3.06.2 Post Construction Stormwater BMP Standards and Specifications

March 2013

DNREC DIVISION OF WATERSHED STEWARDSHIP

3.06.2
Post Construction Stormwater BMP Standards and Specifications

Specifications:

Appendices:

1.0 Stormwater Infiltration

Definition: Practices that capture and temporarily store the design storm volume before allowing it to infiltrate into the soil over a two day period. Design variants include:

- 1-A Infiltration Trench
- 1-B Infiltration Basin

Infiltration practices use temporary surface or underground storage to allow incoming stormwater runoff to exfiltrate into underlying soils. Runoff first passes through multiple pretreatment mechanisms to trap sediment and organic matter before it reaches the practice. As the stormwater penetrates the underlying soil, chemical and physical adsorption processes remove pollutants. Infiltration practices are suitable for use in residential and other urban areas where *measured* soil permeability rates exceed 1 inch per hour. To prevent possible groundwater contamination, infiltration should not be utilized at sites designated as stormwater hotspots. Extraordinary care shall be taken to assure that long-term infiltration rates are achieved through the use of performance bonds, post construction inspection and long-term maintenance.

1.1 Infiltration Stormwater Credit Calculations

Infiltration practices receive 100% retention volume credit (R_v) for the volume stored and infiltrated by the practice (**Table 1.1**). No additional pollutant removal credit is awarded.

Table 1.1 Infiltration Performance Credits

Runoff Reduction	
Retention Allowance	100%
RPv	100% of Retention Storage
Cv	100% of Retention Storage
Fv	100% of Retentions Storage
Pollutant Reduction	
TN Reduction	100% of Load Reduction
TP Reduction	100% of Load Reduction
TSS Reduction	100% of Load Reduction

The practice must be sized using the guidance detailed in ***Section 1.5. Infiltration Design Criteria***

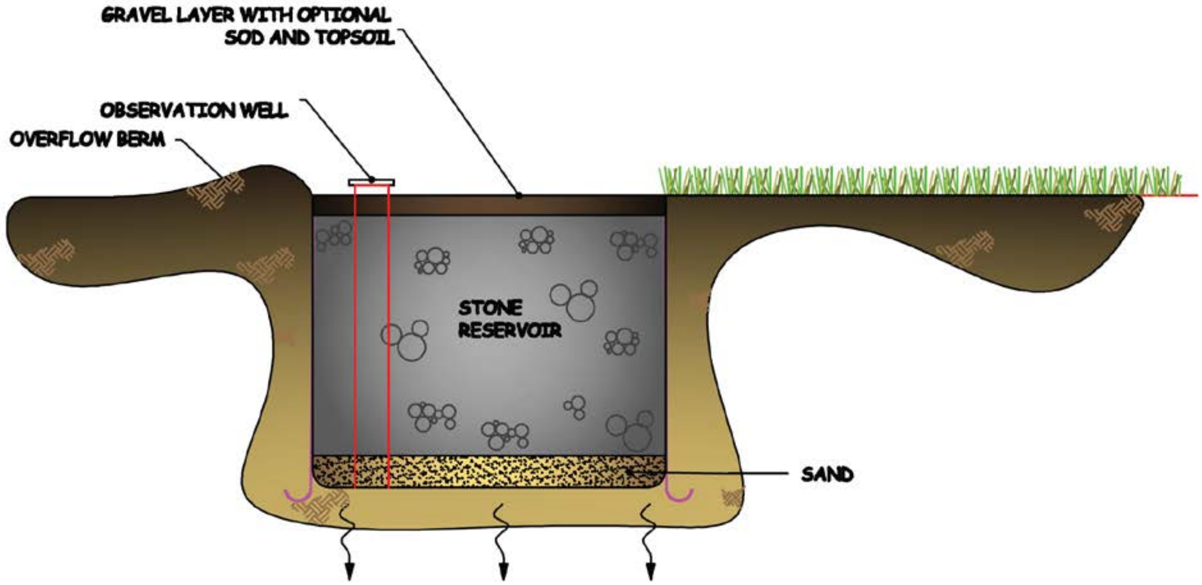

Figure 1.1. Infiltration Trench.

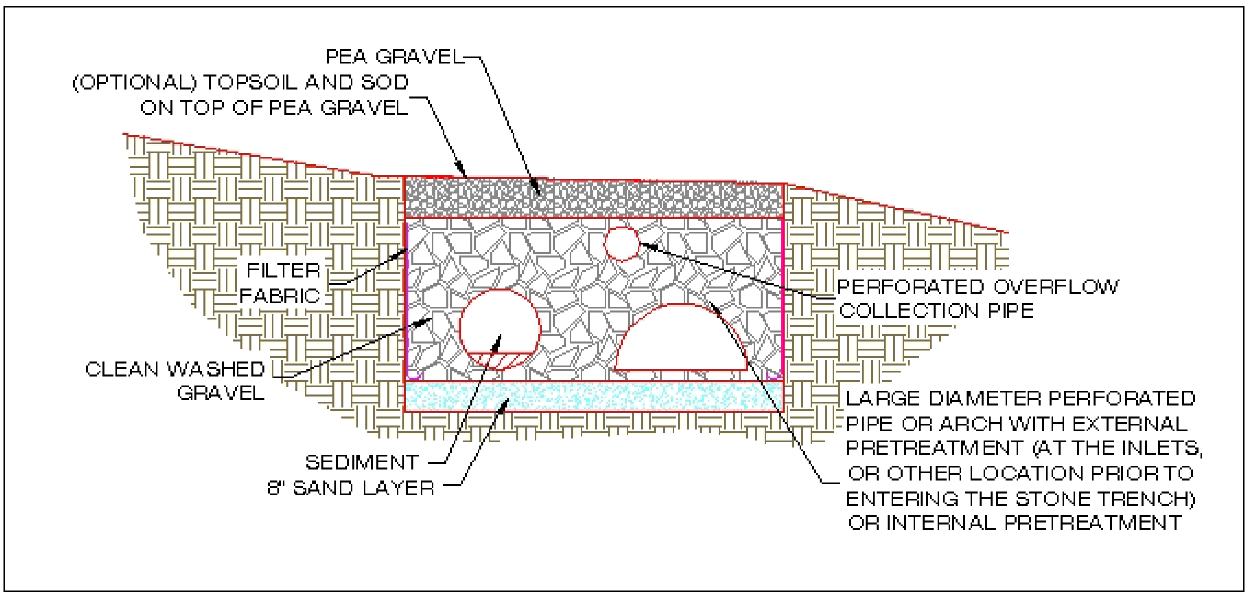

Figure 1.2. Infiltration Section with Supplemental Pipe Storage.

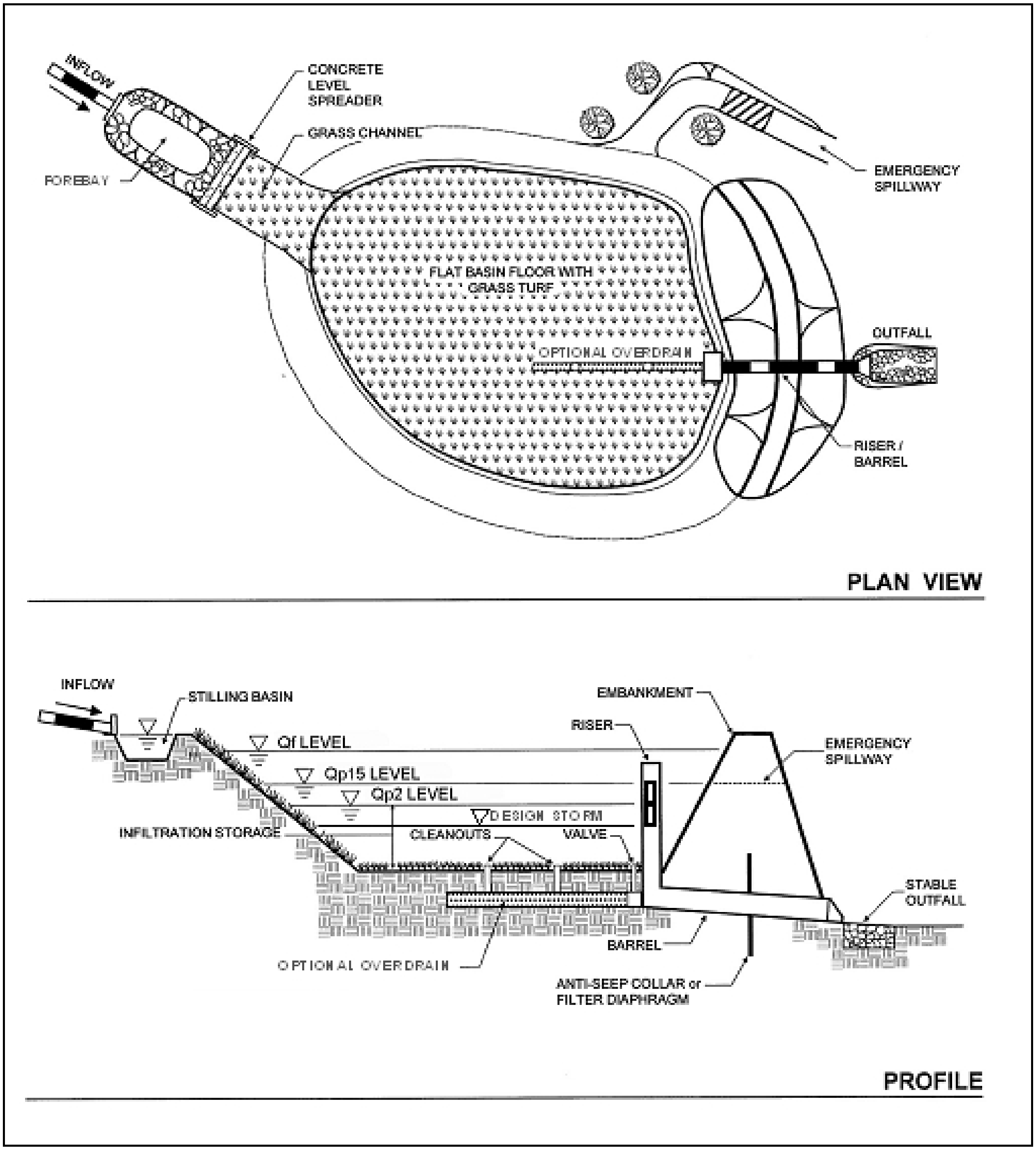

Figure 1.3. Infiltration Basin.

1.2 Infiltration Design Summary

Table 1.2 summarizes design criteria for infiltration practices, and Table 1.3 summarizes the materials specifications for these practices. For more detail, consult Sections 1.3 through 1.7. Section 1.8 describes practice construction and maintenance criteria.

Table 1.2 Infiltration Design Summary

	Basins	Trenches
Feasibility (Section 1.3)	• Minimum soil infiltration of 1"/hr • Restrictions for treating hotspots, high loads, or dry weather flows • 2 foot separation from seasonal high groundwater for infiltration without underdrain • For infiltration with underdrain, invert of underdrain must be above seasonal high groundwater • Setbacks from wells, buildings and utilities	
Conveyance (Section 1.4)	• Must safely convey the Conveyance Event (Cv)	
Pretreatment (Section 1.5)	• 25% to 50% of retention volume in pretreatment, depending on soil infiltration rate • All runoff must be treated • Several pretreatment options may be used	
Sizing (Maximum Depth) (Section 1.6)	$d_{\max} = \frac{1}{2} i \times t_d$	$d_{\max} = \frac{\left(\frac{1}{2} i \times t_d\right)}{\eta_r}$
	Maximum depth limits as well, based on practice size and CDA (See Table 1.4)	
Sizing (Surface Area) (Section 1.6)	$SA = Sv / (d + \frac{1}{2}\, i \text{ x } t_f)$	$SA = Sv / (\eta_r \text{ x } d + \frac{1}{2}\, i \text{ x } t_f)$
Variables:	t_d = maximum drawn down time (days - 2) i = field-verified infiltration rate for the native soils (ft./day) η_r = available porosity of the stone reservoir (assume 0.4) Sv = Retention volume treated by the practice d = Infiltration depth (ft.) t_f = Time to fill the infiltration facility (days – typically 2 hours, or 0.083 days)	
Geometry (Section 1.6)	• Flat trench or basin bottom • 4:1 or flatter internal side slopes for basins • 2' or lower maximum ponding depth for basins	• Wider than they are deep to avoid injection well status
Landscaping (Section 1.7)	Maintain vegetation in the buffers and practice drainage area to minimize erosion and debris	

Table 1.3. Infiltration Material Specifications

Material	Specification	Notes
Surface Layer (optional)	Topsoil and grass layer	
Stone Layer	Clean, aggregate with a maximum diameter of 2.5 inches and a minimum diameter of 0.5 inches (Delaware #3).	
Observation Well	Install a vertical 6-inch Schedule 40 PVC perforated pipe, with a lockable cap and anchor plate	Install one per 50 feet of length of infiltration practice, minimum 1 well per practice
Overflow collection pipe (optional)	Use 4-inch or 6-inch rigid schedule 40 PVC pipe, with 3/8" perforations at 6 inches on center	
Filter Fabric (sides only)	Use polypropylene geotextile with a flow rate of > 110 gallons/min./sq. ft. (e.g.,GD-II)	

1.3 Infiltration Feasibility Criteria

Infiltration practices have very high storage and retention capabilities when sited and designed appropriately. Designers should evaluate the range of soil properties during initial site layout and seek to configure the site to conserve and protect the soils with the greatest recharge and infiltration rates. In particular, areas of Hydrologic Soil Group A or B soils shown on NRCS soil surveys should be considered as primary locations for infiltration practices. Additional information about soil and infiltration are described in more detail later in this section. During initial design phases, designers should carefully identify and evaluate constraints on infiltration, as follows:

EPA Requirements for Class V Injection Wells. Certain types of practices in this category may be classified as a Class V Injection Wells, which are subject to regulations under the Federal Underground Injection Control (UIC) program. In general, if the facility allows stormwater runoff to come in direct contact with groundwater it would meet this criterion. Facilities with a minimum 2' vadose zone separation from the groundwater table would not meet the criterion. Designers are advised to contact the DNREC Groundwater Discharges Section for additional information regarding UIC regulations and possible permitting requirements.

Contributing Drainage Area. To be most effective minimize the contributing drainage area (CDA). The CDA should be as close to 100% impervious as possible to minimize organic capping and maintenance concerns. The facility specific design, pretreatment and maintenance requirements will differ depending on the size of the infiltration practice.

Site Topography. Infiltration shall not be located on slopes greater than 5%. Further, unless slope stability calculations demonstrate otherwise, infiltration practices should be located a minimum horizontal distance of 200 feet from down-gradient slopes greater than 20%. The average slope of the contributing drainage areas should be less than 15%.

Minimum Depth to Water Table or Bedrock. A minimum vertical distance of 2 feet must be provided between the bottom of the infiltration practice and the seasonal high water table or bedrock layer for systems without an underdrain. The minimum vertical distance of 2 feet is relaxed for systems with an underdrain; the design invert of the underdrain must be set such that the seasonal high groundwater does not encroach into system through the underdrain.

Soils. Native soils in proposed infiltration areas must have a minimum infiltration rate of 1 inch per hour (typically Hydrologic Soil Group A and B soils meet this criterion). Initially, soil infiltration rates can be estimated from NRCS soil data, but designers must verify soil permeability by using the on-site soil investigation methods provided in the Soil Investigation Procedures. Soils investigation must be performed by a qualified soils or geotechnical engineer.

Use on Urban Fill Soils/Redevelopment Sites. Sites that have been previously graded or disturbed do not typically retain their original soil permeability due to compaction. Therefore, such sites are often not good candidates for infiltration practices unless the geotechnical investigation shows that the soil infiltration rate exceeds 1.0 in/hr.

Dry Weather Flows. Infiltration practices should not be used on sites receiving regular dry-weather flows from sump pumps, irrigation water, chlorinated wash-water, or other non-stormwater flows.

Setbacks. Infiltration practices should not be hydraulically connected to structure foundations or pavement, in order to avoid harmful seepage. Setbacks to structures vary based on the size of the infiltration facility:

Table 1.4 Minimum Setbacks

Size of Infiltration Facility	Minimum Setback			
	Structure is Up-Grade	Structure is Down-Grade	Septic System	Well
250 to 2,500 square feet	5'	25'	100'	150'
2,500 to 20,000 square feet	10'	50'	100'	150'
20,000 to 100,000 square feet	25'	100'	100'	150'

Proximity to Utilities. No Infiltration facility shall be built within five feet horizontally of an existing underground utility without prior authorization from the utility owner. A proposed underground utility may be built within five feet, horizontally, of an infiltration facility as long as protective measures are in place accounting for future maintenance of the underground utility and meeting the design requirements of the utility owner.

Hotspots and High Loading Situations. Infiltration practices are not intended to treat sites with high sediment or trash/debris loads, because such loads will cause the practice to clog and fail. Infiltration practices should be avoided at potential stormwater hotspots that pose a risk of groundwater contamination. For a list of potential stormwater hotspot operations, consult ***Appendix 4.***

1.4 Infiltration Conveyance Criteria

The nature of the conveyance and overflow to an infiltration practice depends on the scale of infiltration and whether the facility is on-line or off-line. Where possible, conventional infiltration practices should be designed offline to avoid damage from the erosive velocities of larger design storms. If runoff is delivered by a storm drain pipe or along the main conveyance system, the infiltration practice shall be designed as an off-line practice. Pretreatment shall be provided for storm drain pipes systems discharging directly to infiltration systems.

Off-line infiltration: Overflows can either be diverted from entering the infiltration practice or dealt with via an overflow inlet. Optional overflow methods include the following:

- Utilize a low-flow diversion or flow splitter at the inlet to allow only the design volume to enter the facility. This may be achieved with a weir or curb opening sized for the target flow, in combination with a bypass channel. Using a weir or curb opening helps minimize clogging and reduces the maintenance frequency (further guidance on determining the peak flow rate will be necessary in order to ensure proper design of the diversion structure).
- Use landscaping type inlets or standpipes with trash guards as overflow devices.

On-line infiltration: An overflow structure should always be incorporated into on-line designs to safely convey larger storms through the infiltration area. The following criteria apply to overflow structures:

- An overflow mechanism such as an elevated drop inlet or overflow weir should be used to direct high flows to a non-erosive down-slope overflow channel, stabilized water course, or storm sewer system designed to convey the Conveyance Event (Cv).

1.5 Infiltration Pretreatment Criteria

Every infiltration system shall have pretreatment mechanisms to protect the long term integrity of the infiltration rate. One of the following techniques must be installed to pretreat 100% of the inflow in every facility:

- Vegetated Channel (see ***Specification 8. Vegetated Channel)***
- Grass Filter Strip (see ***Specification 9. Sheet flow to Open Space)***
- Forebay (minimum 25% of the retention volume)
- Sand Filter (see ***Specification 12. Stormwater Filtering Systems***)

- Proprietary Practices (see Specification 15. Proprietary Practices)

A minimum pretreatment volume of at least 25% of the design retention volume shall be provided for any infiltration facility which serves a CDA greater than 20,000 sq. ft.

Exit velocities from the pretreatment shall be non-erosive (typically above 4 fps) during the largest design storm that is connected to the facility and flow from the pretreatment chamber should be evenly distributed across the width of the practice (e.g., using a level spreader).

1.6 Infiltration Design Criteria

Facility Slope. The bottom of an infiltration facility should be flat (i.e., 0% longitudinal and lateral slopes) to enable even distribution and infiltration of stormwater, however the bottom may be stepped internally per design specifications.

Infiltration Basin Geometry: The maximum vertical depth to which runoff may be ponded over an infiltration basin is 24 inches. The side-slopes should be no steeper than 4H:1V

Surface Cover (optional): Designers may choose to install a layer of topsoil and grass above the infiltration practice.

Stone Layer: Stone layers must consist of clean, washed aggregate with a maximum diameter of 2.5 inches and a minimum diameter of 0.5 inches (Delaware #3 stone).

Underground Storage (optional): In the underground mode, runoff is stored in the voids of the stones, and infiltrates into the underlying soil matrix. Plastic, concrete, or comparable material structures can be used in conjunction with the stone to increase the available temporary underground storage. In some instances, a combination of filtration and infiltration cells can be installed in the floor of a dry extended detention (ED) pond ***See Specification 12. Detention Practices***.

Overflow Collection Pipe: An optional overflow collection pipe can be installed to convey collected runoff from larger storm events to a downstream conveyance system.
Trench Bottom: To protect the bottom of an infiltration trench from intrusion by underlying soils, a sand layer must be used. The underlying native soils should be separated from the stone layer by a 6 to 8 inch layer of coarse sand (e.g., ASTM C 33, 0.02-0.04 inch).

Filter Fabric: Use a geotextile fabric with a flow rate of > 110 gal./min./sq. ft. (e.g., Delaware GD-II).

Material Specifications: Recommended material specifications for infiltration areas are shown in

Table 1.3 in Section 1.2.

Practice Sizing: The proper approach for designing infiltration practices is to avoid forcing a large amount of infiltration into a small area. Therefore, individual infiltration practices that are limited in size due to soil permeability and available space need not be sized to capture the entire design volume for the contributing drainage area, as long as other stormwater treatment practices are applied at the site to meet the remainder of the design storm volume.

Several equations are needed to size infiltration practices. The first equations establish the maximum depth of the infiltration practice, depending on whether it is a surface basin (**Equation 1.1**) or trench with an underground reservoir (**Equation 1.2**).

Equation 1.1. Maximum Surface Basin Depth (for Infiltration Basins)

$$d_{\max} = {}^{1}\!/_{2}\, i \times t_d$$

Equation 1.2. Maximum Underground Reservoir Depth (for Infiltration Trenches)

$$d_{\max} = \left({}^{1}\!/_{2}\, i \times t_d\right) / \eta_r$$

Where:

d_{max}	=	maximum depth of the infiltration practice (feet)
i	=	field-verified infiltration rate for the native soils(ft./day)
t_d	=	maximum drawn down time (days - 2)
η_r	=	available porosity of the stone reservoir (assume 0.4)

This equation makes the following design assumptions:

- *Conservative Infiltration Rates.* For design purposes, the field-tested subgrade soil infiltration rate (i) is divided by 2 as a factor of safety to account for potential compaction during construction and to approximate long term infiltration rates. On-site infiltration investigations should always be conducted to establish the actual infiltration capacity of underlying soils, using the methods presented in the Soil Investigation Procedures.
- *Stone Layer Porosity.* A porosity value of 0.4 shall be used in the design of stone reservoirs, although a larger value may be used if underground retention chambers are installed within the reservoir.
- *Rapid Drawdown.* Infiltration practices should be sized so that the target runoff reduction volume infiltrates within 48 hours, to prevent nuisance ponding conditions.

Equation 1.3. Surface Basin Surface Area (for Infiltration Basins)

$$SA = Sv / (d + {}^{1}\!/_{2}\, i \times t_f)$$

Equation 1.4. Underground Reservoir Surface Area (for Infiltration Trenches)

$$SA = Sv / (\eta_r \text{ x } d + ½\, i \text{ x } t_f)$$

Where:

SA	=	Surface area (sq. ft.)
Sv	=	Design retention volume treated by the practice
η_r	=	available porosity of the stone reservoir (assume 0.4)
d	=	Infiltration depth (ft.) (maximum depends on the scale of infiltration and the results of **Equation 1.1 or 1.2**)
i	=	field-verified infiltration rate for the native soils (ft/day)
t_f	=	Time to fill the infiltration facility (days – typically 2 hours, or 0.083 days)

Infiltration practices can also be designed to address, in whole or in part, the detention storage needed to comply with channel protection and/or flood control requirements. The designer can model various approaches by factoring in storage chambers within the stone aggregate layer and expected infiltration as part of the design. Routing calculations can also be used to provide a more accurate solution of the peak discharge and required storage volume.

1.7 Infiltration Landscaping Criteria

Infiltration trenches can be effectively integrated into the site plan and aesthetically designed with adjacent native landscaping or turf cover. Vegetation associated with the infiltration practice buffers should be regularly mowed with clippings removed and maintained to keep organic matter out of the infiltration device and maintain enough vegetation to prevent soil erosion from occurring.

1.8 Infiltration Construction Sequence

Infiltration practices are particularly vulnerable to failure during the construction phase for two reasons. First, if the construction sequence is not followed correctly, construction sediment can clog the practice. In addition, heavy construction can result in compaction of the soil, which can then reduce the soil's infiltration rate. For this reason, a careful construction sequence needs to be followed.

During site construction, the following steps are absolutely critical:

- Avoid compaction by preventing construction equipment and vehicles from traveling over the proposed location of the infiltration practice using "Sensitive Area Protection" guidelines during construction.
- Infiltration trenches should remain "off-line" until construction is complete to prevent construction sediment from clogging the stone reservoir layer. Prevent sediment from entering the

infiltration site by using super silt fence, diversion berms or other means. In the erosion and sediment control plan, indicate the earliest time at which stormwater runoff may be directed to an infiltration trench. The erosion and sediment control plan must also indicate the specific methods to be used to temporarily keep runoff from the infiltration facility.

- Infiltration basins should not serve as the sites for temporary sediment control devices (e.g., sediment traps, etc.) during construction unless extensive design and construction methods are employed to protect the infiltration facilities' ability to infiltrate. Examples of these design considerations are the need to remove choking sediment from the facility, tilling the basin, and performing additional geological site investigations to determine that the infiltration rate has been maintained.
- Upland drainage areas need to be completely stabilized with a thick layer of vegetation prior to commencing excavation for an infiltration practice.

Infiltration Installation. The actual installation of an infiltration practice is done using the following steps:

1. Excavate the infiltration practice to the design dimensions *from the side*, using a backhoe or excavator.
2. Install geotextile per design on the trench sides. Large tree roots should be trimmed flush with the sides of infiltration trenches to prevent puncturing or tearing of the filter fabric during subsequent installation procedures. When laying out the geotextile, the width should include sufficient material to compensate for perimeter irregularities in the trench and for a 6-inch minimum overlap at the top of the trench. The filter fabric itself should be tucked under the sand layer on the bottom of the infiltration trench. Stones or other anchoring objects should be placed on the fabric at the trench sides, to keep the trench open during windy periods. Voids may occur between the fabric and the excavated sides of a trench. Natural soils should be placed in all voids, to ensure the fabric conforms smoothly to the sides of excavation.
3. Scarify the bottom of the infiltration practice, and spread 6 inches of sand on the bottom as a filter layer per design.
4. Anchor the observation well(s), and add stone to the practice in 1-foot lifts.
5. Use sod, where applicable to establish a dense turf cover for at least 10 feet around the sides of the infiltration practice, to reduce erosion and sloughing.

Construction Review. Review is needed during construction to ensure that the infiltration practice is built in accordance with the approved design and this specification. Qualified individuals should use detailed inspection checklists to include sign-offs at critical stages of construction, to ensure that the contractor's interpretation of the plan is consistent with the designer's intentions.

1.9 Infiltration Maintenance Criteria

Maintenance is a crucial element that ensures the long-term performance of infiltration practices. The most frequently cited maintenance problem for infiltration practices is clogging of the stone by organic matter and sediment. The following design features can minimize the risk of clogging:

Stabilized CDA. Infiltration systems may not receive runoff until the entire contributing drainage area has been completely stabilized, unless a design and construction method can be shown to remove all clogging sediment prior to site completion.

Observation Well. Infiltration practices should include an observation well, consisting of an anchored 6-inch diameter perforated PVC pipe fitted with a lockable cap installed flush with the ground surface, to facilitate periodic inspection and maintenance.

No Filter Fabric on Bottom. Avoid installing geotextile filter fabric along the bottom of infiltration practices. Experience has shown that filter fabric is prone to clogging. However, permeable filter fabric must be installed on the trench sides to prevent soil piping.

Direct Maintenance Access. Infiltration systems must be covered by a common open space to allow inspection and maintenance. Access must be provided to allow personnel and heavy equipment to perform non-routine maintenance tasks, such as reconstruction or rehabilitation. While a turf cover is permissible for small-scale infiltration practices, the surface must never be covered by an impermeable material, such as asphalt or concrete.

Effective long-term operation of infiltration practices requires an Operation and Maintenance Plan, including maintenance inspection schedule with clear guidelines and schedules, as shown in **Table 1.5** below. Where possible, facility maintenance should be integrated into routine landscaping maintenance tasks.

Table 1.6. Typical maintenance activities for infiltration practices

Maintenance Activity	Schedule
• Replace topsoil and top surface filter fabric (when clogged). • Mow vegetated filter strips as necessary and remove the clippings.	As needed
• Ensure that the contributing drainage area, inlets, and facility surface are clear of debris. • Ensure that the contributing drainage area is stabilized. Perform spot-reseeding if where needed. • Remove sediment and oil/grease from inlets, pre-treatment devices, flow diversion structures, and overflow structures. • Repair undercut and eroded areas at inflow and outflow structures.	Quarterly
• Check observation wells 3 days after a storm event in excess of 1/2 inch in depth. Standing water observed in the well after three days is a clear indication of clogging. • Inspect pre-treatment devices and diversion structures for sediment build-up and structural damage. • Remove trees that start to grow in the vicinity of the infiltration facility that may drop leaf litter, fruits and other vegetative materials that could clog the infiltration device.	Semi-annual inspection
• Clean out accumulated sediments from the pre-treatment cell.	Annually

An Operation and Maintenance Plan for the project will be approved by DNREC or the Delegated Agency prior to project closeout. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize DNREC or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed. Infiltration facilities that are, or will be, owned and maintained by a joint ownership such as a homeowner's association must be located in common areas, community open space, community-owned property, jointly owned property, or within a recorded easement dedicated to public use.

Operation and Maintenance Plans should clearly outline how vegetation in the Infiltration facility and its buffer will be managed or harvested in the future. Periodic mowing of the Infiltration facility is required, unless it is managed as a meadow (mowing every other year) or forest. The maintenance plan should schedule a cleanup at least once a year to remove trash and debris.

Maintenance of an Infiltration facility is driven by annual maintenance reviews that evaluate the condition and performance of the Infiltration facility. Based on maintenance review results, specific maintenance tasks may be required.

1.10 References

No references.

2.0 Bioretention

Definition: Practices that capture and store stormwater runoff and pass it through a filter bed of engineered soil media comprised of sand, lignin and organic matter. Filtered runoff may be collected and returned to the conveyance system, or allowed to infiltrate into the soil. Design variants include:

- ■ 2-A Traditional Bioretention
- ■ 2-B In-Situ Bioretention (including Rain Gardens)
- ■ 2-C Streetscape Bioretention
- ■ 2-D Engineered Tree Boxes
- ■ 2-E Stormwater Planters
- ■ 2-F Advanced Bioretention Systems

Bioretention systems are typically designed to manage stormwater runoff from frequent, small magnitude storm events, but may provide stormwater detention of larger storms (e.g., 10-yr) in some circumstances. Bioretention practices shall generally be designed such that larger storm events bypass the system into a separate facility where site conditions allow.

For each of the design variants above, there are two basic configurations:

- *Underdrain Designs*: Practices with a positive discharge using perforated pipe; pollutant reduction occurs through a combination of runoff reduction and treatment by the filtering media. Addition of an infiltration sump is required to maximize runoff reduction performance. Advanced systems may provide greater pollutant removal capabilities through the use of improved media components and/or internal modifications that encourage partial anaerobic conditions.
- *Infiltration Designs:* Practices with no underdrains that can infiltrate the design storm volume within 48 hours; pollutant reduction is based solely on the load reduction provided by the design retention storage volume.

The particular design configuration to be implemented on a site is typically dependent on specific site conditions and the characteristics of the underlying soils. These criteria are discussed in more detail below.

