 6.9: Vegetated Filter Strip

The EPA defines a Vegetated Filter Strip as a "permanent, maintained strip of planted or indigenous vegetation located between nonpoint sources of pollution and receiving water bodies for the purpose of removing or mitigating the effects of nonpoint source pollutants such as nutrients, pesticides, sediments, and suspended solids."

Key Design Elements

- Sheet Flow across Vegetated Filter Strip
- Filter Strip length is a function of the slope, vegetated cover, and soil type.
- Minimum recommended length of Filter Strip is 25 ft, however shorter lengths provide some water quality benefits as well.
- Maximum Filter Strip slope is based on soil type and vegetated cover.
- Filter strip slope should never exceed 8%. Slopes less than 5% are generally preferred.
- Level spreading devices are recommended to provide uniform sheet flow conditions at the interface of the Filter Strip and the adjacent land cover.
- Maximum contributing drainage area slope is generally less than 5%, unless energy dissipation is provided.
- Filter strip width should always equal the width of the contributing drainage area.
- Construction of filter strip shall entail as little disturbance to existing vegetation at the site as possible.
- See Appendix B for list of acceptable filter strip vegetation.

Potential Applications

Residential: YES
Commercial: YES*
Ultra Urban: LIMITED*
Industrial: LIMITED*
Retrofit: YES
Highway/Road: YES

** Depending on size and site constraints*

Stormwater Functions

Volume Reduction: Low-Med
Recharge: Low-Med
Peak Rate Control: Low
Water Quality: Medium

Pollutant Removal

TSS: 30%
TP: 20%
NO_3: 10%

Other Considerations

- Regular Maintenance required for continued performance

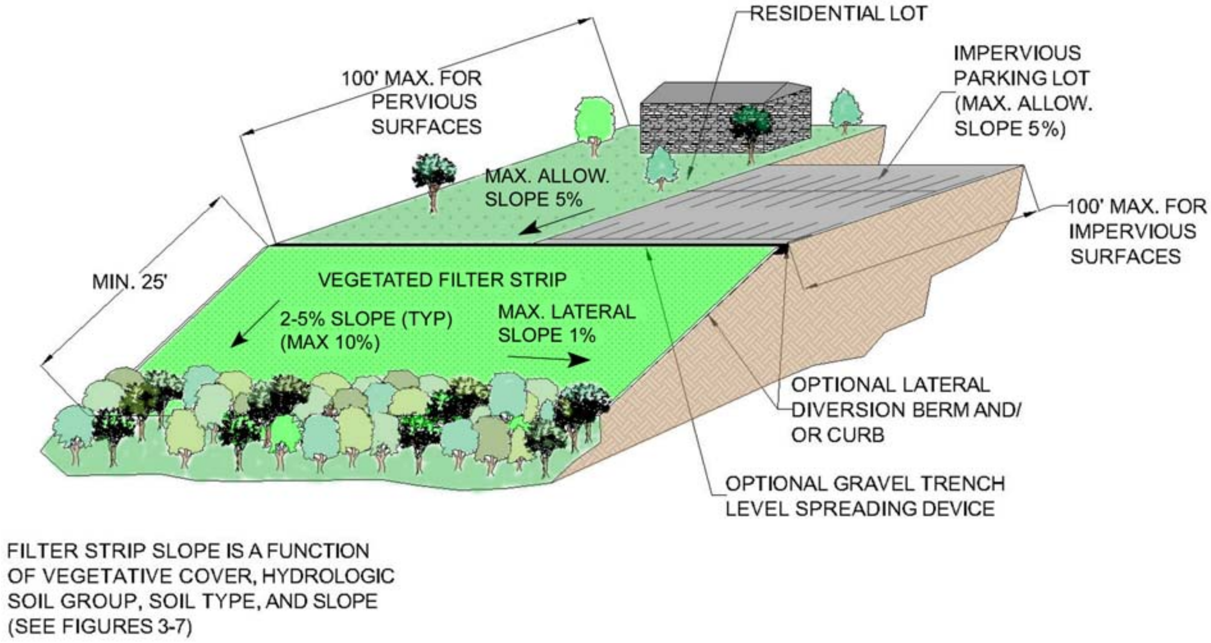


Figure 6.9-1 Vegetated Filter Strip Application

Description

Filter strips are gently sloping, densely vegetated areas that filter, slow, and infiltrate sheet flowing stormwater. Filter strips are best utilized to treat runoff from roads and highways, roof downspouts, small parking lots, and pervious surfaces. In highly impervious areas, they are generally not recommended as “stand alone” features, but as pretreatment systems for other BMPs, such as Infiltration Trenches or Bioretention Areas. Filter Strips are primarily designed to reduced TSS levels, however pollutant levels of hydrocarbons, heavy metals, and nutrients may also be reduced. Pollutant removal mechanisms include sedimentation, filtration, absorption, infiltration, biological uptake, and microbial activity. Depending on hydrologic soil group, vegetative cover type, slope, and length, a filter strip can allow for a modest reduction in runoff volume through infiltration.

The vegetation for Filter Strips may be comprised of:

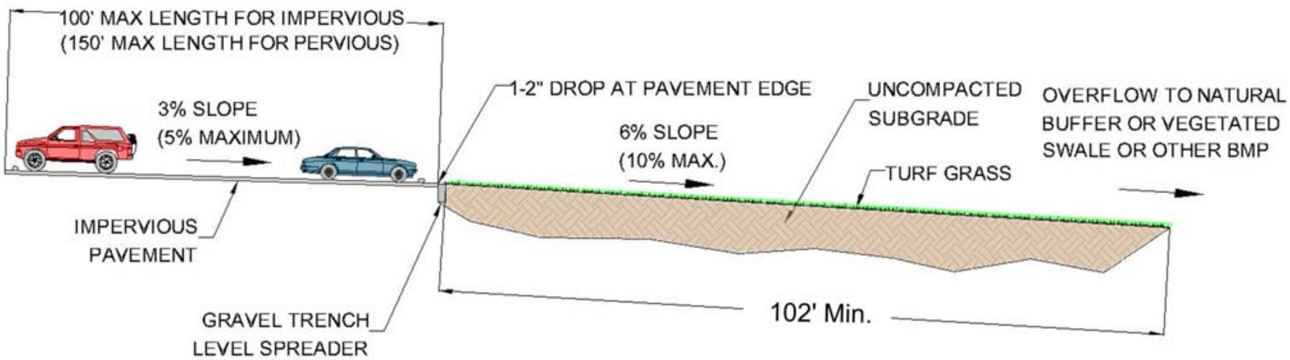
- Turf Grasses
- Meadow grasses, shrubs, and native vegetation, including trees
- Indigenous areas of woods and vegetation.

Filter strips may be comprised of a variety of trees, shrubs, and native vegetation to add aesthetic value as well as water quality benefits. The use of turf grasses will increase the required length of the filter strip, as compared to other vegetation options. The use of indigenous vegetated areas that have surface features that disperse runoff is encouraged, as the use of these areas will also reduce overall site disturbance and soil compaction. Runoff must be distributed so that erosive conditions cannot develop.

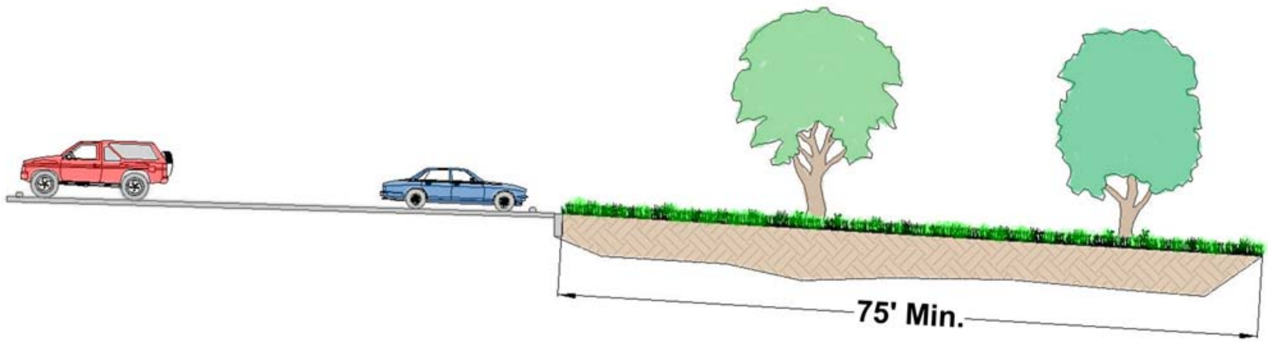
The vegetation in Filter Strips must be dense and healthy. Indigenous wooded areas should have a healthy layer of leaf mulch or duff. Indigenous areas that have surface features that concentrate flow are not acceptable.

The following example shows three filter strips that vary only by cover type. Each strip is on type 'C' soils and has a slope of 6%. Using the recommended sizing approach, the filter strip covered with turf grass required a length of 100 ft, while the strip with indigenous woods required only 50 ft. The strip covered with native grasses and some trees required 75 ft.

FILTER STRIP EXAMPLE #1: TURF GRASS



FILTER STRIP EXAMPLE #2: NATIVE GRASSES AND PLANTED WOODS



FILTER STRIP EXAMPLE #3: INDIGENOUS WOODS

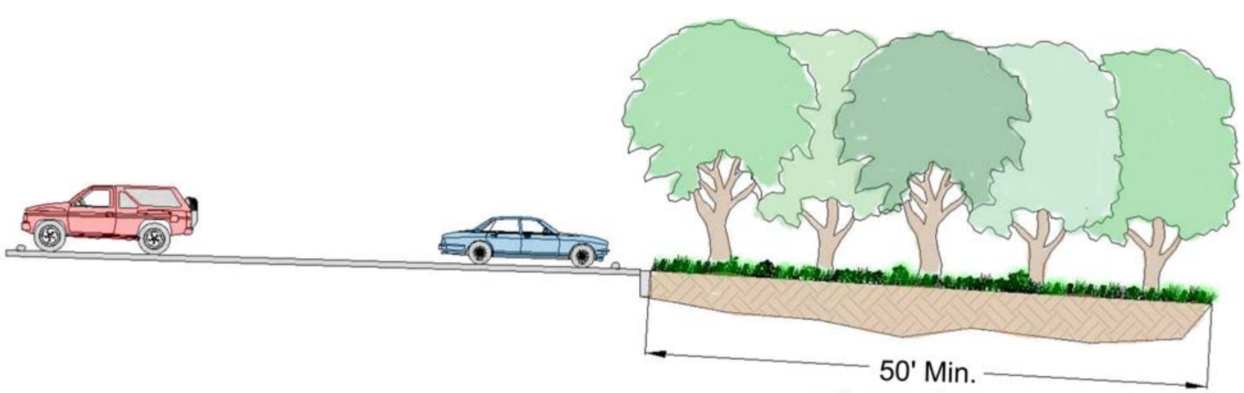


Figure 6.9-2 Design example showing variation in filter strip cover type, with HSG C, 6% slope, (CA, 2004)

Variations

Filter strip effectiveness may be enhanced through the addition of a pervious berm at the toe of the slope. A pervious berm allows for greater runoff velocity and volume reduction and thus better pollutant removal ability, by providing a temporary (very shallow) temporarily ponded area. The berm should have a height of not more than six to twelve inches and be constructed of sand, gravel, and sandy loam to encourage vegetative cover. An outlet pipe(s) or overflow weir should be provided and sized to ensure that the area drains within 24 hours, or to convey larger storm events. The berm must be erosion resistant under the full range of storm events. Likewise, the ponded area should be planted with vegetation that is resistant to frequent inundation.

Check dams may be implemented on filter strips with slopes exceeding 5%. Check dams shall be constructed of durable, nontoxic materials such as rock, brick, wood, not more than six inches in height, and placed at appropriate intervals to encourage ponding and prevent erosion.

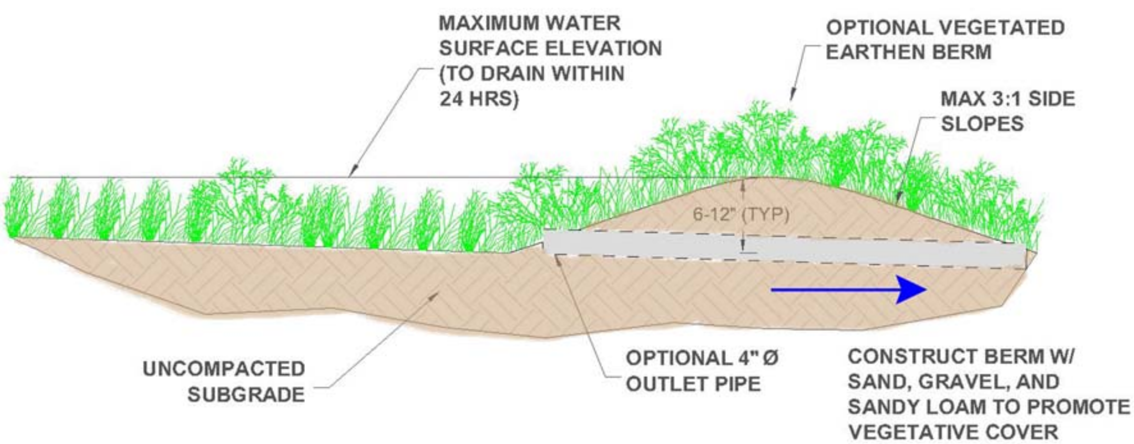


Figure 6.9-3. Optional Earthen Berm at Toe of Filter Strip

Applications

- Residential development lawn and housing areas
- Roads and highways
- Parking lots
- Pretreatment for other structural BMPs (Infiltration Trench, Bioretention, etc.)
- Commercial and light industrial facilities
- As part of a Riparian Buffer (located in Zone 3)

Design Considerations

1. The design of vegetated filter strips is determined by site conditions (contributing drainage area, length, slope, etc.) site soil group, proposed cover type, and filter strip slope. The

filter length can be determined from the appropriate graph (see Figures 6.9-x through 6.9-x).

2. Level spreading devices or other measures are required to provide uniform sheet flow conditions at the interface of the filter strip and the adjacent land cover. Concentrated flows are explicitly discouraged from entering filter strips, as they can lead to erosion and thus failure of the system. Examples of level spreader applications include:

   a. A gravel-filled trench, installed along the entire upgradient edge of the strip. The gravel in the trenches may range from pea gravel (ASTM D 448 size no. 6, 1/8" to 3/8") for most cases to shoulder ballast for roadways. Trenches are typically 12" wide, 24-36" deep, and lined with a nonwoven geotextile. When placed directly adjacent to an impervious surface, a drop (between the pavement edge and the trench) of 1-2" is recommended, in order to inhibit the formation of the initial deposition barrier.

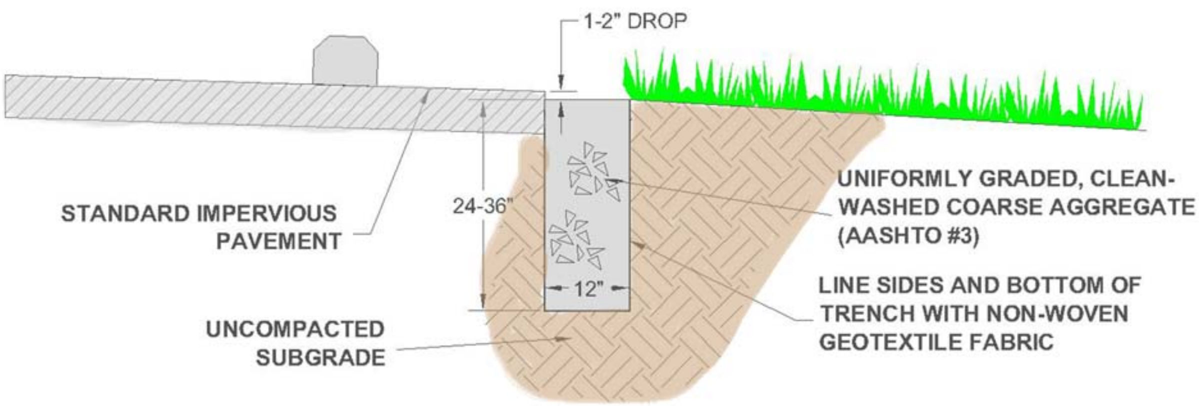


Figure 6.9-4. Filter Strip with Gravel Trench Level Spreader

   b. Curb stops

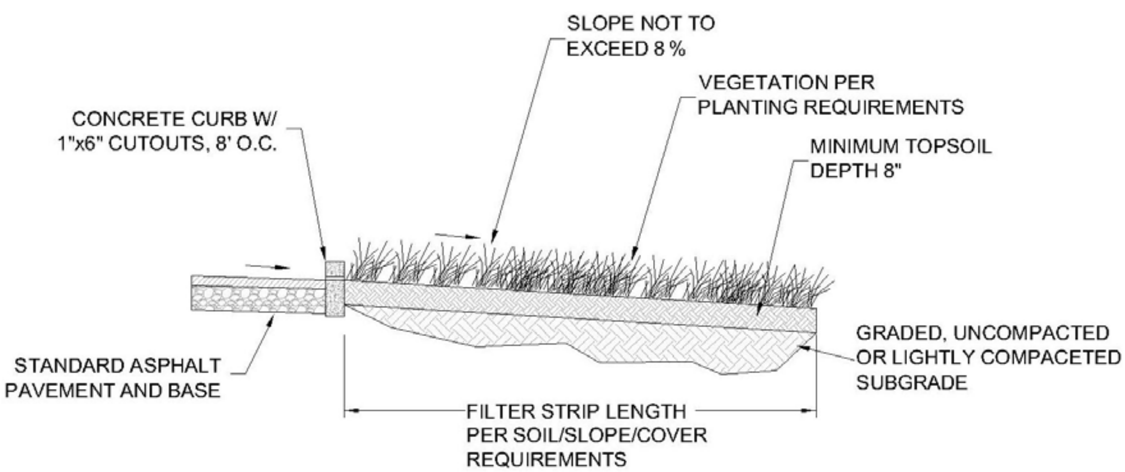


Figure 6.9-5. Filter Strip with Curb Cutout

c. Concrete sill (or lip)

d. Slotted or depressed curbs

e. An earthen berm with optional perforated pipe.