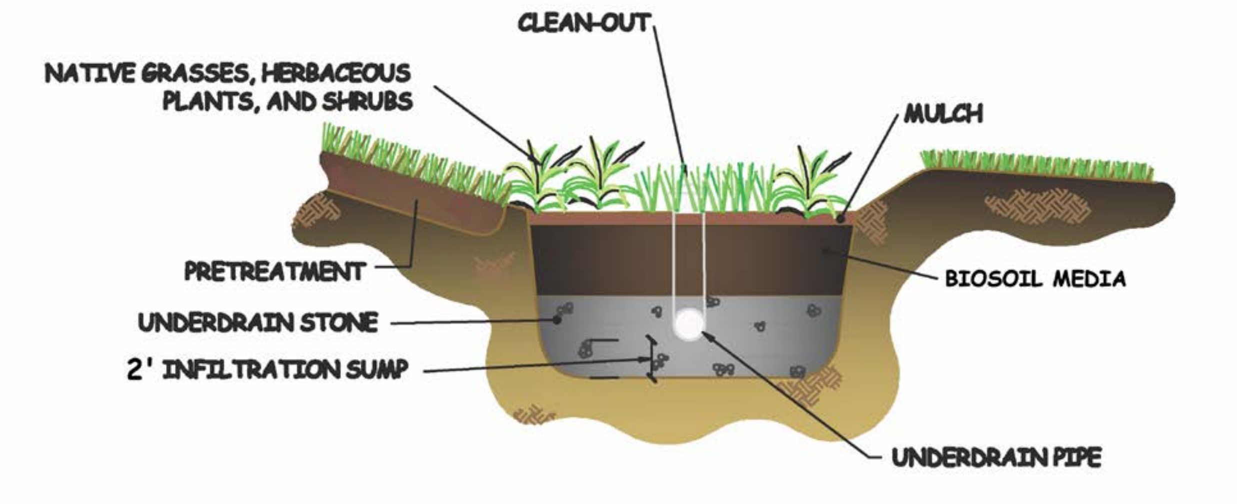

Figure 2.1. Traditional Bioretention Underdrain Design

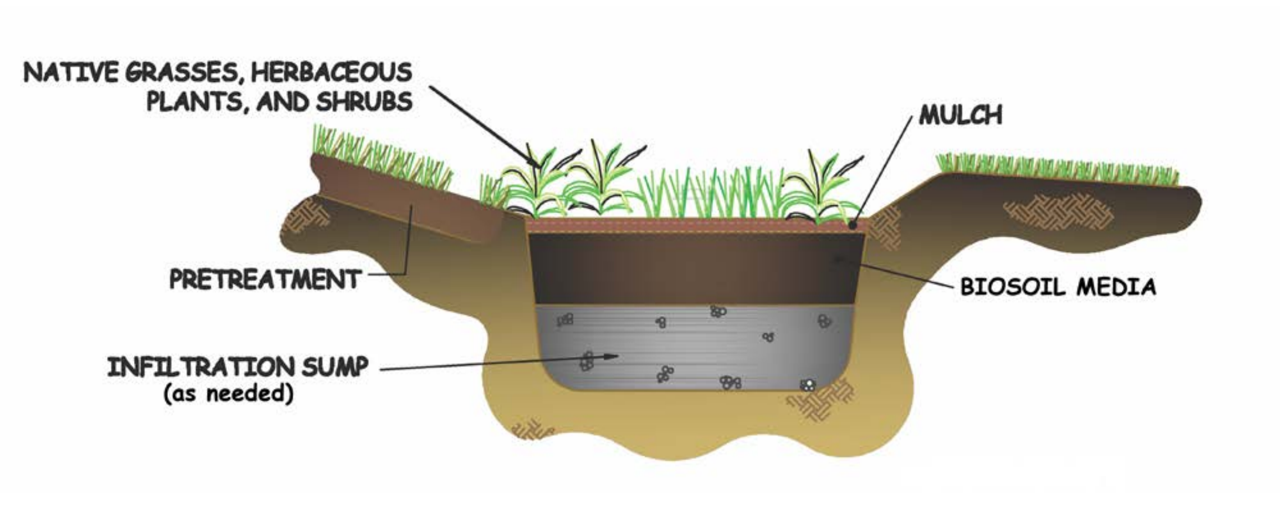

Figure 2.2. Traditional Bioretention Infiltration Design

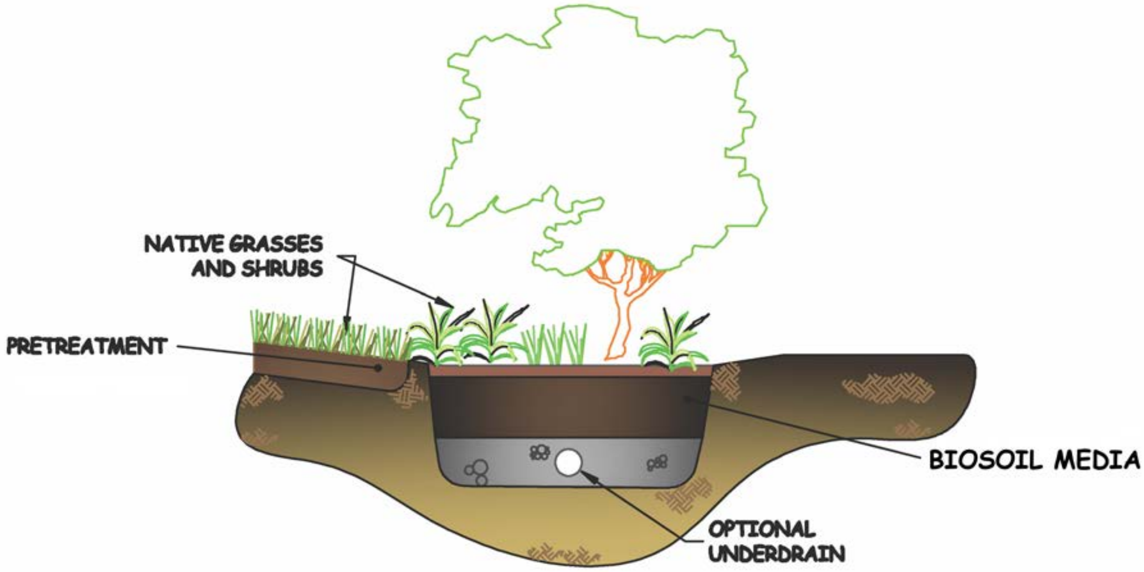

Figure 2.3. Rain Garden

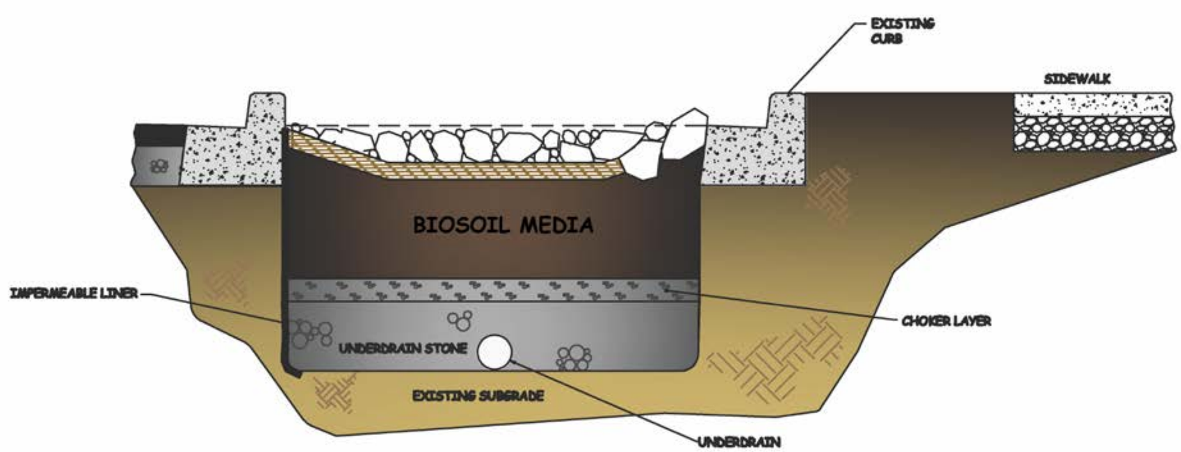

Figure 2.4. Streetscape Bioretention

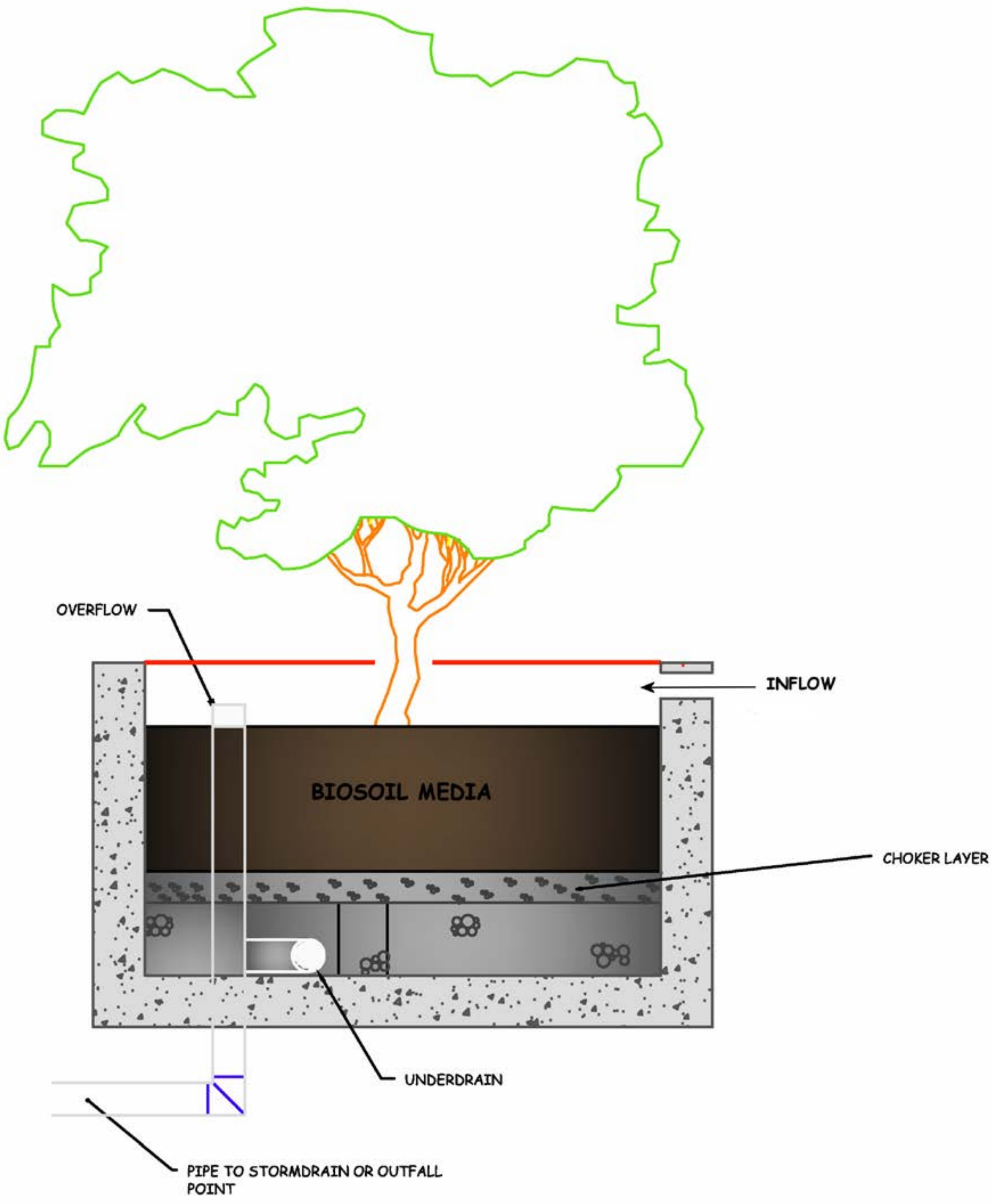

Figure 2.5. Engineered Tree Box

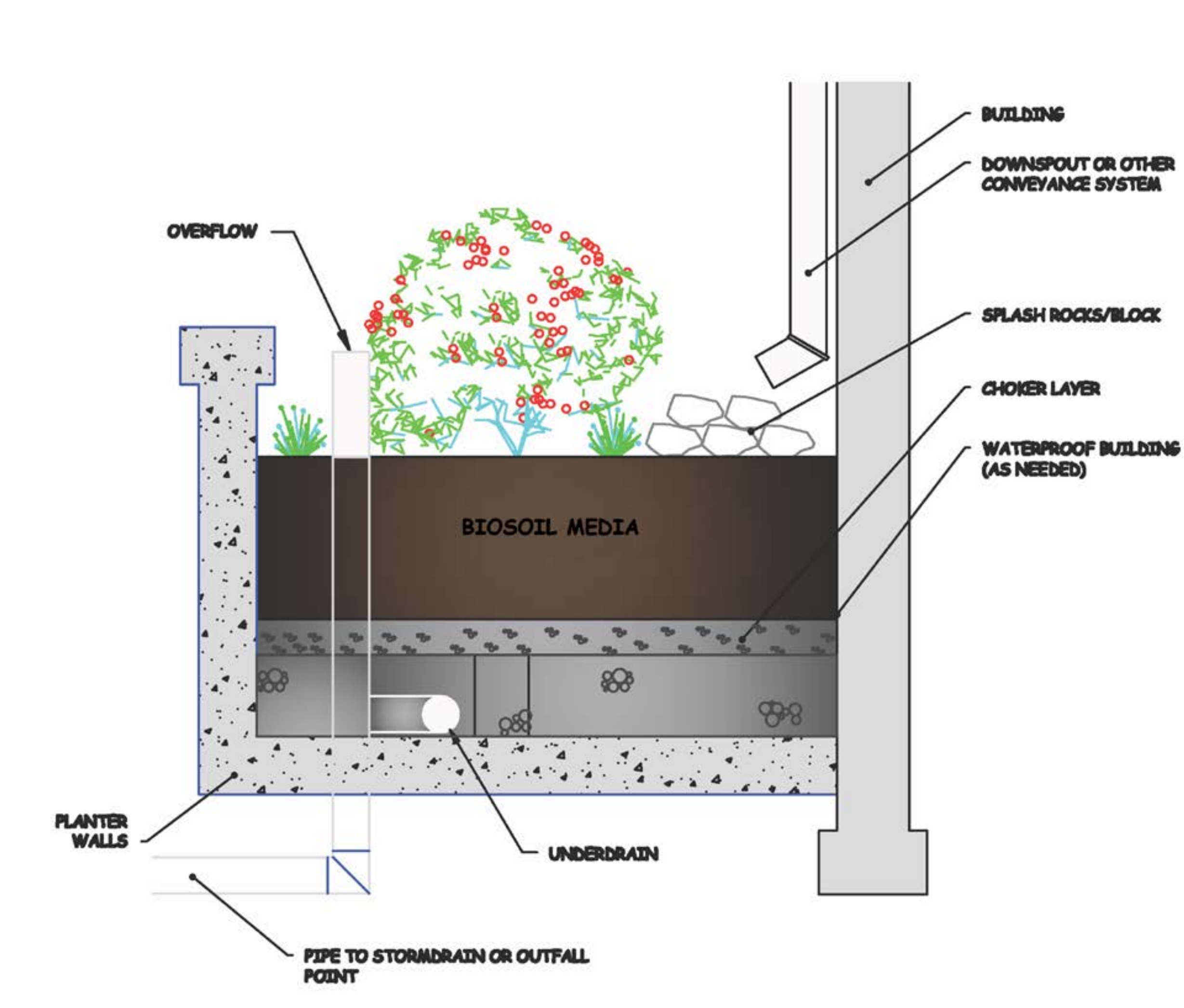

Figure 2.6. Stormwater Planter

2.1 Bioretention Stormwater Credit Calculations

The retention volume credit for Bioretention practices depends on the volume of runoff that is infiltrated from this practice (Table 2.1a & b). In addition, Bioretention systems using an underdrain receive a removal efficiency credit for filtering pollutants as they pass through the soil media.

2.1(a) Bioretention With Underdrain Performance Credits

Runoff Reduction	
Retention Allowance	50%
RPv -A/B Soil	50% of Retention Storage
RPv - C/D Soil	50% of Retention Storage
Cv	5% of Retention Storage
Fv	1% of Retention Storage
Pollutant Reduction*	
TN Reduction	100% of Load Reduction + 30% Removal Efficiency
TP Reduction	100% of Load Reduction + 40% Removal Efficiency
TSS Reduction	100% of Load Reduction + 80% Removal Efficiency

*Advanced systems may provide higher removal efficiencies

2.1(b) Bioretention With Infiltration Performance Credits

Runoff Reduction	
Retention Allowance	100%
RPv -A/B Soil	100% of Retention Storage
RPv - C/D Soil	100% of Retention Storage
Cv	100% of Retention Storage
Fv	100% of Retention Storage
Pollutant Reduction	
TN Reduction	100% of Load Reduction
TP Reduction	100% of Load Reduction
TSS Reduction	100% of Load Reduction

2.2 Bioretention Design Summary

Table 2.2 summarizes design criteria for bioretention practices, and Table 2.3 summarizes the materials specifications for these practices. For more detail, consult the appropriate sections referenced in column 1.

Table 2.2 Bioretention Design Summary

	Standard Underdrain Designs	Infiltration Designs
Feasibility (Section 2.3)	• Can treat hotspots if designed with an impermeable liner, but cannot treat high sediment loads or dry weather flows • Invert of underdrain must not intersect seasonal high groundwater table • Minimum 3-4 feet of head (unless designed for internal water storage)	• Minimum soil infiltration rate IAW Appendix 1 • Restrictions for treating hotspots, high loads, or dry weather flows • 2 foot separation from seasonal high groundwater
	• Small CDA, varying based on practice type (Table 2.4) • Setbacks from wells, buildings and utilities (Table 2.5)	
Conveyance (Section 2.4)	• Can be designed off-line or on-line • Must safely convey the 10-year storm event (Cv) and 100-year storm event (Fv) unless designed to bypass these larger storm events	
Pretreatment (Section 2.5)	• All runoff directed to a bioretention practice must receive pretreatment	
Sizing (Total Storage) (Section 2.6)	$Sv = SA_{filter} \times \left[\left(d_{media} \times \eta_{media}\right) + \left(d_{gravel} \times \eta_{gravel}\right)\right] + (SA_{p-1} + SA_{p-2})/2 \times d_{ponding} + Sv_{pretreatment}$	
Sizing (Min. Surface Area) (Section 2.6)	$SA_{filter} \geq \dfrac{Sv \times d_{media}}{k \times t_f \times \left(d_{ponding}/2 + d_{media}\right)}$	
Sizing (Ponding Volume)	$V_{ponding} = (SA_{p-1} + SA_{p-2})/2 \times d_{ponding} + Sv_{pretreatment}$	
Variables:	d_{media} = depth of the filter media (typically 2 ft) η_{media} = effective porosity of the filter media (typically 0.4) d_{gravel} = depth of the underdrain and underground storage gravel layer(ft) η_{gravel} = effective porosity of the gravel layer (typically 0.4) SA_{p-1} = surface area at the lowest elevation of the ponding area (sq. ft.) [Note SA_{p-1} may be no greater than 2X SA_{filter}] SA_{p-2} = surface area at the depth of ponding $d_{ponding}$ = the maximum ponding depth of the practice (ft). $Sv_{pretreatment}$ = volume stored in pretreatment practices k = filtering media permeability (ft/day; typically assume 5.7) t_d = drawdown time within the filter (2 days maximum)	
Geometry and Dimensions (Section 2.6)	Ponding Depth: RPv: 12”; Cv: 18”, Fv: 24” Media Depth: Minimum 24” (varies for small-scale practices); may require gravel layer to extend into more permeable soil profile Side Slopes: 3:1 side slopes in ponding area; for “curb drop” designs (e.g., streetscape bioretention), maximum drop of 12”	
Landscaping (Section 2.7)	Plant in zones based on elevation within the filter (see Appendix A-2) Maintain vegetation in the drainage area to limit sediment loads to the practice.	

Table 2.3. Bioretention Material Specifications

Material	Specification	Notes
Filter Media (Biosoil-14)	Biosoil-14 Media to contain (by volume): • 60% concrete sand; fineness modulus > 2.75 • 30% triple-shredded hardwood mulch • 10% aged, STA certified compost	• Minimum depth of 24" (may be less for *in-situ* Bioretention practices) • The volume of filter media used should be based on 110% of the calculated design volume, to account for settling
Filter Media Testing	Between 7 and 23 mg/kg of P in the soil media; CECs greater than 10	The media must be procured from approved biosoil media vendors
Mulch Layer	Use aged, shredded hardwood bark mulch	3" layer on the surface of the biosoil media bed
Alternative Surface Cover	Use of river stone or pea gravel, coir and jute matting, or turf cover may be acceptable with prior approval	3" layer to suppress weed growth
Top Soil For Turf Cover	Loamy sand or sandy loam texture, with less than 5% clay content, pH corrected to between 6 and 7, and an organic matter content of at least 2%	3 inch tilled into surface layer
Underdrain stone (as needed)	Rice Gravel (1/4" stone) shall be double-washed and free of all fines	Min. 3" cover on underdrain; min. 2' sump below invert of underdrain
Storage Layer (optional)	To increase storage for larger storm events, chambers, perforated pipe, stone, or other acceptable material can be incorporated below the filter media layer	
Impermeable Liner (optional)	Use a 30 mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd. non-woven geotextile. (NOTE: THIS IS USED ONLY FOR HOTSPOTS AND SMALL PRACTICES NEAR BUILDING FOUNDATIONS, OR IN FILL SOILS AS DETERMINTED BY A GEOTECHNICAL INVESTIGATION)	
Underdrains, Cleanouts, and Observation Wells	• 4- or 6-inch perforated corrugated polyethylene pipe (CPP) for underdrains • 4- or 6-inch SDR 35 (min.) PVC for cleanouts and observation wells	• Under-drains shall be laid flat, be no more than 20-ft apart and daylight to point of adequate conveyance. • Clean-outs shall be provided at all terminal ends and every 100-ft. • An observation well shall be provided for every 500-sq.ft. of filter media surface area.
Plant Materials	See Appendix 2, Stormwater BMP Landscaping Criteria	Establish plant materials as specified in the landscaping plan and the recommended plant list

2.3 Bioretention Feasibility Criteria

Bioretention can be applied in most soils or topography, since runoff simply percolates through an engineered soil bed and is infiltrated or returned to the stormwater system via an underdrain. Key constraints with Bioretention include the following:

EPA Requirements for Class V Injection Wells. Certain types of practices in this category may be classified as Class V Injection Wells, which are subject to regulations under the Federal Underground Injection Control (UIC) program. In general, if the facility allows stormwater runoff to come in direct contact with groundwater it would meet this criterion. Facilities with a minimum 2’ vadose zone separation from the groundwater table would not meet the criterion. Designers are advised to contact the DNREC Groundwater Discharges Section for additional information regarding UIC regulations and possible permitting requirements.

Required Space. Designers can assess the feasibility of using bioretention facilities based on a simple relationship between the contributing drainage area and the corresponding required surface area. The bioretention surface area will usually be between 3% to 6% of the contributing drainage area (CDA), depending on the imperviousness of the CDA and the desired bioretention ponding depth. When a bioretention facility is installed on a private residential lot, its existence and purpose should be noted on the deed of record. A sample Record Plan note is as follows: “This lot contains practices that are intended to meet State regulations related to the management of stormwater runoff. It is the responsibility of the owner to maintain these practices in proper working condition in order fulfill this requirement”.

Site Topography. Bioretention is best applied when the grade of contributing slopes is greater than 1% and less than 5%.

Available Hydraulic Head. Bioretention is fundamentally constrained by the invert elevation of the existing conveyance system to which the practice. In general, 4 to 5 feet of elevation above this invert is needed to accommodate the required ponding and filter media depths. If an inverted or elevated underdrain design is used to accommodate an internal water storage (IWS) design, less hydraulic head may be adequate.

Water Table. Bioretention should always be separated from the water table to ensure that groundwater does not intersect the filter bed. This could otherwise lead to possible groundwater contamination or failure of the Bioretention facility. A separation distance of 2 feet is required between the bottom of the excavated Bioretention facility and the seasonally high ground water table for infiltration designs.

Soils and Underdrains. Soil conditions do not typically constrain the use of Bioretention, although they do determine whether an underdrain is needed. Underdrains are required if the measured permeability of the underlying soils does not meet the requirements for infiltration practices in accordance with ***Appendix 1, Soil Investigation Procedures for Stormwater BMPs***.

A stone sump can be used to extend an infiltrating facility to a more permeable layer, as needed. When designing a Bioretention practice, designers should verify soil permeability by using the methods provided in ***Appendix 1, Soil Investigation Procedures for Stormwater BMPs***.

In fill soil locations, geotechnical investigations are required to determine if the use of an impermeable liner and underdrain are necessary.

Contributing Drainage Area. Bioretention facilities work best with smaller contributing drainage areas, where it is easier to achieve flow distribution over the filter bed. Typical drainage area size for traditional Bioretention facilities (2-A) can range from 0.1 to 5 acres and consist of up to 100% impervious cover. Drainage areas to smaller Bioretention practices (2-B, 2-C, 2-D, and 2-E) typically range from 0.5 acre to 1.0. The maximum recommended impervious area to a single bioretention basin or single cell of a Bioretention facility is 2.5 acres due to limitations in the ability of bioretention to effectively manage large volumes and peak rates of runoff. However, if hydraulic considerations are adequately addressed to manage the potentially large peak inflow of larger drainage areas (such as off-line or low-flow diversions, forebays, etc.), there may be case-by-case instances where these recommended maximums can be adjusted.

Table 2.4. Maximum Recommended CDA to Bioretention

	Traditional Bioretention	Small-scale and Urban Bioretention
Design Variants	2-A, 2-F	2-B, 2-C, 2-D, and 2-E
Maximum CDA	10.0 acres (2.5 ac. impervious)	1.0 acres (0.25 ac. impervious)

Hotspot Land Uses. An impermeable bottom liner and an underdrain system must be employed when a Bioretention facility will receive untreated hotspot runoff. However, Bioretention can still be used to treat “non-hotspot” parts of the site. For a list of potential stormwater hotspots, see ***Appendix 4, Stormwater Hotspots Guidance***.

Floodplains. Bioretention facilites should be constructed outside the limits of the 100-year floodplain.

No Irrigation or Baseflow. The Bioretention facility should not receive baseflow, irrigation water, chlorinated wash-water or other non-stormwater flows.

Setbacks. To avoid the risk of seepage, Bioretention facilities should not be hydraulically connected to structure foundations. The designer should check to ensure footings and foundations of adjacent buildings do not encroach within an assumed 4:1 phreatic zone drawn from the maximum design water elevation in the Bioretention facility. The setback for buildings from Table 2.5 can be used in lieu of a phreatic zone analysis.

Table 2.5. Setbacks for Bioretention Practices

Contributing Drainage Area/ Design Variant	Buildings		Wells	Septic Systems
	Facility Up-Gradient	Facility Down-gradient		
0 to 0.5 Acre CDA	50’	10’		
0.5 to 5 Acre CDA	100’	25’		
Any Practice With a Liner			100’	50’
Any Practice Without a Liner			150’	100’

Proximity to Utilities. Interference with underground utilities should also be avoided, particularly water and sewer lines. Approval from the applicable utility company or agency is required if utility lines will run below or through the bioretention area. Conflicts with water and sewer laterals (e.g., house connections) may be unavoidable, and the construction sequence must be altered, as necessary, to avoid impacts to existing service.

Additionally, designers should ensure that future tree canopy growth in the Bioretention facility will not interfere with existing overhead utility lines.

Minimizing External Impacts. Urban Bioretention practices may be subject to higher public visibility, greater trash loads, pedestrian traffic, vandalism, and vehicular loads. Designers should design these practices in ways that prevent, or at least minimize, such impacts. In addition, designers should clearly recognize the need to perform frequent landscaping maintenance to remove trash, check for clogging, and maintain vigorous plant growth. The urban landscape context may feature naturalized landscaping or a more formal design. When urban Bioretention is used in sidewalk areas of high foot traffic, designers should not impede pedestrian movement or create a safety hazard. Designers may also install low fences or other measures to prevent damage from pedestrian short-cutting across the practices.

2.4 Bioretention Conveyance Criteria

There are two basic design approaches for conveying runoff into, through, and around Bioretention practices:

1. Off-line: Flow is split or diverted so that only the runoff from the design storm enters the Bioretention area. Larger flows by-pass the Bioretention facility.

2. On-line: All runoff from the drainage area flows into the practice. Flows that exceed the design capacity exit the practice via an overflow structure or weir.

Off-line Bioretention: Optional overflow methods include the following:

- Create an alternate flow path at the inflow point into the structure such that when the maximum ponding depth is reached, the incoming flow is diverted past the facility. In this case, the higher flows do not pass over the filter bed and through the facility, and additional flow is able to enter as the ponding water filters through the soil media.

- Utilize a low-flow diversion or flow splitter at the inlet to allow only the design storm volume (e.g., the RP_v or a fraction of the RP_v) to enter the facility. This may be achieved with a weir or curb opening sized for the target flow, in combination with a bypass channel. Using a weir or curb opening helps minimize clogging and reduces the maintenance frequency. Determining the peak flow rate will be necessary in order to ensure proper design of the diversion structure.

On-line Bioretention : An overflow structure should always be incorporated into on-line designs to safely convey larger storms through the Bioretention facility. The following criteria apply to overflow structures:

- An overflow shall be provided within the practice to pass flows not treated by the practice to an adequate conveyance system. Larger events (e.g., the C_v or F_v) may be partially or fully managed by the Bioretention facility as long as the maximum depth of ponding in the bioretention cell does not exceed 18” for the C_v and 24” for F_v .
- Common overflow systems within bioretention practices consist of an outlet structure, where the top of the structure is set so as to control the maximum ponding depth within the bioretention facility. The crest of the outlet structure is therefore typically set at 6 to 18 inches above the surface of the filter bed.
- The overflow capture device should be scaled to the application – this may be a landscape grate or yard inlet for small practices or a commercial-type structure for larger installations.
- The maximum design discharge should be checked for a non-erosive condition at the outlet point. Outlet protection should be provided as necessary.

2.5 Bioretention Pretreatment Criteria

Pre-treatment of runoff entering Bioretention facilities is necessary to trap coarse sediment particles before they reach and prematurely clog the filter bed. Ideally, pre-treatment measures should be designed to evenly spread runoff across the entire width of the bioretention area. Several pre-treatment measures are feasible, depending on the type of the bioretention practice and whether it receives sheet flow, shallow concentrated flow or deeper concentrated flows. The following are appropriate pretreatment options:

For Traditional Bioretention (2-A, 2-F):

- **Pre-treatment Cells** (channel flow): Similar to a forebay, this cell is located at piped inlets or curb cuts leading to the bioretention area and may include an energy dissipater sized for the expected rates of discharge. It has a storage volume equivalent to at least 15% of the total storage volume (inclusive) with a recommended 2:1 length-to-width ratio. The cell may be formed by a wooden or stone check dam or an earthen berm. Pretreatment cells do not need underlying engineered soil media, in contrast to the main bioretention cell.
- **Grass Filter Strips** (sheet flow): Grass filter strips that are perpendicular to incoming sheet flow extend from the edge of pavement (with a slight drop at the pavement edge) to the

bottom of the bioretention basin at a 5:1 slope or flatter. Alternatively, if the Bioretention facility has sides slopes that are 3:1 or flatter, a 5 foot grass filter strip at a maximum 5% (20:1) slope can be used.

- **Gravel or Stone Diaphragms** (sheet flow). A gravel diaphragm located at the edge of the pavement should be oriented perpendicular to the flow path to pre-treat lateral runoff, with a 2 to 4 inch drop from the pavement edge to the top of the stone. The stone must be sized according to the expected rate of discharge.
- **Gravel or Stone Flow Spreaders** (concentrated flow). The gravel flow spreader is located at curb cuts, downspouts, or other concentrated inflow points, and should have a 2 to 4 inch elevation drop from a hard-edged surface into a gravel or stone diaphragm. The gravel should extend the entire width of the opening and create a level stone weir at the bottom or treatment elevation of the basin.
- **Proprietary Practices:** Structures that meet the pre-treatment requirements of ***Specification 15.0, Proprietary Practices*** may be used for pre-treatment.