3. Where possible, more “natural” spreader designs and materials, such as earthen berms, are generally recommended, though they can be more susceptible to failure due to irregularities in berm elevation and density of vegetation. When it is desired to treat runoff from roofs or curbed impervious areas, a more structural approach, such as a gravel trench, is required. In this case, runoff shall be directly conveyed, via pipe from downspout or inlet, into the subsurface gravel and uniformly distributed by a perforated pipe along the trench bottom.

4. The upstream edge of a filter strip should be level and directly abut the contributing drainage area.

5. The seasonal high water table must be at least 2 to 4 ft lower than the bottom of the filter strip.

6. In areas where the soil infiltration rate has been compromised (e.g. by excessive compaction), the filter strip shall be tilled prior to establishment of vegetation. However, tilling will only have an effect on the top 12-18 inches of the soil layer. Therefore, other measures, such as planting trees and shrubs, may be needed to provide deeper aeration. Deep root penetration will promote greater absorptive capacity of the soil.

7. The ratio of contributing drainage area to filter strip area shall never exceed 6:1.

8. The filter strip area shall be densely vegetated with a mix of salt- and drought- tolerant and erosion-resistant plant species. Filter strip vegetation, whether planted or indigenous, may range from turf and native grasses to herbaceous and woody vegetation. The optimal vegetation strategy consists of plants with dense growth patterns, a fibrous root system for stability, good regrowth ability (following dormancy and cutting), and adaptability to local soil and climatic conditions. Native vegetation is always preferred. (See Appendix B for vegetation recommendations.)

9. Natural areas, such as forests and meadows, should never be unduly disturbed by the creation of a filter strip. If these areas are not already functional as natural filters, they may be enhanced by restorative methods or construction of a level spreader.

10. Maximum lateral slope of filter strip is 1%.

11. To prohibit runoff from laterally bypassing a strip, berms and/or curbs can be installed along the sides of the strip, parallel to the direction of flow.

12. Pedestrian and/or vehicular traffic on filter strips should be strictly discouraged. Since the function of filter strips can be easily overlooked or forgotten over time, a highly visible, physical “barrier” is suggested. This can be accomplished, at the discretion of the owner,

by simple post and chain, signage, or even the level-spreading device itself.

13. Vegetated filter strips may be designed to discharge to a variety of features, including natural buffer areas, vegetated swales, infiltration basins, or other structural BMPs.

14. In cold climates, the following recommendations should be considered:
    a. Filter strips often make convenient areas for snow storage. Thus, filter strip vegetation should be salt-tolerant and the maintenance schedule should involve removal of sand buildup at the toe of the slope.
    b. The bottom of the gravel trench (if used as the level spreader) shall be placed below the frost line to prohibit water from freezing in the trench. The perforated pipe in the trench shall be at least 8 in in diameter to further discourage freezing.
    c. Other water quality options may be explored to provide backup to filter strips during the winter, when their pollutant removal ability is reduced.

Required Length as a Function of Slope, Soil Cover

Table 6.9-1. Maximum filter strip slope based on Soil HSG Classification and Soil Type

Filter Strip Soil Type	Hydrologic Soil Group	Maximum Filter Strip Slope (Percent)	
		Turf Grass, Native Grasses, and Meadows	Planted and Indigenous Woods
Sand	A	7	5
Sandy Loam	B	8	7
Loam, Silt Loam	B	8	8
Sandy Clay Loam	C	8	8
Clay Loam, Silty Clay, Clay	D	8	8

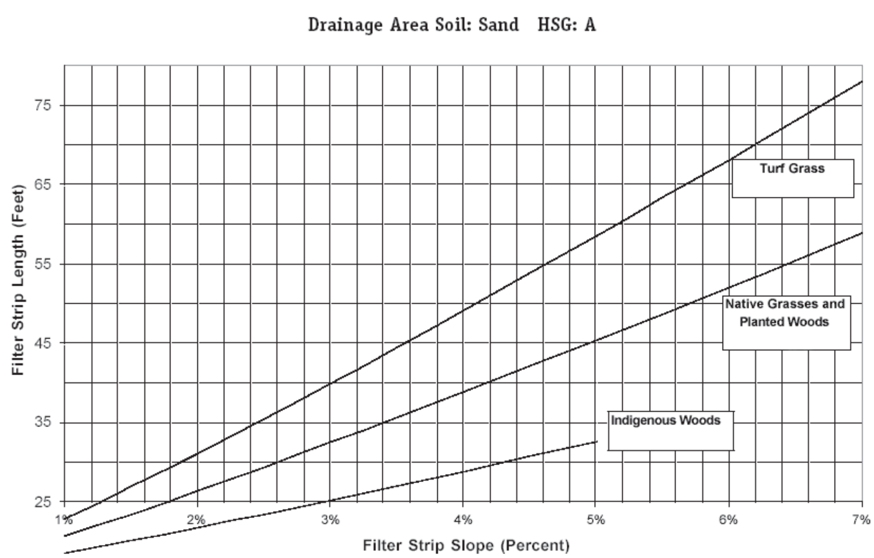


Figure 6.9-6. Vegetated filter strip length based on Soil: Sand and HSG: A, (New Jersey BMP Manual, 2004).

Figure 6.9-7. Vegetated filter strip length based on Soil: Sandy Loam and HSG: B, (New Jersey BMP Manual, 2004).

Figure 6.9-8. Vegetated filter strip length based on Soil: Loam, Silt Loam and HSG: B, (New Jersey BMP Manual, 2004).

Figure 6.9-9. Vegetated filter strip length based on Soil: Sandy clay loam and HSG: C, (New Jersey BMP Manual, 2004).

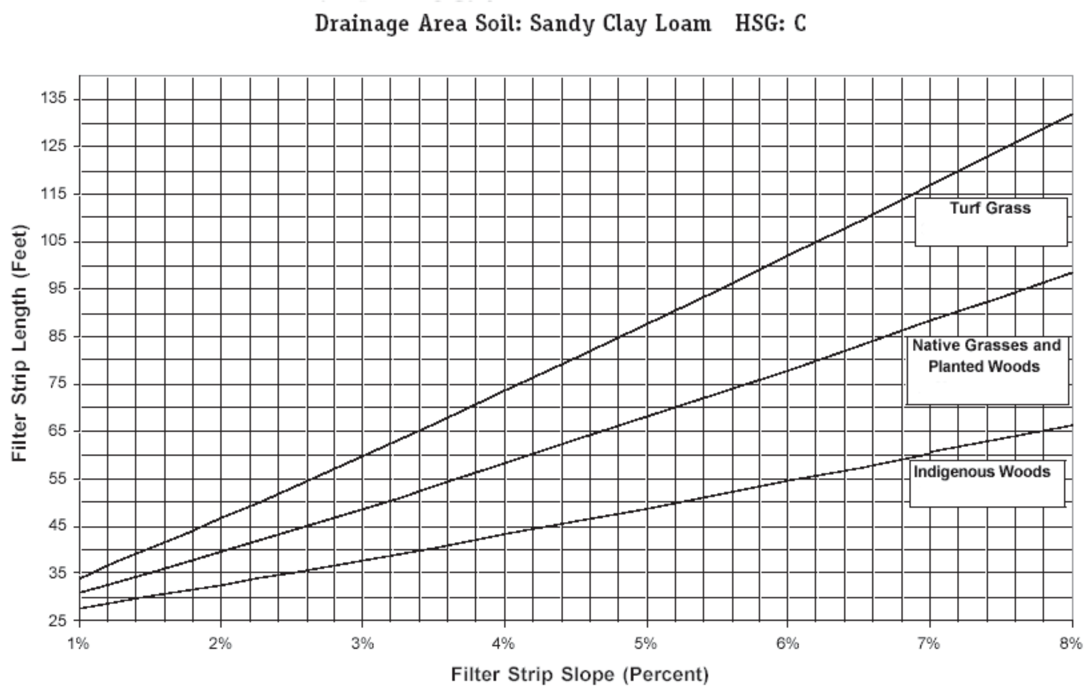
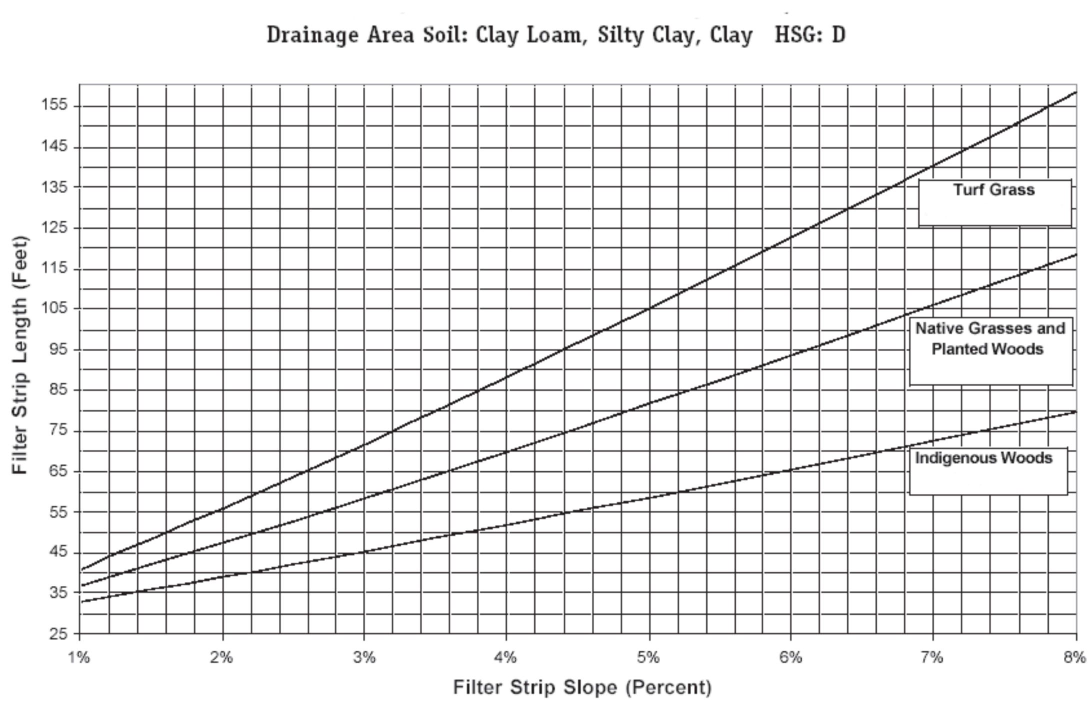


Figure 6.9-10. Vegetated filter strip length based on Soil: Clay Loam and HSG: C, (New Jersey BMP Manual, 2004).



Detailed Stormwater Functions

Volume Reduction Calculations
To determine the volume reduction over the length of a filter strip the following equation is recommended:

Filter Strip Volume Reduction = Filter Strip Area x Infiltration Rate x Storm Duration

When a berm is positioned at the toe of the slope, the total volume reduction shall be defined as the amount calculated above plus the following:

Berm Storage Volume = (Cross-sectional Area Behind Berm x Length of Berm) + (Surface Area Behind Berm x Infiltration Rate x 12 hours)

The inundated area behind the berm shall be designed to drain within 24 hours. An outlet pipe or overflow weir may be needed to provide adequate drain down. In that case, the infiltration volume behind the berm should be adjusted based on the invert of the overflow mechanism.

Peak Rate Mitigation Calculations
See in Section 9 for Peak Rate Mitigation methodology which addresses link between volume reduction and peak rate control.

Water Quality Improvement
See in Section 9 for Water Quality Improvement methodology which addresses pollutant removal effectiveness of this BMP.

Construction Sequence

1. Begin filter strip construction only when the upgradient site has been sufficiently stabilized and temporary erosion and sediment control measures are in place. (Erosion and sediment control methods shall adhere to the Pennsylvania Department of Environmental Protection's Erosion and Sediment Pollution Control Program Manual, March 2000 or latest edition.) The strip shall be installed at a time of the year when successful establishment without irrigation is most likely. However, temporary irrigation may be needed in periods of little rain or drought.

2. For planted (not indigenous Filter Strips) clear and grub site as needed. Care shall be taken to disturb as little existing vegetation as possible, whether in the designated filter strip area or in adjacent areas, and to avoid soil compaction. Grading a level slope may require removal of existing vegetation.

3. Rough grade the filter strip area, including the berm at the toe of the slope, if proposed. Only the lightest, least disruptive equipment may be used, to avoid excessive compaction and/or land disturbance.

4. Construct level spreader device at the upgradient edge of the strip. For gravel trenches, do not compact subgrade. (Follow construction sequence for Infiltration Trench.)

5. Fine grade the filter strip area. Accurate grading is crucial for filter strips. Even the smallest irregularities may compromise sheet flow conditions.

6. Seed or sod, as desired. Plant more substantial vegetation, such as trees and shrubs, if proposed. If sod is proposed, place tiles tightly enough to avoid gaps and stagger the ends to prevent channelization along the strip. Use a roller on sod to prevent air pockets between the sod and soil from forming.

7. Concurrent with #6, stabilize seeded filter strips with appropriate permanent soil stabilization methods, such as erosion control matting or blankets. Erosion control for seeded filter strips shall be required for at least the first 75 days following the first storm event of the season.

8. Once the filter strip is sufficiently stabilized, remove temporary erosion and sediment controls. It is very important that filter strip vegetation be fully established before receiving upland stormwater flow. One full growing season is the recommended minimum time for establishment.

9. Follow maintenance guidelines, as discussed below.

Note: When and if a filter strip is used for temporary sediment control, it must be regraded and reseeded immediately after construction and stabilization has occurred.

Maintenance Issues

As with other vegetated BMPs, filter strips must be properly maintained to ensure their effectiveness. In particular, it is critical that sheet flow conditions and infiltration are sustained throughout the life of the filter strip. Field observations of strips in more urban settings show that their effectiveness can deteriorate due to lack of maintenance, inadequate design/location, and poor vegetative cover. Compared with other vegetated BMPs, filter strips require only minimal maintenance efforts, many of which may overlap with standard landscaping demands.

Vegetated filter strip components that receive or trap sediment and debris shall be inspected for clogging, density of vegetation, damage by foot or vehicular traffic, excessive accumulations, and channelization. Inspections shall be made on a quarterly basis for the first two years following installation, and then on a biannual basis thereafter. Inspections shall also be made after every storm event greater than 1 in during the establishment period Guidance information, usually in written manual form, for operating and maintaining filter strips shall be provided to all facility owners and tenants. Facility owners are encouraged to keep an inspection log, where they can record all inspection dates, observations, and maintenance activities.

Sediment and debris shall be routinely removed (but never less than biannually), or upon observation, when buildup exceeds 2 in in depth in either the strip itself or the level spreader. If erosion is observed, measures shall be taken to improve the level spreader or other dispersion method to address the source of erosion. Rills and gullies observed along the strip may be filled with topsoil, stabilized with erosion control matting, and either seeded or sodded, as desired. For channels less than 12 in wide, filling with crushed gravel, which allows grass to creep in over time, is acceptable. For wider channels, i.e. greater than 12 in, regrading and reseeding may be necessary. (Small bare areas may only require overseeding.) Regrading may also be required when pools of standing water are observed along the slope. (In no case shall standing water be tolerated for longer than 48-72 hours.) If check dams are proposed, they shall be inspected for cracks, rot, structural damage, obstructions, or any other factors that cause altered flow patterns or channelization. Inlets or sediment sumps that drain to filter strips shall be cleaned periodically or as needed.

Sediment shall be removed when the filter strip is thoroughly dry. Trash and debris removed from the site shall be deposited only at suitable disposal/recycling sites and must comply with applicable local, state, and federal waste regulations. In the case where a filter strip is used for sediment control, it shall be regraded and reseeded immediately after construction has concluded.

Maintaining a vigorous vegetative cover on a filter strip is critical for maximizing pollutant removal efficiency and erosion prevention. Grass cover shall be mowed, with low ground pressure equipment, as needed to maintain a height of 4-6 in. Mowing shall be done only when the soil is dry, in order to prevent tracking damage to vegetation, soil compaction, and flow concentrations. Generally speaking, grasses should be allowed to grow as high as possible, but mowed frequently enough to avoid troublesome insects or noxious weeds. Fall mowing should be controlled to a grass height of 6 in, to provide adequate wildlife winter habitat. When and where cutting is desired for aesthetic reasons, a high blade setting shall be used.

If vegetative cover is not fully established within the designated time, it shall be replaced with an alternative species. (It is standard practice to contractually require the contractor to replace dead vegetation.) Unwanted or invasive growth shall be removed on an annual basis. Biweekly inspections are recommended for at least the first growing season, or until the vegetation is permanently established. Once the vegetation is established, inspections of health, diversity, and density shall be performed at least twice per year, during both the growing and non-growing season. Vegetative cover should be sustained at 85% and reestablished if damage greater than 50% is observed. Whenever possible, deficiencies in vegetation are to be mollified without the use of fertilizers or pesticides. These treatment options, as well as any other methods used to achieve optimum vegetative health, may only be used under special circumstances and if they do not compromise the functionality of the filter strip.

Two other maintenance recommendations involve soil aeration and drain down time. If a filter strip exhibits signs of poor drainage and/or vegetative cover, periodic soil aeration may be required. In addition, depending on soil characteristics, the strip may require periodic liming. The design and maintenance plan of filter strips, especially those with flow obstructions such as berms and check dams, must specify the approximate time it should normally take for the system to “drain down” the maximum design storm runoff volume. Post-rainfall inspections shall include evaluations of the filter’s actual drain down time compared to the specified time. If significant differences (either increase or decrease) are observed, or if the 72 hour maximum time is exceeded, strip characteristics such as soils, vegetation, and groundwater levels must be reevaluated. Measures shall be taken to establish, or reestablish as the case may be, the specified drain down time of the system.

Cost Issues

The real cost of filter strips is the land they require. When unused land is readily available at a site, filter strips may prove a sensible and cost-effective approach. However, where land costs are at a premium (i.e. not readily available), this practice may prove cost-prohibitive in the end. The cost of establishing a filter strip itself is relatively minor. Of course, the cost is even less when an existing grass or meadow area is identified as a possible filter strip area before development begins.

The cost of filter strips includes grading, sodding (when applicable), installation of vegetation (trees, shrubs, etc.), the construction of a level spreader, and the construction of a pervious berm, if proposed. Depending on whether seed or sod is applied, not to mention enhanced vegetation use or design variations (such as check dams), construction costs may range anywhere from $0 (assuming the area was to be grassed regardless of use as treatment) to $50,000 per acre. The annual cost of maintaining filter strips (mowing, weeding, inspection, litter removal, etc.) generally runs from $100 to $1400 per acre and in fact, may overlap with standard landscape maintenance costs. Maintenance costs are highly variable, as they are a function of frequency and local labor rates.

Specifications

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. **Topsoil** – See Appendix C

2. **Vegetation** – See Appendix B

3. **Erosion and Sediment** Control components shall conform to the Pennsylvania Department of Environmental Protection's Erosion and Sediment Pollution Control Program Manual, March 2000 or latest edition.

For a gravel trench level spreader:

6. **Pipe** shall be continuously perforated, smooth interior, high-density polyethylene (HDPE) with a minimum inside diameter of 8-inches. The pipe shall meet AASHTO M252, Type S or AASHTO M294, Type S.

7. **Stone** for infiltration trenches shall be 2-inch to 1-inch uniformly graded coarse aggregate, with a wash loss of no more than 0.5%, AASHTO size number 3 per AASHTO Specifications, Part I, 19th Ed., 1998, or later and shall have voids ≥ 35% as measured by ASTM-C29.

   Pea gravel (clean bank-run gravel) may also be used. Pea gravel shall meet ASTM D 448 and be sized as per No.6 or 1/8” to 3/8”.

8. **Non-Woven Geotextile** shall consist of needled non-woven polypropylene fibers and meet the following properties:
   a. Grab Tensile Strength (ASTM-D4632) ≥ 120 lbs
   b. Mullen Burst Strength (ASTM-D3786) ≥ 225 psi
   c. Flow Rate (ASTM-D4491) ≥ 95 gal/min/ft2

d. UV Resistance after 500 hrs (ASTM-D4355) ≥ 70%
e. Heat-set or heat-calendared fabrics are not permitted

Acceptable types include Mirafi 140N, Amoco 4547, and Geotex 451.

9. **Check dams** constructed of natural wood shall be 6 in to 12 in in diameter and notched as necessary. The following species are acceptable: Black Locust, Red Mulberry, Cedars, Catalpa, White Oak, Chestnut Oak, Black Walnut. The following species are not acceptable, as they can rot over time: Ash, Beech, Birch, Elm, Hackberry, Hemlock, Hickories, Maples, Red and Black Oak, Pines, Poplar, Spruce, Sweetgum, and Willow. An earthen check dam shall be constructed of sand, gravel, and sandy loam to encourage grass cover. (Sand: ASTM C-33 fine aggregate concrete sand 0.02 in to 0.04 in, Gravel: AASHTO M-43 0.5 in to 1.0 in). A stone check dam shall be constructed of R-4 rip rap, or equivalent.

10. **Pervious Berms** The berm shall have a height of 6-12 in and be constructed of sand, gravel, and sandy loam to encourage grass cover. (Sand: ASTM C-33 fine aggregate concrete sand 0.02"-0.04", Gravel: AASHTO M-43 ½" to 1")

References

New Jersey BMP Manual, 2004

Portland BMP Manual

Virginia BMP Manual

Georgia BMP Manual

DURMM nonstructural BMPs (March 2001)

Vermont BMP Manual

California BMP Manual

Washington BMP Manual

Florida BMP Manual

EPA Fact Sheet

Auckland BMP Manual

Maryland BMP Manual

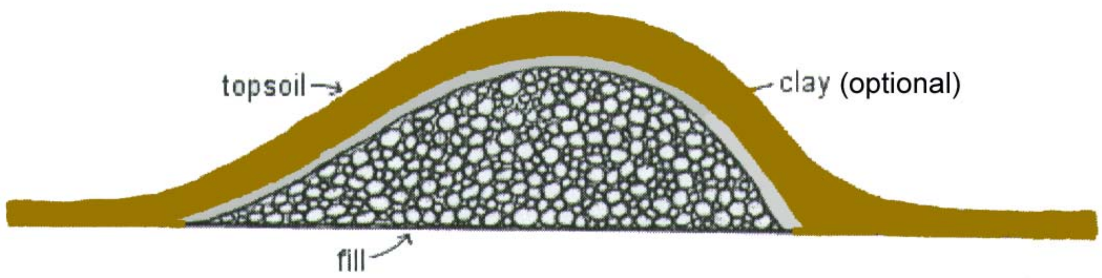
Ontario BMP Manual

Ohio State Univ. – fact sheet

Minnesota Urban Small Sites BMP Manual

CRWR Online Report 97-5: Use of Vegetative Controls For Treatment of Highway Runoff (University of Texas at Austin)

Volume/Peak Rate Reduction by Infiltration BMPs
BMP 6.10: Infiltration Berm & Retentive Grading



ideal substrate layers for a berm

An Infiltration Berm is a mound of compacted earth with sloping sides that is usually located along a contour on relatively gently sloping sites. Berms can also be created through excavation/removal of upslope material, effectively creating a Berm with the original grade. Berms may serve various stormwater drainage functions including: creating a barrier to flow, retaining flow for volume control, and directing flows. Grading may be designed in some cases to prevent rather than promote stormwater flows, through creation of "saucers" or "lips" in site yard areas where temporary retention of stormwater does not interfere with use.

Key Design Elements

- Berms should be relatively low, preferably no more than 24 inches in height.
- If berms are to be mowed the berm side slopes should not exceed a ratio of 4:1 to avoid "scalping" by mower blades.
- Berms must be compacted to prevent soil erosion or berm failure.
- The crest of the berm should be located near one edge of the berm, rather than in the middle, to allow for a more natural, asymmetrical shape.
- Berms must be vegetated with turf grass at a minimum, however more substantial plantings such as meadow vegetation, shrubs and trees are recommended.

Potential Applications

Residential:	YES
Commercial:	YES
Ultra Urban:	LIMITED
Industrial:	YES
Retrofit:	YES
Highway/Road:	YES

Stormwater Functions

Volume Reduction:	Low/Med.
Recharge:	Low/Med.
Peak Rate Control:	Medium
Water Quality:	Med./High

Pollutant Removal

TSS:	60%
TP:	50%
NO_3:	40%

Other Considerations

- **Infiltration Systems Guidelines** and **Soil Investigation Guidelines** should be followed, see Section 6.8.

Description

Infiltration Berms are linear landscape features located along (i.e. parallel to) existing site contours in a moderately sloping area. They can be described as built-up earthen embankments with sloping sides, which function to divert, retain, slow down, or divert stormwater flows. Berms are also utilized for reasons independent of stormwater management, such as to add interest to a flat landscape, create a noise or wind barrier, separate land uses, screen undesirable views or to enhance or emphasize landscape designs. Berms are often used in conjunction with recreational features, such as pathways through woodlands. Therefore, when used for stormwater management, berms and other retentive grading techniques can serve multifunctional purposes and are easily incorporated into the landscape.

Infiltration Berms are shallow depressions created by berms that collect and temporarily store stormwater runoff allowing it to infiltrate into the ground and recharge groundwater. These are usually constructed in series along a gradually sloping area.

1. Infiltration berms can be constructed on disturbed slopes and revegetated as part of the construction process.
2. They can be installed along the contours within an existing woodland area to slow and infiltrate runoff from a development site.
3. May be constructed in combination with a subsurface infiltration trench at the base of the berm.

Infiltration Berms can provide runoff rate and volume control, though the level to which they do is limited by a variety of factors, including design variations (height, length, etc.), soil permeability rates, vegetative cover, and slope. Berms are ideal for mitigating runoff from relatively small impervious areas with limited adjacent open space (e.g. roads, small parking lots). Systems of parallel berms have been used to intercept stormwater from roadways or sloping terrain. Berms can be threaded carefully in contours in wooded hillsides, minimally disturbing existing vegetation and yet still gaining stormwater management credit from the existing woodland used. Conversely, berms are often incapable of controlling runoff from very large, highly impervious sites. Due to their relatively limited volume capacity, the length and/or number of berms required to retain large quantities of runoff make them impractical as the lone BMP in these cases. In these situations, berms are more appropriately used as pre- or additional-treatment for other more distributed infiltration systems closer to the source of runoff (i.e. porous pavement with subsurface infiltration).

Retentive grading may be employed in portions of sites where infiltration has been deemed to be possible and where site uses are compatible. Ideally, such retentive grading will serve to create subtle “saucers,” which contain and infiltrate stormwater flows. The “lip” of such saucers effectively function as a very subtle berm, which can be vertically impervious when vegetated and integrated into the overall landscape.

Variations

Diversion Berms

Diversion Berms can be used to protect slopes from erosion and to slow runoff rate. They can also be used to direct stormwater flow in order to promote longer flow pathways, thus increasing the time of concentration. Diversion berms often:

1. Consist of compacted earth ridges usually constructed across a slope in series to intercept runoff.
2. Can be incorporated within other stormwater BMPs to increase travel time of stormwater flow by creating natural meanders while providing greater opportunity for pollutant removal and infiltration.

Photos of installed infiltration berms in Chester County, PA.
Figure 6.10-1. (Left)Vegetated Berm used as hiking path for residential development.
Figure 6.10-2. (Right), Depression to the left of berm where stormwater is retained and infiltrates into the soil mantle. (CCCD, 2002)

Applications

- **Meadow/Woodland Infiltration Berms**
  Infiltration Berms effectively control both the rate and volume of stormwater runoff. The berms are constructed along the contours and serve to collect and retain stormwater runoff, allowing it to infiltrate through the soil mantle and recharge the groundwater. Depressed areas adjacent to the berms should be level so that concentrated flow paths are not encouraged. Infiltration berms may have a variety of vegetative covers but meadow and woodland are recommended in order to reduce maintenance. If turf grass is used, berms in series should be constructed with enough space between them to allow access for maintenance vehicles. Also, berm side slopes should not exceed a 4:1 ratio. Woodland infiltration berms can be installed within existing wooded areas for additional stormwater management. Berms in wooded areas can even improve the health of existing vegetation, through enhanced groundwater recharge.

Care shall be taken during construction to ensure minimum disturbance to existing vegetation, especially tree roots.

- **Slope Protection**
  Diversion Berms can be used to protect steeply sloping areas from erosion. Berms may divert concentrated discharge from a developed area away from the sloped area. Additionally, berms may be installed in series down the slope to retain flow and spread it out along multiple level berms to discourage concentrated flow.

- **Flow Pathway Creation**
  Berms may be utilized to create or enhance stormwater flow pathways within existing or proposed BMPs, or as part of an LID strategy. Berms can be installed such that vegetated stormwater flow pathways are allowed to "meander" so that stormwater travel time is increased. For example, berms can be utilized within existing BMPs as part of a retrofit strategy to eliminate short-circuited inlet/outlet situations within detention basins. Flow pathway creation can be utilized as part of an LID strategy to disconnect roof leaders and attenuate runoff, while increasing pervious flow pathways within developed areas. Berms should be designed to compliment the landscape while diverting runoff across vegetated areas and allowing for longer travel times to encourage pollutant removal and infiltration.

- **Constructed Wetland Berms**
  Berms are often utilized within constructed wetland systems in order to create elongated flow pathways with a variety of water depths. See BMP 6.13 – Constructed Wetlands.

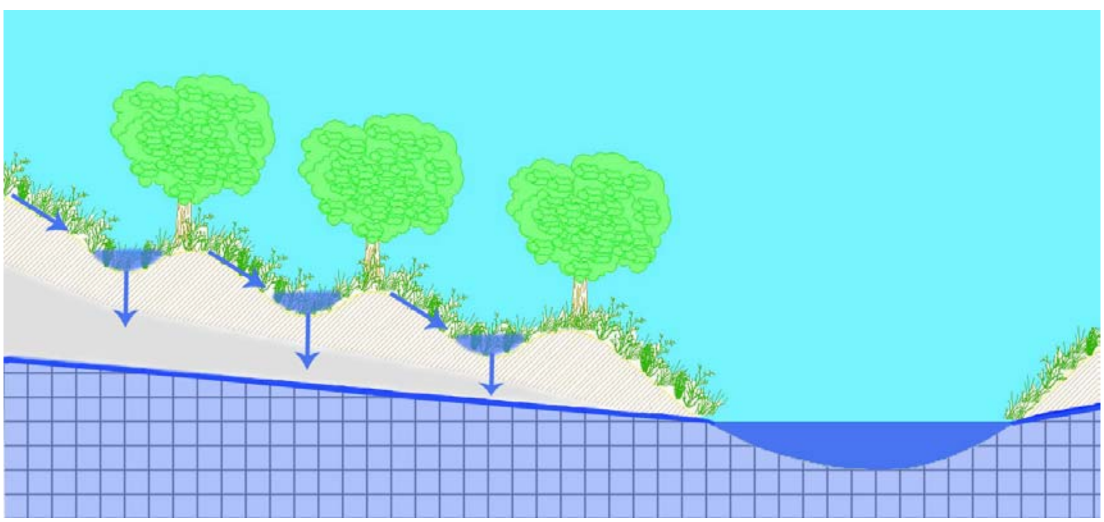


Figure 6.10-3. Woodland Infiltration Berms

Design Considerations

1. Sizing criteria are dependent on berm function, location and storage volume requirements.
   a. Low **berm height** (less than or equal to 24 inches) is recommended to encourage maximum infiltration and to prevent excessive ponding behind the berm. Greater

heights may be used where berms are being used to divert flow or to create "meandering" or lengthened flow pathways. In these cases, stormwater is designed to flow adjacent to (parallel to), rather than over the crest of the berm. Generally, more berms of smaller size are preferable to fewer berms of large size.

b. **Berm length** is dependent on functional need and site size. Berms installed along the contours should be level and located across the slope. Maximum length will depend on width of the slope. Generally speaking, diversion berm length will vary with the size and constraints of the site in question.

2. **Infiltration Berms** should be constructed along (parallel to) contours at a constant level elevation.

3. **Soil**. A berm may consist entirely of high quality topsoil. To reduce cost, only the top foot needs to consist of high quality Topsoil, with well-drained soil making up the remainder of the berm. The use of gravel is not recommended in the layers directly underneath the topsoil because of the tendency of the soil to wash through the gravel. In some cases, the use of clay may be required due to its cohesive qualities (especially where the berm height is high or relatively steeply sloped). However, well-compacted soil usually is sufficient provided that the angle of repose (see below) is adequate for the soil medium used.

   A more sustainable alternative to importing berm soil from off-site is to balance berm cut and fill material as much as possible, provided on-site soil is deemed suitable as per the Specifications below. Ideally, the concave segment (infiltration area) of the berm is excavated to a maximum depth of 12 inches and then used to construct the convex segment (crest of berm).