For Small-Scale Bioretention (2-B, 2-C, 2-D, 2-E):

- **Leaf Screens** as part of the gutter system serve to keep the heavy loading of organic debris from accumulating in the bioretention cell.
- **Grass Filter Strips** (for sheet flow), applied on residential lots, where the lawn area can serve as a grass filter strip adjacent to a rain garden.
- **Gravel or Stone Diaphragm** (for either sheet flow or concentrated flow); this is a gravel diaphragm at the end of a downspout or other concentrated inflow point that should run perpendicular to the flow path to promote settling.
- **Trash Racks** (for either sheet flow or concentrated flow) between the pre-treatment cell and the main filter bed or across curb cuts. These will allow trash to collect in specific locations and create easier maintenance.
- **Pre-treatment Cell** (see below) located above ground or covered by a manhole or grate. This type of pretreatment is not recommended for residential rain gardens (B-5).

2.6 Bioretention Design Criteria

Design Geometry: Bioretention facilities must be designed with an internal flow path geometry such that the treatment mechanisms provided by the bioretention are not bypassed or short-circuited during the Resource Protection Event (RPv). In order for these Bioretention facilities to have an acceptable internal geometry, the “travel time” from each inlet to the outlet should be maximized by locating the inlets and outlets as far apart as possible. In addition, incoming flow must be distributed as evenly as possible across the entire filter surface area.

Inlets and Energy Dissipation: Where appropriate, the inlet(s) to Streetscape Bioretention (2-C), Engineered Tree Boxes (2-D) and Stormwater Planters (2-E) should be stabilized using DE No. 3 stone, splash block, river stone or other acceptable energy dissipation measures. Iinlet protection practices that could be considered include:

- o Downspouts to stone energy dissipaters.
- o Sheet flow over a depressed curb with a 3-inch drop.
- o Curb cuts allowing runoff into the bioretention area.
- o Covered drains that convey flows across sidewalks from the curb or downspouts.
- o Grates or trench drains that capture runoff from a sidewalk or plaza area.

Ponding Depth: The maximum surface ponding depth is 12” for the RPv. Ponding depths can be increased to a maximum of 18” for management of the Cv and a maximum of 24” for the Fv. However, if these greater ponding depths are used, the design must carefully consider issues such as safety, aesthetics, the viability and survival of plants, and erosion and scour of side slopes. The depth of ponding in the bioretention area should never exceed 24”. Shallower ponding depths (typically 6 to 12 inches) are recommended for Streetscape Bioretention (2-C), Engineered Tree Boxes (2-D), and Stormwater Planters (2-E).

Side Slopes: Traditional Bioretention facilities (2-A, 2-F) and Rain Gardens (2-B) should be constructed with side slopes of 3:1 or flatter. In highly urbanized or space constrained areas, a drop curb design or a precast structure can be used to create stable, vertical side walls. For safety purposes, drop curb designs should not exceed a vertical drop of more than 12 inches.

Biosoil Media and Surface Cover: The filter media and surface cover are the two most important elements of a Bioretention facility in terms of long-term performance. The following are key factors to consider in determining an acceptable soil media mixture.

- **General Biosoil Media Composition.** The Biosoil-14 soil mixture has the following volumetric composition:
  - o 60% coarse concrete sand (Fineness Modulus > 2.75)
  - o 30% triple shredded hardwood mulch
  - o 10% aged, STA certified compost

  For systems intended to meet regulatory requirements, biosoil media must be obtained from an approved vendor that can certify conformance with the media composition and standards in this specification.

  Phosphorus Content. The recommended range for phosphorus content for the soil component is between 7 mg/kg and 23 mg/kg.

- **Compost.** Compost used for Bioretention facilities shall meet the requirements ***Appendix 3, Compost Material Properties***.

- **Cation Exchange Capacity (CEC).** The CEC of a soil refers to the total amount of positively charged elements that a soil can hold; it is expressed in milliequivalents per 100 grams (meq/100g) of soil. For agricultural purposes, these elements are the basic cations of calcium (Ca^{+2}), magnesium (Mg^{+2}), potassium (K^{+1}) and sodium (Na^{+1}) and the acidic cations of hydrogen (H^{+1}) and aluminum (Al^{+3}). The CEC of the soil is determined in part by the amount of clay and/or humus or organic matter present. Soils with CECs exceeding 10 are preferred for pollutant removal. Increasing the organic matter content of any soil will help to increase the CEC.

- **Biosoil Infiltration Rate.** The biosoil media must meet the minimum infiltration rate established in the Department’s testing protocol for Bioretention soil.

- **Biosoil Depth.** The biosoil media bed depth should be a minimum of 24 inches although this can be reduced for small-scale bioretention practices (practices 2-B, 2-C, 2-D and 2-E) as noted elsewhere in this specification. A rice gravel layer may be added below the filter media if a greater depth is required to reach a more permeable layer in the soil profile. If trees are included in the bioretention planting plan, tree planting holes in the filter should be deep enough to provide enough soil volume for the root structure of the selected mature trees. Trees are not recommended for underdrain systems. Native grasses, perennials or shrubs should be used instead of trees to landscape shallower filter beds and underdrain systems.

- **Mulch.** A 2 to 3 inch layer of mulch on the surface of the filter bed enhances plant survival, suppresses weed growth, and pre-treats runoff before it reaches the filter media. Shredded hardwood bark mulch, aged for at least 6 months, makes a very good surface cover, as it retains a significant amount of pollutants and typically will not float away.

- **Alternative to Mulch Cover.** In some situations, designers may consider alternative surface covers such as turf, native groundcover, river rock, or pea gravel. Use of such alternative covers require prior approval from the appropriate approval authority.

Underdrains: For Bioretention designs that require an underdrain (see **Section 2.3**), the underdrain shall be a 4- or 6-inch perforated corrugated polyethylene pipe (CPP). The underdrain must be sized so that the bioretention practice fully drains within 48 hours. The underdrain shall be encased in a layer of clean, washed “rice gravel” (nominal 1/4” bank-run gravel) with a minimum of 3” of cover. The gravel layer should be extended a minimum of 2’ below the invert of the underdrain to enhance the infiltration capabilities of the system. This may also serve as an aerobic/anaerobic zone for situations in which the water table fluctuates below the invert.

Each underdrain should be located no more than 20 feet from the next pipe.

All traditional Bioretention practices should include at least one observation well and/or cleanout pipe. The observation wells/cleanouts should be appropriately sized PVC tied into any T’s or Y’s in the underdrain system, and should extend slightly above the surface, with a screw-on or locking cap.

Underground Storage Layer (optional): For Bioretention facilities with an underdrain, an underground storage layer consisting of chambers, perforated pipe, stone, or other acceptable material can be incorporated below the filter media layer to increase storage for larger storm events. The depth and volume of the storage layer will depend on the target treatment and storage volumes needed to meet water quality, channel protection, and/or flood protection criteria.

Impermeable Liner: This material should be used only for appropriate hotspot designs, small scale practices (i.e., B-4) that do not meet the necessary separation requirements from buildings, or in fill applications where deemed necessary by a geotechnical investigation. Designers should use a thirty mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd. non-woven geotextile.

Material Specifications: Recommended material specifications for Bioretention facilities are shown in Table 2.3.

Signage: Bioretention facilities in highly urbanized areas may be stenciled or permanently marked to designate them as a stormwater management facility in order to avoid potential complaints about an otherwise properly functioning system. The stencil or plaque should indicate (1) its water quality purpose, (2) that it may pond briefly after a storm, and (3) that it is not to be disturbed except for required maintenance.

Specific Design Issues for In-Situ Bioretention, including Rain Gardens (2-B):
In some cases, the native soil profile may be adequate to support infiltration of the RPv without the need for a more elaborate traditional-type system. Certified yard waste compost may also be mixed with the native soils instead of biosoil media. It is generally recommended that this approach be used for projects with small CDAs and/or outlying areas within larger projects that cannot be easily captured by a primary facility. For some residential applications, front, side, and/or rear yard bioretention may be an acceptable option. This form of bioretention captures roof, lawn, and driveway runoff from low- to medium- density residential lots in a depressed area (6 to 12 inches) between the home and the primary stormwater conveyance system (roadside ditch or pipe system).

The planting media must be deep enough to extend below the topsoil and into the more permeable subsoil. If the permeable soil layer is relatively close to the surface, it may be possible to simply excavate to provide the necessary design storage volume and incorporate 3”-4” of certified yard waste compost into the native soil. Although this type of system is particularly conducive to the inclusion of trees in the planting plan, tree planting holes should be deep enough to provide enough soil volume for the root structure of the selected mature trees. Shredded hardwood mulch is added as a top dressing to complete the installation.

It is preferred that this category of bioretention be designed as an infiltration practice. However, if an underdrain is required to ensure adequate function or to retro-fit a failing system, it may be connected to a storm drain or open channel conveyance system.

Specific Design Issues for Streetscape Bioretention (2-C): Streetscape Bioretention is installed in the road right-of-way either in the sidewalk area or in the road itself. In many cases, Streetscape Bioretention areas can also serve as a traffic calming or street parking control devices. The basic design adaptation is to move the raised concrete curb closer to the street or in the street, and then create inlets or curb cuts that divert street runoff into depressed vegetated areas within the expanded right of way. Roadway stability can be a design issue where streetscape bioretention practices are installed. Designers should consult design standards pertaining to roadway drainage. It may be necessary to provide an impermeable liner on the road side of the Bioretention facility to keep water from saturating the road's sub-base.

Specific Design Issues for Engineered Tree Boxes (2-D): Engineered Tree Boxes are installed in the sidewalk zone near the street where urban street trees are normally installed. The soil volume for the tree box is increased and used to capture and treat stormwater. Treatment is increased by using a series of connected tree planting areas together in a row. The surface of the enlarged planting area may be mulch, grates, permeable pavers, or conventional pavement. The large and shared rooting space and a reliable water supply increase the growth and survival rates in this otherwise harsh planting environment.

When designing Engineered Tree Boxes, the following criteria should be considered:

- The bottom of the soil layer must be a minimum of 4 inches below the root ball of plants to be installed.
- Engineered Tree Box designs sometimes cover portions of the filter media with pervious pavers or cantilevered sidewalks. In these situations, it is important that the filter media is connected beneath the surface so that stormwater and tree roots can share this space.
- Installing an Engineered Tree Box grate over filter bed media is one possible solution to prevent pedestrian traffic and trash accumulation.
- Low, wrought iron fences can help restrict pedestrian traffic across the tree box bed and serve as a protective barrier if there is a dropoff from the pavement to the micro-bioretention cell.
- A removable grate may be used to allow the tree to grow through it.
- Each tree needs a minimum of 400 cubic feet of root space.

Specific Design Issues for Stormwater Planters (2-E): Stormwater Planters are a useful option to disconnect and treat rooftop runoff, particularly in ultra-urban areas. They consist of confined planters that store and/or infiltrate runoff in a soil bed to reduce runoff volumes and pollutant loads. Stormwater Planters combine an aesthetic landscaping feature with a functional form of stormwater treatment. Stormwater Planters generally receive runoff from adjacent rooftop downspouts and are landscaped with plants that are tolerant to periods of both drought and inundation. The two basic design variations for stormwater planters are the infiltration Stormwater Planter and the filter Stormwater Planter.

An **infiltration** Stormwater Planter filters rooftop runoff through soil in the planter followed by infiltration into soils below the planter. The recommended minimum depth is 30 inches, with the shape and length determined by architectural considerations. The planter should be sized to treat at least 1/2-inch of runoff from the contributing rooftop area. Infiltration planters should be placed at least 10 feet away from a building to prevent possible flooding or basement seepage damage.

A **filter** Stormwater Planter does not allow for infiltration and is constructed with a watertight concrete shell or an impermeable liner on the bottom to prevent seepage. Since a filter Stormwater Planter is self-contained and does not infiltrate into the ground, it can be installed right next to a building. The minimum planter depth is 18 inches, with the shape and length determined by architectural considerations. Runoff is captured and temporarily ponded above the planter bed. Overflow pipes are installed to discharge runoff when maximum ponding depths are exceeded. In addition, an underdrain is used to carry runoff to the storm sewer system.

All planters should be placed at or above finished grade elevation. Plant materials should be capable of withstanding moist and seasonally dry conditions. Planting media should have an infiltration rate of at least 2 inches per hour. The sand and gravel on the bottom of the planter should have a minimum infiltration rate of 5 inches per hour. The planter can be constructed of stone, concrete, brick, wood or other durable material.

Specific Design Issues for Advanced Systems (2-F): Recent research on Bioretention has led to more advanced systems that are capable of greater reductions of certain targeted pollutants. One promising technology for reducing phosphorus levels in stormwater runoff involves the use of *water treatment residuals (WTR)* in the media mix. Other media supplements such as activated charcoal, sawdust and even shredded paper have also been shown to improve removal of certain constituents from stormwater runoff. Another approach employs modifications to the configuration of the bioretention system to retain a portion of the accumulated stormwater. This so-called *internal water storage (IWS)* design has been shown to reduce soluble nitrogen levels by inducing an anaerobic condition within the Bioretention facility itself. While this research looks promising, design specifications have not been developed to date. However, the Department recognizes that the technology in this field is evolving rapidly and encourages the use of the latest advances in science. Advanced systems will be evaluated on a case-by-case basis and assigned performance credits as deemed appropriate by the Department until formally adopted into these Standards and Specifications.

Practice Sizing: Bioretention will typically be sized to treat all or a portion of the RP_v, and can also partially meet the C_v through volume contained in the surface ponding area, soil media, and gravel reservoir layers of the practice. The following equations are provided to assist designers in determining an optimal sizing for the facility. However traditional sizing approaches using design volume, void ratio of the stone and biosoil media, etc. are also acceptable.

First, designers should calculate the total storage volume of the practice using **Equation 2.1**

Equation 2.1

$$Sv = SA_{filter} \times \left[\left(d_{media} \times \eta_{media} \right) + \left(d_{gravel} \times \eta_{gravel} \right) \right] + (SA_{p-1} + SA_{p-2}) / 2 \times d_{ponding} + Sv_{pretreatment}$$

Where:

Sv	=	total storage volume of practice (cu. ft.)
SA_{filter}	=	surface area of the top of the filter media (sq. ft.)
d_{media}	=	depth of the filter media (typically 2 ft)
η_{media}	=	effective porosity of the filter media (typically 0.4)
d_{gravel}	=	depth of the underdrain and underground storage gravel layer(ft)
η_{gravel}	=	effective porosity of the gravel layer (typically 0.4)
SA_{p-1}	=	surface area at the lowest elevation of the ponding area (sq. ft.) [Note SA_{p-1} may be no greater than 2X SA_{filter}]
SA_{p-2}	=	surface area at the depth of ponding
$d_{ponding}$	=	the maximum ponding depth of the practice (ft).
$Sv_{pretreatment}$	=	volume stored in pretreatment practices

Equation 2.1 can be modified if the storage depths of the biosoil media, gravel layer, or ponded water vary in the actual design or with the addition of any surface or subsurface storage components (e.g., additional area of surface ponding, subsurface storage chambers, etc.). The maximum depth of ponding in the Bioretention facility should not exceed 24 inches. If storage practices will be provided off-line or in series with the bioretention area, the storage practices should be sized using the guidance in ***Specification 10.0, Detention Practices***

Minimum Filter Surface Area

The filter should be designed with sufficient surface area to dewater within 48 hours (Equation 2.2). If the surface area used in Equation 2.1 is insufficient to allow for this drawdown time, the designer should increase the surface area of the practice, or adjust the value of Sv to reflect a volume that can be drawn down in this time.

Equation 2.2

$$SA_{filter} \geq \frac{\mathrm{Sv} \times d_{media}}{k \times t_d \times \left(d_{ponding}/2 + d_{media} \right)}$$

Where:

k	=	filtering media permeability (ft/day; typically assume 5.7)
t_d	=	drawdown time within the filter (2 days maximum)

Infiltration Volume:
The amount of stormwater that enters the stormwater practice can either be filtered and discharge through an underdrain, or be infiltrated. The volume infiltrated depends on the design variation and is calculated using Equations 2.3 or 2.4.

Infiltration Designs with an Underdrain and Sump
For designs with an underdrain, Bioretention practices must include a sump (i.e., storage below the underdrain, see figure 2.2). The volume stored in the sump is assumed to infiltrate within 48 hours for the purposes of Equation 2.3.

Equation 2.3

$$Sv_{infiltration} = SA_{filter} \times \min\left[\left(d_{sump} \times \eta_{gravel}\right), 2i\right]$$

Where:

$Sv_{infiltration}$	=	volume infiltrated through from the practice (cu. ft.)
d_{sump}	=	depth of underground storage gravel layer below the underdrain(ft)
i	=	field-measured infiltration rate for the native soils (ft./day)

Infiltration Designs
For practices without an underdrain, the volume infiltrated is equal to the entire storage volume, provided that the soil's infiltration rate is sufficient to infiltrate this volume within 48 hours (equation 2.4).

Equation 2.4

$$Sv_{infiltration} = \min\left(Sv, 2i\right)$$

Filtering Volume:
The volume treated by filtration (i.e., filtered through the practice medium and discharged through an underdrain), is defined as $Sv_{filtering}$, and is calculated using equation 2.5. Filtering alone is only acceptable for small-scale bioretention variants. For such designs, the filtering volume is equal to the total storage volume. However, the filter must be sized to achieve the minimum treatment volume.

Equation 2.5

$$Sv_{filtering} = Sv - Sv_{infiltration}$$

Ponding Volume:
During high intensity storm events, the bioretention practice will fill up faster than the collected stormwater is able to filter through the soil media. Consequently, it is critical to ensure that sufficient volume is ponded, or stored prior to the filter. The ponding volume is calculated in equation 2.6.

Equation 2.6

$$V_{ponding} = (SA_{p-1} + SA_{p-2}) / 2 \times d_{ponding} + Sv_{pretreatment}$$

Bioretention can be designed to address, in whole or in part, the detention storage needed to comply with conveyance and/or flood control requirements. The *Sv* can be discounted from the 10-yr or 100-yr runoff volumes to satisfy stormwater quantity control requirements.

2.7 Bioretention Landscaping Criteria

Landscaping is critical to the performance and function of bioretention areas. Therefore, a landscaping plan shall be provided for all Bioretention facilities.

Minimum plan elements should include the proposed bioretention template to be used, delineation of planting areas, the planting plan, including the size, the list of planting stock, sources of plant species, and the planting sequence, including post-nursery care and initial maintenance requirements. Planting plans must be prepared by a qualified professional.

Native plant species are preferred over non-native species, but some ornamental species may be used for landscaping effect if they are not aggressive or invasive. Some popular native species that work well in bioretention areas and are commercially available can be found in ***Appendix 2, Stormwater BMP Landscaping Criteria***.

The degree of landscape maintenance that will be provided will also determine some of the planting choices for urban bioretention areas. Plant selection differs if the area will be frequently mowed, pruned, and weeded, in contrast to a site which will receive minimum annual maintenance. In areas where less maintenance will be provided and where trash accumulation in shrubbery or herbaceous plants is a concern, consider a “turf and trees” landscaping model where the turf is mowed along with other turf areas on the site. Spaces for herbaceous flowering plants can be included

2.8 Bioretention Construction Sequence

Erosion and Sediment Controls. Bioretention facilities should be fully protected by silt fence or construction fencing. Ideally, Bioretention facilities should remain undisturbed during construction to prevent soil compaction by heavy equipment. Large Bioretention facilities may be used as small sediment traps or basins during construction. However, these must be accompanied by notes and graphic details on the Sediment & Stormwater Plan specifying that (1) the maximum excavation depth of the trap or basin at the construction stage must be at least 1 foot higher than the post-construction (final) invert (bottom of the facility), and (2) the bottom of the facility shall be ripped, tilled or otherwise scarified upon final excavation. If the facility is designed for infiltration, the original field-measured infiltration rate must be verified through retesting. The plan must also show the proper procedures for converting the temporary sediment control practice to a permanent Bioretention facility, including dewatering, cleanout and stabilization.

Bioretention Installation. The following is a typical construction sequence to properly install a Bioretention facility (also see **Figure 2.3**). The construction sequence for small-scale Bioretention is more simplified. These steps may be modified to reflect different Bioretention applications or expected site conditions:

Step 1. Construction of the Bioretention facility may only begin after the entire contributing drainage area has been stabilized with vegetation. It may be necessary to block certain curb or other inlets while the bioretention area is being constructed. The proposed site should be checked for existing utilities prior to any excavation.

Step 2. The designer and the installer should have a preconstruction meeting, checking the boundaries of the contributing drainage area and the actual inlet elevations to ensure they conform to original design. Since other contractors may be responsible for constructing portions of the site, it is quite common to find subtle differences in site grading, drainage and paving elevations that can produce hydraulically important differences for the proposed Bioretention facility. The designer should clearly communicate, in writing, any project changes determined during the preconstruction meeting to the installer and the plan review/inspection authority.

Step 3. Temporary erosion and sediment controls (e.g., diversion dikes, reinforced silt fence) are needed during construction of the Bioretention facility to divert stormwater away from the Bioretention facility until it is completed. Special protection measures such as erosion control fabrics may be needed to protect vulnerable side slopes from erosion during the construction process.

Step 4. Any pre-treatment cells should be excavated first.

Step 5. Excavators or backhoes should work from the sides to excavate the Bioretention facility to its appropriate design depth and dimensions. Excavating equipment should have adequate reach so they do not have to sit inside the footprint of the Bioretention facility. Contractors should use a cell construction approach in larger bioretention basins, whereby the basin is split into 500 to 1,000 sq. ft. temporary cells with a 10-15 foot earth bridge in between, so that cells can be excavated from the side.

Step 6. It may be necessary to rip or till the bottom soils to a depth of 6 to 12 inches to promote greater infiltration if a bucket without teeth is used for excavation.

Step 7. If a stone storage layer will be used for an underdrain design, place the appropriate depth of rice gravel on the bottom, install the perforated underdrain pipe, pack rice gravel to 3 inches above the underdrain pipe. A layer of rice gravel may also be necessary for an infiltrating design if the 24” biosoil media does not reach a permeable layer in the soil profile.

Step 8. The biosoil media must come from an approved supplier. If not used upon delivery, store it on an adjacent impervious area or plastic sheeting. Apply the media in 12-inch lifts until the desired top elevation of the Bioretention facility is achieved. Wait a few days to check for settlement, and add additional media, as needed, to achieve the design elevation. Sprinkling with water between lifts may reduce the amount of settling that occurs.

Step 9. Prepare planting holes for any shrubs and plants, install the vegetation, and water accordingly. Install any temporary irrigation.

Step 10. Place the surface cover in both cells (mulch, river rock, etc.), depending on the design. If stabilization matting will be used in areas that will be planted, the matting will need to be installed prior to planting (**Step 9**), and holes or slits will have to be cut in the matting to install the plants.

Step 11. Install the plant materials as shown in the landscaping plan, and water them during weeks of no rain for the first two months.

Step 12. If curb cuts or inlets are blocked during bioretention installation, unblock these after the drainage area and side slopes have good vegetative cover. It is recommended that unblocking curb cuts and inlets take place after two to three storm events if the drainage area includes newly installed asphalt, since new asphalt tends to produce a lot of fines and grit during the first several storms.

Step 13. Conduct the final construction inspection (see **below**), then log the GPS coordinates for each bioretention facility and submit them for entry into the local maintenance tracking database.

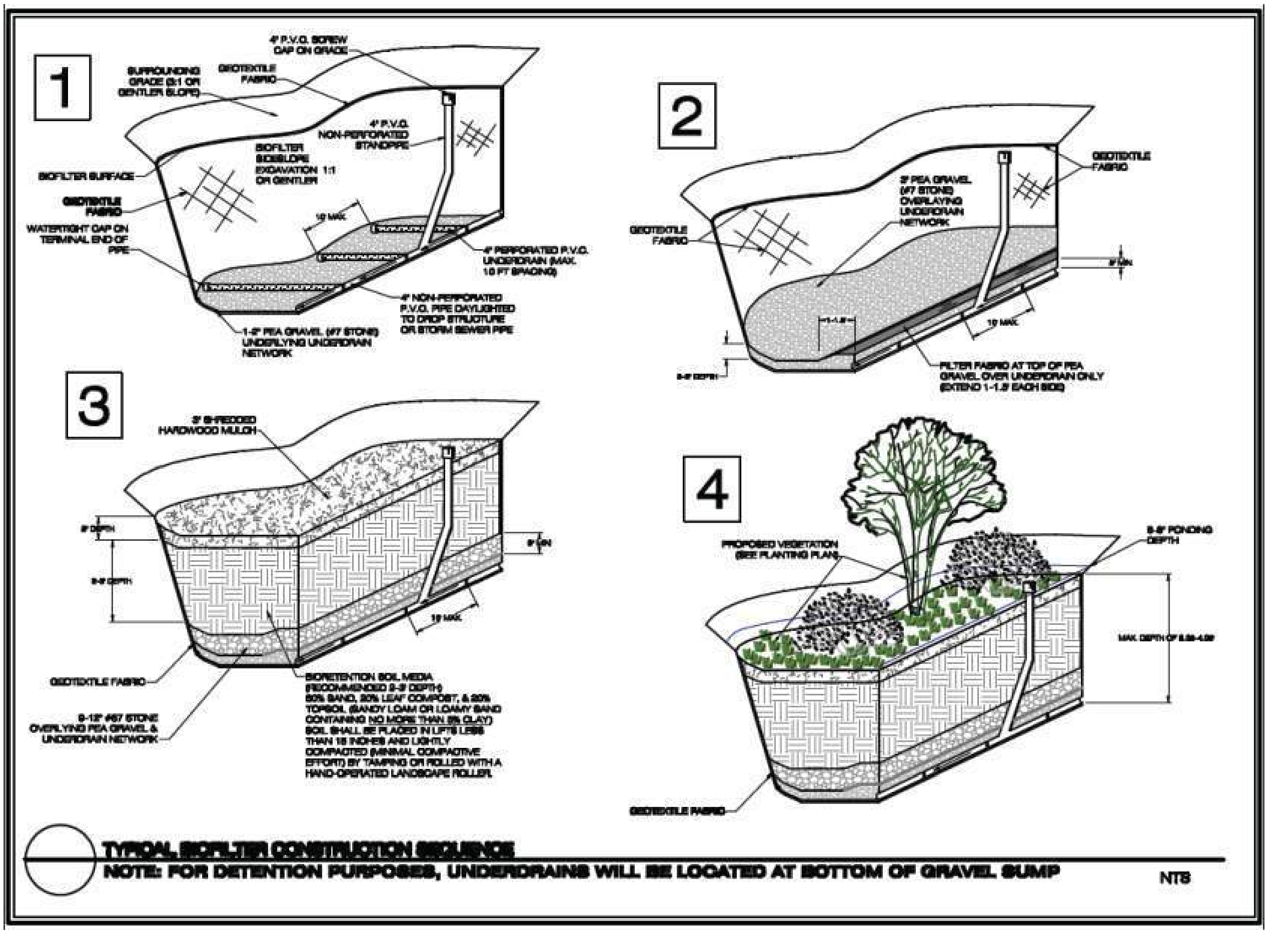

Figure 2.3. Typical Bioretention Construction Sequence

Construction Inspection. An example construction phase inspection checklist is available in the appropriate section of the Technical Document.

Post Construction Verification Documentation. The following items shall be included in the Post Construction Verification Documentation for Bioretention Practices:

- Surface dimensions of biosoil bed.
- Depth of biosoil media.
- Volume dimensions of any pre-treatment component.
- Elevations of any structural components, including inverts of pipes, weirs, etc.

2.9 Bioretention Maintenance Criteria

An Operation and Maintenance Plan for the project will be approved by the Department or the Delegated Agency prior to project closeout. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize the Department or

Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed. Bioretention Practices that are, or will be, owned and maintained by a joint ownership such as a homeowner's association must be located in common areas, community open space, community-owned property, jointly owned property, or within a recorded easement dedicated to public use.

Operation and Maintenance Plans should clearly outline how vegetation in the Bioretention Practice will be managed or harvested in the future. The Operation and Maintenance Plan should schedule a cleanup at least once a year to remove trash and debris.

Maintenance of Bioretention Practices is driven by annual maintenance reviews that evaluate the condition and performance of the practice. Based on maintenance review results, specific maintenance tasks may be required.

Table 2.6. Typical Bioretention Maintenance Items and Frequency

Frequency	Maintenance Items
During establishment, as needed (first year)	• Inspect the site after storm event that exceeds 0.5 inches of rainfall. • Stabilize any bare or eroding areas in the contributing drainage area including the Bioretention perimeter area • Water trees and shrubs planted in the Bioretention planting bed during the first growing season. In general, water every 3 days for first month, and then weekly during the remainder of the first growing season (April - October), depending on rainfall.
Quarterly or after major storms (>1 inch of rainfall)	• Remove debris and blockages • Repair undercut, eroded, and bare soil areas
Twice a year	• Mowing of the Bioretention vegetated perimeter area and banks (as directed in approved O&M plan)
Annually	• Cleanup to remove trash, debris and floatables • A full maintenance review • Check condition of outlet structure • Repair broken mechanical components, if needed
One time –during the second year following construction	• Bioretention planting bed replacement/reinforcement plantings
Every 5 to 7 years	• Forebay sediment removal (as applicable) • Flush underdrain system (as applicable)
From 5 to 25 years	• Repair pipes, outlet structure and spillway, as needed • Remove any accumulated sediment within facility, as needed

2.10 References

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3.0 Permeable Pavement Systems

Definition: Paving surfaces that capture and temporarily store stormwater by filtering runoff through voids in the pavement surface into an underlying reservoir. Filtered runoff may be collected and returned to the conveyance system, or allowed to infiltrate into the soil.

Design variants include:

- 3-A Porous Asphalt (PA)
- 3-B Pervious Concrete (PC)
- 3-C Permeable interlocking concrete Pavers (PP) or Concrete grid Pavers (CP)
- 3-D Plastic Grid Pavers (GP)

Other variations of permeable pavement that are DNREC approved permeable pavement surface materials are also encompassed in this section.

Permeable pavement systems may be designed to provide stormwater detention for all design storm events. Permeable pavement practices that are unable to infiltrate all design storms are often combined with a separate facilities to provide controls for larger runoff events.

Regardless of which design variant is chosen, the runoff reduction credit applied to the practice is the volume of runoff that is being stored in the reservoir layer underneath the permeable pavement and infiltrated over a period of 48-hours. It is recommended that an underdrain and control structure be constructed within the reservoir for long term maintenance and facility inspections.

The particular design configuration to be implemented on a site is typically dependent on specific site conditions and the characteristics of the native soils.