4. The **Angle of Repose of Soil** is the angle at which the soil will rest and not be subject to slope failure. The angle of repose of any soil will vary with the texture, water content, compaction, and vegetative cover. Typical angles of repose are given below:

   a. Non-compacted clay: 5-20%
   b. Dry Sand: 33%
   c. Loam: 35-40%
   d. Compacted clay: 50-80%

5. **Slope**. The angle of repose for the soil used in the berm should determine the maximum slope of the berm with additional consideration to aesthetic, drainage, and maintenance needs. If a berm is to be mowed, the slope should not exceed a 4:1 ratio (horizontal to vertical) in order to avoid "scalping" by mower blades. If trees are to be planted on berms, the slope should not exceed a 5:1 to 7:1 ratio. Other herbaceous plants, which do not require mowing, can tolerate slopes of 3:1, though this may promote increased runoff rate and erosive conditions. Berm side slopes should never exceed a 2:1 ratio.

6. **Plant Materials.** It is important to consider the function and form of the berm when selecting plant materials. If using trees, plant them in a pattern that appears natural and accentuates the berm's form. Consider tree species from a rolling prairie or upland forest habitat. If turf will be combined with woody and herbaceous plants, the turf should be placed to allow for easy maneuverability while mowing. Low maintenance plantings, such

as trees and meadow plants, rather than turf and formal landscaping, are encouraged.

7. **Infiltration Design.** Infiltration berms located along slopes should be composed of low berms (less than 12 inches high) and should be vegetated. Subsurface soils should be uncompacted to encourage infiltration behind the berms. Soil testing is not required where berms are located within an existing woodland, but soil maps/data should be consulted when siting the berms. Where feasible, surface soil testing should be conducted in order to estimate potential infiltration rates.

8. **Infiltration Trench Option.** Soil testing is required for infiltration berms that will utilize a subsurface infiltration trench. Infiltration trenches are not recommended in existing woodland areas as excavation and installation of subsurface trenches could damage tree root systems. See BMP 6.4 – Infiltration Trench, for information on infiltration trench design.

9. **Aesthetics.** To the extent possible, berms should reflect the surrounding landscape. Berms should be graded so that the top of the berm is smoothly convex and the toes of the berms are smoothly concave. Natural, asymmetrical berms are usually more effective and attractive than symmetrical berms. The crest of the berm should be located near one end of the berm rather than in the middle.

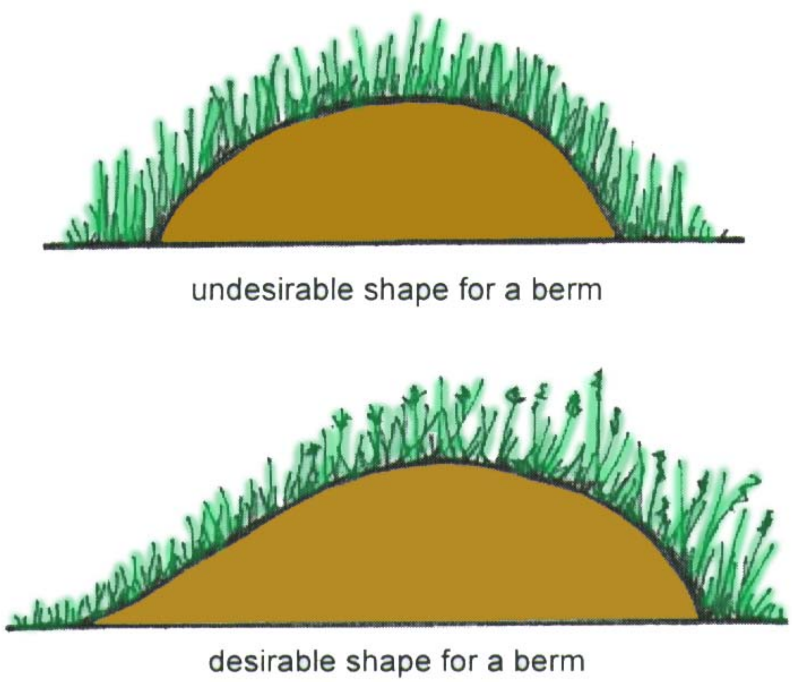


Figure 6.10-4. Asymmetrical Berm

Detailed Stormwater Functions

Infiltration Area

The Infiltration Area is the ponding area behind the berm, defined as:
Length of ponding x Width ponding area = Infiltration Area (Ponding Area)

If an infiltration trench is utilized behind the berm, infiltration area is defined as follows:
Length of trench x Width of trench = Infiltration Area (Area of trench)

Volume Reduction Calculations

Storage volume can be calculated for Infiltration Berms. The storage volume is defined as the ponding area created behind the berm, beneath the discharge invert (i.e. the crest of the berm). Storage volume can be calculated differently depending on the variations utilized in the design.

Surface Storage Volume is defined as the volume of water stored on the surface at the ponding depth. This is equal to:
Cross-sectional area x Berm length = Surface Storage Volume

Subsurface Storage Volume is defined as the volume of water stored within a subsurface storage/ infiltration trench (if this variation is utilized). The subsurface storage volume is calculated in addition to the surface storage volume and is used when additional storage volume is necessary to meet volume/rate requirements.

This is equal to:
Length x Width x Depth below invert x Void Ratio in Stone = Subsurface Storage Volume

The void ratio in stone is 40% for AASHTO No 3. If the conveyance pipe or a perforated distribution pipe is within the Storage Volume area, the volume of the pipe may also be included. All Infiltration beds should be designed to infiltrate or empty within 48 hours.

Peak Rate Mitigation:

See Section 9 for Peak Rate Mitigation methodology which addresses link between volume reduction and peak rate control.

Water Quality Improvement:

See Section 9 for Water Quality Improvement methodology which addresses pollutant removal effectiveness of this BMP.

Construction Sequence

The following is a typical construction sequence for a infiltration berm without a subsurface infiltration trench, though alterations will be necessary depending on design variations.

1. Install temporary sediment and erosion control BMPs as per the Pennsylvania Erosion and Sediment Pollution Control Program Manual.

2. Complete site grading and stabilize within the limit of disturbance except where Infiltration Berms will be constructed; make every effort to minimize berm footprint and necessary zone of disturbance (including both removal of exiting vegetation and disturbance of empty soil) in order to maximize infiltration.

3. Lightly scarify the soil in the area of the proposed berm before delivering soil to site.

4. Bring in fill material to make up the major portion of the berm. Soil should be added in 8-inch lifts and compacted after each addition according to design specifications. The slope and shape of the berm should graded out as soil is added.

5. Protect the surface ponding area at the base of the berm from compaction. If compaction of this area does occur, scarify soil to a depth of at least 8 inches.

6. Complete final grading of the berm after the top layer of soil is added. Tamp soil down lightly and smooth sides of the berm. The crest and base of the berm should be level along the contour.

7. Plant berm with turf, meadow plants, shrubs or trees, as desired.

8. Mulch planted and disturbed areas with compost mulch to prevent erosion while plants become established.

Maintenance Issues

Infiltration Berms have low to moderate maintenance requirements, depending on the design.

Infiltration Berms

- Regularly inspect to ensure they are infiltrating; monitor drawdown time after major storm events
- Inspect any structural components, such as inlet structures to ensure proper functionality
- If planted in turf grass, maintain by mowing. Other vegetation will require less maintenance. Trees and shrubs may require annual mulching, while meadow planting requires annual mowing and clippings removal.
- Avoid running heavy equipment over the infiltration area at the base of the berms. The crest of the berm may be used as access for heavy equipment when necessary to limit disturbance.
- Do not apply pesticides or fertilizers in and around infiltration structures.
- Routinely remove accumulated trash and debris.
- Remove invasive plants as needed
- Inspect for signs of flow channelization; restore level spreading immediately after deficiencies are observed

Diversion Berms

- Regularly inspect for erosion or other failures.

- Regularly inspect structural components to ensure functionality.
- Maintain turf grass and other vegetation by mowing and re-mulching.
- Do not apply pesticides or fertilizers where stormwater will be conveyed.
- Remove invasive plants as needed.
- Routinely remove accumulated trash and debris.

Cost Issues

Generally speaking, construction and maintenance costs are comparable to that of large stormwater basins. Because berms can be incorporated into the landscape and can provide aesthetic value some of their cost can be offset. Woodland infiltration berms can be less expensive than other BMP options because clearing and grubbing of existing woodlands is not necessary for installation of other stormwater management features. Cost will depend on height and width of berms as well as desired vegetation.

Specifications

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. <u>Soil Materials</u>
   a. Satisfactory soil materials are defined as those complying with ASTM D2487 soil classification groups GW, GP, GM, SM, SW, and SP.
   b. Unsatisfactory soil materials are defined as those complying with ASTM D2487 soil classification groups GC, SC, ML, MH, CL, CH, OL, OH, and PT.
   c. Topsoil: Topsoil stripped and stockpiled on the site should be used for fine grading. Topsoil is defined as the top layer of earth on the site, which produces heavy growths of crops, grass or other vegetation.
   d. Soils excavated from on-site may be used for berm construction provided they are deemed satisfactory as per the above recommendations or by a soil scientist.

2. <u>Placing and Compacting of Berm Area Soil</u>
   a. Ground Surface Preparation: Remove vegetation, debris, unsatisfactory soil materials, obstructions, and deleterious materials from ground surface prior to placement of fill. Plow strip, or break up sloped surfaces steeper than I vertical to 4 horizontal so that fill material will bond with existing surface.
   b. When existing ground surface has a density less than that specified under g. (below) for particular area classification, break up ground surface, pulverize, bring the moisture-condition to optimum moisture content, and compact to required depth and percentage of maximum density.
   c. Place backfill and fill materials in layers not more than 8 inches in loose depth for material to be compacted by heavy compaction equipment, and not more than 4 inches in loose depth for material to be compacted by hand-operated tampers.
   d. Before compaction, moisten or aerate each layer as necessary to provide optimum moisture content. Compact each layer to required percentage of maximum dry density or relative dry density for each area classification. Do not place backfill or fill material on surfaces that are muddy, frozen, or contain frost or ice.

e. Place backfill and fill materials evenly adjacent to structures, piping, or conduit to required elevations. Prevent wedging action of backfill against structures or displacement of piping or same elevation in each lift.

f. Control soil and fill compaction, providing minimum percentage of density specified for each area classification indicated below. Correct improperly compacted areas or lifts if soil density tests indicate inadequate compaction.

g. Percentage of Maximum Density Requirements: Compact soil to not less than the following percentages of maximum density, in accordance with ASTM D 1557:
   - Under lawn or unpaved areas, compact top 6 inches of subgrade and each layer of backfill or fill material at 85 percent maximum density.
   - Under infiltration areas no compaction shall be permitted.

3. **<u>Grading</u>**
   a. General: Uniformly grade areas within limits of grading under this section, including adjacent transition areas. Smooth finished surface within specified tolerances; compact with uniform levels or slopes between points where elevations are indicated or between such points and existing grades.
   b. Lawn or Unpaved Areas: Finish areas to receive topsoil to within not more than 0.10 foot above or below required subgrade elevations.
   c. Compaction: After grading, compact subgrade surfaces to the depth and indicated percentage of maximum or relative density for each area classification.

4. **<u>Temporary Seeding</u>**
   a. Temporary seeding and mulching shall be required on all freshly graded areas immediately following earth moving procedures. Seed-free straw or salt hay mulch shall be applied at a rate of 75 lbs. per 1,000 square feet over temporary seeded areas. Straw bale barriers shall be placed in swale areas until vegetation is established.
   b. Should temporary seeding not be possible or not establish itself properly, mulch as described above, pending fine grading or permanent seeding.

5. **<u>Finish Grading</u>**
   a. Spreading of topsoil and finish grading shall be coordinated with the work of the Landscape Contractor.
   b. Verify that the rough grades meet requirements for tolerances, materials, and compaction.
   c. Surface of subgrades shall be loosened and made friable by cross-discing or harrowing to a depth of 2 inches. Stones and debris more than 1-1.5 inches in any dimension shall be raked up and grade stakes and rubbish removed.
   d. Topsoil shall be uniformly spread to minimum depths after settlement of 6 inches on areas to be seeded and 4 inches on areas to be sodded. Correct any surface irregularities to prevent formation of low spots and pockets that would retain water.
   e. Topsoil shall not be placed when the subgrade is frozen, excessively wet, or extremely dry and no topsoil shall be handled when in a frozen or muddy condition. During all operations following topsoil spreading, the surface shall be kept free from stones over 1-1.5 inches in size or any rubbish, debris, or other foreign material.
   f. After placing topsoil rake soil to a smooth, even-draining surface and compact lightly with an empty water roller. Leave finish graded areas clean and well raked, ready for lawn work.

References

AMEC Earth and Environmental Center for Watershed Protection et al. *Georgia Stormwater Management Manual*. 2001.

Harris, C. and Dines, N. *Time Saver Standards for Landscape Architecture, 2nd Edition*. New York, NY: McGraw-Hill, 1998.

University of Minnesota. “Building Soil Berms.” *Sustainable Urban Landscape Information Series (SULIS)*. 1998. <http://www.sustland.umn.edu/implement/soil_berms.html>

Chester County Conservation District. *Chester County Stormwater BMP Tour Guide-Infiltration Trenches (Infiltration Berms).* 2002.

Williams, G.P. *Canadian Building Digest - Drainage and Erosion at Construction Sites*. National Research Council Canada. 2004. <http://irc.nrc-cnrc.gc.ca/cbd/cbd183e.html>

6.5 Volume/Peak Rate Reduction BMPs

Volume/Peak Rate Reduction BMPs

BMP 6.11: Vegetated Roof

An extensive vegetated roof cover is a veneer of vegetation that is grown on and completely covers an otherwise conventional flat or pitched roof, endowing the roof ($\geq 30^{o}$ slope) with hydrologic characteristics that more closely match surface vegetation than the roof. The overall thickness of the veneer may range from 2 to 6 inches and may contain multiple layers, consisting of waterproofing, synthetic insulation, non-soil engineered growth media, fabrics, and synthetic components. Vegetated roof covers can be optimized to achieve water quantity and water quality benefits. Through the appropriate selection of materials, even thin vegetated covers can provide significant rainfall retention and detention functions.

Key Design Elements

- 2-6 inches of non-soil engineered media; assemblies that are 4 inches and deeper may include more than one type of engineered media
- Engineered media should have a high mineral content. Engineered media for extensive vegetated roof covers is typically 85% to 97% non-organic (wet combustion or loss on ignition methods).
- Vegetated roof covers intended to achieve water quality benefits should not be fertilized
- Irrigation is not a desirable component of vegetated covers used as best management practices
- Internal building drainage, including provisions to cover and protect deck drains or scuppers, must anticipate the need to manage large rainfall events without inundating the cover.
- Assemblies planned for roofs with pitches steeper than 2:12 must incorporate supplemental measures to insure stability against sliding.

Potential Applications

Residential:	YES
Commercial:	YES
Ultra Urban:	YES
Industrial:	YES
Retrofit:	YES
Highway/Road:	NO

Stormwater Functions

Volume Reduction:	Med/V. High
Recharge:	Medium
Peak Rate Control:	Med/V. High
Water Quality:	Low to High

Pollutant Removal

TSS:	85%
TP:	85%
NO_3:	30%

Other Considerations

- The roof structure must be evaluated for compatibility with the maximum predicted dead and live loads. Typical dead loads for wet extensive vegetated covers range from 8 to 36 pounds per square foot. Live load is a function of rainfall retention. For example, 2 inches of rain equals 10.4 lbs. per square foot of live load.. It requires 20 inches of snow to have the same live load per square foot.
- The waterproofing must be resistant to biological and root attack. In many instances a supplemental root-fast layer is installed to protect the primary waterproofing membrane from plant roots.
- Standards and guidelines (in English) for the design of green roofs are available from FLL[1], a European non-profit trade organization. In the United States, new standards and guidelines are in development by ASTM (American Standard Testing Methods).

[1] *Guidelines for the Planning, Installation, and Maintenance in Roof Greening, 1995, English Version (Richtlinen für die Planung, Ausführung und Pflege von Dachbegrünungen), Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V.*

Description

Extensive vegetated roof covers are 6 inches, or less, in depth and are typically intended to achieve a specific environmental benefit, such as rainfall runoff mitigation. For this reason they are most commonly un-irrigated. While some installations are open to public access, most extensive vegetated roof covers are for viewing only. In order to make them practical for installation on conventional roof structures, lightweight materials are used in the preparation of most engineered media. Developments in the last 40 years that have made these systems viable include: 1) recognition of the value of vegetated covers in restoring near open-space hydrologic performance on impervious surfaces, 2) advances in waterproofing materials and methods, and 3) development of a reliable temperate climate plant list that can thrive under the extreme growing conditions on a roof.

Vegetated roof covers that are 10 inches, or deeper, are referred to as 'intensive' vegetated roof covers. These are more familiar in the United States and include many urban landscaped plazas. Intensive assemblies can also provide substantial environmental benefits, but are intended primarily to achieve aesthetic and architectural objectives. These types of systems are considered "roof gardens" and are not to be confused with the simple "extensive" design.