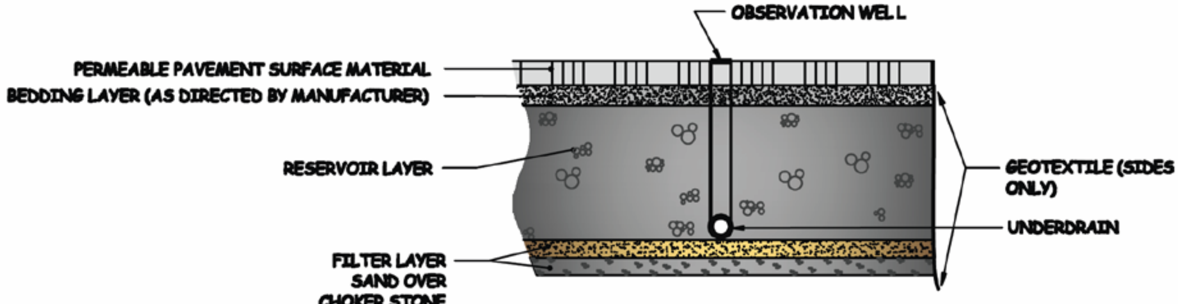

FIGURE 3.1: PERMEABLE PAVEMENT WITH UNDERDRAIN

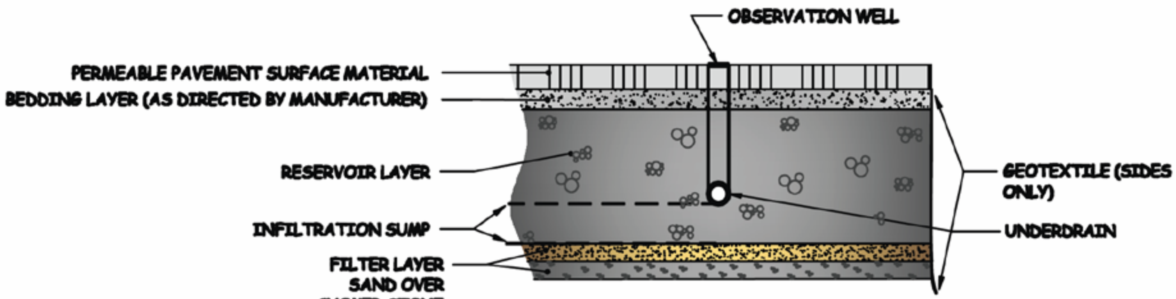

FIGURE 3.2: PERMEABLE PAVEMENT WITH UNDERDRAIN AND SUMP

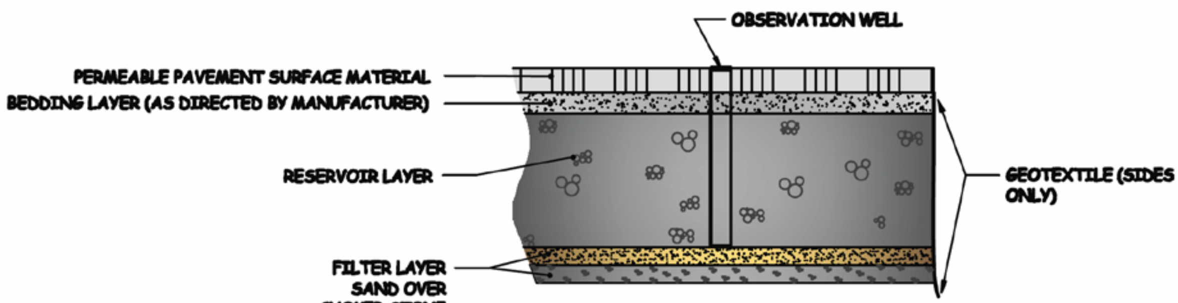

FIGURE 3.3: PERMEABLE PAVEMENT WITHOUT UNDERDRAIN

3.1 Permeable Pavement Stormwater Credit Calculations

The retention volume credit for permeable pavement depends on the volume of runoff that is infiltrated from this practice (Table 3.1).

3.1 Permeable Pavement Performance Credits

Runoff Reduction	
Retention Allowance	100%
RPv -A/B Soil	100% of Retention Storage
RPv - C/D Soil	100% of Retention Storage
Cv	100% of Retention Storage
Fv	100% of Retention Storage
Pollutant Reduction	
TN Reduction	100% of Load Reduction
TP Reduction	100% of Load Reduction
TSS Reduction	100% of Load Reduction

The practice must be sized using the guidance detailed in ***Section 3.6. Permeable Pavement Design Criteria.***

3.2 Permeable Pavement Design Summary

Table 3.2 summarizes design criteria for permeable pavement, and Tables 3.3 and 3.4 summarize the materials specifications for this practice. For more detail, consult Sections 3.3 through 3.7. Sections 3.8 and 3.9 describes practice construction and maintenance criteria.

Table 3.2 Permeable Pavement Design Summary

Feasibility (Section 3.3)	• Minimum soil infiltration of 1"/hr, unless an underdrain is used • External drainage close to 100% impervious • Pavement surface < 3% slope • Minimum 2' separation to seasonal high groundwater, unless an underdrain is used. If an underdrain is used the seasonal high groundwater shall not enter into the reservoir • Cannot treat hotspots or areas with high pollutant loads • Cannot treat high speed roads • Setbacks from wells, buildings and utilities (Table 3.5)
Conveyance (Section 3.4)	• Safely convey Cv and Fv design storms
Pretreatment (Section 3.5)	• Not needed
Sizing (Reservoir Layer Depth) (Section 3.6)	$$d_p = \frac{\{(d_c \times R) + P - (\frac{1}{2} i \times t_f)\}}{\eta_r}$$
Variables:	d_p = Depth of the reservoir layer (ft.) d_c = Depth of runoff from the contributing drainage area (not including the permeable pavement surface) for the design storm (ft.) R = A_c/A_p = The ratio of the contributing drainage area (A_c) (not including the permeable pavement surface) to the permeable pavement surface area (A_p) P = The rainfall depth for the design storm (ft.) i = The field-verified infiltration rate for the native soils (ft./day). If an impermeable liner is used in the design then i = 0. t_f = The time to fill the reservoir layer (day) – assume 1 day η_r = The effective porosity for the reservoir layer (0.4)
Landscaping (Section 3.7)	Not applicable

Material Specifications: Permeable pavement material specifications vary according to the specific pavement product selected. A general comparison of different permeable pavements is provided in **Table 3.3**, but designers should consult manufacturer's technical specifications for specific criteria and guidance.

Table 3.3. Different Permeable Pavement Specifications

Material	Specification	Notes
Permeable Interlocking Concrete Pavers (PP)	Surface open area: 5% to 15%. Thickness: 3.125 inches for vehicles. Compressive strength: 55 Mpa. Open void fill media: aggregate	Must conform to ASTM C936 specifications. Reservoir layer required to support the structural load.
Concrete Grid Pavers (CP)	Open void content: 20% to 50%. Thickness: 3.5 inches. Compressive strength: 35 Mpa. Open void fill media: aggregate, topsoil and grass, coarse sand.	Must conform to ASTM C 1319 specifications. Reservoir layer required to support the structural load.
Plastic Reinforced Grid Pavers (GP)	Void content: depends on fill material. Compressive strength: varies, depending on fill material. Open void fill media: aggregate, topsoil and grass, coarse sand.	Reservoir layer required to support the structural load.
Pervious Concrete (PC)	Void content: 15% to 25 %. Thickness: typically 4 to 8 inches. Compressive strength: 2.8 to 28 Mpa. Open void fill media: None	May not require a reservoir layer to support the structural load.
Porous Asphalt (PA)	Void content: 15% to 20 %. Thickness: typically 3 to 7 in. (depending on traffic load). Open void fill media: None.	Reservoir layer required to support the structural load.

Table 3.4 describes general material specifications for the component structures installed beneath the permeable pavement. Note that the size of stone materials used in the reservoir and filter layers may differ depending on the type of surface material.

Table 3.4. Material Specifications for Underneath the Pavement Surface

Material	Specification	Notes
Bedding Layer	PP: 2 in. depth of No. 8 stone over 3 to 4 inches of No. 57 stone PC: None PA: 2 in. depth of No. 8 stone	ASTM D448 size No. 8 stone (e.g., 3/8 to 3/16 inch in size). Should be double-washed and free of all fines.
Reservoir Layer	PP: No. 57 stone PC: No. 57 stone PA: No. 2 stone	ASTM D448 size No. 57 stone (e.g. 1 1/2 to 1/2 inch in size); No. 2 Stone (e.g. 3 inch to 3/4 inch in size). Depth is based on the pavement structural and hydraulic requirements. Should be double-washed and clean and free of all fines. The reservoir layer shall be at least 6” deep.
Underdrain	Use 4 to 6 inch diameter perforated PVC pipe (or equivalent corrugated HDPE may be used for smaller load-bearing applications), with 3/8-inch perforations at 6 inches on center. Perforated pipe installed for the full length of the permeable pavement cell, and non-perforated pipe, as needed, is used to connect with the storm drain system. T’s and Y’s installed as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface with vented caps at the Ts and Ys.	
Infiltration Sump	An aggregate storage layer below the underdrain invert. The depth of the reservoir layer above the invert of the underdrain must be at least 12 inches. The material specifications are the same as Reservoir Layer.	
Filter Layer (optional)	The underlying native soils may require separation from the stone reservoir by a thin layer of choker stone as determined by geotechnical investigation.	The choker stone layer should be a minimum of 1” thick, and a minimum of 1” per foot of reservoir depth.
Non-woven Geotextile (optional)	Use a needled, non-woven, polypropylene geotextile with a Flow Rate greater than 125 gpm/sq. ft. (ASTM D4491), and an Apparent Opening Size (AOS) equivalent to a US # 70 or # 80 sieve (ASTM D4751).	
Observation Well	Use a perforated 4 to 6 inch vertical PVC pipe (AASHTO M 252) with a lockable cap, installed flush with the surface or just beneath PP.	

3.3 Permeable Pavement Feasibility Criteria

Since permeable pavement has a very high runoff reduction capability, it should always be considered as an alternative to conventional pavement. Permeable pavement is subject to the same feasibility constraints as most infiltration practices, as described below.

Required Space. A prime advantage of permeable pavement is that it does not normally require additional space at a new development or redevelopment site, which can be important for tight sites or areas where land prices are high.

Soils. Soil conditions do not typically constrain the use of permeable pavement, although they do determine whether an underdrain is needed. Underdrains are required if the measured permeability of the native soils is less than 1.0 in/hr, per the on-site soil investigation methods provided in ***Appendix 1***.

External Drainage Area. Any external drainage area contributing runoff to permeable pavement should never exceed five times the surface area of the permeable pavement (two times is recommended), and it should be as close to 100% impervious as possible.

Pavement Surface Slope. Steep pavement surface slopes can reduce the stormwater storage capability of permeable pavement and may cause shifting of the pavement surface and base materials. Designers should use a terraced design for permeable pavement when the local slope is 3 percent or greater.

Pavement Bottom Slope. The bottom slope of a permeable pavement installation should be as flat as possible (i.e., 0% longitudinal and lateral slopes) to enable even distribution and infiltration of stormwater. On sloped sites, internal check dams or terraces can be incorporated into the subsurface to encourage infiltration. If an underdrain is used, low-grade longitudinal slopes are permissible on a case-by-case basis.

Minimum Hydraulic Head. The elevation difference needed for permeable pavement to function properly is generally nominal.

Minimum Depth to Water Table. A minimum vertical distance of 2 feet must be provided between the bottom of the permeable pavement installation (i.e., the bottom invert of the reservoir layer) and the seasonal high water table if an underdrain system is not used. If an underdrain is used, the seasonal high groundwater may not encroach into the reservoir layer.

Setbacks. To avoid the risk of seepage, permeable pavement practices should not be hydraulically connected to structure foundations. Setbacks to structures vary based on the size of the permeable pavement installation (Table 3.5)

Table 3.5. Setbacks for Permeable Pavement

Pavement Area	Buildings		Wells/ Utilities
	Up-Gradient	Down-Gradient	
250 to 1,000 sf	5’	25’	100’ from wells 5’ down-gradient from utility lines
1,000 to 10,000 sf	10’	50’	
>10,000 sf	25’	100’	
*Note: In some cases, the use of an impermeable liner along the sides of the permeable pavement practice (extending from the surface to the bottom of the reservoir layer) may be used as an added precaution against seepage, and the setback requirements may be removed or relaxed on a case-by-case basis.			

Hotspot Land Uses. Permeable pavements should not be used to treat hotspot runoff. For a list of potential stormwater hotspot operations, consult ***Appendix 4***.

High Pollutant Loading Situations. Permeable pavement is not intended to treat sites with sediment or trash/debris loads, since such loads will cause the practice to clog and fail. Sites with significant pervious area (newly established turf and landscaping) are considered high loading sites and the pervious areas should be diverted from the permeable pavement area. If unavoidable, an increased maintenance schedule to check for clogging may be required on a case-by-case basis.

High Speed Roads. Permeable pavement is recommended for sidewalks, driveways, residential streets, parking areas, shoulders, and gutter sections. Permeable pavement should not be used for high speed roads with prior approval from DelDOT or other applicable roadway agency.

3.4 Permeable Pavement Conveyance Criteria

Permeable pavement designs should include methods to convey larger storms (e.g., Cv, Fv) to other stormwater management facilities. The following is a list of methods that can be used to accomplish this:

- Place an underdrain in the bottom of the reservoir layer and attached to a control structure, designed to pass excess flows after water has filled the reservoir layer.
- Place an over flow pipe; a perforated pipe horizontally near the top of the reservoir layer, to pass excess flows after stormwater has filled the reservoir layer.
- Increase the thickness of the reservoir layer to increase storage (i.e., create freeboard) to accommodate the Cv and Fv events.
- Create additional underground detention within the reservoir layer of the permeable pavement system using structural void space. Reservoir storage may be augmented by plastic or concrete arch structures, etc.
- Route excess flows to another detention or conveyance system that is designed for the management of greater event flows.
- Set the storm drain inlets flush with the elevation of the permeable pavement surface to effectively convey excess stormwater runoff past the system. The design should also make allowances for relief of unacceptable ponding depths during larger rainfall events.

3.5 Permeable Pavement Pretreatment Criteria

Pretreatment for most permeable pavement applications is not necessary, since the surface acts as pretreatment to the reservoir layer below. Pretreatment is necessary if the pavement receives run-on from adjacent pervious areas. For example, a gravel or grass buffer strip can be placed adjacent to pervious (landscaped) areas to trap coarse sediment particles before they reach the pavement surface, in order to minimize clogging.

3.6 Permeable Pavement Design Criteria

Type of Surface Pavement: The type of pavement should be selected based on a review of the pavement specifications and properties, and designed according to the product manufacturer's recommendations.

Internal Geometry and Drawdowns:

- **Rapid Drawdown.** Permeable pavement should be designed so that the target storage volume is detained in the reservoir for as long as possible – up to 48 hours - before completely discharging through infiltration. An underdrain attached to a control structure with a minimum orifice size of 0.5" (recommended regardless of the calculated drawdown time) may also be employed. Runoff Reduction retention volumes will only be based off of runoff infiltrated.
- **Infiltration Sump.** To promote greater runoff reduction for permeable pavement located on marginal soils, an infiltration sump can be installed to create a storage layer below the underdrain invert.
- **Conservative Infiltration Rates.** Designers should always decrease the measured infiltration rate by a factor of 2 during design, to approximate long term infiltration rates.

Reservoir layer: The reservoir layer consists of the stone underneath the pavement section and above the bottom filter layer or underlying soils. The total thickness of the reservoir layer is determined by runoff storage needs, the infiltration rate of native soils, structural requirements of the pavement sub-base, depth to the seasonal high water table and bedrock, and frost depth conditions. A geotechnical engineer should be consulted regarding the suitability of the soil subgrade.

- The reservoir layer should be composed of clean, double-washed stone aggregate and sized for both the storm event to be treated and the structural requirements of the expected traffic loading.
- The reservoir layer should consist of clean double-washed Delaware No. 3 stone, unless a specific site constraint or structural concern requires different stone sizing.
- The bottom of the reservoir layer should be completely flat so that runoff will be able to infiltrate evenly through the entire surface. For sites with native slope that do not allow for a flat bottom, the bottom should either be terraced or check dams should be installed.

Underdrains: Most permeable pavement designs will require an underdrain (see **Section 3.3**). Underdrains can also be used to keep detained stormwater from flooding permeable pavement during extreme events. Flat terrain may affect proper drainage of permeable pavement designs, so underdrains should have a minimum 0.5% slope. Underdrains should be located 20 feet or less from the next pipe. The underdrain should be perforated schedule 40 PVC pipe, with 3/8-inch perforations at 6 inches on center, or corrugated HDPE depending on load-bearing application. The underdrain should be encased in a layer of clean, washed No.57 stone with a minimum of 2" of stone below the underdrain pipe. The underdrain system should include a flow control to ensure that the reservoir layer drains slowly; however it should completely drain within 48 hours.

- The underdrain outlet can be fitted with a flow-reduction orifice within a weir or other easily inspected and maintained configuration in the downstream manhole as a means of regulating the stormwater detention time. The minimum diameter of any orifice should be 0.5 inch. The designer will verify that the volume will draw down completely within 48 hours

- For infiltration designs, an underdrain(s) can be installed into a control structure that has an outlet higher than the underdrain inlet in order to promote the full infiltration volume, while still allowing for overflow within the system. In this scenario, a lower capped drain should also be installed for future maintenance.
- Alternatively, an underdrain(s) can be installed and capped at the downstream structure for future use if maintenance observations indicate a reduction in the soil permeability.

All permeable pavement practices should include observation wells. The observation well is used to observe the rate of drawdown within the reservoir layer following a storm event and to facilitate periodic inspection and maintenance. The observation wells should consist of a well-anchored, perforated 4 to 6 inch (diameter) PVC pipe that is tied into the underdrain system. The well should extend vertically to the bottom of the reservoir layer and extend upwards to be flush with the surface (or just under pavers) with a lockable cap. In addition, cleanout pipes should be provided if the pavement surface area exceeds 1,000 sq. ft.

Infiltration Sump (optional): An optional upturned elbow, elevated underdrain, or other control structure configuration can be used to promote greater runoff reduction for permeable pavement located on marginal soils (see Figure 3.2). The Infiltration Sump allows for the design of infiltration reservoirs even in marginal soils. The depth of the reservoir layer above the invert of the underdrain must be at least 12 inches. The depth of th infiltration sump is sized so that the design storm can infiltrate into the native soil within a 48 hour period. If no underdrain is employed, the bottom of infiltration sump must be at least 2 feet above the seasonal high water table. The inclusion of an infiltration sump is not permitted for designs with an impermeable liner.

Filter Layer (optional): To protect the bottom of the reservoir layer from intrusion by underlying soils, a filter layer is required in marginal soils. The native soils should be separated from the stone reservoir by a thin, (minimum 1”, or 1”/foot of reservoir) layer of choker stone (No. 8 or approved equal).

Non-woven Geotextile (optional): Non-woven filter fabric is not recommended for the bottom of the reservoir layer as filter fabric can become a future plane of clogging within the system. Permeable non-woven filter fabric is still recommended to protect the excavated sides of the reservoir layer, in order to prevent soil piping. A needled, non-woven, polypropylene geotextile with a Flow Rate greater than 125 gpm/sq. ft. (ASTM D4491), and an Apparent Opening Size (AOS) equivalent to a US # 70 or # 80 sieve (ASTM D4751). The geotextile AOS selection is based on the percent passing the No. 200 sieve in “A” soil subgrade, using FHWA or AASHTO selection criteria.

Impermeable Liner (optional): This material should be used only for appropriate fill applications where deemed necessary by a geotechnical investigation. Use a thirty mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd. non-woven geotextile. The usage of an impermeable liner precludes any runoff reduction from the permeable pavement. However, the system may still be employed as a stormwater capturing and routing facility particularly in densely urban areas.

Permeable Pavement Sizing: The thickness of the reservoir layer is determined by both a structural and hydraulic design analysis. The reservoir layer serves to retain stormwater and also supports the design traffic loads for the pavement. Permeable pavement structural and hydraulic sizing criteria are discussed below:

Structural Design. The pavement surface must be able to support the maximum anticipated traffic load. The structural design process will vary according to the type of pavement selected, and the manufacturer's specific recommendations. The thickness of the permeable pavement and reservoir layer must be sized to support structural loads and to temporarily store and then infiltrate the design storm volume (e.g., the water quality, channel protection, and/or flood control volumes). On most new development and redevelopment sites, the structural support requirements will dictate the depth of the underlying stone reservoir.

The structural design of permeable pavements involves consideration of four main site elements:

- Total traffic;
- Native soil strength;
- Environmental elements; and
- Bedding and Reservoir layer design.

The resulting structural requirements may include, but are not limited to, the thickness of the pavement, filter, and reservoir layer. Designers should note that if the native soils have a California Bearing Ratio (CBR) less than 4%, they may need to be compacted to at least 95% of the Standard Proctor Density, which generally rules out their use for infiltration. As such, if the underlying soils are found to be sub-standard an additional amount of subsoil may need to be excavated and replaced to increase the structural capacity of the system.

Designers should determine structural design requirements by consulting transportation design guidance sources, such as the following:

- AASHTO Guide for Design of Pavement Structures (1993); and,
- AASHTO Supplement to the Guide for Design of Pavement Structures (1998).

Hydraulic Design. Permeable pavement is typically sized to store stormwater runoff in the reservoir layer. The storage volume in the permeable pavement system must account for the underlying infiltration rate and flow through any underdrain or overflow structure. The design storm is routed through the pavement to accurately determine the required reservoir depth.

The depth of the reservoir layer or infiltration sump needed to store the design storm can be determined by using **Equation 3.1**.

Equation 3.1

$$d_p = \frac{\{(d_c \times R) + P - (\frac{1}{2} i \times t_f)\ \}}{\eta_r}$$

Where:

d_p	=	Depth of the reservoir layer (ft.)
d_c	=	Depth of runoff from the contributing drainage area (not including the permeable pavement surface) for the design storm (ft.)
R	=	A_c/A_p = The ratio of the contributing drainage area (A_c) (not including the permeable pavement surface) to the permeable pavement surface area (A_p)
P	=	The rainfall depth for the design storm (ft.)
i	=	The field-verified infiltration rate for the native soils (ft./day). If an impermeable liner is used in the design then i = 0.
t_f	=	The time to fill the reservoir layer (day) – assume 24 hours or 1 day
η_r	=	The effective porosity for the reservoir layer (0.4)

This equation makes the following design assumptions:

- The contributing drainage area (A_c) does not contain pervious areas.
- For design purposes, the field-tested subgrade soil infiltration rate (i) is divided by 2 as a factor of safety to account for potential compaction during construction. If the native soil will be compacted to meet structural design requirements of the pavement section, the design infiltration rate of the subgrade soil shall be based on measurement of the infiltration rate of the subgrade soil subjected to the compaction requirements.

For design with underdrains, calculate the drawdown times using the hydrological routing or modeling procedures used for detention systems with the depth and head adjusted for the porosity of the aggregate to ensure that the practice will draw down within 48 hours.

The depth of the reservoir layer cannot be less than the depth required to meet the pavement structural requirement. The depth of the reservoir layer may need to be increased to meet structural or larger storage requirements, and shall always be a minimum of 6” deep.

For crediting purposes (see ***Section 3.1 Permeable Pavement Stormwater Credit Calculations***), the total storage volume provided by the practice, *Sv*, should be determined using **Equation 3.2.**

Equation 3.2.

$$Sv = d_p \times \eta_r \times A_p$$

Depending on the design option, all or a portion of the design volume will be designed to infiltrate, as calculated using Equation 3.3. This equation also ensures that the volume credited with infiltration will draw down within 48 hours. This equation also assumes that the measured soil infiltration rate is divided by 2 due to compaction during construction.

Equation 3.3.

$$Sv_{\inf iltration} = \min(d_s \times \eta_r, i) \times A_p$$

Where:

$Sv_{infiltration}$ = Volume designed to infiltrate through the porous pavement section.

d_s = depth of the sump or, for designs without an underdrain, depth of the reservoir

Some of the volume stored in the infiltration practice is not designed to infiltrate, but is contained within the reservoir, during which time a portion of the volume is evaporated, or detained for a long period. Although the volume calculated as filtering can be equal to the entire storage volume minus the amount infiltrated, no more than 1" of storage within this reservoir can be considered in crediting this practice. This volume is calculated using equation 3.4.

Equation 3.4.

$$Sv_{filtering} = \min\left(Sv - Sv_{\inf iltration}, A_p \times 3{,}630\right)$$

Detention Storage Design: Permeable pavement can also be designed to address, in whole or in part, the detention storage needed to comply with Cv and/or Fv requirements. Various approaches can be modeled by factoring in storage within the stone aggregate layer, expected infiltration, and any outlet structures used as part of the design. Routing calculations can also be used to provide a more accurate solution of the peak discharge and required storage volume.

Once runoff passes through the surface of the permeable pavement system, designers should calculate outflow pathways to handle subsurface flows. Subsurface flows can be regulated using underdrains, the volume of storage in the reservoir layer, the bed slope of the reservoir layer, and/or a control structure at the outlet (see ***Section 3.4 Permeable Pavement Conveyance Criteria***).

3.7 Permeable Pavement Landscaping Criteria

Permeable pavement does not have any landscaping needs associated with it. However, large-scale permeable pavement applications should be carefully planned to integrate the typical landscaping features of a parking lot (such as trees and islands) in a manner that maximizes runoff treatment and minimizes the risk that sediment, mulch, grass clippings, leaves, nuts, and fruits will inadvertently clog the paving surface.

3.8 Permeable Pavement Construction Sequence

Experience has shown that proper installation is absolutely critical to the effective operation of a permeable pavement system.

Erosion and Sediment Controls. The following erosion and sediment control guidelines must be followed during construction:

- All permeable pavement areas should be fully protected from sediment intrusion by silt fence or construction fencing to prevent construction traffic tracking.
- Permeable pavement areas should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. Permeable pavement areas should be clearly marked on all construction documents and grading plans. To prevent soil compaction, heavy vehicular and foot traffic should be kept out of permeable pavement areas during and immediately after construction. If compaction occurs, an additional geotechnical investigation may be required to determine that the native soils are still capable of infiltrating. All stormwater calculations will need to be revised to match the revised compacted native soil infiltration capacity.
- During construction, care must be taken to avoid tracking sediments onto any permeable pavement surface to avoid clogging.
- Areas intended to be permeable pavement shall not be used as a temporary sediment basin. When locating a sediment basin on an area intended for permeable pavement is unavoidable, the invert of the sediment basin must be a minimum of 1 foot above the final design elevation of the bottom of the reservoir course. All sediment deposits in the excavated area shall be carefully removed prior to installing the subbase.

Permeable Pavement Installation. The installation of permeable pavement systems should follow the manufacturers recommended guidelines. The following is a typical construction sequence, which will be modified per manufacturer's recommendations:

Step 1. Construction of the permeable pavement shall only begin after the entire contributing drainage area has been stabilized. The proposed site should be checked for existing utilities prior to any excavation. Do not install the system in rain or snow, and do not install frozen bedding materials.

Step 2. As noted above, temporary erosion and sediment controls are needed during installation to divert stormwater away from the permeable pavement area until it is completed. Additional protective measures such as erosion control fabrics may be needed to protect vulnerable side slopes from erosion during the excavation process. The proposed permeable pavement area must be kept free from sediment during the entire construction process. Construction materials contaminated by sediments must be removed and replaced with clean materials.

Step 3. Heavy equipment should work from the sides to excavate the reservoir layer to its appropriate design depth and dimensions to minimize compaction of the subsoil. For small pavement applications, excavating equipment should have arms with adequate extension so they do not have to work inside the footprint of the permeable pavement area. For larger pavement applications, contractors can utilize a cell construction approach, whereby the proposed permeable pavement area is split into 500 to 1000 sq. ft. temporary cells with a 10 to 15 foot earth bridge in between, so cells can be excavated from the side. Excavated material should be placed away from the open excavation so as to not jeopardize the stability of the side walls.

Step 4. The native soils along the bottom of the permeable pavement system should be scarified or tilled to a depth of 3 to 4 inches.

Step 5. Provide a minimum of 2 inches of aggregate above and below the underdrain. The underdrain should slope towards the outlet at a grade of 0.5% or steeper. The up-gradient ends of the underdrain should be capped. Where an underdrain pipe is connected to a structure, there shall be no perforations within 1 foot of the structure. There are to be no perforations in the clean-outs and observation wells within 1 foot of the surface.

Step 6. Spread 6-inch lifts of the appropriate washed stone aggregate (Delaware No. 3 or approved equal). Place at least 2 inches of additional aggregate cover above the underdrain, and then compact until there is no visible movement of the aggregate, but do not crush the aggregate with the compaction equipment.

Step 7. Install the bedding layer, per manufacturer's recommendations.

Step 8. Paving materials shall be installed in accordance with manufacturer, industry, or engineer's specifications for the particular type of pavement. Examples as shown below:

- **Installation of Porous Asphalt.** The following has been excerpted from various documents, most notably Jackson (2007).
  - Install porous asphalt pavement similarly to regular asphalt pavement. The pavement should be laid in a single lift over the bedding course. The laying temperature should be between 230^{o}F and 260^{o}F, with a minimum air temperature of 50^{o}F.
  - Complete compaction of the surface course when the surface is cool enough to resist a 10-ton roller. One or two passes of the roller are required for proper compaction. More rolling could cause a reduction in the porosity of the pavement.
  - The mixing plant must provide certification of the aggregate mix, abrasion loss factor, and asphalt content in the mix. Test the asphalt mix for its resistance to stripping by water using ASTM 1664.
  - Transport the mix to the site in a clean vehicle with smooth dump beds sprayed with a non-petroleum release agent. The mix shall be covered during transportation to control cooling.
  - Test the permeability of the pavement surface by application of clean water at a rate of at least five gallons per minute over the entire surface. All water must infiltrate directly, without puddle formation or surface runoff.
  - Inspect the facility 18 to 30 hours after a rainfall greater than 1/2 inch, to determine if the facility is draining properly.

- **Installation of Pervious Concrete.** The basic installation sequence for pervious concrete is outlined by the American Concrete Institute (2008). It is strongly recommended that concrete installers successfully complete a recognized pervious concrete installers training program, such as the Pervious Concrete Contractor Certification Program offered by the NRMCA. The basic installation procedure is as follows:

- Drive the concrete truck as close to the project site as possible.
- Water the underlying aggregate (reservoir layer) before the concrete is placed, so the aggregate does not draw moisture from the freshly laid pervious concrete.
- After the concrete is placed, approximately 3/8 to 1/2 inch is struck off, using a vibratory screed to allow for compaction.
- Compact the pavement with a steel pipe roller per manufacturer's recommendation.
- Cut joints for the concrete to a depth of 1/4 inch.
- The curing process is very important for pervious concrete. Cover the pavement with plastic sheeting within 20 minutes of the strike-off, and keep it covered for at least seven (7) days. Do not allow traffic on the pavement during this time period.
- Remove the plastic sheeting only after the proper curing time. Inspect the facility 18 to 30 hours after a rainfall greater than 1/2 inch, to determine if the facility is draining properly.

- **Installation of Permeable Interlocking Concrete Pavers.** The basic installation process is described in greater detail by Smith (2006).
  - Place edge restraints for open-jointed pavement blocks before the bedding layer and pavement blocks are installed. Permeable interlocking concrete pavement (IP) systems require edge restraints to prevent vehicle loads from moving the paver blocks. Edge restraints may be standard curbs or gutter pans, or precast or cast-in-place reinforced concrete borders a minimum of 6 inches wide and 18 inches deep, constructed with Class A3 concrete. Edge restraints along the traffic side of a permeable pavement block system are recommended.
  - Place the No. 57 stone in a single lift. Level the filter course and compact it into the reservoir course beneath with at least four (4) passes of a 10-ton steel drum static roller until there is no visible movement. The first two (2) passes are in vibratory mode, with the final two (2) passes in static mode. The filter aggregate should be moist to facilitate movement into the reservoir course.
  - Place and screed the bedding course material (typically No. 8 stone).
  - Fill gaps at the edge of the paved areas with cut pavers or edge units. Cut pavers no smaller than one-third (1/3) of the full unit size.
  - Fill the joints and openings with stone. Joint openings must be filled with ASTM D 448 No. 8 stone, although No. 8P or No. 9 stone may be used where needed to fill narrower joints.
  - Compact and seat the pavers into the bedding course with a minimum low-amplitude 5,000-lbf, 75- to 95-Hz plate compactor.
  - Do not compact within 6 feet of the unrestrained edges of the pavers.
  - The system must be thoroughly swept by a mechanical sweeper or vacuumed immediately after construction to remove any sediment or excess aggregate.
  - Inspect the area for settlement. Any blocks that settle must be reset and re-inspected.
  - Inspect the facility 18 to 30 hours after a rainfall greater than 1/2 inch, to determine if the facility is draining properly.

Construction Inspection. Inspections before, during and after construction are needed to ensure permeable pavement is built in accordance with these specifications. Use detailed inspection checklists that require sign-offs by qualified individuals at critical stages of construction, to ensure the contractor's interpretation of the plan is consistent with the designer's intent. An example construction phase inspection checklist for permeable pavement practices can be found in ***Article 4.***

Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of permeable pavement installation:

- Store materials in a protected area to keep them free from mud, dirt, and other foreign materials.
- The contributing drainage area should be stabilized prior to directing water to the permeable pavement area.
- Check the aggregate material to confirm it is double washed, meets specifications and is installed to the correct depth.
- Check elevations (e.g., the invert of the underdrain, inverts for the inflow and outflow points, etc.) and the surface slope.
- Make sure the permeable pavement surface is even and the storage bed drains within 48 hours.
- Ensure caps are placed on the upstream end of the underdrain.
- Inspect any pretreatment structures to make sure they are properly installed and working effectively.
- Once the final construction inspection has been completed, log the GPS coordinates for each facility and submit them for entry into the local BMP maintenance tracking database.

It is recommended to divert the runoff from the first few runoff-producing storms away from larger permeable pavement applications, particularly when up-gradient conventional asphalt areas drain to the permeable pavement. This can help reduce the input of fine particles often produced shortly after conventional asphalt is laid down.

3.9 Permeable Pavement Maintenance Criteria

Maintenance is a crucial element to ensure the long-term performance of permeable pavement. The most frequently cited maintenance problem is surface clogging caused by organic matter and sediment. Periodic street sweeping will remove accumulated sediment and help prevent clogging, however, it is also critical to ensure that surrounding land areas remain stabilized.

The following tasks must be avoided on ALL permeable pavements:

- sanding
- re-sealing
- re-surfacing
- power washing

- storage of snow piles containing sand
- storage of mulch or soil materials
- construction staging

An Operation and Maintenance Plan for the project shall be approved by DNREC or the Delegated Agency prior to project closeout. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize DNREC or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed. Permeable Pavement practices that are, or will be, owned and maintained by a joint ownership such as a homeowner's association must be located in common areas, community open space, community-owned property, jointly owned property, or within a recorded easement dedicated to public use.

Maintenance of Permeable Pavement practices is driven by annual maintenance reviews that evaluate the condition and performance of the practice. Based on maintenance review results, specific maintenance tasks may be required.

Recommended maintenance tasks are outlined in **Table 3.6**.

Table 3.6. Recommended maintenance tasks for permeable pavement practices.

Maintenance Tasks	Frequency[1]
▪ For the first 6 months following construction, the practice and CDA should be inspected at least twice and after storm events that exceed 1/2 inch of rainfall. Conduct any needed repairs or stabilization.	After installation
▪ Mow grass in grid paver applications	As needed during the growing season
▪ Stabilize the contributing drainage area to prevent erosion ▪ Remove any soil or sediment deposited on pavement. ▪ Replace or repair any necessary pavement surface areas that are degenerating or spalling	As needed
▪ Vacuum pavement with a standard street sweeper to prevent clogging	2-4 times per year (depending on use)
▪ Conduct a maintenance inspection ▪ Spot weeding of grass applications	Annually
▪ Remove any accumulated sediment in pre-treatment cells and inflow points	Once every 2 to 3 years
▪ Conduct maintenance using a regenerative street sweeper ▪ Replace any necessary joint material	If clogged
[1] Required frequency of maintenance will depend on pavement use, traffic loads, and surrounding land use.	

Winter Maintenance Considerations: Winter maintenance on permeable pavements is similar to standard pavements, with a few additional considerations:

- Large snow storage piles should be located in adjacent grassy areas so that sediments and pollutants in snowmelt are deposited before they reach the permeable pavement.
- Sand or cinders should never be applied for winter traction over permeable pavement or areas of impervious pavement that drain toward permeable pavement.
- When plowing plastic reinforced grid pavements, snow plow blades should be lifted 1/2 inch to 1 inch above the pavement surface to prevent damage to the paving blocks or turf. Porous

asphalt (PA), pervious concrete (PC) and permeable interlocking concrete pavers (PICP) can be plowed similar to traditional pavements, using similar equipment and settings.

- Owners should be judicious when using chloride products for deicing over all permeable pavements designed for infiltration, since the salts will most assuredly be transmitted into the groundwater. Salt can be applied but environmentally sensitive deicers are recommended. Permeable pavement applications will generally require less salt application than traditional pavements.

When permeable pavements are installed on private residential lots, homeowners will need to (1) be educated about their routine maintenance needs, (2) understand the long-term maintenance plan, and (3) be subject to a maintenance agreement as described above.

It is highly recommended that a spring maintenance inspection and cleanup be conducted at each permeable pavement site, particularly at large-scale applications. Example maintenance inspection checklists for permeable pavements can be found in ***Article 5.***

3.10 References

Hunt, W. and K. Collins. 2008. “Permeable Pavement: Research Update and Design Implications.” *North Carolina Cooperative Extension Service Bulletin*. Urban Waterways Series.

Jackson, N. 2007. *Design, Construction and Maintenance Guide for Porous Asphalt Pavements*. National Asphalt Pavement Association. Information Series 131. Lanham, MD.

Smith, D. 2006. *Permeable Interlocking Concrete Pavement-selection design, construction and maintenance. Third Edition*. Interlocking Concrete Pavement Institute. Herndon, VA.

4.0 Vegetated Roofs

Definition:

Practices, on top a building, that capture and store rainfall in an engineered growing media, which is designed to support plant growth. A portion of the captured rainfall evaporates or is taken up by plants, which helps reduce runoff volumes, peak runoff rates, and pollutant loads on development sites. Vegetated Roofs, also known as green roofs, typically contain a layered system of roofing, which is designed to support plant growth and retain water for plant uptake while preventing ponding on the roof surface. The roofs are designed so that water drains vertically through the media and then horizontally along a waterproofing layer towards the outlet. Two types of vegetated roofs exist: extensive or intensive. They vary based on the depth of soil and type of plants.

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Design variants include:

- 4-A Extensive Vegetated Roofs: Shallow growing media with drought resistant succulent plants, such as sedums
- 4-B Intensive Vegetated Roofs: Deep growing media with traditional plantings and irrigation

Vegetated Roofs provide runoff reduction and water quality treatment for small storms, including the Resource Protection event (RPv). Typically they are not designed to provide stormwater detention of larger Cv and Fv storms although some intensive vegetated roof systems may be designed to meet or partially meet these criteria, or the vegetated roof could be integrated with a rainwater harvesting system. However, most vegetated roof designs generally are combined with a separate facility located away from the building to provide large storm controls.

This specification is intended for situations where the primary design objective of the Vegetated Roof is stormwater management. Green roof benefits go beyond just stormwater management, but the ancillary benefits are not covered within this specification.

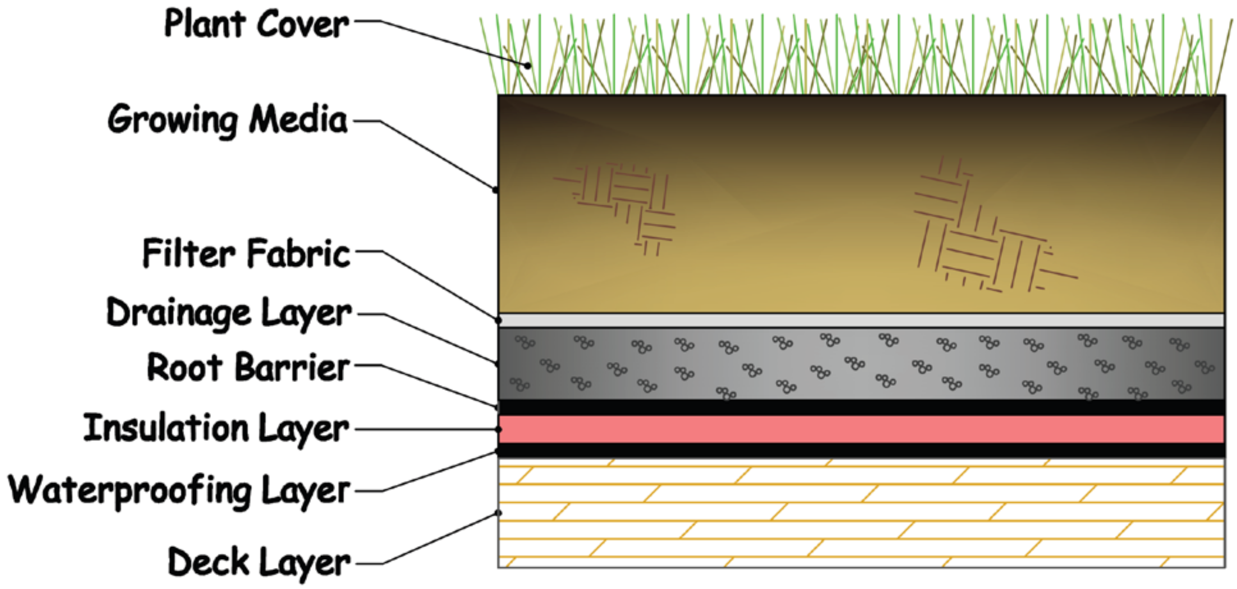

Figure 4.1. Typical Layers for a Vegetated Roof.

4.1 Vegetated Roof Stormwater Credit Calculations

Extensive Vegetated Roofs receive 50% annual runoff reduction credit (RR) for the contributing roof area, along with associated pollutant removals identified in Table 4.1 below. Intensive Vegetated Roofs exhibit greater annual runoff reduction at 75% capture rate.

4.1(a) Extensive Vegetated Roof Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv -A/B Soil*	50%
RPv - C/D Soil*	N/A
Cv	5%
Fv	1%
Pollutant Reduction	
TN Reduction	100% of Load Reduction
TP Reduction	100% of Load Reduction
TSS Reduction	N/A
Retention Allowance	0%

4.1(b) Intensive Vegetated Roof Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv -A/B Soil*	75%
RPv - C/D Soil*	N/A
Cv	8%
Fv	2%
Pollutant Reduction	
TN Reduction	100% of Load Reduction
TP Reduction	100% of Load Reduction
TSS Reduction	N/A
Retention Allowance	0%

*The growing media used for vegetated roofs is classified as an A/B soil for calculation purposes. Therefore, the vegetated roof performance is not dependent on the existing soil conditions and the credit for C/D soils is not applicable (N/A).

The practice must be designed using the guidance detailed in ***Section 4.6 Vegetated Roof Design Criteria*** in order to receive the above performance credits.

4.2 Vegetated Roof Design Summary

Table 4.2 summarizes design criteria for Vegetated Roofs, and Table 4.3 summarizes the materials specifications for this practice. For more detail, consult Sections 4.3 through 4.7. Sections 4.8 and 4.9 describe practice construction and maintenance criteria.

Table 4.2 Vegetated Roof Design Summary

Feasibility (Section 4.3)	• Needs to conform with local building codes • Needs to have roof access for maintenance and construction • Structural capability of the roof must be assessed by a qualified licensed professional • Setbacks: 2' plant setback from building edge; 1' from roof penetrations; Do not locate electrical and HVAC components within the drainage system. • Roof Slope, Extensive: Minimum 1% (1/8" per foot); Preferred 2% slope (1/4" per foot); Maximum 21% (2.5" per foot). • Roof Slope, Intensive: Minimum 1%; Maximum 2% slope (1/4" per foot)
Conveyance (Section 4.4)	• Drainage layer needs to convey overflow capacity of the downspout system without backing up the green roof. • Designed to prevent the media from clogging the conveyance system
Pretreatment (Section 4.5)	• Not needed
Sizing (Section 4.6)	• Surface area of the vegetated roof must be at least 3/4 of contributing drainage area.
Landscaping (Section 4.7)	• Landscape plan required. • Only intensive roofs may have plants other than drought resistant succulents.

Table 4.3. Vegetated Roof Material Specifications

Material	Specification
Waterproof Membrane	• EPDM single-ply rubber is typically used, but any manufacturer recommended waterproofing layer for roofs can be used so long as it meets local, state and federal building codes for waterproofing.
Root Barrier	• Impermeable liner that impedes root penetration of the membrane.
Drainage Layer	• Depth of the drainage layer is generally 0.25 to 1.5 inches thick for extensive designs. • The drainage layer should consist of synthetic or inorganic materials (e.g., gravel, recycled polyethylene, etc.) that can provide efficient drainage. • Designers should consult the material specifications as outlined in ASTM E2396 and E2398. • Roof drains and emergency overflow should be designed in accordance with state and local building codes
Filter Fabric	• Needled, non-woven, polypropylene geotextile. • Density (ASTM D3776) > 16 oz./sq. yd., or approved equivalent. • Puncture resistance (ASTM D4833) > 220 lbs., or approved equivalent. • Some manufacturers may combine with the drainage layer.
Growth Media	• Extensive: Media depth between 3 and 6 inches; 90% lightweight inorganic materials and 10% organic matter (e.g. well-aged compost). • Intensive: Media depth upwards of 6 inches; Organic content can increase up to 40%.
Plant Materials	• Extensive: Succulent plants, such as sedums, that are shallow-rooted, self-sustaining, and tolerant of direct sunlight, drought, wind, and frost. • Intensive: Any non-invasive plantings, though the media depth must satisfy selected plantings, and the building's height and sun and wind exposure should be accounted for.
Irrigation	• Extensive: Watering for 1st year required; permanent watering / irrigation recommended. • Intensive: Irrigation required.

4.3 Vegetated Roof Feasibility Criteria

Vegetated roofs are ideal for use on commercial, institutional, municipal and multi-family residential buildings, although they can also be incorporated on single family residential homes. They are particularly well-suited for use on ultra-urban development and redevelopment sites. Key constraints with vegetated roofs include the following:

Structural Capacity of the Roof. Vegetated roofs can be limited by the additional weight of the fully saturated soil and plants, in terms of the physical capacity of the roof to bear structural loads. The designer must consult with a qualified licensed professional to ensure that the building will be able to support the additional live and dead structural load. The structural capability and verification shall comply with local building codes. The maximum depth of the vegetated roof system or the need structural reinforcement must be determined during this consultation.

In most cases, fully-saturated extensive vegetated roofs have loads of about 15 to 30 lbs./sq. ft., which is fairly similar to traditional new rooftops that have a waterproofing layer anchored with stone ballast (12 to 15 lbs./sq. ft.). Intensive systems vary widely depending on the soil depth and landscape features, and may be upwards of 100 lbs/sq.ft. For a discussion of vegetated roof structural design issues, consult Chapter 9 in Weiler and Scholz-Barth (2009) and ASTM E-2397-05, *Standard Practice for Determination of Dead Loads and Live Loads Associated with Green (Vegetated) Roof Systems*. In addition, use standard test methods ASTM E2398-05 for *Water Capture and Media Retention of Geocomposite Drain Layers for Green (Vegetated) Roof Systems*, and ASTM E2399-05 for *Maximum Media Density for Dead Load Analysis*.

Roof Pitch. Vegetated roof storage volume is maximized on relatively flat roofs. Some pitch is needed to promote positive drainage and prevent ponding and/or saturation of the growing media, so the minimum slope is 1% (1/8" per foot), while the preferred slope is 2% (1/4" per foot). Extensive roofs may be pitched up to 21% (2.5" per foot) for stormwater management purposes, while intensive roofs must remain relatively flat, at maximum 2% (1/4" per foot).

Roof Access. Access to the roof must be available to deliver construction materials and perform routine maintenance. Designers must also consider how they will get construction and maintenance materials up to the roof (e.g., by elevator or crane) and how materials will be stockpiled in the confined space. Access requirements shall comply with local building codes.

When the Vegetated Roof occurs on a private residential lot, its existence and purpose should be noted on the deed of record. A sample Record Plan note could be as follows: "A Vegetated Roof is located on the residence as part of the overall stormwater management system. This Vegetated Roof shall be maintained by the owner and access for maintenance reviews shall be made available to the Delaware Department of Natural Resources and Environmental Control, Sediment and Stormwater Program, or its assigned agent."

Roof Deck Type. The roof deck layer is the foundation of a vegetated roof. It may be composed of concrete, wood, metal, plastic, gypsum or a composite material. The type of deck material determines the strength, load bearing capacity, longevity and potential need for insulation in the vegetated roof system. In general, concrete decks are preferred for vegetated roofs, although other materials can be used as long as the appropriate system components are matched to them. Certain roof materials, such as exposed treated wood and galvanized metal, may not be appropriate for vegetated rooftops due to pollutant leaching through the media (Clark et al, 2008). The roof deck type should be coordinated with the building's designers, only requirement is that it complies with the applicable building codes.

Buffers. Rooftop electrical and HVAC systems must not be located within the drainage way of the vegetated roof. A 2-foot wide vegetation-free zone is required along the perimeter of the roof, with a 1-foot vegetation-free zone around all roof penetrations, to act as a firebreak.

Local Building Codes. Building codes often differ in each municipality, and local planning and zoning authorities should be consulted to obtain proper permits. In addition, the vegetated roof design must comply with all federal, state and local building codes with respect to structural loadings, roof drains, waterproofing, and all other building related requirements.

4.4 Vegetated Roof Conveyance Criteria

The vegetated roof drainage layer (refer to 4.6: Functional Elements of a Vegetated Roof System) should convey flow from under the growing media directly to an outlet or overflow system such as a traditional rooftop downspout drainage system. Any collection systems near the soil media must be protected to prevent clogging; either by filter fabric and stone surround, or by raising the drains above the media by 3". Any drains that are raised shall only be considered emergency flow, and sufficient drainage should be utilized in other areas to prevent their use under normal rain conditions.

4.5 Vegetated Roof Pretreatment Criteria

Pretreatment is not necessary for vegetated roofs.

4.6 Vegetated Roof Design Criteria

Functional Elements of a Vegetated Roof System: A vegetated roof is composed of up to seven different systems or layers that are combined together to protect the roof and provide soil and plant conditions that can reduce the impervious effects of the building. These components are placed on top the roof deck layer, as mentioned in Section 4.3. Designers can employ a wide range of materials for each layer, which can differ in cost, performance, and structural load. The entire system as a whole must be assessed to meet design requirements. Some manufacturers offer proprietary systems which contain many of the below elements, or in other cases the components are installed individually. Additional information can be found in Weiler and

Scholz-Barth (2009), Snodgrass and Snodgrass (2006) and Dunnett and Kingsbury (2004). The design layers include:

1. **Waterproofing Layer:** All vegetated roof systems must include an effective and reliable waterproofing layer to prevent water damage to the building structure. A wide range of waterproofing materials can be used, including built up roofs, modified bitumen, single-ply EPDM rubber, and liquid-applied methods). The waterproofing layer must be 100% waterproof and have an expected life span as long as any other element of the vegetated roof system. The waterproofing layer must be designed in accordance to local, state and federal building codes – the only requirement of this specification is to include waterproofing.

2. **Insulation Layer:** Many vegetated rooftops contain an insulation layer, usually located above, but sometimes below, the waterproofing layer. The insulation increases the energy efficiency of the building, and can protect the roof deck, particularly for metal roofs. Whether to use insulation and its location if installed should be coordinated with the building designers, and is not a requirement of this specification.

3. **Root Barrier:** The next layer of a vegetated roof system is a root barrier that protects the waterproofing membrane from root penetration and ultimately failure. A wide range of root barrier options are available, but are typically high density polyethylene. Chemical root barriers or physical root barriers that have been impregnated with pesticides, metals or other chemicals that could leach into stormwater runoff must be avoided. Some waterproofing layers may also serve as a root barrier, but should only be used in combination if recommended by the manufacturer.

4. **Drainage Layer and Drainage System:** A drainage layer placed between the root barrier and the growing media is used to quickly remove excess water from the vegetation root zone. The depth of the drainage layer is generally 0.25 to 1.5 inches thick with the deeper depths for intensive designs. The drainage layer should consist of synthetic or inorganic materials (e.g., clean, washed granular material, such as ASTM D 448 size No. 8 stone, or polyethylene drainage mats) that are capable of providing efficient drainage. The drainage layer should convey the runoff to a traditional system of protected roof drains, conductors and roof leaders. American Society for Testing and Materials (ASTM) E2396 and E2398 can be used to evaluate alternative material specifications.

5. **Root-Permeable Filter Fabric:** A semi-permeable, non-woven polypropylene filter fabric is normally placed between the drainage layer and the growing media to prevent the media from migrating into the drainage layer and clogging it, but allowing the roots to penetrate through. Many manufactured drainage layers come with a filter fabric attached, which is acceptable.

6. **Growing Media:** The next layer in a Vegetated Roof is the growing media. For an

Extensive system, the media ranges from 3 to 6 inches deep, with 3 to 4 inches being the standard depth. The recommended growing media for Extensive Vegetated Roofs is composed of approximately 90% lightweight inorganic materials, such as expanded slates, shales or clays, pumice, scoria or other similar materials that are synthetically produced. The remaining media should contain no more than 10% organic matter, normally well-aged compost (see *Specification 14 – Soil Amendments*). The percentage of organic matter should be limited, since it can leach nutrients into the runoff from the roof and clog the permeable filter fabric. The growing media should have a maximum water retention capacity of 30%. It is advisable to mix the media in a batch facility prior to delivery to the roof, or opt for a proprietary engineered green roof growing media. More information on growing media can be found in Weiler and Scholz-Barth (2009) and Snodgrass and Snodgrass (2006).

The composition of growing media for Intensive Vegetated Roofs may be different, and it is often much greater in depth (e.g., 6 to 48 inches). If trees are included in the vegetated roof landscape plan, the growing media must be at least 4 feet deep to provide enough soil volume for the root structure of mature trees. A higher composition of organic matter may be needed to support the larger shrubs and trees, and should be altered per the recommendations of a Landscape Architect, up to 40% maximum organic content.

7. **Plant Cover:** Minimum 75% plant coverage must be planted and maintained on the vegetated roof. The plant coverage is increased to minimum 90% for pitched roofs above 5%. For Extensive systems, sedums or other succulent plants must be planted individually, supplied in a rolled mat format, or in pre-planted trays. Though non-native, these slow-growing, shallow-rooted, perennial plants can withstand harsh conditions at the roof surface. See ***Section 4.7 Vegetated Roof Landscaping Criteria*** for additional succulent plant information. For Intensive Vegetated Roofs, the plant type can be broadened to any non-invasive plant, though the plants survivability on the roof top must be accounted for. The plants for both types of systems should be per the recommendations of a qualified professional.

Material Specifications: Standards specifications for North American vegetated roofs continue to evolve, and no universal material specifications exist that cover the wide range of roof types and system components currently available. The ASTM has recently issued several overarching vegetated roof standards, which are described and referenced in **Table 4.3 (See Section 4.2)**.

Designers and reviewers should also fully understand manufacturer specifications for each system component, particularly if they choose to install proprietary “complete” vegetated roof systems or modules.

Vegetated Roof Sizing: Vegetated Roofs shall be designed and constructed with the minimum or maximum material specifications stated above. In addition, the size of the Vegetated Roof, both Extensive and Intensive, must be minimum 75% of the total contributing drainage area.

Specific volume requirements are not required. If the guidance is followed, Extensive Vegetated Roofs have been shown to reduce the annual runoff by 50% (Berghage et al, 2009), and Intensive Vegetated Roofs by 75% (Mentens et al, 2005).

Vegetated Roofs, especially Intensive systems, can have dramatic rate attenuation effects on larger storm events, and may be used, in part, to manage a portion of the 10- and 100-year events. Designers can model the higher storm events by factoring in storage within the drainage layer, using a porosity of 0.30 for the soil media (or manufacturer's stated porosity). The drainage layer can also be accounted for and varies depending on type (ie, modules with storage cups versus stone drainage; the manufacturer's recommendations on sizing or the standard porosity per stone type should be used to calculate the storage in the drainage layer).

4.7 Vegetated Roof Landscaping Criteria

Plant selection, placement and maintenance are critical to the performance and function of Vegetated Roofs. Therefore, a landscaping plan shall be provided. The landscape plan must be prepared for a Vegetated Roof by a licensed design professional experienced with vegetated roofs, and it must be reviewed and approved by the local development review authority.

Plant selection for vegetated rooftops is an integral design consideration, which is governed by local climate and design objectives. The ground cover for Extensive Vegetated Roof installations are hardy, low-growing succulents, such as *Sedum, Delosperma, Talinum, Semperivum* or *Hieracium*, that can tolerate the difficult growing conditions found on building rooftops. See ASTM E2400-06, *Guide for Selection, Installation and Maintenance of Plants for Green (Vegetated) Roof Systems*. Additional guidance on selecting the appropriate vegetated roof plants for hardiness zones in the Delaware region can be found in Snodgrass and Snodgrass (2006).

A list of some common Extensive Vegetated Roof plant species that work well the Delaware region can be found in **Table 4.4** below.

Table 4.4. Ground Covers appropriate for Extensive Vegetated Roofs in Delaware.

Plant	Light	Moisture Requirement	Notes
Delosperma cooperii	Full Sun	Dry	Pink flowers; grows rapidly
Delosperma 'Kelaidis'	Full Sun	Dry	Salmon flowers; grows rapidly
Delosperma nubigenum 'Basutoland'	Full Sun	Moist-Dry	Yellow flowers; very hardy
Sedum album	Full Sun	Dry	White flowers; hardy
Sedum lanceolatum	Full Sun	Dry	Yellow flowers; native to U.S.

Plant	Light	Moisture Requirement	Notes
Sedum oreganum	Part Shade	Moist	Yellow flowers; native to U.S.
Sedum stoloniferum	Sun	Moist	Pink flowers; drought tolerant
Sedum telephiodes	Sun	Dry	Blue green foliage; native to region
Sedum ternatum	Part Shade-Shade	Dry-Moist	White flowers; grows in shade
Talinum calycinum	Sun	Dry	Pink flowers; self sows
Note: Designers should choose species based on shade tolerance, ability to sow or not, foliage height, and spreading rate. See Snodgrass and Snodgrass (2006) for definitive list of vegetated roof plants, including accent plants.			

Plant choices can be much more diverse for Intensive Vegetated Roof systems. Herbs, forbs, grasses, shrubs and even trees can be used, but designers should understand they have higher watering, weeding and landscape maintenance requirements than an Extensive system.

Additional Landscaping Criteria and Notes:

- The species and layout of the landscape plan shall reflect the location of building, in terms of its height, exposure to wind, snow loading, heat stress, orientation to the sun, and shading by surrounding buildings. In addition, plants should be selected that are fire resistant and must be able to withstand heat, cold and high winds.
- Designers must also match species to the expected rooting depth of the growing media, which can also provide enough lateral growth to stabilize the growing media surface. The landscape plan should usually include several accent plants to provide diversity and seasonal color. For a comprehensive resource on vegetated roof plant selection, consult Snodgrass and Snodgrass (2006).
- It is also important to note that most Extensive vegetated roof plant species will *not* be native to the Delaware region (which contrasts with *native* plant recommendations for other stormwater practices, such as bioretention and constructed wetlands).
- Given the limited number of vegetated roof plant nurseries in the region, it is advisable to determine the lead time for delivery and to have the plant materials contract-grown.
- When appropriate species are selected, most Extensive Vegetated Roofs in Delaware will not require supplemental irrigation, except for temporary watering during the first year of establishment. It is recommended to have a permanent watering or irrigation system for especially dry conditions, but watering is only a requirement for the first year after planting. Some proprietary systems contain water storage cups as part of the drainage layer that stores additional runoff which the plant roots can utilize in dry periods. These systems can help reduce watering needs and increase plant survivability.

- For Intensive Vegetated Roofs, irrigation is a permanent requirement. It is recommended to explore *Specification 5.0 Rainwatering Harvesting*, for irrigation needs to increase water reuse and stormwater credit.
- The planting window extends from the spring to mid-fall, as it is important to allow plants to root thoroughly before the first killing frost.
- Plants can be established using cuttings, plugs, and mats. Several vendors also sell mats, rolls, or proprietary pre-vegetated roof planting modules. For the pros and cons of each method, see Snodgrass and Snodgrass (2006). The minimum plant coverage must be achieved after planting and maintained throughout the life of the greenroof.
- The vegetated roof design should include non-vegetated walkways to allow for easy access to the roof for weeding and making spot repairs (however, the vegetated roof portion must be minimum three-quarters of the total drainage area).

4.8 Vegetated Roof Construction Sequence

Installation. Given the diversity of Vegetated Roof designs, there is no typical step-by-step construction sequence for proper installation. The following general construction considerations are noted:

- Construct the roof deck with the appropriate slope and material.
- Install the waterproofing membrane, according to manufacturer's specifications.
- Conduct a flood test to ensure the system is water tight by placing at least 2 inches of water over the membrane for 48 hours to confirm the integrity of the waterproofing system.
- Add additional system components (e.g., insulation, root barrier, drainage layer and interior drainage system, and filter fabric), taking care not to damage the waterproofing. Drain collars and protective flashing should be installed to ensure free flow of excess stormwater.
- The growing media should be mixed prior to delivery to the site. Media should be spread evenly over the filter fabric surface. The growing media should be covered until planting to prevent weeds from growing. Sheets of exterior grade plywood can also be laid over the growing media to accommodate foot or wheelbarrow traffic, although the traffic should be limited over the growing media to reduce compaction.
- The growing media should be moistened prior to planting, and then planted per the landscape plan, or in accordance with ASTM E2400. Plants should be watered immediately after installation and routinely during establishment.
- It generally takes 12 to 18 months to fully establish the vegetated roof. An initial fertilization using slow release fertilizer (e.g., 14-14-14) with adequate minerals is often needed to support growth, followed by a second application the second growing year. Temporary watering may also be needed during the first summer, if drought conditions persist. Hand weeding is also critical in the first two years (see Table 10.1 of Weiler and Scholz-Barth, 2009, for a photo guide of common rooftop weeds).

- Most construction contracts should contain a Care and Replacement Warranty that specifies a 75% minimum survival after the first growing season of species planted and a minimum effective vegetative ground cover of 75% for flat roofs and 90% for pitched roofs.

Construction Review. Reviews during construction are needed to ensure that the vegetated roof is built in accordance with these specifications. Detailed review checklists should be used that include sign-offs by qualified individuals at critical stages of construction and confirm that the contractor's interpretation of the plan is consistent with the intent of the designer and/or manufacturer.

An experienced installer should be retained to construct the vegetated roof system. The vegetated roof should be constructed in sections for easier inspection and maintenance access to the membrane and roof drains. Careful construction oversight is needed during several steps of vegetated roof installation, as follows:

- During placement of the waterproofing layer, to ensure that it is properly installed and watertight;
- During placement of the drainage layer and drainage system, to prevent future ponding water;
- During placement of the growing media, to confirm that it meets the ;
- Upon installation of plants, to ensure they conform to the landscape plan;
- Before issuing use and/or occupancy approvals; and
- At the end of the first or second growing season, to ensure desired surface cover specified in the Care and Replacement Warranty has been achieved.

Reference the example Construction Review Checklist for Vegetated Roof practices**.**

4.9 Vegetated Roof Maintenance Criteria

An Operation and Maintenance Plan for the project shall be approved by the Department or the Delegated Agency prior to project closeout. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review, or for corrective action in the event that proper maintenance is not performed. Vegetated Roofs that are, or will be, owned and maintained by a joint ownership such as a homeowner's association must be located in common areas, community open space, community-owned property, jointly owned property, or within a recorded easement dedicated to public use. When the Vegetated Roof occurs on a private residential lot, its existence and purpose must be noted on the deed of record. The developer shall provide subsequent homeowners with a simple document that explains the purpose and routine maintenance needs for the Vegetated Roof.