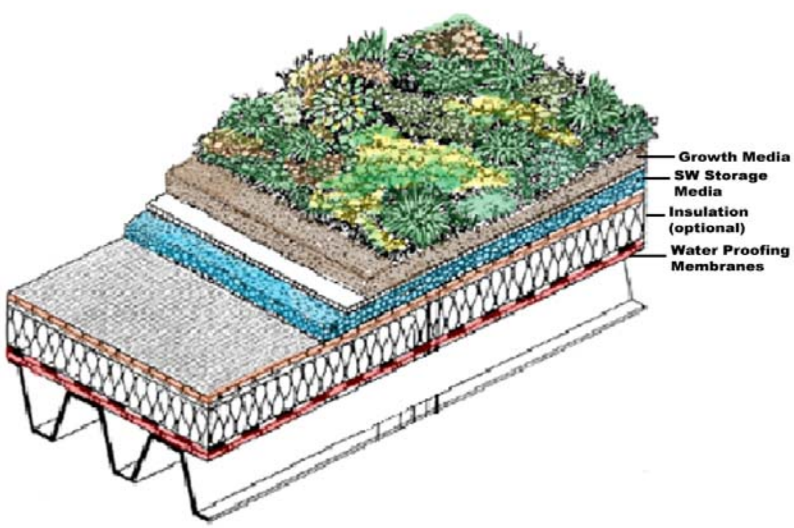


Figure 6.11-1. Cross-section diagram showing layers in vegetated roof system (Roofscapes, Inc.)

Variations

Most extensive vegetated roof covers fall into three categories

- Single media with synthetic under-drain layer
- Dual media
- Dual media with synthetic retention/detention layer

All vegetated roof covers will require a premium waterproofing system. Depending on the waterproofing materials selected, a supplemental root-fast layer may be required to protect the primary waterproofing membrane from plant roots.

Insulation, if included in the roof covering system, may be installed either above or below the primary waterproofing membrane. Most vegetated roof cover system can be adapted to either roofing configuration. In the descriptions that follow, the assemblies refer to the conventional configuration, in which the insulation layer is below the primary waterproofing.

All three extensive roof cover variations can be installed without irrigation. Un-irrigated assemblies are strongly recommended. While this may place some limits on the type of plants that can be grown, the benefits are that assembly will perform better as a stormwater BMP, and the maintenance requirements will be substantially reduced.

Some assemblies are installed in tray-like modules to facilitate installation, especially in confined locations.

Single media assemblies
Single media assemblies are commonly used for pitched roof applications and for thin and lightweight installations. These systems typically incorporate very drought tolerant plants and utilize coarse engineered media with high permeability. A typical profile would include the following layers.

- Waterproofing membrane
- **Root-barrier** (optional, depending on the root-fastness of the waterproofing)
- Semi-rigid plastic **geocomposite drain** or **mat** (typical mats are made from non-biodegradable fabric or plastic foam)
- Separation geotextile
- Engineered **growth media**
- Foliage layer

Pitched roof applications may require the addition of slope bars, rigid slope stabilization panels, cribbing, reinforcing mesh, or similar method of preventing sliding instability.

Flat roof applications with mats as foundations typically require a network of perforated internal drainage conduit to enhance drainage of percolated rainfall to the deck drains or scuppers.

Assemblies with mats can be irrigated from beneath, while assemblies with drainage composites require direct drainage.

Dual media assemblies
Dual media assemblies utilize two types of non-soil media. In this case a finer-grained media with some organic content is placed over a basal layer of coarse lightweight mineral aggregate. They do not include a geocomposite drain. The objective is to improve drought resistance by replicating a natural growing environment in which sandy topsoil overlies gravelly subsoil. These assemblies are typically 4 to 6 inches thick and include the following layers:

- Waterproofing membrane
- Protection layer
- Coarse-grained **drainage media**
- Root-permeable nonwoven separation geotextile
- Fine-grained engineered growth media layer
- Foliage layer

These assemblies are suitable for roofs with pitches less than, or equal to, 1.5:12. Large vegetated covers will generally incorporate a network of perforated internal drainage conduit.

Dual media systems are ideal for in combination with base irrigation methods.

Dual media with synthetic retention/detention layer
These assemblies introduce plastic panels with cup-like receptacles on their upper surface (i.e., a modified geocomposite drain sheet). The panels are in-filled with coarse lightweight mineral aggregate. The cups trap and retain water. They also introduce an air layer at the bottom of the assembly. A typical profile would include:

- Waterproofing membrane
- Felt fabric
- Retention/detention panel
- Coarse-grained drainage media
- Separation geotextile
- Fine grained ‘growth’ media layer
  - **Foliage layer**

Figure 6.11-2. Stabilization of media during initial planting

These assemblies are suitable on roof with pitches less than or equal to 1:12. Due to their complexity, these system are usually 5 inches or deeper.

If required, irrigation can be provided via surface spray or mid-level drip.

- Stormwater Volume and Rate Control

  Vegetated roof covers are an “at source” measure for reducing the rate and volume of runoff released during rainfall events. The water retention and detention properties of vegetated roof covers can be enhanced through selection of the engineered media and plants.

- Runoff Water Quality Improvements

  Direct runoff from roofs is a contributor to NPS pollutant releases. Vegetated roof covers can significantly reduce this source of pollution. Assemblies intended to produce water quality benefits will employ engineered media with 100% mineral content. Furthermore, following the plant establishment period (usually about 18 months), on-going fertilization of the cover should not be permitted. Experience indicates that it will take five or more years for a water quality vegetated cover to attain its potential pollutant removal efficiency.

- **In Combination with Infiltration Measures**

  Vegetated roof covers are frequently combined with ground infiltration measures. Vegetated roof covers improve the efficiency of infiltration devices by:

  - Reducing the peak runoff rate
  - Prolonging the runoff
  - Filtering runoff to produce a clear effluent

  Roofs that are designed to achieve water quality improvements will also reduce pollutant inputs to infiltration devices.

- Habitat Restoration/Creation

  Vegetated roof covers have been used to create functional meadows and wetlands to mitigate the development of open space. This can be accomplished with assemblies as thin as 6 inches.

Design Considerations

1. Live and **dead load** bearing capacity of the roof must be established. Dead loads should be estimated using media weights determined using a standardized laboratory procedure.[1]

2. **Waterproofing** materials must be durable under the conditions associated with vegetated covers. A supplemental root-barrier layer should be installed in conjunction with materials that are not root-fast.

3. Roof flashings should extend 6 inches higher than the top of the growth media surface and be protected by counter-flashings.

4. The design should incorporate measures to protect the waterproofing membrane from physical damage during and after installation of the vegetated cover assembly.

5. Vegetated roof covers should incorporate internal drainage capacity sufficient to accommodate a two-year return frequency rainfall without generating surface runoff flow.

6. Deck drains, scuppers, or gravel stops serving as methods to discharge water from the roof area should be protected with an **access chambers**. These enclosures should include removable lids in order to allow ready access for inspection.

7. The physical properties of the engineered media should be selected appropriately in order to achieve the desired hydrologic performance.

8. Engineered media should contain no clay size particles and should contain no more than 15% **organic matter** (wet combustion or loss on ignition methods)

9. Media used in constructing vegetated roof covers should have a maximum moisture capacity[2] of between 30% and 40%.

Figure 6.11-3. Ponding of water on a standard rooftop

Figure 6.11-4. A vegetated roof

10. Plants should be selected which will create a vigorous, drought-tolerant ground cover. In Pennsylvania the most successful and commonly used ground covers for un-irrigated projects are varieties of Sedum and Delosperma. In the Pennsylvania climate Delosperma is deciduous. Both deciduous and evergreen varieties of *Sedum* are available. Deeper assemblies (i.e., 4 to 6 inches) can also incorporate a wider range of plants including *Dianthus, Phlox, Antennaria,* and *Carex.*

11. Roofs with pitches exceeding 2:12 will require supplemental measures to insure stability against sliding

Detailed Stormwater Functions

The performance of vegetated roof covers as stormwater best management practices cannot be represented by a simple algebraic expression. Conventional methods are used to estimate surface runoff from various types of surfaces. In the analysis of vegetated roof covers, the water that is discharged from the roof is not surface runoff, but rather underflow, i.e., or percolated water. The rate and quantity of water released during a particular design storm can be predicted based on knowledge of key physical properties, including:

- Maximum media water retention
- Field capacity
- Plant cover type
- Saturated hydraulic conductivity
- Non-capillary porosity

The maximum media water retention is the maximum quantity of water that can be held against gravity under drained conditions. Standards that have been developed specifically for measuring this quantity in roof media are available from FLL and ASTM (draft).

Conventional runoff coefficients, such as the NRCS **runoff curve number**, CN or the **rational method runoff coefficient**, C, can be back-calculated from computer simulation of vegetated roof cover assemblies. However, these coefficients will only apply for the specific design storm for which they have been determined.

Peak Rate Mitigation

Vegetated roof covers can exert a large influence on runoff peak rates derived from roofs. An evaluation of peak runoff rates requires either computer simulation or measurements made using prototype assemblies.

A general rule for vegetated roof covers is that rate of runoff from the covered roof surface will be less than or equal to that of open space (i.e., NRCS curve number of 65) for storm events with total rainfall volumes equal to 3 times the maximum media water retention of the assembly. For example, a representative vegetated roof cover with a maximum moisture retention of 1 inch will react like open space for storms up to and including the 3-inch magnitude storm.

Using the German RWS program, the designer could generate a table of C or CN values for specific design storms. The table would relate maximum moisture capacity to the C and/or CN coefficients. For the table to be used, a vegetated cover would have to comply with European guidelines.

Volume Reduction Calculations

All vegetated roof covers have both a retention and a detention volume component. Benchmarks for these volumes can be developed from the physical properties described above (*Detailed Stormwater Functions*).

The interaction of retention and detention produce both short-term effects (i.e., control of single storms) and long-term effects (i.e., reductions in total seasonal or annual roof runoff). Continuous simulation using a representative annual rainfall record from a local weather station is required in order to predict the long-term runoff versus rainfall benefit. The effectiveness of vegetated roof covers will vary according to the regional pattern of rainfall.

Using the German RWS program, the designer could generate a table of volume reductions for several regions in Pennsylvania. The table would relate the runoff ratio (runoff/rainfall) based on one or two types of cover assemblies and selected regions in PA for which good weather data is available. For the table to be used, a vegetated cover would have to comply with European guidelines.

Water Quality Improvement

Once the plant cover is established, nutrient additions should be suspended. Experience indicates that the efficiency of vegetated covers in reducing pollutant and nutrient releases from roofs will increase with time. The vegetated cover should reach its optimum performance after about five years.

See in Section 9 for Water Quality Improvement methodology that addresses pollutants removal effectiveness of this BMP.

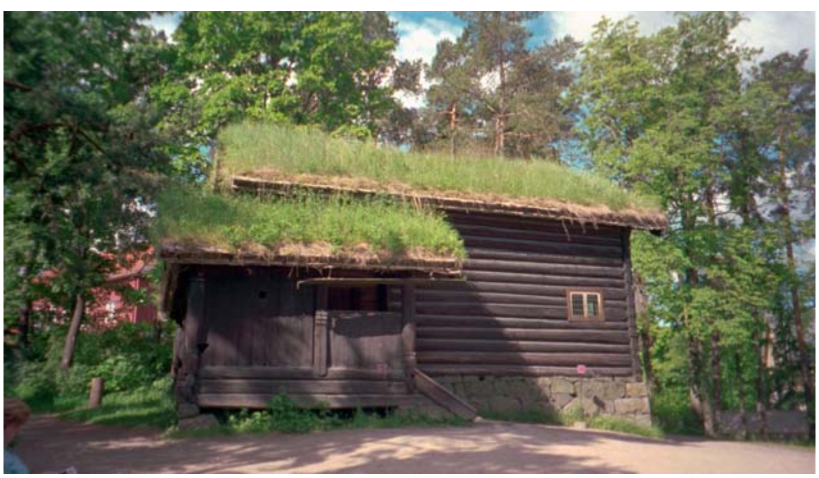


Figure 6.11-5. 350-year old vegetated roof system in Stockhom, Sweden

Construction Sequence

1. Visually inspect the completed waterproofing to identify any apparent flaws, irregularities, or conditions that will be interfere with the security or functionality of the vegetated covers system. The waterproofing should be tested for watertightness by the roofing applicator.

2. Institute a protection program

3. Introduce measures to protect the finished waterproofing from physical damage

4. Install slope stabilization measures (pitched roofs with pitches in excess of 2:12) *

5. If the waterproofing materials are not root fast, install a root-barrier layer

6. Layout key drainage and irrigation components, including drain access chambers, internal drainage conduit, confinement border units, and isolation frames (for root-top utilities, hatches and penetrations)

7. Install walkways and paths (projects with public access)

8. Test irrigation systems (as relevant for roof gardens)

9. Install the drainage layer. Depending on the variation type, this could be a geocomposite drain, mat, or course of drainage media.

10. Cover the drainage layer with the separation fabric (in some assemblies, the separation fabric is pre-bonded to a synthetic drainage layer.

11. Install the upper growth media layer (dual media assemblies only)

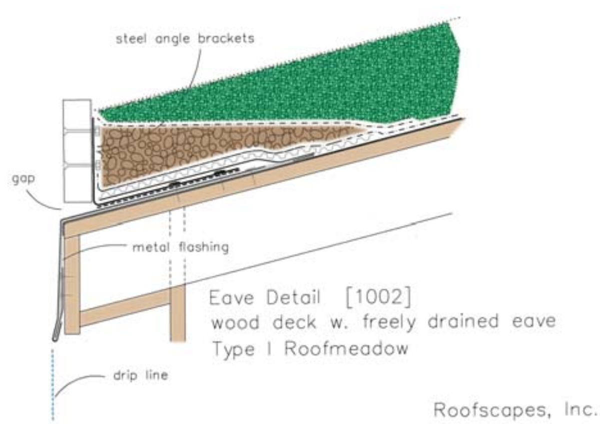


Figure 6.11-6. Cross section showing edge detail courtesy of Roofscapes, Inc.

12. Establish the foliage cover plantings from cuttings, seed, plugs or pre-grown mats

13. Provide protection from wind disruptions as warranted by the project conditions, and plant establishment method.

* In some installations slope stabilizing measures can be introduced as part of the roof structure and will be already be in-place at the start of the construction sequence.

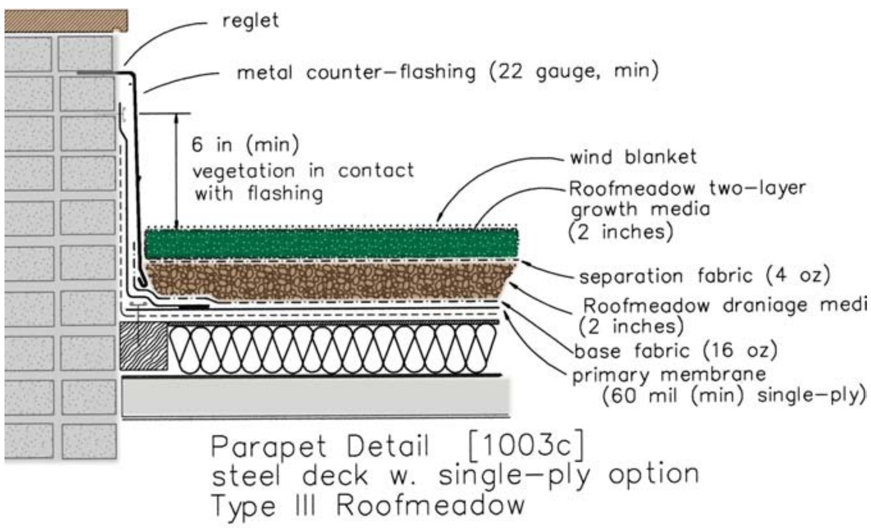


Figure 6.11-7. Parapet detail courtesy of Roofscapes, Inc.

Maintenance Issues

- During the plant establishment period, periodic irrigation may be required

- During the plant establishment period, three to four visits to conduct basic weeding, fertilization, and in-fill planting is recommended. Thereafter, only two annual visits for inspection and light weeding should be required (irrigated assemblies will require more intensive maintenance).

Cost Issues

The construction cost of vegetated roof covers can vary greatly, depending on factors such as:

- Height of the building
- Accessibility to the structure by large equipment such as cranes and trailers
- Depth and complexity of the assembly
- Remoteness of the project from sources of material supply
- Size of the project

However, under present market conditions (2004), extensive vegetated covers for roof will typically range between $8 and $15 per square foot, including design, installation, and warranty service. Basic maintenance for extensive vegetated covers typically requires about 3 man-hours per 1,000 square feet, annually.

Specifications

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

Due to the very large variation in assembly types and methods, it is not possible to provide a comprehensive specification. Performance specifications, describing the assembly elements and their physical properties can be obtained from commercial providers of vegetated roof covers. The references provided also offer specific guidance for the selection of materials and methods.