Maintenance of Vegetated Roofs is driven by annual maintenance reviews that evaluate the condition and performance of the practice. Based on maintenance review results, specific maintenance tasks may be required. Since Vegetated Roofs are living systems on top of a building, it is recommended to perform two reviews per year, though only one is required.

Vegetated Roofs must be reviewed during the growing season to assess vegetative cover, and to look for leaks, drainage problems and any rooftop structural concerns (see **Table 4.5** below). In addition, the vegetated roof should be hand-weeded to remove invasive or volunteer plants, and plants/media should be added to repair bare areas (refer to ASTM E2400 (ASTM, 2006)).

If a roof leak is suspected, it is advisable to perform an electric leak survey (i.e., Electrical Field Vector Mapping) to pinpoint the exact location, make localized repairs, and then reestablish system components and ground cover.

The use of herbicides, insecticides, and fungicides are to be avoided, since their presence could hasten degradation of the waterproof membrane. Also, power-washing and other exterior maintenance operations should be avoided so that cleaning agents and other chemicals do not harm the vegetated roof plants.

Maintenance reviews shall be performed by a qualified reviewer, and the inspection checklist should be sent to the Department or the appropriate Delegated Agency. Both the Department or the appropriate Delegated Agency shall have the right to inspect the Vegetated Roof should the need arise, on all commercial, institutional, residential buildings.

Reference the example Maintenance Review Checklist for Vegetated Roofs.

Table 4.5. Typical Maintenance Activities Associated with Vegetated Roofs

Frequency	Maintenance Items
As Needed	• Water to promote plant growth and survival. • Replace any dead or dying vegetation.
Semi-Annually	• Inspect the waterproof membrane for leaking or cracks. • Annual fertilization (for first two years only). • Weeding to remove invasive plants (no digging or using pointed tools). • Check roof drains, scuppers and gutters to ensure they are not overgrown or have organic matter deposits. Remove any accumulated organic matter or debris. • Replace any dead or dying vegetation.

4.10 References

ASTM International. 2006. *Standard Guide for Selection, Installation and Maintenance of Plants for Green (Vegetated) Roof Systems*. Standard E2400-06. ASTM, International. West Conshohocken, PA. available online: http://www.astm.org/Standards/ E2400.htm.

ASTM International. 2005. *Standard Test Method for Water Capture and Media Retention of Geocomposite Drain Layers for Green Roof Systems.* Standard E2398-05. ASTM, International. West Conshohocken, PA. available online: http://www.astm.org/Standards/ E2398.htm.

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Dunnett, N. and N. Kingsbury. 2004. *Planting Green Roofs and Living Walls*. Timber Press. Portland, Oregon.

Northern Virginia Regional Commission (NVRC). 2007. *Low Impact Development Manual*. "Vegetated Roofs." Fairfax, VA.

Snodgrass, E. and L. Snodgrass. 2006. *Green Roof Plants: a resource and planting guide*. Timber Press. Portland, OR.

Weiler, S. and K. Scholz-Barth 2009. *Green Roof Systems: A Guide to the Planning, Design, and Construction of Landscapes over Structure.* Wiley Press. New York, NY.

Mentens, J., D. Raes, and M. Hermy. 2005. *Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century?* Landscape and Urban Planning, KULeuven, Belgium.

Berghage, R., D. Beattie, A. Jarrett, C. Thuring, F. Razaei, and T. O'Connor. 2009. *Green Roofs for Stormwater Runoff Control.* Office of Research and Development, United States Environmental Protection Agency.

5.0 Rainwater Harvesting

Photo courtesy of Lake County (IL) Stormwater Management Commission

Definition: Rainwater Harvesting systems intercept, divert, store and release rainfall for future use. Rainwater that falls onto impervious surfaces is collected and conveyed into an above- or below-ground storage tank (also referred to as a cistern or rain tank), where it can be used for non-potable water uses and on-site stormwater disposal/infiltration. Non-potable uses may include landscape irrigation, exterior washing (e.g. car washes, building facades, sidewalks, street sweepers, fire trucks, etc.), flushing of toilets and urinals, fire suppression (sprinkler) systems, supply for chilled water cooling towers, replenishing and operation of water features, distribution to a green wall or living wall system, and laundry. In many instances, Rainwater Harvesting can be combined with a secondary stormwater practice to enhance stormwater retention and/or provide treatment of overflow from the Rainwater Harvesting system.

Rainwater Harvesting systems are separated into two categories. Design variants include:

- 5-A Seasonal Rainwater Harvesting Systems
- 5-B Continuous Rainwater Harvesting Systems

By providing a renewable source of water to end users, Rainwater Harvesting systems can have environmental and economic benefits beyond stormwater management (e.g., increased water conservation, water supply during drought and mandatory municipal water supply restrictions, decreased demand on municipal or groundwater supply, decreased water costs for the end-user, potential for increased groundwater recharge, etc.).

5.1 Rainwater Harvesting Stormwater Credit Calculations

The performance credits for Rainwater Harvesting systems are based upon a design prepared in accordance with the guidelines of Section 5.6. Tables 5.1(a) and 5.1(b) list the credits for retention and pollutant reduction.

5.1(a) Seasonal Rainwater Harvesting Performance Credits

Runoff Reduction	
Retention Allowance	50%
RPv -A/B Soil	50% of Retention Storage
RPv - C/D Soil	50% of Retention Storage
Cv	0%
Fv	0%
Pollutant Reduction	
TN Reduction	100% of Load Reduction
TP Reduction	100% of Load Reduction
TSS Reduction	100% of Load Reduction

5.1(b) Continuous Rainwater Harvesting Performance Credits

Runoff Reduction	
Retention Allowance	75%
RPv -A/B Soil	75% of Retention Storage
RPv - C/D Soil	75% of Retention Storage
Cv	0%
Fv	0%
Pollutant Reduction	
TN Reduction	100% of Load Reduction
TP Reduction	100% of Load Reduction
TSS Reduction	100% of Load Reduction

5.2 Rainwater Harvesting Design Summary

Table 5.2 summarizes design criteria for Rainwater Harvesting, and Table 5.3 summarizes the materials specifications for this practice. For more detail, consult Sections 5.3 through 5.7. Sections 5.8 and 5.9 describes practice construction and maintenance criteria.

Table 5.2 Rainwater Harvesting Design Summary

Feasibility (Section 5.3)	• Harvested rainwater may be used for non-potable uses; pipes and spigots conveying harvested rainwater labeled as non-potable • Conform with local plumbing codes • Harvested water separated from main water supply • Risk assessment conducted if reuse will include human contact or affect human health • Adequate space provided for storage tank and overflow • Backflow from the discharge point into the storage tank not allowed • Tanks should be buried above the groundwater table; if the tank is in groundwater it must be secured from floating • Bearing capacity of soil must be considered for a full storage tank • pH of the soil must be considered in relation to interaction with tank material • Underground components setback from utilities in accordance with setback requirements of the utility • Underground storage tanks recommended being at least 10 ft. from building foundations • Often used to separate rooftop runoff from hotspots; evaluate risk of collecting runoff from industrial roofs that may be considered hotpots themselves
Conveyance (Section 5.4)	• Pipes connecting downspouts to storage tank must have minimum slope of 1.5% • Overflow must be provided with capacity equal to or greater than inflow pipe • Overflow capacity sufficient to drain the tank while maintaining freeboard • Overflow must be screened to prevent rodents and birds from entering the tank
Pretreatment (Section 5.5)	• Pre-treatment is required for all tanks • Small tank systems must have leaf screens or gutter guards at a minimum • Large tank systems requires full capture pretreatment
Storage Tanks (Section 5.6)	• Aboveground tanks UV and impact resistant • Underground tanks designed to support overlying soil and any vehicle or other loads • Underground tanks fully accessible for entry to perform maintenance and repair. Standard size manhole for access must be secured or locked • Sealed using a water-safe, non-toxic material • Aboveground tanks must be opaque • Openings screened • Foundation to support full tank • Backflow prevention if hooked up to a municipal backup water supply
Distribution Systems (Section 5.6)	• Include appropriately sized pump that produces sufficient pressure for all intended end uses • Distribution lines buried beneath frost line; aboveground pipes insulated or heatwrapped if system will be in continuous use. • Include a drain plug or cleanout sump to empty the tank
Sizing Criteria (Section 5.6)	Seasonal Rainwater Harvesting Systems: • Weekly irrigation demand must be at least 50% of the stored volume Continuous Rainwater Harvesting Systems: • Minimum of 50% of demand is met through non-irrigation needs • Weekly water demand during the growing season must be 50% of stored volume • Weekly water demand during the non-growing season must be 25% of stored volume • Designed to withstand freezing conditions Alternative: • Evaluate water needs and runoff volumes on a daily basis for at least a 15-year modeling period to demonstrate that the volume retained is as large as volume credited for RPv
Landscaping Criteria (Section 5.7)	• Plan showing area to be irrigated, plants to be used, and expected water demand necessary to maintain plants

Table 5.3. Material Specifications for Rainwater Harvesting systems

Item	Specification
Pipes, Gutters and Downspouts	• Common conveyance materials for non-roof runoff include concrete, HDPE, PVC, aluminum and galvanized steel • Common roof runoff conveyance materials: polyvinylchloride (PVC) pipe, vinyl, aluminum and galvanized steel • Recommended roof runoff conveyance materials: aluminum, round-bottom gutters and round downspouts • Lead should not be used as gutter and downspout solder, since rainwater can dissolve the lead and contaminate the water supply
Storage Tanks	• Aboveground tank material UV and impact resistant • Storage tanks water tight and sealed using a water-safe, non-toxic substance • Tanks must be opaque to prevent the growth of algae • Re-used tanks must be acceptable for potable water or food-grade products
Note: This table does not address indoor systems or pumps.	

5.3 Rainwater Harvesting Feasibility Criteria

A number of site-specific features influence how Rainwater Harvesting systems are designed and/or utilized. These should not be considered comprehensive and conclusive considerations, but rather some recommendations that should be considered during the process of planning to incorporate Rainwater Harvesting systems into the site design. The following are key considerations for Rainwater Harvesting feasibility:

Plumbing Code. Harvested rainwater may be used for non-potable uses. This specification does not address indoor plumbing or disinfection issues. Designers and plan reviewers should consult local building codes to determine the allowable indoor uses and required treatment for harvested rainwater. In cases where a municipal backup supply is used, Rainwater Harvesting systems must have backflow preventers or air gaps to keep harvested water separate from the main water supply. Pipes and spigots using rainwater must be clearly labeled as non-potable.

Water Reuse. Harvested rainwater may be used for non-potable uses; however, when harvested rainwater will be reused where human contact and human health should be considered, documentation of a risk assessment for the reuse of stormwater that outlines the design assumptions and evaluation process must be submitted to the Department.

Available Space. Adequate space is needed to house the storage tank and any overflow. Space limitations are rarely a concern with Rainwater Harvesting systems if they are considered during the initial building design and site layout. Storage tanks can be placed underground, indoors, on rooftops that are structurally designed to support the added weight, and adjacent to buildings. Designers can work with architects and landscape architects to creatively site the tanks. Underground utilities or other obstructions should always be identified prior to final determination of the tank location. When the rainwater harvesting system occurs on a private residential lot, its existence and purpose should be noted on the deed of record.

Site Topography. Site topography and storage tank location should be considered as they relate to all of the inlet and outlet invert elevations in the Rainwater Harvesting system.

The final invert of the outlet pipe from the storage tank must be at an elevation that will not allow water from the discharge point to backflow into the storage tank. The elevation drops associated with the various components of a Rainwater Harvesting system and the resulting invert elevations should be considered early in the design, in order to ensure that the Rainwater Harvesting system is feasible for the particular site.

Site topography and storage tank location will also affect pumping requirements. Locating storage tanks in low areas will make it easier to convey runoff from impervious surfaces and roofs of buildings to cisterns. However, it will increase the amount of pumping needed to distribute the harvested rainwater back into the building or to irrigated areas situated on higher ground. Conversely, placing storage tanks at higher elevations may require larger diameter conveyance systems with flatter slopes. However, this will also reduce the amount of pumping needed for distribution. It is often best to locate a cistern close to the impervious source, ensuring that minimal conveyance lengths are needed.

Available Hydraulic Head. The required hydraulic head depends on the intended use of the water. For residential landscaping uses, the cistern should be sited up-gradient of the landscaping areas or on a raised stand. Pumps are commonly used to convey stored rainwater to the end use in order to provide the required head. When the water is being routed from the cistern to the inside of a building for non-potable use, often a pump is used to feed a much smaller pressure tank inside the building which then serves the internal water demands. Cisterns can also use gravity to accomplish indoor residential uses (e.g., laundry) that do not require high water pressure.

Water Table. Underground storage tanks are most appropriate in areas where the tank can be buried **above** the water table. The tank should be located in a manner that will not subject it to flooding. In areas where the tank is to be buried partially below the water table, special design features must be employed, such as sufficiently securing the tank (to keep it from “floating”), and conducting buoyancy calculations when the tank is empty. The tank may need to be secured appropriately with fasteners or weighted to avoid uplift buoyancy. The tank must also be installed according to the tank manufacturer’s specifications.

Soils. Storage tanks should only be placed on native soils or on fill in accordance with the manufacturer's guidelines. The bearing capacity of the soil upon which the cistern will be placed must be considered, as full cisterns can be very heavy. This is particularly important for above-ground cisterns, as significant settling could cause the cistern to lean or in some cases to potentially topple. A sufficient aggregate, or concrete base, may be appropriate depending on the soils. The pH of the soil should also be considered in relation to its interaction with the cistern material.

Proximity of Underground Utilities. All underground utilities must be taken into consideration during the design of underground Rainwater Harvesting systems, treating all of the Rainwater Harvesting system components and storm drains as typical stormwater facilities and pipes. The underground utilities must be marked and avoided during the installation of underground tanks and piping associated with the system. Underground Rainwater Harvesting system components must be set back from other underground utilities in accordance with the setback requirements of the other utilities.

Contributing Drainage Area. The contributing drainage area (CDA) to the cistern is the impervious area draining to the tank. Areas of any size, including portions of drainage areas, can be used based on the sizing guidelines in this design specification. Runoff should be routed directly from impervious surfaces to Rainwater Harvesting systems in closed roof drain systems or storm drain pipes, avoiding surface drainage, which could allow for increased contamination of the water.

Water Quality of Harvested Rainwater. The quality of the harvested rainwater will vary according to the impervious surface over which it flows. Water harvested from certain types of rooftops, such as asphalt sealcoats, tar and gravel, painted roofs, galvanized metal roofs, sheet metal or any material that may contain asbestos may leach trace metals and other toxic compounds. In general, harvesting rainwater from such roofs should be avoided. If a sealant or paint roof surface is desired, it is recommended to use one that has been certified for such purposes by the National Sanitation Foundation (ANSI/NSF standard).

Chemicals, sealants, salts or other potential pollutants that may be applied to impervious surfaces should be considered prior to reuse or irrigation of harvested rainwater. Collection systems from non-rooftop sources should include pre-treatment to remove sediment and hydrocarbons that may be present on driving surfaces. Acidic rainfall may result in leaching of metals from the roof surface, tank lining or water laterals to interior connections. Limestone or other materials may be added in the tank to buffer acidity, following the results of a pH test, if desired.

Hotspot Land Uses. Harvesting rainwater can be an effective method to prevent contamination of rooftop runoff that would result from mixing it with ground-level runoff from a stormwater hotspot operation. In some cases, however, industrial roof surfaces may also be designated as stormwater hotspots. Runoff from roof surfaces that may be contaminated should not be collected for reuse without first evaluating the effect that the pollutants in the runoff will have on the reuse system.

Setbacks from Buildings. Storage tank overflow devices should be designed to avoid causing ponding or soil saturation within 10 feet of building foundations. Tanks must be designed to be watertight to prevent water damage when placed near building foundations. In general, it is recommended that underground tanks be set at least 10 feet from any building foundation.

Vehicle Loading. Whenever possible, underground Rainwater Harvesting systems should be placed in areas without vehicle traffic or be designed to support live loads from heavy trucks, a requirement that may significantly increase construction costs.

Storage Tank Material. Rainwater Harvesting systems may be ordered from a manufacturer or can be constructed on site from a variety of materials. **Table 5.4** below compares the advantages and disadvantages of different storage tank materials.

Table 5.4. Advantages and Disadvantages of Various Cistern Materials
(Source: Cabell Brand Center, 2007; Cabell Brand Center, 2009)

Tank Material	Advantages	Disadvantages
Fiberglass	Commercially available, alterable and moveable; durable with little maintenance; light weight; integral fittings (no leaks); broad application	Must be installed on smooth, solid, level footing; pressure proof for below-ground installation; expensive in smaller sizes
Polyethylene	Commercially available, alterable, moveable, affordable; available in wide range of sizes; can install above or below ground; little maintenance; broad application	Can be UV-degradable; must be painted or tinted for above-ground installations; pressure-proof for below- ground installation
Modular Storage	Can modify to topography; can alter footprint and create various shapes to fit site; relatively inexpensive	Longevity may be less than other materials; higher risk of puncturing of water tight membrane during construction
Plastic Barrels	Commercially available; inexpensive	Low storage capacity (20 to 50 gallons); limited application
Aluminized Steel	Commercially available; designs for above and below ground applications; aluminum alloy layer protects from corrosion; long service life	May need to be lined for potable use; soil pH may reduce service life
Steel Drums	Commercially available, alterable and moveable	Small storage capacity; prone to corrosion, and rust can lead to leaching of metals; verify prior to reuse for toxics; water pH and soil pH may also limit applications
FerroConcrete	Durable and immoveable; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; expensive
Cast in Place Concrete	Durable, immoveable, versatile; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; permanent; will need to provide adequate platform and design for placement in clay soils
Stone or Concrete Block	Durable and immoveable; keeps water cool in summer months	Difficult to maintain; expensive to build
Steel Reinforced Polyethylene	Commercially available; can create very large cisterns (greaterh than 100,000 gallons); long service life; can support high cover and shallow burial depths	Not available for above ground applications

5.4 Rainwater Harvesting Conveyance Criteria

Collection and Conveyance. The collection and conveyance system consists of the gutters, downspouts and pipes that channel rainfall into storage tanks. Roof gutters and downspouts should be designed as they would for a building without a Rainwater Harvesting system. Aluminum, round-bottom gutters and round downspouts are generally recommended for Rainwater Harvesting. Minimum slopes of gutters must be specified on the Sediment and Stormwater Management Plan. If the system will be used for management of larger storm events, the conveyance system must be designed to convey the appropriate storm intensities.

Conveyance pipes to the cistern tank must be at a minimum slope of 1.5% and sized/designed to convey the intended design storm, as specified above. In some cases, a steeper slope and larger sizes may be recommended and/or necessary to convey the required runoff, depending on the design objective and design storm intensity. All conveyance pipes to the storage tank, including gutters and downspouts, must be kept clean and free of sediment, debris and rust.

Overflow. An overflow mechanism must be included in the Rainwater Harvesting system design in order to handle an individual storm event or multiple storms in succession that exceed the capacity of the tank. Overflow pipes must have a capacity equal to or greater than the inflow pipe(s) and have a diameter and slope sufficient to drain the cistern while maintaining an adequate freeboard height. The overflow pipe must be screened to prevent access to the tank by rodents and birds.

5.5 Rainwater Harvesting Pretreatment Criteria

Pre-treatment is required to keep sediment, leaves, contaminants and other debris from the system. Minimum pre-treatment requirements differ between small and large tank systems. All pre-treatment devices should be low-maintenance or maintenance-free. The purpose of pre-treatment is to significantly cut down on maintenance by preventing organic buildup in the tank, thereby decreasing microbial food sources.

Small Tank Rainwater Harvesting Systems. Leaf screens and gutter guards meet the minimal requirement for pre-treatment of small tank systems (less than 2,500 gallons) collecting roof runoff, although direct water filtration is preferred. Leaf screens are mesh screens installed over either the gutter or downspout to separate leaves and other large debris from rooftop runoff. Leaf screens must be regularly cleaned to be effective; if not maintained, they can become clogged and prevent rainwater from flowing into the storage tanks. Built-up debris can also harbor bacterial growth within gutters or downspouts (TWDB, 2005). Other acceptable pre-treatment devices for small tank systems include:

- **First Flush Diverters:** First flush diverters direct the initial pulse of rainfall away from the storage tank. While leaf screens effectively remove larger debris such as leaves, twigs and blooms from harvested rainwater, first flush diverters can be used to remove smaller contaminants such as dust, pollen and bird and rodent feces (**Figure 5.2**). Simple first flush diverters require active management, by draining the first flush water volume to a pervious area following each rainstorm.

- **Roof Washers:** Roof washers are placed just ahead of storage tanks and are used to filter small debris from rainwater harvested from roof surfaces (**Figure 5.3**). Roof washers consist of a tank, usually between 25 and 50 gallons in size, with leaf strainers and a filter with openings as small as 30-microns. The filter functions to remove very small particulate matter from harvested rainwater. All roof washers must be cleaned on a regular basis.

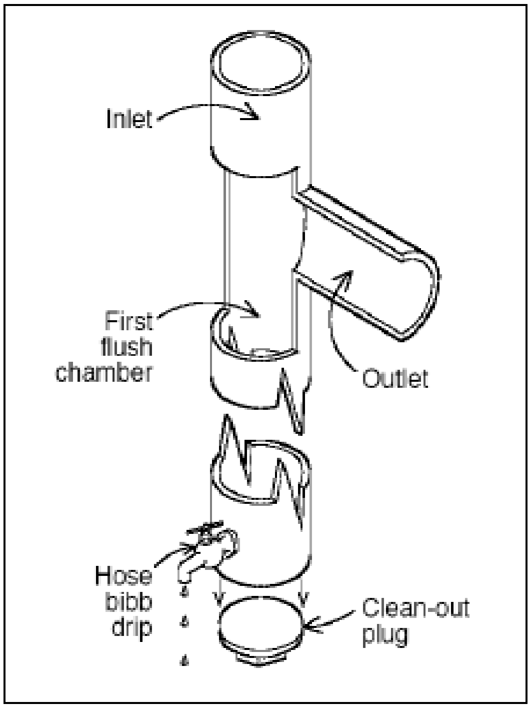

Figure 5.2. First Flush Diverter
(Source: TWRB, 2005)

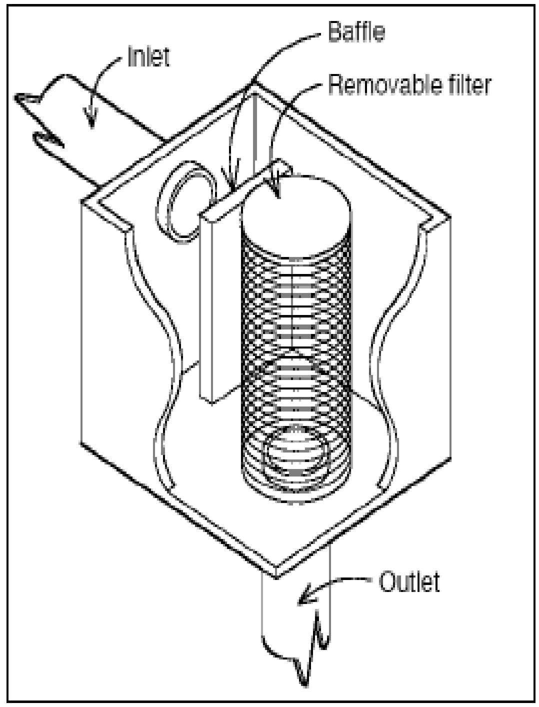

Figure 5.3. Roof Washer
(Source: TWRB, 2005)

Large Tank Rainwater Harvesting Systems. Large tank systems (greater than 2,500 gallons) should include a full-capture pretreatment system capable of treating and conveying the flow rate generated by the Resource Protection event from the contributing impervious surface drainage area. A design intensity of 1.2 inches/hour is necessary to capture the Resource Protection event. This design intensity captures a significant portion of the total rainfall during a large majority of rainfall events (NOAA, 2004).

- **Proprietary Devices:** For large scale applications, proprietary vortex devices and filters can provide filtering of harvested rainwater from larger impervious areas. A proprietary vortex device or filter may serve as an effective pre-tank filtration device.

5.6 Rainwater Harvesting Design Criteria

System Components:

The following compose a Rainwater Harvesting system:

- Impervious surface
- Collection and conveyance system (e.g., gutter and downspouts, storm drain)
- Pre-Treatment
- Storage tanks
- Distribution system
- Overflow, filter path or secondary stormwater retention practice

The system components are discussed below:

1. Impervious Surface: Only runoff from impervious surfaces should be collected for reuse on the site. Collection of runoff from roofs and sidewalk areas are preferred over roads, driveways and parking lots because runoff from these areas requires less pre-treatment prior to reuse on the site. Runoff from impervious surfaces that are treated with salt or other chemicals detrimental to plant health should not be reused on site for landscape irrigation. When collecting runoff from roofs, the rooftop should be made of smooth, non-porous material with efficient drainage either from a sloped roof or an efficient roof drain system. Slow drainage of the roof leads to poor rinsing and a prolonged first flush, which can decrease water quality.

2. Collection and Conveyance System: Runoff collected from impervious areas should be conveyed to the storage tank in a closed pipe conveyance system to prevent further contamination of the runoff. Roof gutters and downspouts should be designed as they would for a building without a Rainwater Harvesting system. If the system will be used for management of larger storm events, the conveyance pipes should be designed to convey the appropriate storm intensities. Pipes connecting downspouts to the cistern tank should be at a minimum slope of 1.5% and sized/designed to convey the intended design storm, as specified above. See ***Section 5.4. Rainwater Harvesting Conveyance Criteria.***

3. Pre-Treatment: Pre-treatment is required to keep sediment, leaves, contaminants and other debris out of the storage tank. Minimum pre-treatment requirements differ between small and large tank systems. All pre-treatment devices should be low-maintenance or maintenance-free. The purpose of pre-treatment is to significantly cut down on maintenance by preventing organic buildup in the tank, and decrease microbial food sources, thereby improving the quality of the stored water resource. Leaf screens and gutter guards meet the minimal requirement for pre-treatment of small tank systems (less than 2,500 gallons), although direct water filtration is preferred. For large tank systems (greater than 2,500 gallons), should include a full-capture pretreatment system capable of treating and conveying the flow rate generated by the Resource Protection event from the contributing impervious surface drainage area. A design intensity of 1.2 inches/hour is necessary to capture the Resource Protection event. See ***Section 5.5. Rainwater Harvesting Pretreatment Criteria.***

4. Storage Tanks: The storage tank is the most important and typically the most expensive component of a Rainwater Harvesting system. Cistern capacities range from 250 to over 30,000 gallons. Multiple tanks can be placed adjacent to each other and connected with pipes to balance water levels and increase overall storage on-site as needed. Typical Rainwater Harvesting system capacities for residential use range from 1,500 to 5,000 gallons. Storage tank volumes are calculated to meet the water demand and stormwater storage volume credit objectives, as described in further detail below in this specification.

While many graphics and photos depict cisterns with a cylindrical shape, the tanks can be made of many materials and configured in various shapes, depending on the type used and the site conditions where the tanks will be installed. For example, configurations can be rectangular, L-shaped, or step vertically to match the topography of a site. The following factors that must be considered when designing a Rainwater Harvesting system and selecting a storage tank:

- Aboveground storage tanks must be UV and impact resistant.
- Underground storage tanks must be designed to support the overlying soil and any other anticipated loads (e.g., vehicles, pedestrian traffic, etc.).
- Underground Rainwater Harvesting systems must have a standard size manhole or equivalent opening to allow access for cleaning, inspection, maintenance and repair purposes. This access point should be secured or locked to prevent unwanted access.
- All Rainwater Harvesting systems must be sealed using a water-safe, non-toxic substance.
- Rainwater Harvesting systems may be ordered from a manufacturer or can be constructed on site from a variety of materials. **Table 5.4** in **5.3 Rainwater Harvesting Feasibility Criteria** compares the advantages and disadvantages of different storage tank materials.
- Aboveground storage tanks must be opaque or otherwise protected from direct sunlight to inhibit algae growth
- Storage tanks must be screened to discourage mosquito breeding and reproduction.
- A suitable foundation must be provided to support the storage tank when it is filled to capacity.
- Dead storage below the outlet to the distribution system and an air gap at the top of the tank must be added to the total volume. For gravity-fed systems, a minimum of 6 inches of dead storage should be provided. For systems using a pump, the dead storage depth will be based on the pump specifications.
- Any hookup to a municipal backup water supply must have a backflow prevention device to keep municipal water separate from stored rainwater; this may include incorporating an air gap to separate the two supplies.

5. Distribution Systems: Most distribution systems require a pump to convey harvested rainwater from the storage tank to its final destination, whether inside the building, an automated irrigation system, or gradually discharged to a secondary stormwater treatment practice. The Rainwater Harvesting system must be equipped with an appropriately-sized pump that produces sufficient pressure for all intended end-uses.

The typical pump and pressure tank arrangement consists of a multi-stage centrifugal pump, which draws water out of the storage tank and sends it into the pressure tank, where it is stored for distribution. When water is drawn out of the pressure tank, the pump activates to supply additional water to the distribution system. The backflow preventer is required to separate harvested rainwater from the main potable water distribution lines.

Distribution lines from the Rainwater Harvesting system must be buried beneath the frost line. Lines from the Rainwater Harvesting system to the building should have shut-off valves that are accessible when snow cover is present. A drain plug or cleanout sump, also draining to a pervious area, must be installed to allow the system to be completely emptied, if needed. Above-ground outdoor pipes must be insulated or heat-wrapped to prevent freezing and ensure uninterrupted operation during winter.

6. Overflow: An overflow mechanism must be included in the Rainwater Harvesting system design in order to handle an individual storm event or multiple storms in succession that exceed the capacity of the tank. Overflow pipes must have a capacity equal to or greater than the inflow pipe(s) and have a diameter and slope sufficient to drain the cistern while maintaining an adequate freeboard height. The overflow pipe must be screened to prevent access to the tank by rodents and birds. See ***Section 5.4. Rainwater Harvesting Conveyance Criteria.***

Rainwater Harvesting Material Specifications: Gutters and downspouts used to convey roof runoff to the storage tank may be composed of polyvinylchloride (PVC) pipe, vinyl, aluminum and galvanized steel. Lead may not be used as gutter and downspout solder, due to the possibility of contamination of runoff. Common conveyance materials for non-roof runoff include concrete, HDPE, PVC, aluminum and galvanized steel.

Storage tanks must be structurally sound, watertight, and sealed using a water-safe, non-toxic material. Re-purposed tanks used to store rainwater for reuse must be acceptable for potable water or food-grade products. Above-ground storage tanks must be opaque to prevent the growth of algae in the tank. Underground storage tanks should have 18 to 24 inches of soil cover and be located below the frost line.

The basic material specifications for Rainwater Harvesting systems are presented in **Table 5.3**. Designers should consult with experienced Rainwater Harvesting system and irrigation installers on the choice of recommended manufacturers of prefabricated tanks and other system components.

Design Objectives and System Configuration: Many Rainwater Harvesting system variations can be designed to meet user demand and stormwater objectives. This specification focuses on providing a design framework for addressing the resource protection volume (RPv) credit objectives and achieving compliance with the regulations. From a Rainwater Harvesting standpoint, there are numerous potential configurations that could be implemented. However, in terms of the goal of addressing the design storm, this specification adheres to the following concepts in order to properly meet the stormwater retention goals:

- System is designed to use rainwater as a resource to meet on-site demand
- System is designed to manage rainwater in conjunction with other stormwater treatment practices (especially those that promote groundwater recharge).
- Peak flow reduction is realized through reduced volume and temporary storage of runoff.

Rainwater Harvesting system design configurations may be targeted for seasonal or continuous (year-round) use of rainwater through (1) internal use, (2) irrigation, and/or (3) treatment in a secondary practice.