Some key components and associated performance-related properties are as follows:

1. **Root-barriers** should be thermoplastic membranes with a thickness of at least 30 mils. Thermoplastic sheets can be bonded using hot-air fusion methods, rendering the seams safe from root penetration. Membranes that have been certified for use as root-barriers are recommended. At present only FLL offers a recognized test for root-barriers. Several FLL-certified materials are available in the United States. Interested American manufactures can submit products for testing to FLL-certified labs.

2. **Granular drainage media** should be a non-carbonate mineral aggregate conforming to the following specifications:

Saturated Hydraulic Conductivity[2]	≥ 25 in/min
Total Organic Matter, by Wet Combustion (MSA)	≤ 1%
Abrasion Resistance (ASTM-C131-96)	≤ 25% loss
Soundness (ASTM-C88 or T103 or T103-91)	≤ 5% loss
Porosity (ASTM-C29)	≥ 25%
Alkalinity, CaCO3 equivalents (MSA)	≤ 1 %
Grain-Size Distribution (ASTM-C136)	
Pct. Passing US#18 sieve	≤ 1%
Pct. Passing ¼-inch sieve	≤ 30%
Pct. Passing 3/8-inch sieve	≥ 80%

3. **Growth media** should be a soil-like mixture containing not more than 15% organic content (wet combustion or loss on ignition methods). The appropriate grain-size distribution is essential for achieving the proper moisture content, permeability, nutrient management, and non-capillary porosity, and ‘soil’ structure. The grain-size guidelines vary for single and dual media vegetated cover assemblies.

Non-capillary Pore Space at Field Capacity, 0.333 bar (TMECC 03.01, A)	≥ 15% (vol)
Moisture Content at Field Capacity (TMECC 03.01, A)	≥ 12% (vol)
Maximum Media Water Retention (FLL)	≥ 30% (vol)
Alkalinity, Ca CO3 equivalents (MSA)	≤ 2.5%
Total Organic Matter by Wet Combustion (MSA)	≤ 3-15% (dry wt.)
pH (RCSTP)	6.5-8.0
Soluble Salts (DTPA saturated media extraction)"(RCSTP)	≤ 6 mmhos/cm
Cation exchange capacity (MSA)	≥ 10 meq/100g
Saturated Hydraulic Conductivity for Single Media Assemblies (FLL)[3]	≥ 0.05 in/min
Saturated Hydraulic Conductivity for Dual Media Assemblies (FLL)	≥ 0.30 in/min

Grain-size Distribution of the Mineral Fraction (ASTM-D422)

Single Media Assemblies

Clay fraction (2 micron)	0
Pct. Passing US#200 sieve (i.e., silt fraction)	≤ 5%
Pct. Passing US#60 sieve	≤ 10%
Pct. Passing US#18 sieve	5 - 50%
Pct. Passing 1/8-inch sieve	20 - 70%
Pct. Passing 3/8-inch sieve	75 -100%

Dual Media Assemblies

Clay fraction (2 micron)	0
Pct. Passing US#200 sieve (i.e., silt fraction)	5-15%
Pct. Passing US#60 sieve	10-25%
Pct. Passing US#18 sieve	20 - 50%
Pct. Passing 1/8-inch sieve	55 - 95%
Pct. Passing 3/8-inch sieve	90 -100%

Macro- and micro-nutrients shall be incorporated in the formulation in initial proportions suitable for support the specified planting.

4. **Separation fabric** should be readily penetrated by roots, but provide a durable separation between the drainage and growth media layers (Only lightweight nonwoven geotextiles are recommended for this function.

Unit Weight (ASTM-D3776)	≤ 4.25 oz/yd2
Grab tensile (ASTM-D4632)	≤)90 lb
Mullen Burst Strength (ASTM-D4632)	≥ 135 lb/in
Permittivity (ASTM-D4491)	≥ 2 sec-1

References

FLL: Guidelines for the Planning, Installation, and Maintenance in Roof Greening, 1995, English Version (*Richtlinen für die Planung, Ausführung und Pflege von Dachbegrünungen*), Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V.

ASTM: American Standard Testing Methods

Planting Green Roofs and Living Walls, 2004, Dunnett, N, and Kingsbury, N, Timber Press [ISBN 0-88192-640-X]

FOOTNOTES

[1] FLL or ASTM procedures for determining the maximum density and associated moisture content under compressed and hydrated conditions. See ASTM Draft: Standard Test Method for Maximum Media Density for Dead Load Analysis of Green Roof Systems , and ASTM Draft Standard Practice for Determination of Dead Loads and Live Loads f or Green Roof Systems

[2] ASTM Draft: Standard Test Method for Saturated Hydraulic Conductivity of Granular Drainage Media [Falling-Head Method] for Green Roof Systems

Volume/Peak Rate Reduction BMPs
BMP 6.12: Rooftop Runoff - Capture & Reuse

Capture and Reuse encompasses a wide variety of water storage techniques designed to "capture" precipitation, hold it for a period of time, and reuse the water. Heavy rainfall may require slow release over time.

Key Design Elements

- Storage devices designed to capture a portion of the small, frequent storm events
- Storage techniques may include cisterns, underground tanks, above-ground vertical storage tanks, "rain barrels", or other systems.
- Systems must provide for overflow or bypass of large storm events
- Collection and placement of storage elements up gradient of areas of reuse may reduce or eliminate pumping needs
- Water must be used or discharged before next storm event.
- Most effective when designed to meet a specific water need for reuse.

Potential Applications

Residential:	**Yes**
Commercial:	**YES**
Ultra Urban:	**YES**
Industrial:	**YES**
Retrofit:	**YES**
Highway/Road:	**LIMITED**

Stormwater Functions

Volume Reduction:	**Med./High**
Recharge:	**Low**
Peak Rate Control:	**Low***
Water Quality:	**Medium**

** Depending on design scale*

Pollutant Removal

TSS:	**100%**
TP:	**100%**
NO_3:	**100%**

Other Considerations

- Guidelines for Infiltration Systems apply if designed with Infiltration

Description

Cisterns, Rain Barrels, Vertical Storage, and similar devices have been used for centuries to capture storm water from the roofs of buildings, and in many parts of the world these systems serve as a primary water supply source. In the U.S., the reuse of stormwater for potable needs is not advised without water treatment, although many homes in the U.S. were storing water in cisterns for reuse as little as a century ago. In the U.S. these systems can reduce potable water needs for uses such as irrigation and fire protection while also reducing stormwater discharges.

Storage/reuse techniques range from small, residential systems such as Rain Barrels that are maintained by the homeowner to supplement garden needs, to large, "vertical storage" units that can provide fire needs. Storage/reuse techniques are useful in urban areas where there is little physical space to manage storm water.

Variations

Cisterns – large, underground or surface containers designed to hold large volumes of water (500 gallons or more). Cisterns may be comprised of fiberglass, concrete, plastic, brick or other materials.

Figure 6.12-1. Cisterns are available from a variety of manufacturers, in a variety of sizes and materials.

Rain barrels – barrel (or large container) that collect drainage from roof leaders and store water until needed for irrigation.

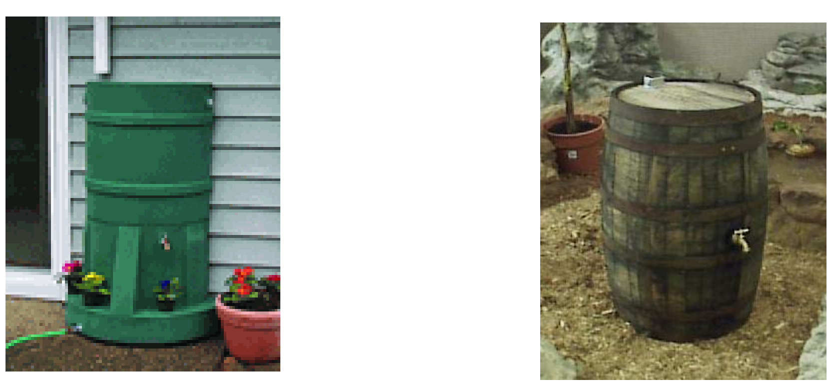


Figure 6.12-2. Rain Barrels are available in a variety of materials and sizes

Vertical Storage – stand along "towers", or "fat downspouts" that usually rest against a building performing the same capture, storage and release functions as cisterns and rain barrels.

Figure 6.12-3. Vertical storage units for vegetated roof plaza maintenance are common in Germany

Storage Beneath Structure – Storage may be incorporated into elements such as paths and walkways to supplement irrigation with the use of structural plastic storage units, such as RainStore or other products.

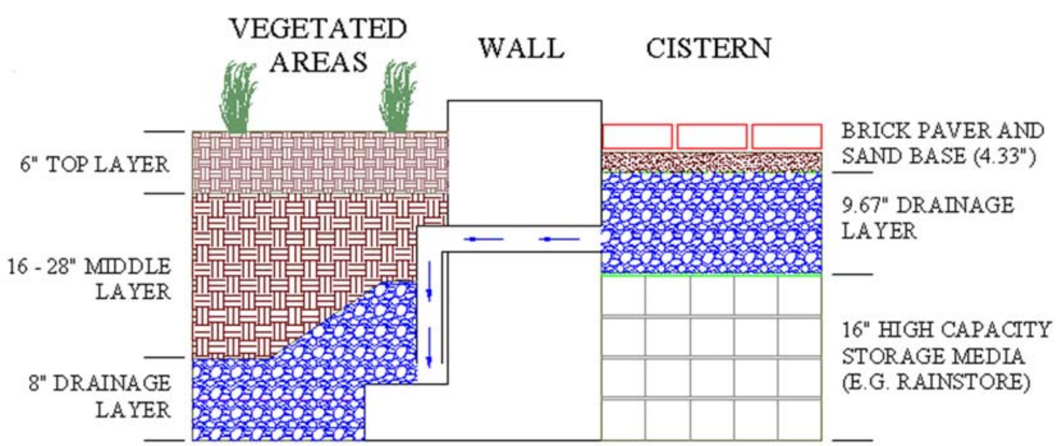


Figure 6.12-4. Cross-section detail showing storage of roof runoff beneath brick walkway using RainStore units.

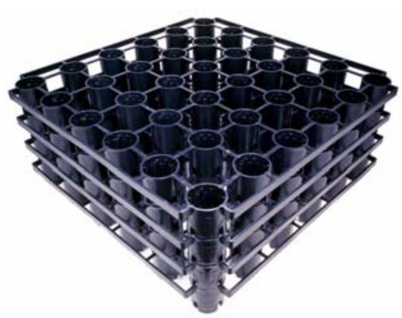


Figure 6.12-5. RainStore

Applications

- Landscaped areas and gardens to meet irrigation needs
- Storage for fire needs
- Urban areas and Combined Sewer areas to reduce peak surcharges.
- Reuse for greywater needs such as flushing toilets.
- Reuse for athletic field irrigation

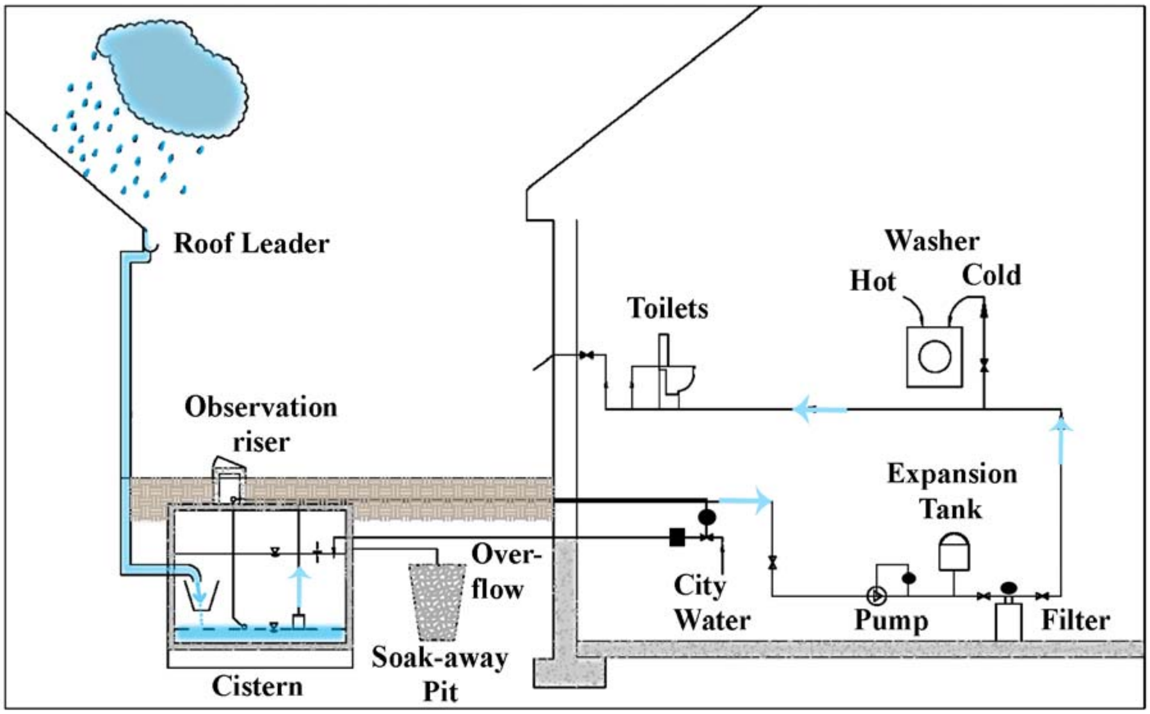


Figure 6.12-6. Cistern harvesting system for reuse to meet greywater needs (modified, from www.advancedbuildings.org/_frames/fr_t_plumbing_cisterns.htm)

Figure 6.12-7. Excavation of former residential water supply cistern in Ann Arbor, Michigan.

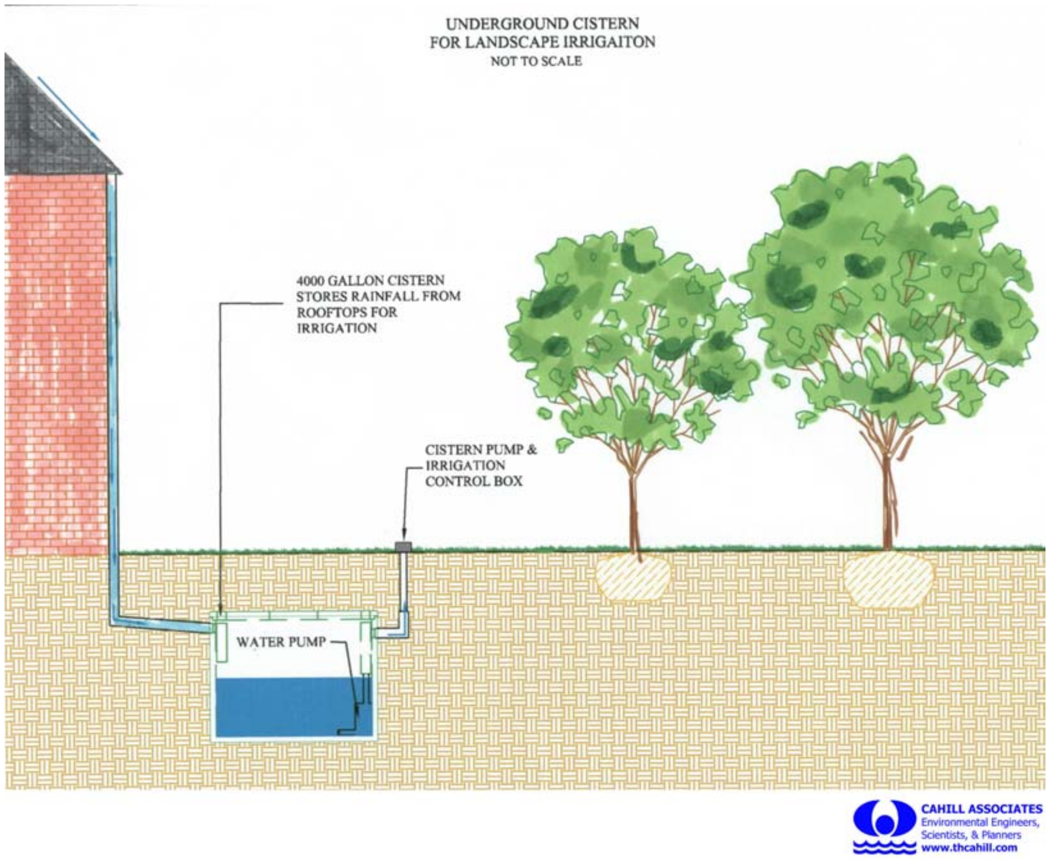


Figure 6.12-8. Schematic cross-section showing roof runoff connected to underground cistern.

Design Considerations

1. The Designer must **calculate the water need** for the intended uses. For example, what will the collected water be used for and when will it be needed? If a 2,000 square foot area of lawn requires irrigation for 4 months in the summer at a rate of 1” per week, how much will be needed and how often will the storage unit be refilled? The usage requirements and the expected rainfall volume and frequency must be determined.

2. **Drawdown** – the Designer must provide for use or release of the stored water between storm events in order for the necessary stormwater storage volume to be available.