Sizing of Rainwater Harvesting Systems

Size the cistern to meet the required runoff reduction volume generated from the contributing drainage area based on the Resource Protection Event. However, any storage provided in a Rainwater Harvesting system, either not meeting or exceeding the RPv volume, will be accounted. In addition, the designer needs to consider both the water supply (i.e., runoff volume) and the demand (i.e., the irrigation and other water use needs). The water demand component is critical, and the designer needs to determine both how much water is needed, and whether that demand is seasonal or throughout the year. Even though more intense rainfall typically occurs during the growing season, it is desirable to use at least a portion of the volume in the cistern throughout the year.

<u>Seasonal Rainwater Harvesting Systems:</u>

In the Seasonal Rainwater Harvesting System design, water demand is for landscape irrigation, and occurs only during the growing season. For this design, weekly irrigation demand must be at least 50% of the stored volume.

<u>Continuous Rainwater Harvesting Systems:</u>

In the Continuous Rainwater Harvesting System design, the demand is spread throughout the year, so that a minimum of 50% of the demand is met through non-irrigation needs, such as plumbing, process water, car washing, or other uses that are present throughout the year. In addition, the Rainwater Harvesting System must be designed to withstand freezing temperatures without incurring damage to the system.

<u>Alternative Sizing:</u>

As an alternative to these sizing options, the designer may complete daily modeling analyses to determine the runoff volume for the RPv event. This modeling would evaluate both water needs and runoff volumes on a daily basis for at least a 15-year modeling period, based on local rainfall data, and would provide output to demonstrate that the volume retained in the cistern for the RPv event over the modeling period is at least as large as the volume credited in Section 5.1.

5.7 Rainwater Harvesting Landscaping Criteria

If the harvested water is to be used for irrigation, the design plan must include the delineation of the proposed planting areas to be irrigated, the planting plan, and quantification of the expected water demand based upon the area to be planted and the types of plants selected. Native plants are recommended for the planting plan as they will best tolerate dry periods and will not require supplemental irrigation from another water source. Calculations to determine expected irrigation demand may be completed in accordance with the procedure provided in U.S. Green Building Council's document "LEED for Homes Rating System", January 2008.

5.8 Rainwater Harvesting Construction Sequence

Rainwater Harvesting Installation. It is advisable to have a single contractor to install the Rainwater Harvesting system, outdoor irrigation system and secondary runoff reduction practices. The contractor should be familiar with Rainwater Harvesting system sizing, installation, and placement. A licensed plumber is required to install the Rainwater Harvesting system components connecting to the internal plumbing system.

A standard construction sequence for proper Rainwater Harvesting system installation is provided below. This can be modified to reflect different Rainwater Harvesting system applications or expected site conditions.

1. Properly install the storage tank at the design location.
2. Route all downspouts, roof drains, and conveyance pipes to pretreatment devices.
3. Route all pipes from pretreatment devices to the storage tank.
4. Install the pump (if needed) and piping to end-uses (indoor, outdoor irrigation, or tank dewatering release). Test system for proper function.
5. Flush roof drains, downspouts, conveyance pipes and storage tank.
6. Stormwater should not be allowed to overflow until the overflow filter path has been stabilized with vegetation.

Construction Inspection. The following items should be inspected prior to final sign-off and acceptance of a Rainwater Harvesting system:

- Collected impervious area matches plans
- Diversion system is installed in accordance with the plan
- Pretreatment system is installed
- Mosquito screens are installed on all tank openings
- Overflow device is directed as shown on plans
- Rainwater Harvesting system foundation is constructed as shown on plans
- Catchment area and overflow area are stabilized
- Landscape / lawn irrigation system and/or secondary stormwater treatment practice(s) is installed as shown on plans
- Piping to reuse system constructed as designed on the plan

5.9 Rainwater Harvesting Maintenance Criteria

Maintenance Agreements

An Operation and Maintenance Plan for the project will be approved by the Department or the Delegated Agency prior to project closeout. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed.

Operation and Maintenance Plans should clearly outline how Rainwater Harvesting Systems will be managed. Maintenance of a Rainwater Harvesting Systems is driven by annual maintenance reviews that evaluate the condition and performance of the system. Based on maintenance review results, specific maintenance tasks may be required. It is highly recommended that periodic self-inspections and maintenance be conducted for each system as well.

Rainwater Harvesting System Maintenance Schedule

Maintenance requirements for Rainwater Harvesting systems vary according to use. Systems that are used to provide supplemental irrigation water have relatively low maintenance requirements, while systems designed for indoor uses have much higher maintenance requirements. **Table 5.5** describes routine maintenance tasks to keep Rainwater Harvesting systems in working condition. Inspections of proprietary components of the Rainwater Harvesting system should be conducted by a qualified inspector as determine by the manufacturer.

Table 5.5. Suggested maintenance items for Rainwater Harvesting systems

Frequency	Maintenance Items
Twice a year	Keep gutters, downspouts, and conveyance pipes free of leaves and other debris
Four times a year	Inspect and clean pretreatment devices
Once a year	Inspect and clean storage tank lids, paying special attention to vents and screens on inflow and outflow spigots. Check mosquito screens and patch holes or gaps immediately
Once a year	Inspect condition of overflow pipes, overflow filter path and/or secondary stormwater treatment practices
Every third year	Inspect tank for sediment buildup
Every third year	Check integrity of backflow preventer
Every third year	Inspect structural integrity of tank, pump, pipe and electrical system
As needed	Replace damaged or defective system components
As needed	Clear overhanging vegetation and trees over impervious surface

Mosquitoes. In some situations, poorly designed Rainwater Harvesting systems can create habitat suitable for mosquito breeding and reproduction. Screens on above- and below-ground tanks are required to prevent mosquitoes and other insects from entering the tanks. However, if screening is not sufficient in deterring mosquitoes, dunks or pellets containing larvicide can be added to cisterns when water is intended for landscaping use.

Cold Climate Considerations

Rainwater Harvesting systems have a number of components that can be impacted by freezing winter temperatures. Designers should give careful consideration to these conditions to prevent system damage and costly repairs.

For above-ground systems, winter-time operation may be more challenging, depending on tank size and whether heat tape is used on piping. If not protected from freezing, these Rainwater Harvesting systems must be taken offline for the winter and stormwater treatment credit may not be granted for the practice during that off-line period. At the start of the winter season, vulnerable above-ground systems that have not been designed to incorporate special precautions should be disconnected and drained. It may be possible to reconnect the former roof leader systems for the winter.

For underground and indoor systems, downspouts and overflow components should be checked for ice blockages during snowmelt events.

5.10 References

Cabell Brand Center. 2007. *Virginia Rainwater Harvesting Manual*. Salem, VA. http://www.cabellbrandcenter.org

Cabell Brand Center. 2009. *Virginia Rainwater Harvesting Manual, Version 2.0*. Salem, VA. (Draft Form) http://www.cabellbrandcenter.org

Forasté, J. Alex and Lawson, Sarah. 2009. *Cistern Design Spreadsheet*, McKee-Carson, Rainwater Management Systems, Inc., and Center for Watershed Protection, Inc.

National Oceanic and Atmospheric Administration (NOAA). 2004. *NOAA Atlas 14 Precipitation-Frequency Atlas of the United States, Volume 2, Version 3.0*. Revised 2006. Silver Spring, MD.

Texas Regional Water Board (TWDB). 2005. The Texas Manual Rainwater Harvesting. Third Ed. Austin, TX.

U. S. Green Building Council. 2008. LEED for Homes Rating System January 2008.

6.0 Restoration Practices

Definition: Restoration Practices include Regnerative Stormwater Conveyance Systems, also known as Coastal Plain Outfalls, and other practices that restore existing degraded natural systems to their former functional condition. Streambank stabilization is also included in this category.

Photo: Hala Flores, Anne Arundel Co., MD

Regenerative Stormwater Conveyance Systems (RSCS) are open-channel conveyance structures that convert, through attenuation ponds and a sand seepage filter, surface storm flow to shallow groundwater flow. In doing so, these systems safely convey, attenuate, and treat the quality of stormwater runoff. These structures utilize a series of constructed shallow aquatic pools, riffle grade control, native vegetation, and an underlying sand/woodchip mix filter bed media. The physical characteristics of the RSCS channel are best characterized by the Rosgen A or B stream classification types, where "bedform occurs as a step/pool, cascading channel which often stores large amounts of sediment in the pools associated with debris dams" (Rosgen, 1996). The pretreatment, recharge, and water quality sizing criteria presented in these guidelines are similar to criteria for a typical stormwater filtering device. These structures feature surface/subsurface runoff storage seams and an energy dissipation design that is aimed at attenuating the flow to a desired level through energy and hydraulic power equivalency principles.

Streambank stabilization includes bioengineering techniques as well as structural solutions to abate the mass wasting of soil as a result of the movement of water. Despite the name, many of these practices can be used to stabilize shorelines as well as streambanks.

Design variants for Restoration Practices include:

- 6-A. Step Pool RSCS
- 6-B. Seepage Wetland RSCS
- 6-C. Streambank Stabilization

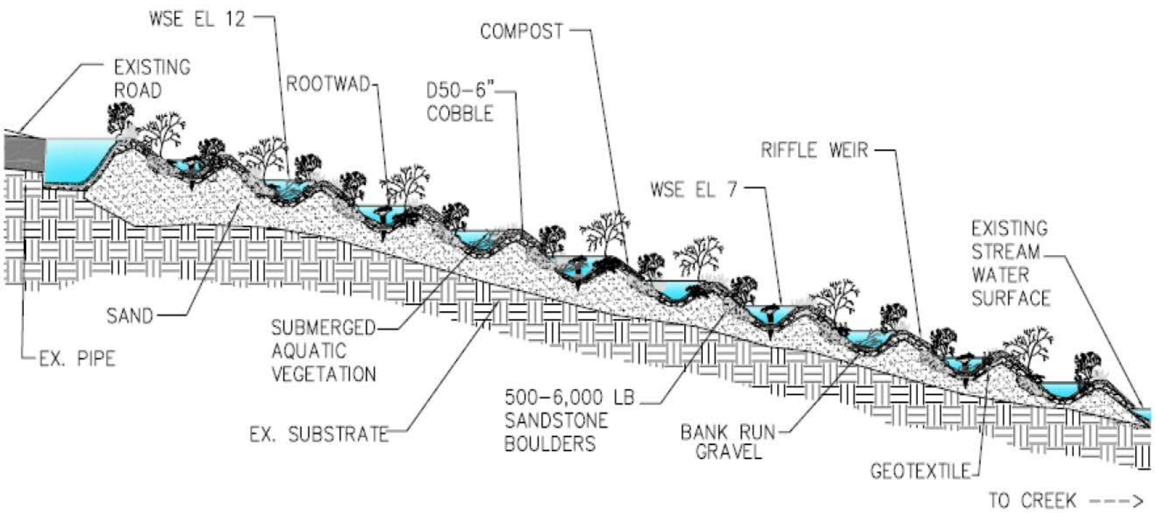

Figure 6.1 Example of a Step Pool RSCS

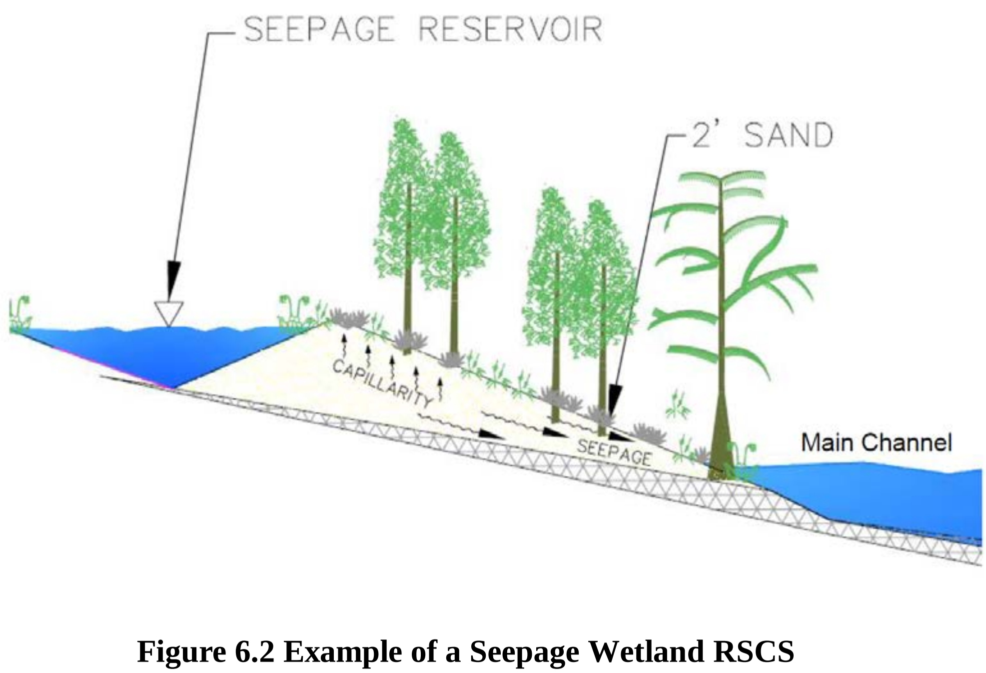

Figure 6.2 Example of a Seepage Wetland RSCS

6.1 Restoration Practices Credit Calculations

The performance of Restoration Practices from both a runoff reduction and pollutant reduction standpoint is highly dependent on the design and site characteristics for a given application. For this reason, performance credits will be determined by the Department on a case-by-case basis until more data becomes available.

6.1 Restoration Practices Performance Credits

Runoff Reduction	
Retention Allowance	TBD on Case-by-Case Basis
RPv -A/B Soil	TBD on Case-by-Case Basis
RPv - C/D Soil	TBD on Case-by-Case Basis
Cv	TBD on Case-by-Case Basis
Fv	TBD on Case-by-Case Basis
Pollutant Reduction	
TN Reduction	TBD on Case-by-Case Basis
TP Reduction	TBD on Case-by-Case Basis
TSS Reduction	TBD on Case-by-Case Basis

6.2 Restoration Practices Design Summary

The design of Regenerative Stormwater Conveyance Systems and Streambank Stabilization Practices requires specialized knowledge and skills. However, some general awareness of these systems and how they function may be helpful in evaluating potential applications for this practice. As of this date, the best available design criteria for Regenerative Stormwater Conveyance Systems have been developed by Anne Arundel County, Maryland. Therefore, the Department is recommending this document to serve as the primary design tool for RSCS applications in Delaware. The Anne Arundel County guidance has been included for reference as Appendix 6-1 of this document. This document is frequently updated. Therefore, designers are advised to check Anne Arundel County's Website to see if a newer version has been released prior to initiating a proposed design.

The USDA Natural Resources Conservation Service (NRCS) has developed design guidance for bioengineering and other streambank stabilization techniques in Chapter 16 of its Engineering Field Handbook. The Department is recommending this document to serve as the primary design tool for these practices in Delaware. This chapter is included as Appendix 6-2 of this document.

6.3 References

Anne Arundel County, Dept. of Public Works, Bureau of Engineering. "Design Guidelines for Regenerative Step Pool Storm Conveyance (SPSC)". Rev. 4, November 2011.

USDA, Natural Resource Conservation Service, Part 650, Engineering Field Handbook, Chapter 16, "Streambank and Shoreline Protection". 1996.

APPENDIX 6-1

ANNE ARUNDEL COUNTY, MD DESIGN GUIDELINES FOR REGENERATIVE STEP POOL STORM CONVEYANCE (SPSC)

Regenerative Step Pool Storm Conveyance (SPSC) – also known as Coastal Plain Outfalls

Design Guidelines


Home Port Farms - Immediately after


Home Port Farms - One year after construction


Homeport Farms - Six years after construction

ANNE ARUNDEL COUNTY
MARYLAND
County Executive John R. Leopold

DPW
Ron Bowen, P.E.

Original : June 2009
Revision 1: August 2010
Revision 2: November 2010
Revision 3: July 2011
Revision 4: November 2011
Revision 5: December 2012

Technical Advisory Committee

This document was prepared by Hala Flores, P.E., Dennis McMonigle, and Keith Underwood; and updated by Ken Pensyl. This document is maintained on the Anne Arundel County website and can be accessed through http://www.aacounty.org/DPW/Watershed/StepPoolStormConveyance.cfm.

Updates and revisions to this document are reviewed by the Technical Advisory Committee as follows.

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See last page for summary of revisions.

Important Note

This document features design guidelines and procedural steps to aid design engineers in sizing a Regenerative Step Pool Storm Conveyance (SPSC) system. It is the responsibility of the design engineer to check the feasibility and acceptability for using these systems at their project site. SPSCs can be used in lieu of stormdrains as roadside conveyance/attenuation systems. SPSCs may be used for peak flow management or steep slope stability treatment and are considered structural Stormwater Best Management Practices (BMPs) if they are sized to accommodate the volume control requirements specified in Chapter 2 of the 2000 Maryland Storm water Design Manual, Volumes I and II (the State Manual). In general, SPSCs may be used as a structural stormwater management device to provide water quality treatment as part of the treatment train or at the downstream outfall after all Environmental Site Design (ESD) techniques have been exhausted to the Maximum Extent Practical (MEP) as dictated in the State Manual. Under special circumstance, the SPSC may be used as part of the ESD when the design conforms to the criteria found in Chapter 5 of the State Manual for microbioretention or bio-swale and the general configuration conforms to the principles of ESD: using small-scale practices distributed uniformly around the site to capture runoff close to the source. While SPSC systems can be implemented on steep slopes, in no circumstance can water quality credit be claimed for SPSC segments with a longitudinal profile slope that exceeds 5 percent.

Introduction

Regenerative SPSCs are open-channel conveyance structures that convert, through surface pools and a subsurface sand seepage filter, surface storm flow to shallow groundwater flow. These systems are designed to safely convey and treat the quality of storm flow and may have differing design configurations to accommodate various site implementation conditions. The three design configurations for SPSC systems are as follows:

- A series of constructed shallow aquatic pools, riffle grade controls, native vegetation, and underlying sand/woodchip mix filter bed medium. The physical characteristics of this SPSC channel are best characterized by the Rosgen A or B stream classification types, where "bedform occurs as a step/pool, cascading channel which often stores large amounts of sediment in the pools associated with debris dams" (Rosgen, 1996). This is the typical SPSC configuration, historically known as the coastal plain outfall, and is best suited for ephemeral and perennial entrenched gully systems with moderate to steep channel and valley slopes, larger than 2 percent.

- A series of riffle grade controls aimed at diverting flow from the main channel to created shallow moats on the adjacent floodplain. A sand/woodchip mix filter is placed lateral to the channel to allow the flow from these shallow pools to filter back to the main channel. Typically, the main channel is limited in capacity to the baseflow and all storm flow is directed to the floodplain where wetland areas form and flourish. The physical characteristics of this SPSC channel are best characterized by the Rosgen DA stream classification type, where streams are "highly interconnected channel systems developing in gentle relief terrain areas consisting of cohesive soil materials and exhibiting wetland environments with stable channel conditions." (Rosgen, 1996). This configuration is best suited for perennial moderately entrenched systems with gentle channel and valley gradients, smaller than 2 percent. This SPSC configuration is also known as a wetland seepage system.

- A series of one or more instream rock riffles strategically placed in an entrenched perennial stream to encourage upstream sedimentation and connection of the channel with the adjacent floodplain. The instream riffle is ideally set such that only the baseflow is contained in the channel and all storm flow has unimpeded access to the adjacent floodplain. Over time, a Rosgen DA channel is formed and the floodplain storage and pollutant removal actions are restored. This configuration is best suited for entrenched perennial channels. This SPSC configuration is also known as a constructed instream riffle.

The pretreatment, recharge, and water quality sizing criteria presented in these guidelines follow closely the State of Maryland's criteria for a typical stormwater filtering device. These structures feature surface/subsurface runoff storage seams and an energy dissipation design that is aimed at attenuating the flow to a desired level through energy and hydraulic power equivalency principles.

SPSC structures can be designed to provide energy dissipation and extreme flood conveyance/attenuation functions, as well as recharge and water quality treatment in excess of ESD. The inherent energy dissipation achieved in the step pool design is directly linked through hydraulic design computations to reduced stream power and bank shear stresses in the receiving streams. The reduced energy and velocity at the downstream end of these structures result in reduced channel erosion impacts commonly seen between conventional stormwater practice outfalls and ultimate receiving waters.

SPSC structures are generally best suited in natural ravines and are the preferred method of stormwater conveyance throughout the water train on a developed site. ESD techniques such as alternative pavement, greenroofs, rooftop disconnections, vegetated swales, etc., should be considered and utilized to the MEP in the upstream area of a proposed SPSC system.

A secondary benefit provided by the pools and plant material is to reduce flow velocity and enhance the removal of suspended particles and their associated nutrients and/or pollutants. Additionally, uptake of dissolved nutrients and adsorption of oils and greases by the plant material yield secondary water quality benefits above and beyond the benefits achieved through the primary water quality sand/woodchip mix filter.

The design material and plant list featured within this document have been adapted to the Anne Arundel County coastal plain environment. The materials used within the SPSC, to the extent possible, are taken from the coastal plain. The sand medium is quarried throughout the region and can be readily obtained. The boulders found in these systems are sandstone (e.g., bog iron, iron stone, ferracrete). Sandstone's porosity, as well as its ability to retain water, allows it to naturalize quickly, providing habitat for ferns, moss, and other organisms that persist in these systems. While sandstone is the preferred material for use as boulders within these systems, granite may be substituted if sandstone availability is demonstrated to be of a concern. Further, broken sandstone boulders that meet the hydraulic sizing criteria maybe used in lieu of silica cobbles in the riffle construction. The use of other alternative boulder and cobble material must be approved by the Anne Arundel County reviewer and/or project manager. Maintenance of the pH levels is profound in ensuring the survival of these habitat systems; thus, the use of limestone or cement-based stone products is prohibited.

General Design Situations

SPSC structures consist of an open channel conveyance with alternating riffles and pools. These systems are best suited for ditches, outfalls, ephemeral and intermittent channels with longitudinal profile slopes that are less than 10 percent. However, the design can be easily adapted for sites where the slope exceeds 10 percent. For these sites, the size and quantity of the cobbles and rows of boulders inherent in the design computations are increased to mitigate for the stability issues associated with steep slopes. It is noted that the utilization of two or more rows of boulders typically will result in a water cascade. In extreme slope situations (larger than 50 percent), the designer may elect to use specially designed retaining structures to safely traverse the grade.

In order to preserve the integrity and habitat functions of non-tidal wetlands and streams, the designer is encouraged to minimize to the extent possible changes to the drainage pattern. This is achieved by placing proposed SPSC systems within the site following the native drainage paths. While this may result in temporary construction impacts, in the long run it will preserve the hydraulic input which is crucial to the survivability of habitat functions within non-tidal streams and wetlands. It should be noted though that the computations presented in this document are minimum design guidelines to ensure that the constructed system will not degrade. However, if the pools are over designed these systems may trap sediment. Sediment trapping in the pools is a natural energy balancing phenomena and is generally not cause for concern, unless this is clearly interfering with the project design goals and in that case undesired sediment deposition should be removed as part of a routine maintenance plan.

"The current condition of single gravel-bedded channels with high, fine grained banks and relatively dry valley-flat surfaces disconnected from groundwater is in stark contrast to the pre-settlement condition of swampy meadows (shrub-scrub) and shallow branching streams." (Walter, R., & Merritts, D. 2008). Current stormwater management regulations require that proposed development plans include appropriate mitigation measures and be contingent on the presence of a stable outfall. According to the Anne Arundel County Watershed Master Plans, problem area inventories such as erosion, buffer deficiencies, headcuts, infrastructure impacts, and suboptimal habitats are notable in varying degrees in more than 90 percent of the surveyed stream segments. For projects that drain to stream channels with active incisions, it is imperative that proper tie-in design be established between the SPSC system and the connecting downstream channel. This could be accomplished by installing an instream riffle at the proper elevation to promote upstream floodplain connection and prevent headcut erosion from unraveling the proposed SPSC systems. It is noted that each case should be evaluated carefully and that design engineers propose appropriate solutions based on the individual circumstance surrounding each case. Additionally, the designer/engineer is responsible for notifying and obtaining all required approvals from the Local, State and Federal authorities.

It is important to acknowledge that each site has unique and defining features that require site-specific design and analysis. The guidance provided below is intended to provide the fundamentals for sizing the facility to meet the regulatory requirements but is not intended to substitute engineering judgment regarding the validity and feasibility associated with site-specific implementation. Designers need to be familiar with the hydrologic and hydraulic engineering principles that are the foundation of the design and they should also enlist the expertise of qualified individuals in stormwater management and stream restoration plantings with respect to developing appropriate planting plans and habitat improvement features.

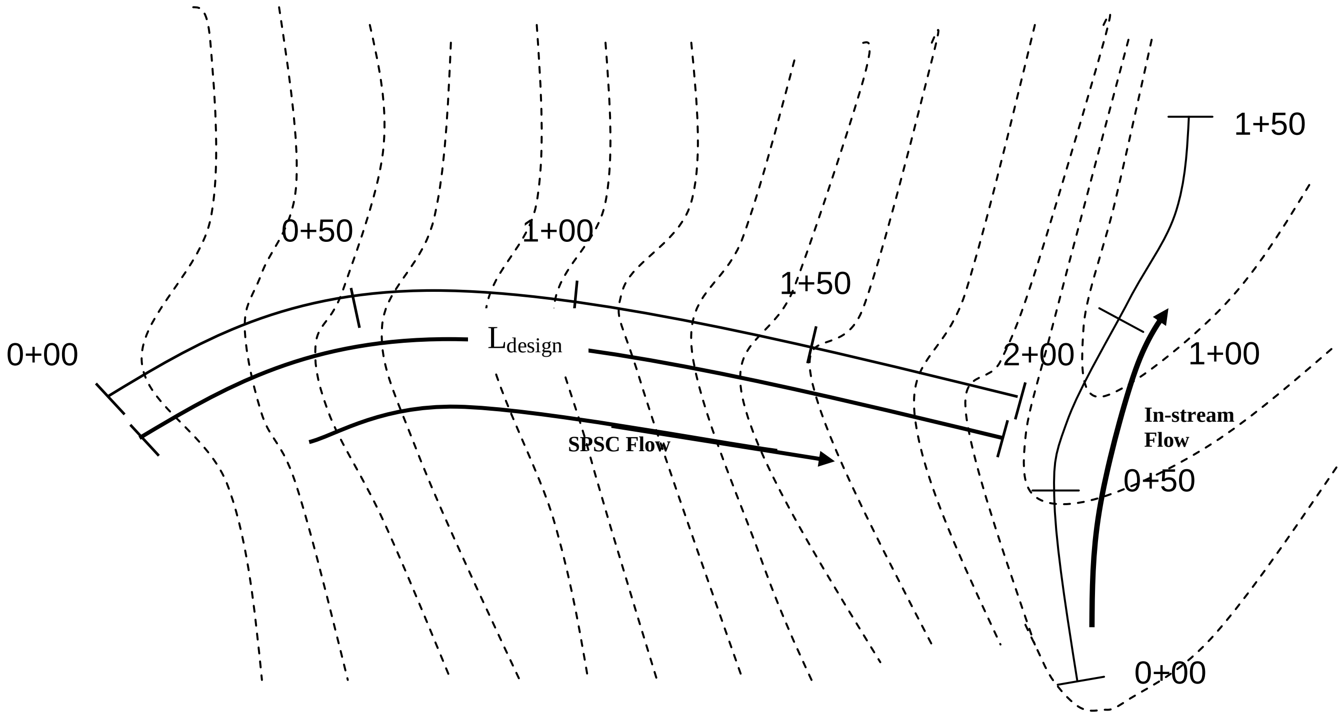
Hydraulic Design of SPSC Systems

SPSC systems can be used to reduce a surface water discharge. This is accomplished by converting up to the 100 year surface discharge to subsurface flow/spring head seep. The design of the SPSC should be based on specific established restoration goals for the project. The sand/woodchip mix filter medium is specifically required for retrofit projects with water quality restoration goals. The depth and quantity of the pool structures are linked to water quality, energy dissipation, and flow attenuation/peak management requirements. Additionally the SPSC design parameters may be determined based on the specific needs to retrofit an existing eroded channel outfall. The dimensions of the riffle and pool segments are designed in a manner to ensure adequate and safe conveyance of the design flow. The downstream tie-in to the receiving channel aims to correct an existing deficiency, such as incision and erosion, and promote long-term stable outfall conditions. This is a requirement for all proposed developments. The downstream tie-in design may result in additional water quality benefit for the contributory drainage area, however, this may not be claimed as water quality mitigation for new development related impacts. Rather this benefit may be claimed for select redevelopment projects and will be evaluated by the Anne Arundel County Department of Public Works for consideration as credits toward the County's National Pollution Discharge Elimination System Municipal Separate Storm Sewer System (NPDES-MS4) permit conditions. The construction cost of these systems makes it imperative for the design/engineer to carefully target the specific restoration goals prior to providing a design solution. The following steps have been formulated to aid the designer engineer in preparing the minimum design elements for the SPSC.

1. Develop the hydrologic design parameters for the project
    - The drainage area should be delineated to the outfall point of the SPSC and the connecting channel tie-in location if applicable. In new development projects, ESD shall be used to the MEP such as to minimize alterations to the existing drainage patterns for the site.
    - Using the USDA-NRCS TR55, determine the flow path, time of concentration, and weighted runoff curve numbers for all points of investigations and required landuse scenarios.
    - Using USDA-NRCS TR20, determine the 1, 10, and 100 year peak discharges for all points of investigations and required landuse scenarios.
    - Include pertinent model input and output hydrology parameters for all points of investigations and required landuse scenarios on the construction plans.

2. <u>Establish and quantify the restoration goals for the project</u>
   - Establish the goals for the SPSC. The goals may include, but are not limited to, the following:
     - ☐ Providing safe open channel surface conveyance in lieu of stormdrains.
     - ☐ Providing structural water quality mitigation in excess of ESD to the MEP.
     - ☐ Providing slope and outfall stabilization.
     - ☐ Subwatershed retrofits as outlined in local comprehensive watershed assessment studies and Chesapeake Bay TMDL Watershed Implementation Plan (WIP).
   - The restoration goal for the project and the provided quantities of water quality treatment shall be listed on the construction plans.

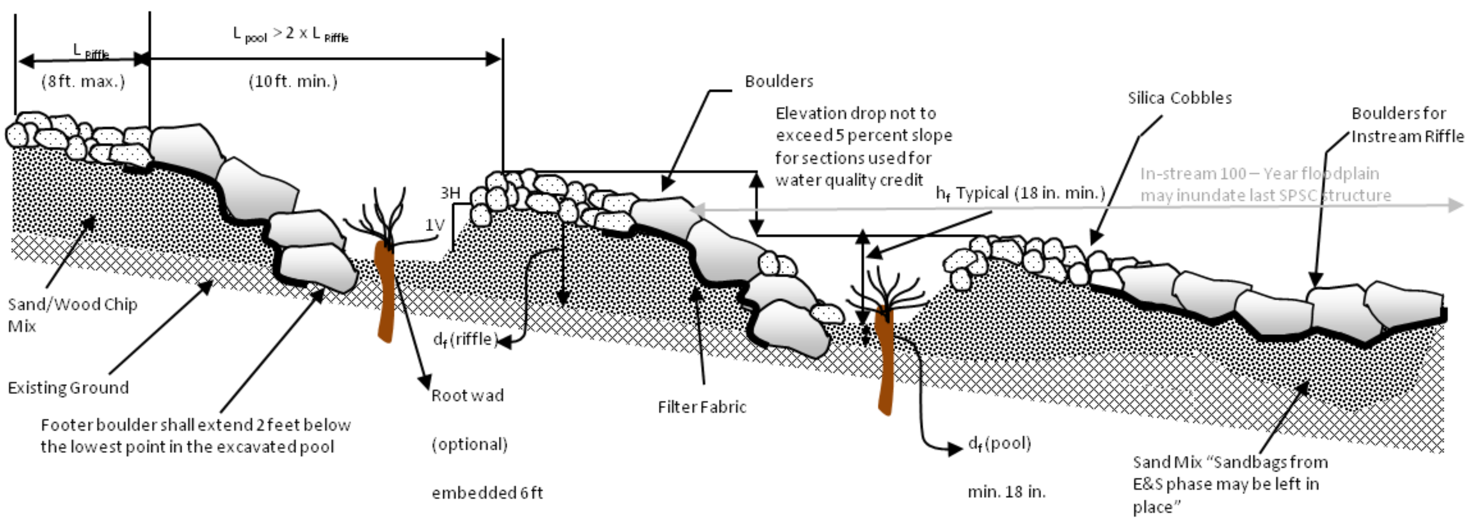
3. <u>Map the horizontal alignment for the project</u>
   - Develop a geometric plan sheet showing the SPSC alignment with stations and tabulated coordinates. The SPSC will be placed in the landscape following a curvilinear flow path whenever possible that generally follows the shape of the ravine or localized drainage path.
   - Special attention should be followed to minimize impacts to natural features. This could be accomplished through innovative/adaptive construction phasing and tree protection plans.
   - Special effort shall be made by the designer to avoid entrenched linear designs of the step pool structure. Storage opportunities on the floodplain lateral to the structure should be utilized to the maximum extent possible.
   - Measure the length of the reach along the plan view alignment from its input to the discharge location. This length shall be described in the design formulas as L_{design}. The discharge location shall be at the receiving channel. In the event that the receiving channel is incised/disconnected from the floodplain, an instream riffle may be utilized to connect the receiving channel with the floodplain. A horizontal alignment shall be established for the instream work. Design guidelines for the instream riffle tie-in are included in this document.