3. The **Catchment Area** on which the rain falls must be considered. The catchment area typically handles roof runoff.

4. The **Conveyance System** must keep reused stormwater or greywater from other potable water piping systems. Do not connect to domestic or commercial potable water system.

5. Pipes or storage units should be clearly marked “Caution: Reclaimed water, Do Not Drink”.

6. Screens may be used to filter debris from storage units.

7. The **first flush** runoff may be diverted away from storage in order to minimize sediment

and pollutant entry. However, rooftop runoff contains very low concentrations of NPS pollutants.

8. Storage elements should be protected from direct sunlight by positioning and landscaping. (Limit light into devices to minimize algae growth.)

9. The proximity to building foundations should be considered for overflow conditions.

10. Climate is an important consideration, and capture/reuse systems should be disconnected during winter to prevent freezing.

11. Cisterns should be watertight (joints sealed with nontoxic waterproof material) with a smooth interior surface, and capable of receiving water from rainwater harvesting system.

12. Covers (lids) should have a tight fit to keep out surface water, animals, dust and light.

13. Positive outlet for overflow should be provided a few inches from the top of the cistern.

14. Observation risers should be at least 6" above grade for buried cisterns.

15. Reuse may require pressurization. Water stored has a pressure of 0.43 psi per foot of water elevation. A ten-foot tank would have a head of 0.43*10 = 4.3 psi. Most irrigation systems require at least 15 psi. To add pressure, a pump, pressure tank and fine mesh filter can be used, which adds to the cost of the system, but creates a more usable system.

Table 6.12-1. Annual Rainfall Yield (Gallons) for Impervious Surfaces (Square feet)

Annual Rainfall Yield in Gallons for Various Impervious Surface Sizes and Rainfall Amounts

Impervious Surface Area sf	Rainfall (inches)								
	20	24	28	32	36	40	44	48	52
1000	11844	14213	16582	18951	21319	23688	26057	28426	30795
1100	13029	15634	18240	20846	23451	26057	28663	31268	33874
1200	14213	17056	19898	22741	25583	28426	31268	34111	36954
1300	15397	18477	21556	24636	27715	30795	33874	36954	40033
1400	16582	19898	23214	26531	29847	33164	36480	39796	43113
1500	17766	21319	24873	28426	31979	35532	39086	42639	46192
1600	18951	22741	26531	30321	34111	37901	41691	45481	49272
1700	20135	24162	28189	32216	36243	40270	44297	48324	52351
1800	21319	25583	29847	34111	38375	42639	46903	51167	55431
1900	22504	27005	31505	36006	40507	45008	49508	54009	58510
2000	23688	28426	33164	37901	42639	47377	52114	56852	61589
2100	24873	29847	34822	39796	44771	49745	54720	59694	64669
2200	26057	31268	36480	41691	46903	52114	57326	62537	67748
2300	27241	32690	38138	43586	49035	54483	59931	65380	70828
2400	28426	34111	39796	45481	51167	56852	62537	68222	73907
2500	29610	35532	41454	47377	53299	59221	65143	71065	76987
2600	30795	36954	43113	49272	55431	61589	67748	73907	80066
2700	31979	38375	44771	51167	57562	63958	70354	76750	83146
2800	33164	39796	46429	53062	59694	66327	72960	79593	86225

* Values represent 95% of actual precipitation to account for any storage and/or losses.

Table 6.12-2. Capacities (cubic feet) of Cisterns, by depth and diameter

Capacities of Various sized Cisterns (cf)							
	Diameter of Round Types (ft)						
Depth (ft)	**6**	**8**	**10**	**12**	**14**	**16**	**18**
6	1266	2256	3522	5076	6906	9018	11412
8	1688	3008	4696	6768	9208	12024	15216
10	2110	3760	5870	8460	11510	15030	19020
12	2532	4512	7044	8532	13812	18036	22824
14	2954	5264	8218	11844	16114	21042	26628
* Harvested Rainwater Guidelines, GreenBuilder.com							

Detailed Stormwater Functions

Volume Reduction Calculations

Volume reduction is actual volume of container, taking into consideration how many times it is emptied.

Peak Rate Mitigation Calculations:

Overall, capture and reuse takes a volume of water out of site runoff and puts it back into the ground. This reduction in volume will translate to a lower overall peak rate for the site.

Water Quality Improvement

Pollutant removal takes place through filtration of recycled primary storage, and/or natural filtration through soil and vegetation for overflow discharge. Quantifying pollutant removal will depend on design. Sedimentation will depend on area below outlet that is designed for sediment accumulation, time in storage, and maintenance frequency. Filtration through soil will depend on flow draining to an area of soil, the type of soil (infiltration capacity), and design specifics (stone bed, etc.).

Construction Sequence

Install per manufacturer's instructions.

Maintenance Issues

Flush cisterns to remove sediment. Brush the inside surfaces and thoroughly disinfect.

Winter concern: Do not allow water to freeze in devices. (Empty out before water freezes.)

Cost Issues

Rain Barrel: ranges from $80 to $200, average for residential use is $150

Cistern: varies, depending on material used (reinforced concrete, steel, plastic are common), size, and pump characteristics

Vertical Storage: ranges from $88 for 64-gallon capacity to $10,516 for 12,000-gallon capacity (for a plastic, manufactured product). Storage costs $1.25/gallon.

General: the reuse of water for irrigation or other uses saves money on water costs over time.

Specifications:

The following specifications are provided for informational purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. **Vertical Storage** All storage containers should meet FDA specifications for stored drinking water if potable water is the intended use. Follow Manufacturer's specifications for vertical storage containers.

References

City of Tucson, Water Harvesting Guidance Manual, March 2003 (edited by Ann Audrey Phillips, prepared for the City of Tucson, Department of Transportation, Stormwater Section)

"What are Rainwater Harvesting and Stormwater Recycling?" Heather Kinkade-Levario, ASLA and Hari Krishna Ph.D., P.E., Ann Phillips, Tim Pope

Sustainable Building Sourcebook, "Harvested Rainwater Guidelines", sections 1.0, 2.0, 3.0 www.greenbuilder.com

"Rainwater Harvesting" www.ci.austin.tx.us/greenbuilder/fs_rainharvest.htm City of Austin, TX

Portland, OR's Code Guide Office of Planning & Development Review "Rainwater Harvesting – ICC – RES/34/#1 & UPC/6/#2, March 2001

U.S. EPA National Pollutant Discharge Elimination System, "Post-Construction Storm Water Management in New Development & Redevelopment, On-Lot Treatment"

City of Vancouver, Engineering Services, Water and Sewers "Rain Barrel Program"

"Cisterns/Rainwater Harvesting Systems, www.advancedbuildings.org Technologies and Practices, Plumbing & Water Heating

CSIRO, Land and Water, "Urban Water Reuse – Frequently Asked Questions" (south Australia)

"Rain Barrels – Truth or Consequences" Karen Sands, AICP and Thomas Chapman, P.E., Milwaukee Metropolitan Sewerage District, Milwaukee, Wisconsin

"Hydrologic Processes at the Residential Scale" Qingfu Xiao, E. Gregory McPherson, James R. Simpson, Hydrologic Sciences Program, UC Davis, Center for Urban Forest Research, USDA Forest Service

"Black Vertical Storage Tanks by Norwesco" www.precisionpump.net/storagetanksystems.htm

6.6 Runoff Quality/Peak Rate BMPs

Runoff Quality/Peak Rate BMPs
BMP 6.13: Constructed Wetland


U.S. Fish and Wildlife Service, 2001

Constructed Wetlands are shallow marsh systems planted with emergent vegetation that are designed to treat stormwater runoff.

Key Design Elements

- Adequate drainage area (usually 5 to 10 acres minimum)
- Maintenance of permanent water surface
- Multiple vegetative growth zones through varying depths
- Robust and diverse vegetation
- Relatively impermeable soils or engineered liner
- Sediment collection and removal
- Adjustable permanent pool and dewatering mechanism

Potential Applications

Residential:	**YES**
Commercial:	**YES**
Ultra Urban:	**LIMITED**
Industrial:	**YES**
Retrofit:	**YES**
Highway/Road:	**YES**

Stormwater Functions

Volume Reduction:	**Low**
Recharge:	**Low**
Peak Rate Control:	**High**
Water Quality:	**High**

Pollutant Removal

TSS:	**85%**
TP:	**85%**
NO_3:	**30%**

Figure 6.13-1 Demonstration Constructed Wetlands in Arizona (http://ag.arizona.edu/AZWATER/arroyo/094wet.html)

Description

Constructed Wetlands are shallow marsh systems planted with emergent vegetation that are designed to treat stormwater runoff. While they are one of the best BMPs for pollutant removal, Constructed Wetlands (CWs) can also mitigate peak rates and even reduce runoff volume to a certain degree. They also can provide considerable aesthetic and wildlife benefits. CWs use a relatively large amount of space and require an adequate source of inflow to maintain the permanent water surface.

Variations

Constructed Wetlands can be designed as either an online or offline facilities. They can also be used effectively in series with other flow/sediment reducing BMPs that reduce the sediment load and equalize incoming flows to the CW. Constructed Wetlands are a good option for retrofitting existing detention basins. CWs are often organized into four groups:

- Shallow Wetlands are large surface area CWs that primarily accomplish water quality improvement through displacement of the permanent pool.
- Extended Detention Shallow Wetlands are similar to Shallow Wetlands but use extended detention as another mechanism for water quality and peak rate control.
- Pocket Wetlands are smaller CWs that serve drainage areas between approximately 5 and 10 acres and are constructed near the water table.
- Pond/Wetland systems are a combination of a wet pond and a constructed wetland.

Although this BMP focuses on surface flow Constructed Wetlands as described above, subsurface flow CWs can also be used to treat stormwater runoff. While typically used for wastewater treatment, subsurface flow CWs for stormwater may offer some advantages over surface flow wetlands, such as improved reduction of total suspended solids and oxygen demand. They also can reduce the risk of vectors (especially mosquitoes) and safety risks associated with open water. However, nitrogen removal may be deficient (Campbell and Ogden, 1999). Perhaps the biggest disadvantage is the relatively low treatment capacities of subsurface flow CWs – they are generally only able to treat small flows. For more information, please consult the “References and Additional Resources” list.

Applications

- **Alternating bands of deeper water and shallow marsh.**

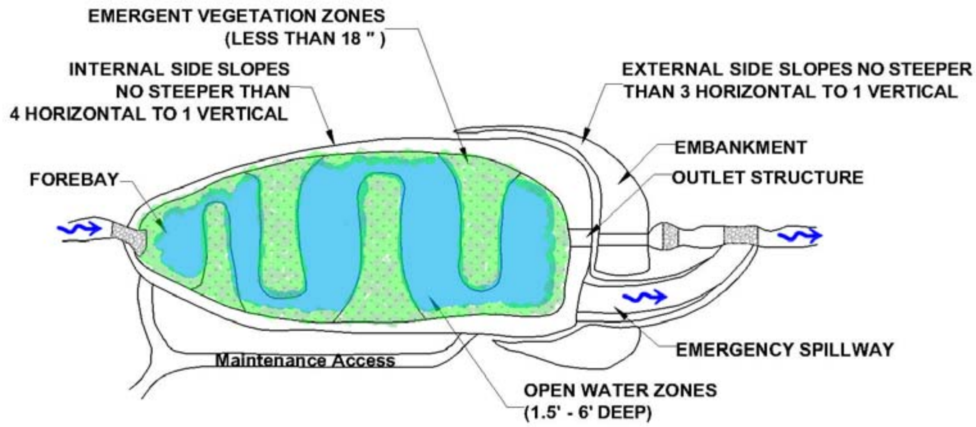


Figure 6.13-2 "Banded Bathymetric" Constructed Wetland (Auckland pp 6-10).

- **Wet Pond/Wetland System**

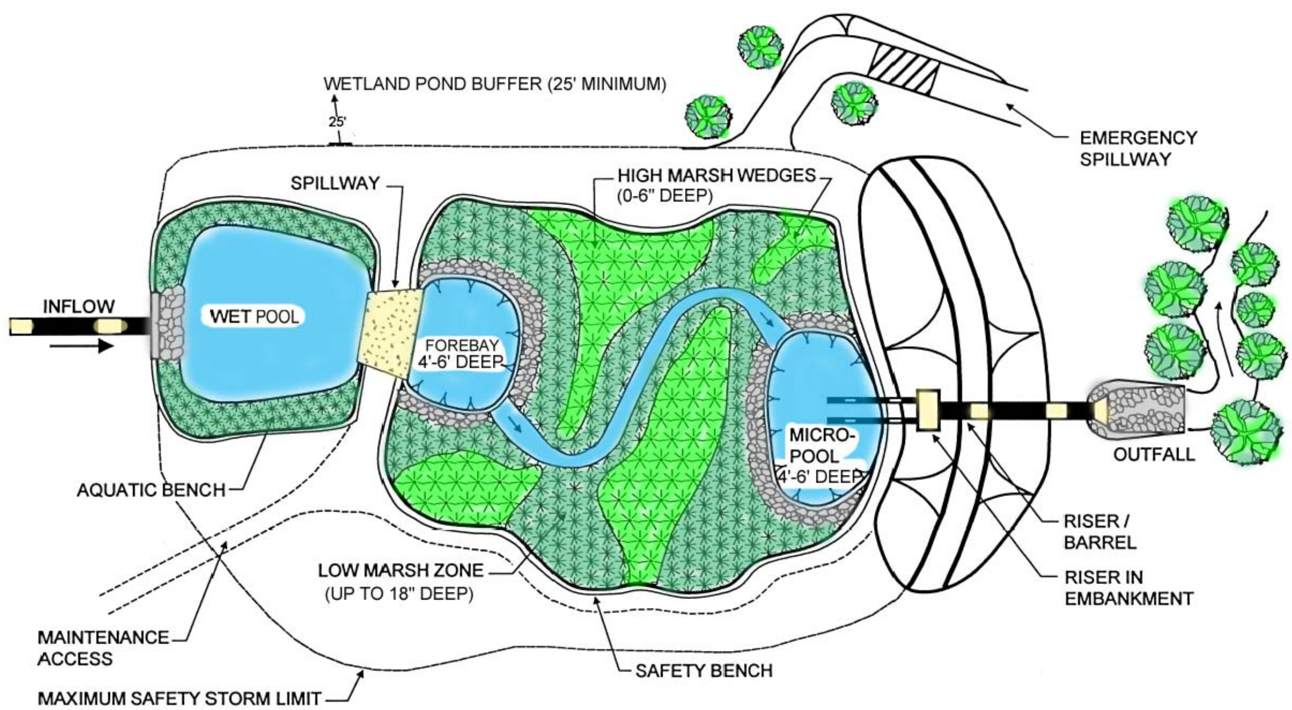
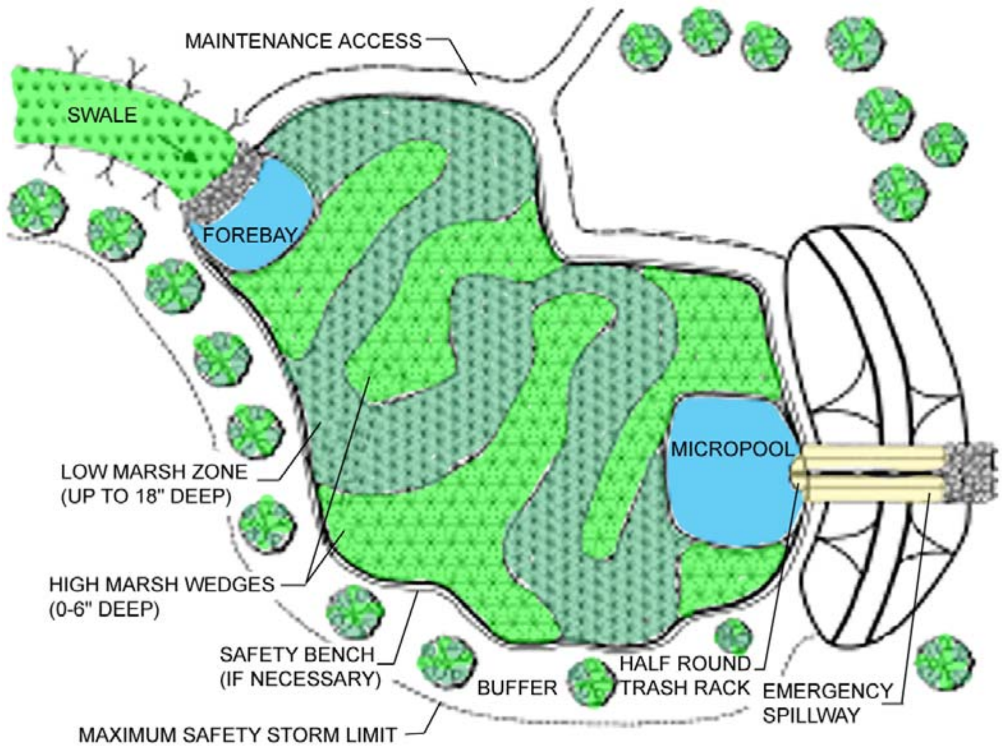


Figure 6.13-3 Pond/Wetland System (Maryland pp 3.19).

- **Pocket Wetland**



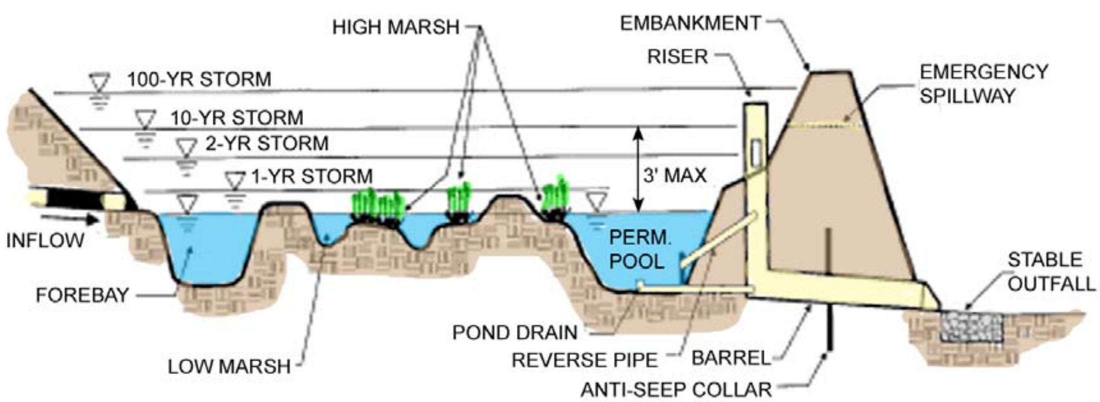


Figure 6.13-4 Pocket Wetland (Georgia Vol. 2, Section 20-3-2-2).

- **Offline Constructed Wetland**
- **Retrofit of existing detention basins**

Figure 6.13-5 Constructed Wetland Created from an Existing Detention Basin (Tredyffrin Twp., PA)

Design Considerations

1. HYDROLOGY. Constructed Wetlands must be able to receive and retain enough flow from rain, runoff, and groundwater to ensure long-term viability. Hydrologic calculations (or a water balance) should be performed to verify this. Shallow marsh areas can become dry at the surface but not for greater than one month, even in the most severe drought. A permanent water surface in the deeper areas of the CW should be maintained during all but the driest periods. A relatively stable normal water surface elevation will reduce the stress on wetland vegetation. A CW must have a drainage area of at least 10 acres (5 acres for "pocket" wetlands) or some means of sustaining constant inflow. Even with a large drainage area, a constant source of inflow can improve the biological health and

Figure 6.13-6 Example of stabilized inflow channel during construction.

Table 6.13-1 Definitions of Wetland Vegetation Zones

Vegetation Zone	Description
Open Water	Areas between 18 inches and 6 feet deep
Emergent Vegetation	Areas up to 18 inches deep, contains the majority of aquatic vegetation
Low Marsh	Portion of Emergent Vegetation Zone between 6 and 18 inches deep
High Marsh	Portion of Emergent Vegetation Zone up to 6 inches deep
Ephemeral Storage	Area that is periodically inundated during runoff events
Buffer	Area outside of maximum water surface area

effectiveness of a Constructed Wetland. Pennsylvania's precipitation is generally well distributed throughout the year and is therefore suited for CWs.

2. UNDERLYING SOILS. Underlying soils must be identified and tested. Generally hydrologic soil groups "C" and "D" are suitable without modification, "A" and "B" soils may require a clay or synthetic liner. Soil permeability must be tested in the proposed Constructed Wetland location to ensure that excessive infiltration will not cause the CW to dry out. If necessary, CWs should have a highly- compacted subsoil or an impermeable liner to minimize infiltration.
3. PLANTING SOIL. Organic soils should be used for Constructed Wetlands. Organic soils can serve as a sink for pollutants and generally have high water holding capacities. They will also facilitate plant growth and propagation and may hinder invasion of undesirable species.
4. SIZE AND VOLUME. The area required for a CW is generally 3 to 5 percent of its drainage area. CWs should be sized to treat the water quality volume and, if necessary, to mitigate the peak rates for larger events.

Figure 6.13-7 Example of recently planted constructed wetland.

5. VEGETATION. Vegetation is an integral part of a Wetland system. Vegetation may help to reduce flow velocities, promote settling, provide growth surfaces for beneficial microbes, uptake pollutants, prevent resuspension, provide filtering, limit erosion, prevent short-circuiting, and maintain healthy bottom sediments (Braskerud, 2001). Constructed Wetlands should have several different zones of vegetation as described in Table 1. The emergent vegetation zone (areas not more than 18" deep) should comprise about 60 to 65 percent of the normal water surface area, although recommendations in recent literature

range from less than 50 to over 80 percent. Robust, non-invasive, perennial plants that establish quickly are ideal for CWs. The designer should select species that are tolerant of a range of depths, inundation periods, etc. Monoculture planting must be avoided due to the risk from pests and disease. Use local recommended plant lists.

6. CONFIGURATION.
   a. General. Constructed Wetlands should be designed with a length to width ratio of at least 2:1 wherever possible. If the length to width ratio is lower, the flow pathway through the CW should be maximized. CWs should not be constructed within 10 feet of the property line or within 50 feet of a private well or septic system. CWs should be designed so that the 10-year water surface elevation does not exceed the normal water surface elevation by more than 3 feet. Slopes in and around Constructed Wetlands should be 4:1 to 5:1 (horizontal:vertical) whenever possible.
   b. Forebay/Inflows. Constructed Wetlands should have a forebay at all major inflow points to capture coarse sediment, prevent excessive sediment accumulation in the remainder of the CW, and minimize erosion by inflow. The forebays should contain 10 to 15 percent of the total permanent pool volume and should be 4 to 6 feet deep (at least as deep as other open water areas). They should be physically separated from the rest of the wetland by a berm, gabion wall, etc. Flows exiting the forebay must be non-erosive to the newly constructed CW. Vegetation within forebays can increase sedimentation and reduce resuspension/erosion. The forebay bottom can be hardened to facilitate sediment removal. Forebays should be installed with permanent vertical markers that indicate sediment depth. Inflow channels should be fully stabilized. Inflow pipes can discharge to the surface or be partially submerged. CWs must be protected from the erosive force of the inflow.
   c. Vegetation and Open Water Zones. About half of the emergent vegetation zone should be high marsh (up to 6” deep) and half should be low marsh (6” to 18” deep). Varying depths throughout the CW can improve plant diversity and health. The open water zone (approx. 35 to 40% of the total surface area) should be between 18 inches and 6 feet deep. Allowing a limited 5-foot deep area can prevent short-circuiting by encouraging mixing, enhance aeration of water, prevent resuspension, minimize thermal impacts, and limit mosquito growth. Alternating areas of emergent vegetation zone (up to 18 inches deep) and open water zone – as shown in Figures 6.13-2 and 6.13-4 – can also minimize short-circuiting and hinder mosquito propagation.
   d. Outlet. Outlet control devices should be in open water areas 4 to 6 feet deep comprising about 5 percent of the total surface area to prevent clogging and allow the CW to be drained for maintenance. Outlet devices are generally multistage structures with pipes, orifices, or weirs for flow control. Orifices should be at least 2.5 inches in diameter and should be protected from clogging. Outlet devices should be installed in the embankment for accessibility. It is recommended that outlet devices enable the normal water surface to be varied. This allows the water level to be adjusted (if necessary) seasonally, as the CW accumulates sediment over time, if desired grades are not achieved, or for mosquito control. The outlet pipe should generally be fitted with an anti-seep collar. Online facilities should have an emergency spillway that can safely pass the 100-year storm with 1 foot of freeboard. All outflows should be conveyed downstream in a safe and stable manner.
   e. Safety Benches. All areas that are deeper than 4 feet should have two safety benches, each 4 to 6 feet wide. One should be situated about 1 to 1.5 feet above

the normal water elevation and the other 2 to 2.5 feet below the water surface.

7. CONSTRUCTED WETLAND BUFFER. To enhance habitat value, visual aesthetics, and wetland health, a 25-foot buffer should be added from the maximum water surface elevation. The buffer should be planted with trees, shrubs, and native ground covers. Existing trees within the buffer should be preserved. If soils in the buffer will become compacted during construction, soil restoration should take place to aid buffer vegetation.
8. MAINTENANCE ACCESS. Permanent access must be provided to the forebay, outlet, and embankment areas. It should be at least 9 feet wide, have a maximum slope of 15%, and be stabilized for vehicles.
9. PLAN ELEMENTS. The plans detailing the Constructed Wetlands should clearly show the CW configuration, elevations and grades, depth/vegetation zones, and the location, quantity, and propagation methods of wetland/buffer vegetation. Plans should also include site preparation techniques, construction sequence, as well as maintenance schedules and requirements.
10. REGULATION. Constructed Wetlands that have drainage areas over 100 acres, embankments greater than 15 feet high, or a capacity greater than 50 acre-feet may be regulated as a dam by PADEP (see Title 25, Chapter 105 of the Pennsylvania Code). Once established, CWs may be regulated as Wetlands.

Detailed Stormwater Functions

Volume Reduction Calculations

Although not typically considered a volume-reducing BMP, Constructed Wetlands can achieve some volume reduction through infiltration and evapotranspiration, especially during small storms. Hydrologic calculations that should be performed to verify that the CW will have a viable amount of inflow can also predict the water surface elevation under varying conditions. The volume stored between the predicted water level and the lowest outlet elevation will be removed from the storm that occurs under those conditions.

Peak Rate Mitigation Calculations

Peak rate is primarily controlled in Constructed Wetlands through the transient storage above the normal water surface. See in Section 9 for Peak Rate Mitigation methodology.

Water Quality Improvement

Constructed Wetlands improve runoff quality through settling, filtration, uptake, chemical and biological decomposition, volatilization, and adsorption. CWs are effective at removing many common stormwater pollutants including suspended solids, heavy metals, total phosphorus, total nitrogen, toxic organics, and petroleum products. The pollutant removal effectiveness varies by season and may be affected by the age of the CW. It has been suggested that CWs do not remove nutrients in the long term unless vegetation is harvested because captured nutrients are released back into the water by decaying plant material. Even if this is true, nutrients are generally released gradually and during the non-growing season when downstream susceptibility is generally low (Hammer, 1990). See in Section 9 for Water Quality Improvement methodology which addresses pollutant removal effectiveness of this BMP.

Construction Sequence

1. Separate wetland area from contributing drainage area:
    a. All channels/pipes conveying flows to the CW must be routed away from the CW area until it is completed and stabilized.
    b. The area immediately adjacent to the CW must be stabilized in accordance with the PADEP's Erosion and Sediment Pollution Control Program Manual (2000 or latest edition) prior to construction of the CW.

2. Clearing and Grubbing:
    a. Clear the area to be excavated of all vegetation.
    b. Remove all tree roots, rocks, and boulders.
    c. Fill all stump holes, crevices and similar areas with impermeable materials.

3. Excavate bottom of CW to desired elevation (Rough Grading).

4. Install surrounding embankments and inlet and outlet control structures.

5. Grade and compact subsoil.

6. Apply and grade planting soil.
a. Matching design grades is crucial because aquatic plants can be very sensitive to depth.

7. Apply geo-textiles and other erosion-control measures.

8. Seed, plant and mulch according to Planting Plan

9. Install any anti-grazing measures, if necessary.

10. Follow required maintenance and monitoring guidelines.

Figure 6.13-8 Installation of Clay Liner

Maintenance Issues

Constructed Wetlands must have a maintenance plan and privately owned facilities should have an easement, deed restriction, or other legal measure to prevent neglect or removal. During the first growing season, vegetation should be inspected every 2 to 3 weeks. During the first 2 years, CWs should be inspected at least 4 times per year and after major storms (greater than 2 inches in 24 hours). Inspections should access the vegetation, erosion, flow channelization, bank stability, inlet/outlet conditions, and sediment/debris accumulation. Problems should be corrected as soon as possible. Wetland and buffer vegetation may require support – watering, weeding, mulching, replanting, etc. – during the first 3 years. Undesirable species should be removed and desirable replacements planted if necessary.

Once established, properly designed and installed Constructed Wetlands should require little maintenance. They should be inspected at least biannually and after major storms as well as rapid ice breakup. Vegetation should maintain at least an 85 percent cover of the emergent vegetation zone. Annual harvesting of vegetation may increase the nutrient removal of CWs; it should generally be done in the summer so that there is adequate regrowth before winter. Care should be taken to minimize disturbance, especially of bottom sediments, during harvesting. The potential disturbance from harvesting may outweigh its benefits unless the CW receives a particularly high nutrient load or discharges to a nutrient sensitive waterbody. Sediment should be removed from the forebay before it occupies 50 percent of the forebay, typically every 3 to 7 years.

Cost Issues

The construction cost of Constructed Wetlands can vary greatly depending on the configuration, location, site-specific conditions, etc. Typical construction costs in 2004 dollars range from approximately $30,000 to $65,000 per acre (USEPA Wetlands Fact Sheet, 1999). Costs are generally most dependent on the amount of earthwork and the planting. Annual maintenance costs have been reported to be approximately 2 to 5 percent of the capital costs although there is very little data available to support this.

Specifications:

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

1. **Excavation**
   a. The area to be used for the CW should be excavated to the required depth below the desired bottom elevation to accommodate any required impermeable liner, organic matter, and/or planting soil.
   b. The compaction of the subgrade and/or the installation of any impermeable liners will follow immediately.
2. **Subsoil Preparation**
   a. Subsoil shall be free from hard clods, stiff clay, hardpan, ashes, slag, construction debris, petroleum hydrocarbons, or other undesirable material. Subsoil must not be delivered in a frozen or muddy state.

b. Scarify the subsoil to a depth of 8 to 10 inches with a disk, rototiller, or similar equipment.
c. Roll the subsoil under optimum moisture conditions to a dense seal layer with four to six passes of a sheepsfoot roller or equivalent. The compacted seal layer shall be at least 8 inches thick.

3. **Impermeable Liner**
   a. If necessary, install impermeable liner in accordance with manufacturer's guidelines.
   b. Place a minimum 12 inches of subsoil on top of impermeable liner in addition to planting soil.
4. **Planting Soil (Topsoil)**
   a. See Local Specifications and Appendix C for general Planting Soil requirements.
   b. Use a minimum of 12 inches of topsoil in marsh areas of the Wetland. If natural topsoil from the site is to be used it must have at least 8 percent organic carbon content (by weight) in the A-horizon for sandy soils and 12% for other soil types.
   c. If planting soil is being imported it should be made up of equivalent proportions of organic and mineral materials.
   d. Lime should not be added to planting soil unless absolutely necessary as it may encourage the propagation of invasive species.
   e. The final elevations and hydrology of the wetland zones should be evaluated prior to planting to determine if grading or planting changes are required.
5. **Vegetation**
   a. Plant Lists for CWs can be found in Appendix B. No substitutions of specified plants will be accepted without prior approval of the designer. Planting locations shall be based on the Planting Plan and directed in the field by a qualified wetland ecologist.
   b. All wetland plant stock shall exhibit live buds or shoots. All plant stock shall be turgid, firm, and resilient. Internodes of rhizomes may be flexible and not necessarily rigid. Soft or mushy stock shall be rejected. The stock shall be free of deleterious insect infestation, disease and defects such as knots, sun-scald, injuries, abrasions, or disfigurement that could adversely affect the survival or performance of the plants.
   c. All stock shall be free from invasive or nuisance plants or seeds such as those listed in Appendix B.
   d. During all phases of the work, including transport and onsite handling, the plant materials shall be carefully handled and packed to prevent injuries and desiccation. During transit and onsite handling, the plant material shall be kept from freezing and shall be kept covered, moist, cool, out of the weather, and out of the wind and sun. Plants shall be watered to maintain moist soil and/or plant conditions until accepted.
   e. Plants not meeting these specifications or damaged during handling, loading, and unloading will be rejected.
   f. Detailed planting specifications can be found in Appendix B.

6. **Outlet Control Structure**
   a. Outlet control structures shall be constructed of non-corrodible material.
   b. Outlets shall be resistant to clogging by debris, sediment, floatables, plant material, or ice.
   c. Materials shall comply with applicable specifications (PennDOT or AASHTO, latest edition)

References

Auckland Manual

Braskerud, B.C. "Influence of Vegetation on Sedimentation and Resuspension of Soil Particles in Small Constructed Wetlands," Journal of Environmental Quality, Vol. 30: pp. 1447-1457, 2001.

California Manual

Campbell, C. and Ogden, M. Constructed Wetlands in the Sustainable Landscape. John Wiley & Sons Inc., 1999.

Caraco, D. and Claytor, R. Stormwater BMP Design Supplement for Cold Climates. 1997.
USEPA BMP Fact Sheet

Georgia Manual

Hammer, D. (Editor). Constructed Wetlands for Wastewater Treatment. Lewis Publishers, 1990.

Maryland Manual

Mosquito Control in Wetlands (Univ. of California)

NJ Manual

PA Manual

Portland Manual

Wetlands: Characteristics and Boundaries. Committee on Characterization of Wetlands, National Research Council (1995)