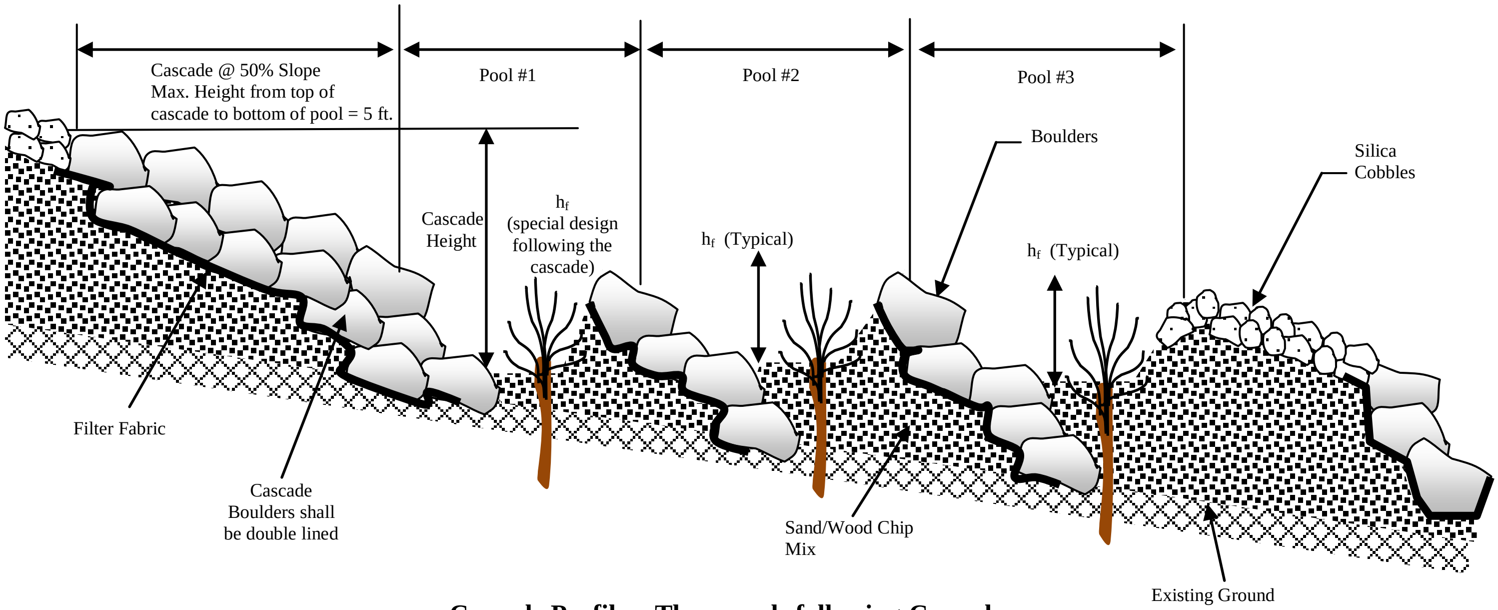
4. Map a preliminary vertical alignment for the project
   Measure the elevation difference "ΔE" between the top and the bottom of the proposed SPSC. In the event that the proposed SPSC connects to an incised downstream channel, the elevation of the floodplain terrace shall be used as the downstream elevation. An instream riffle design with a top of weir elevation set at the floodplain terrace is required at the tie-in location.
   - Compute the average outfall slope, S, by dividing ΔE by $L_{design.}$
   - SPSC segments utilized for water quality shall not exceed 5 percent in longitudinal slope. If the overall slope exceeds 5 percent, boulder cascades will be needed for traversing the grade. Boulder cascades may be placed at a maximum of 50 percent slope (1V:2H). A maximum 5 feet of vertical drop from the top of the cascade to the lowest point in the downstream pool shall be permitted for cascades with a 50 percent slope. Multiple cascades may be required along the length of the project to traverse steeper grades. Longer cascades at a flatter slope maybe used in accordance with the cascade design chart below. The location of the cascade shall be selected to minimize site disturbances and environmental impacts.
   - Use a minimum 4 foot cobble apron at the rising limb of the pool. Refer to schematic drawings.
   - The length of the pools must be at least twice the length of the riffles and could be selected longer to reduce the number of structures used. The maximum length of riffle shall not exceed 8 feet "excluding the cobble apron length on the rising limb of the pool" so as not to build excessive energies.
   - All unarmored sides of the pool shall be laid at no steeper than 3H:1V.

- For an SPSC system with a 6 foot long cobble riffle, a 14 foot long pool, a 1 foot elevation drop over the riffle and pool combined segments is used. The overall slope is 1/20 or 5 percent.
- A minimum 18 inch fixed pool depth is required.
- Alternate pool and riffle channels.
- Three consecutive pools separated by boulder weir grade control structures shall be used following a cascade.
- Using the information above and not considering the need for cascades, the number of riffle and associated pools ($N_{pools/riffles}$) = $L_{design}/(L_{pool} + L_{riffle})$.
- In the event the connecting stream is incised, Boulders shall be used to construct an in-stream weir.

Cascade Height (ft)	Maximum Allowable Cascade Slope (ft/ft)	Minimum Required Cascade length (ft)
4	0.5	8
5	0.5	10
6	0.4	15
7	0.3	23
8	0.2	40
9	0.1	90
>10	0.1	>100
The cascade height is measured from the top of the cascade to the low est point in the subsequent pool. Three full size pools are required at the bottom of a cascade.		



Typical Profile – Alternating Pools and Riffles

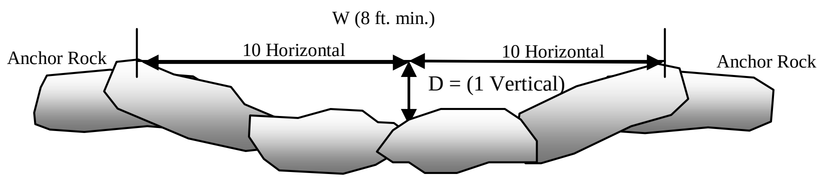


Cascade Profile – Three pools following Cascade

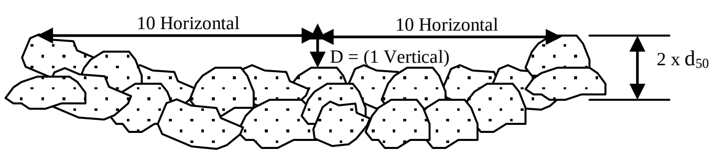
5. <u>Design the typical cross-section for the riffle/weir/cascade and pool channel segments</u>
   - The riffle/weir/cascade and pool channels shall be parabolic in shape.
   - Design the riffle/weir/cascade and pool channels to carry the Q_{design} for the unmanaged 100 year storm flow in a parabolic shape. The area and hydraulic radius of a parabola are computed as follows:

$$Area = \frac{2WD}{3} \qquad \textit{Mathematical Solution}$$

$$Hydraulic \quad Radius = \frac{2W^2D}{3W^2 + 8D^2} \qquad Chow, 1959$$



Riffle Section through Boulder



Riffle Section through Cobble

- The minimum freeboard for lined waterways or outlets shall be 0.25 feet above design high water in areas where erosion-resistant vegetation cannot be grown and maintained. No freeboard is required if vegetation can be grown and maintained. (USDA, 2006.)
- Select a trial constructed riffle/weir channel width (W). The width is the dimension perpendicular to the flow and shall be minimum 8ft.
- Select a trial constructed riffle/weir channel depth (D). The side slopes of the parabolic channel shall not be steeper than 10H:1V. For retrofit projects with limited right of way and/or floodplain constraints, the engineer may increase the cross-sectional entrenchment up to 5H:1V if it can be demonstrated that the section will remain stable for the design storm.
- The dead storage depth within the pool shall not be considered when checking for adequacy of conveyance.
- Design using a trial cobble with a d_{50} of 6 inches. The calculated d_{50} shall be the median stone size diameter to be used in riffle channels and shall be rounded up to the D50 Median stone sizes shown on the table below. The density of the stone shall be specified. The depth of the cobble material is equal to 2 x d_{50} (MDSHA, Highway Drainage Manual, 1981. Show the cobble gradation table below clearly on the plans.

Cobble Gradation Table

D50 MEDIAN STONE SIZE (INCHES)	% OF MATERIAL SMALLER THAN TYPICAL STONE	TYPICAL STONE EQUIVALENT DIAMETER (INCHES)	TYPICAL STONE WEIGHT (POUNDS)
6	70 - 100 50 - 70 35 - 50 2 - 10	12 9 6 2	85 35 10 0.4
9	70 - 100 50 - 70 35 - 50 2 - 10	15 12 9 3	160 85 35 1.3
12	70 - 100 50 - 70 35 - 50 2 - 10	21 18 12 4	440 275 85 3
18	100 50 - 70 35 - 50 2 - 10	30 24 18 6	1280 650 275 10
24	100 50 - 70 35 - 50 2 - 10	42 33 24 9	3500 1700 650 35

- Calculate the Manning's n roughness coefficient based on the constructed depth, D, associated with the 100 year ultimate flow conditions and the cobble size:

$n = D^{1/6} / (21.6 \log (D/ d_{50})+14)$, (USDA, 2006).

Where:

n = Manning's n, use 0.05 for cascades.
D = depth of water in the riffle channel associated with unmanaged 100 year Q_{design}, feet,
d_{50} = Median cobble size, feet

- Use the Manning formula to calculate the flow and velocity associated with the trial parameters D, W, and d_{50}. The design flow shall meet or exceed the 100 year ultimate flow conditions.

$$Q = (1.49/n) (A) (R_h)^{2/3} (S)^{1/2}$$

Where:

Q = 100 year ultimate flow (cfs)
1.49 = conversion factor
n = Manning's n, determined by USDA, 2006 equation
A = cross-section area of a riffle channel, which for a parabola = 2/3(W)(D), where W is top constructed width (feet) and D is the constructed depth (feet)
R_h = hydraulic radius (feet), calculated using Chow 1959 relationship for parabolas
S = average slope over entire length of project (feet/feet)
V = velocity in the riffle channel (feet/second), V = Q/A

- Using small incremental depths (0.1 feet), develop a hydraulic rating curve/table for the channel to ensure that subcritical flow conditions prevail to the greatest extent possible. This is achieved by calculating the Froude number. A Froude number exceeding 1 indicates that the flow is supercritical, while a Froude number of less than 1 indicates that the flow is subcritical in nature. The Isbash coefficient for high turbulence should be used when sizing the cobble stones to accommodate supercritical conditions. Increasing the cobble size or the width depth ratio of the riffle channel can increase roughness and reduce velocity. This can further assist in meeting subcritical flow conditions.

$$Fr = \frac{V}{\sqrt{gD}}$$

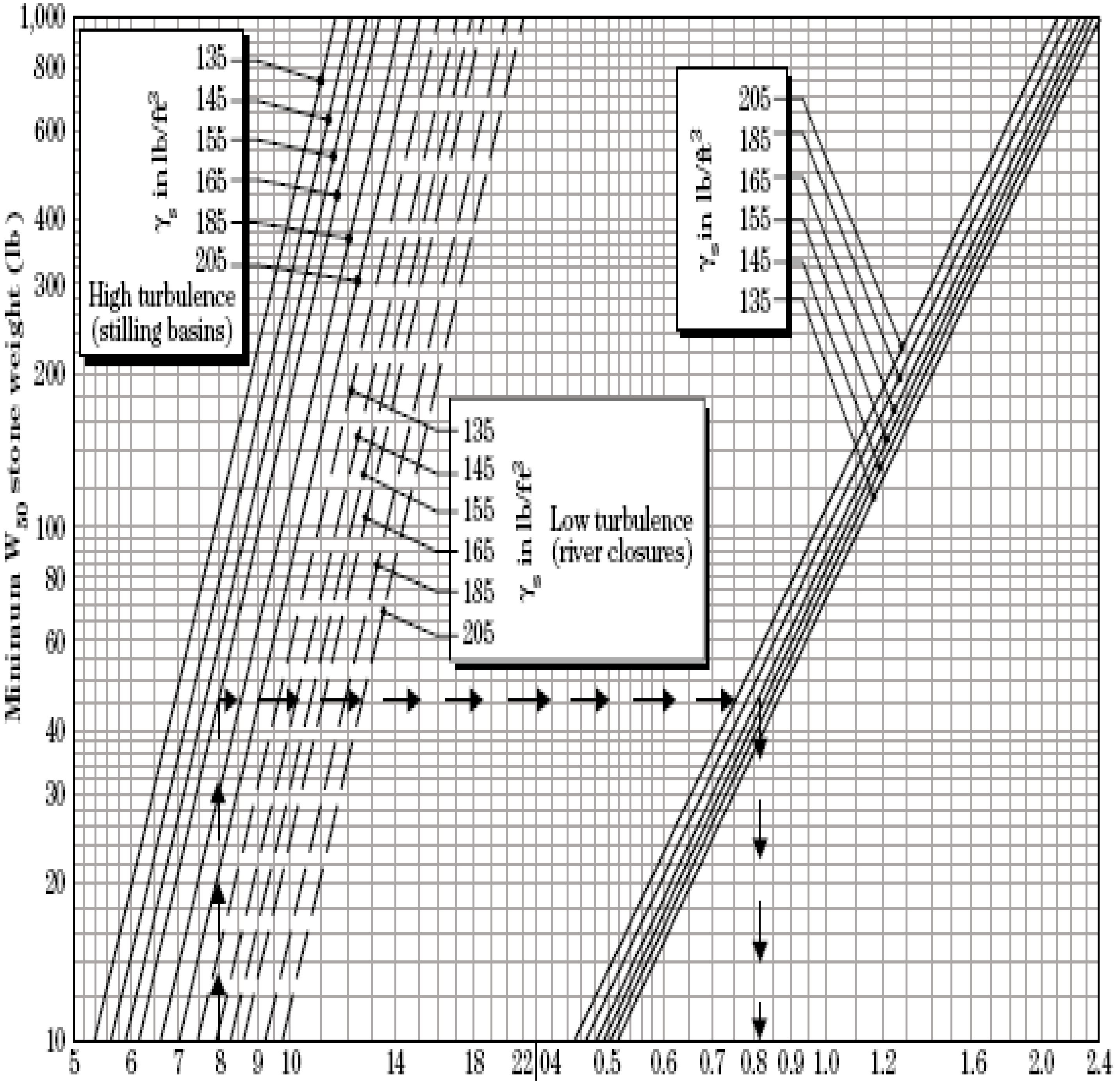
- The design velocity shall be checked to ensure that it is below the maximum allowable velocity estimated from the Isbash formula below (NRCS, 2007). A graphical solution of the Isbash formula is also shown. This will be an iterative design process. Spreadsheets can be used to streamline the calculations.

$$Maximum\ Allowable\ Velocity = C \times \left(2 \times g \times \frac{\gamma_s - \gamma_w}{\gamma_w}\right)^{0.5} \times (d_{50})^{0.5} \qquad Isbash\ Formula$$

Where:

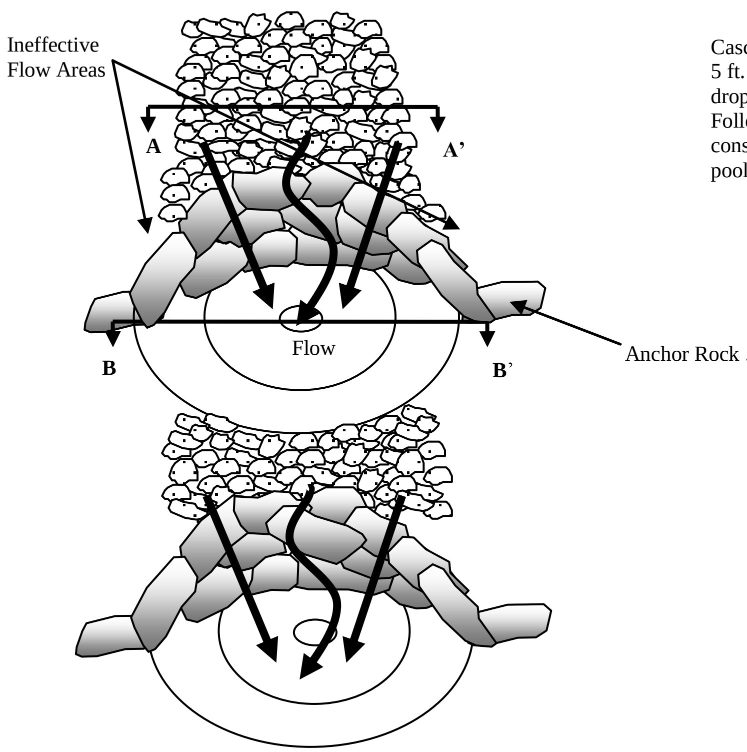
C = 0.86 for prevailing supercritical flow and 1.2 for prevailing subcritical flow
g = 32.2 ft/sec^2
γ_s = stone density (lb/ft^3)
γ_w = water density (lb/ft^3)
d_{50} = For the purpose of SPSC design, D_{50} is a median size of cobble stone diameter (feet).

Graphical Solution for Isbash technique
Figure TS14C-6, (210-VI-NEH, August 2007, TS14C-4

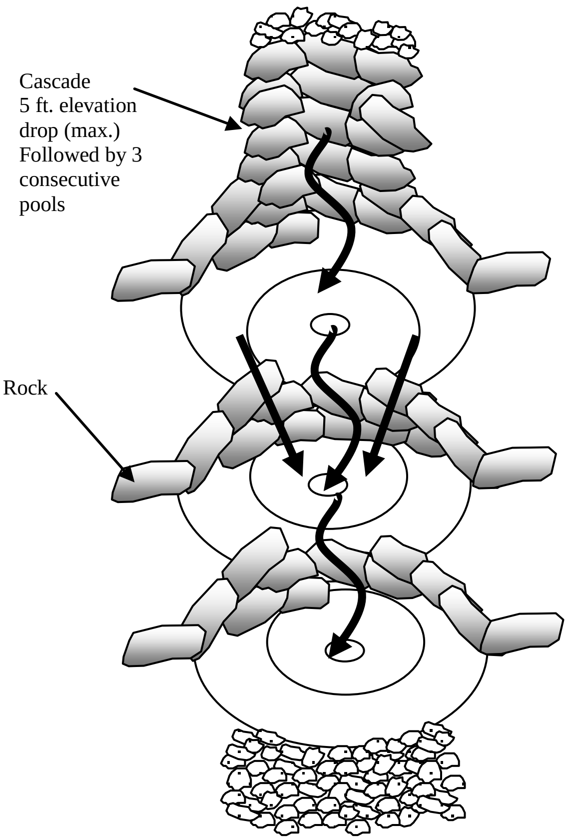


Average velocity (ft/s)

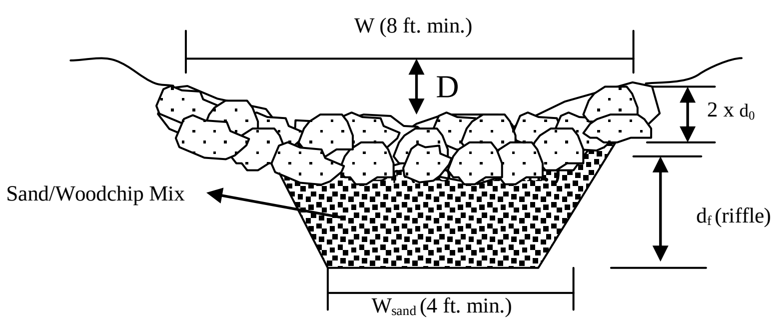
Spherical diameter, d_{50} (ft)



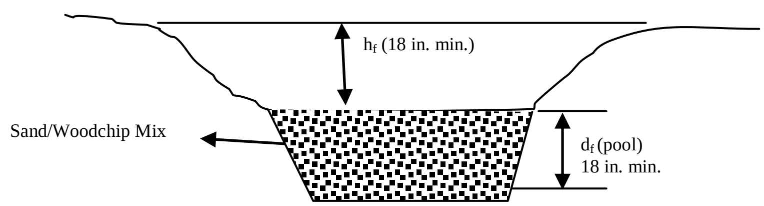
Riffle – Pool Sequence (Typical)



Cascade Sequence



Section A-A'
Riffle Weir Cross Section through Cobble



Section B-B'
Pool Cross Section

- The constructed depth of the typical pools (h_f) and the pool directly following a cascade ($h_{f\ cascade}$) shall not be less than 18 inches and shall not exceed 3 feet. Floodplain storage should be sought in the event that additional volume of storage is required. This will result in a pool geometric design with less than 3 feet of embankment and will meet the Code 378 exemption criteria as specified in Appendix B.1 of the State Manual. This exempts the SPSC system from the Soil Conservation District small pond approval. The minimum design depth of the pools shall be estimated based on the use of the solved form of the Bernoulli conservation of energy equation shown below. The Bernoulli equation was solved to achieve a pool channel velocity of 4 feet/second. D and V correspond to the riffle/cascade channel design depth and velocity respectively.

$$h_f \text{ or } h_{f\,cascade} = D + \frac{V^2}{2g} - 0.25$$

- To ensure stability, the pools shall be constructed with a minimum side slope of 3H:1V. The minimum width depth ratio for the pools is 10H:1V.

- The sand/wood chip filter medium shall meet the AASHTO-M-6 or ASTM-C-33, 0.02 inches to 0.04 inches in size. Sand substitutions such as Diabase and Graystone (AASHTO) #10 are not acceptable. No calcium carbonate or dolomitic sand substitutions are acceptable. No “rock dust” can be used for sand. The woodchips are added to the sand mix, approximately 20 percent by volume, to increase the organic content and promote plant growth and sustainability.

- The minimum depth of the sand/woodchip mix filter medium, d_f, below the invert of the pools, shall be 18 inches.

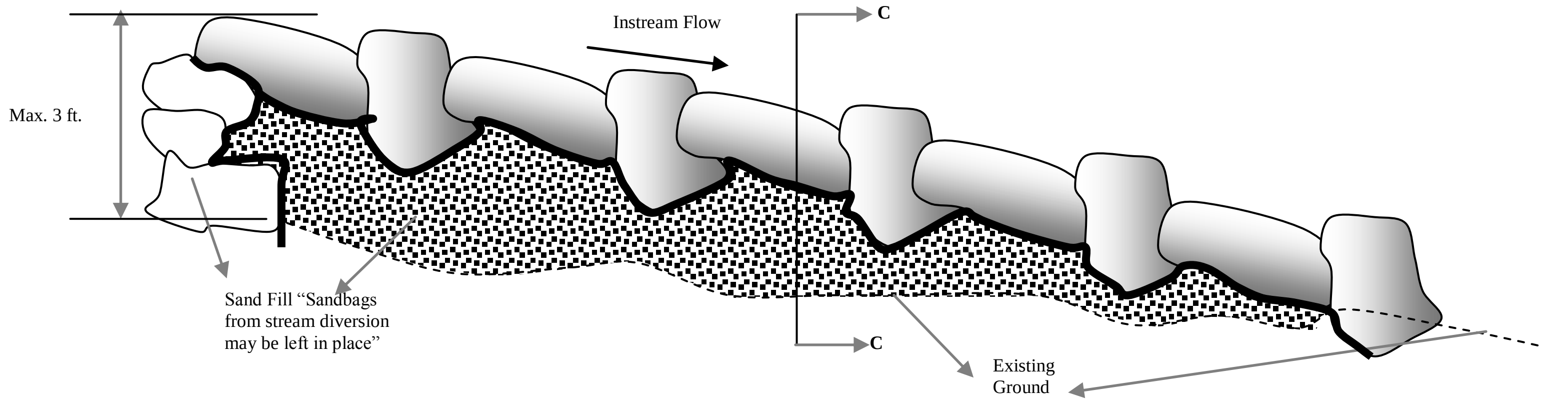
- Filter fabric shall be placed under all boulders. Refer to design figures for placement location. To prevent undercutting, a continuous sheet of filter fabric shall be used along the cross-section. Filter fabric shall not be placed in the pools so as not to impede filtration.

- The sandstone boulders serve as the weir component of the riffle grade control structure. The boulders should be arranged in a curved manner as shown on the riffle pool sequence schematic and the sandstone weir elevation view. This arrangement is intended to encourage flow deflection to the center of the pool and the creation of ineffective flow areas near the channel banks. To achieve this, the sandstone boulders shall be arranged horizontally in the center of the channel and the arms on either side of the channel shall be extended parabolically/ approximately 20 degree angle longitudinally to the center of the pool. The sandstone boulders should be sized by the engineer to be at least three to four times heavier than the riffle channel cobble. Typically, the diameter of sandstone boulders shall not be less than 2 feet in length. The typical boulder size shall be designed and specified on the plans by the engineer to best fit the channel shape, i.e., smaller cross-sections will require smaller boulders, while larger channel cross-sections may require larger boulders. The sandstone boulders should be tabular in shape to maximize interlocking. Boulders shall be used to line cascade segments.

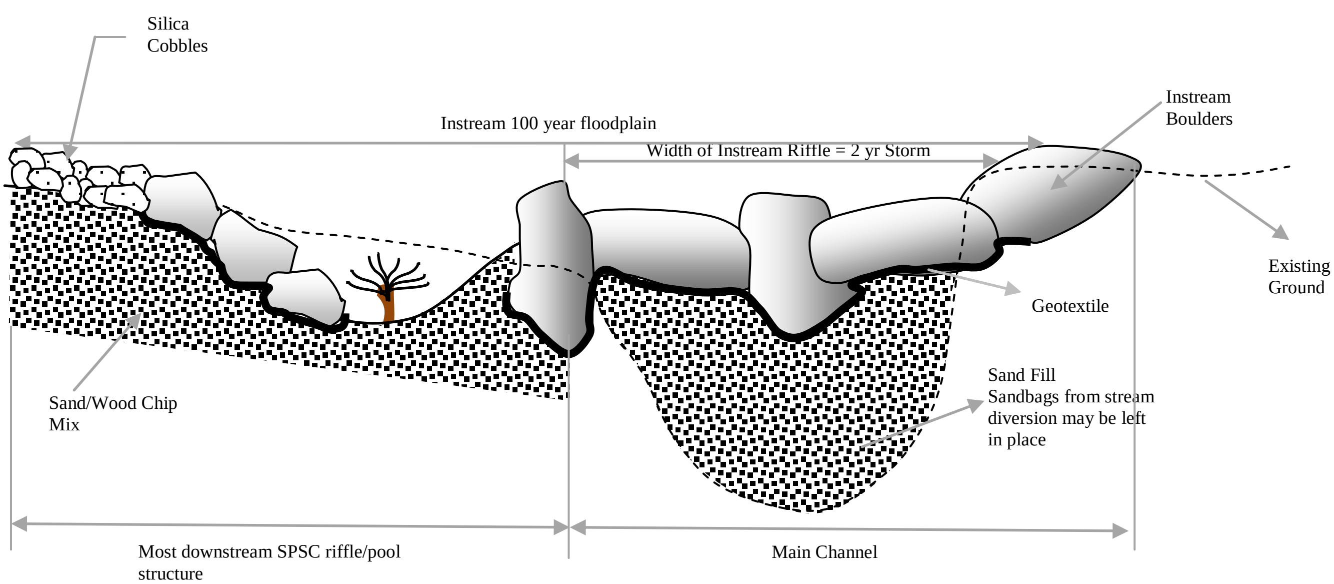
- The footer rocks provide added stability to the sandstone boulder in the event that excessive erosion is experienced in the energy dissipation pools. The footer rocks may not be necessary in the event that the utilized sandstone boulders size is adequately anchored (2 feet below the lowest elevation point in the pool). The footer rocks shall be equivalent in size to the sandstone boulders and should be tabular in shape to allow for maximum interlocking. Boulders shall be stacked as a double layer when used to armor a cascade. All footer rocks shall be anchored 2 feet below the lowest excavated elevation in the pool. Further, all boulder weir structures shall be anchored by a minimum of 2 ft to existing soils in the bank

6. <u>Design the instream riffle tie-in structure (if applicable)</u>
   - The instream riffle shall be set approximately 30 feet downstream of the tie-in location. The top elevation of the weir shall be set at the desired/historic floodplain elevation as determined appropriate by the engineer and approval authority. This is intended such as to impede headcut through the SPSC and inundate the floodplain for all flows above the base-flow conditions, thus enhance the water quality conditions.
   - The instream riffle shall be connected longitudinally to the upstream and downstream existing grade through a maximum 4 percent slope boulder channel. This will ensure gradual transition and that flow velocities do not impede the fish passage.
   - Sand shall be used for filling the stream bed to the desired elevation. Sand bags utilized as part of the erosion and sediment control plan for creating instream diversion may be left in place. Geotextile shall be used to separate the sand fill and the overlay boulders that line the channel. The boulders shall extend in cross-section to the 2-year storm.
   - The instream boulders shall be sized to remain in place under the 100 year velocity and shear stress, and shall be placed in a manner to create maximum hydraulic friction.
   - The last two structures within the SPSC system may be inundated by the instream 100 year flood elevations.
   - HEC-RAS shall be used to estimate the instream 100 year water surface elevation. The HEC-RAS sections shall be extended upstream to the point where the existing and proposed 100 year floodplains converge. The

proposed instream design shall not result in degradation to the hydraulic adequacy of upstream public facilities or in increased flooding on private properties.



Instream riffle longitudinal profile



Section C-C: Cross section at constructed instream riffle tie in with SPSC

7. <u>Check and adjust the design parameters based on the project goals</u>
   - The provided sand/woodchip mix filter bed area can be computed by multiplying the average width of the sand/woodchip mix medium, where the provided sand/woodchip mix depth is at least 18 inches, Chapter 3.4 of the State Manual, by the length of the sand/woodchip mix medium, L_{sand}, in the direction of the flow.

Where,

$$A_f = \frac{WQ_v \; x \; d_f}{K\,(h_f + d_f)\,t_f}, \qquad \textit{Filtering Sizing Criteria MDE } 2000$$

A_f	=	required sand/woodchip mix filter bed area (ft^2)
$A_{provided}$	=	provided sand/woodchip mix filter bed area (ft^2)
W_{sand}	=	width of sand/woodchip mix filter bed (feet), minimum = 4 feet
L_{sand}	=	length (feet) along the project (L_{pre})
WQ_v	=	prescribed Water Quality Volume (ft^3)
d_f	=	sand/woodchip mix filter bed depth (feet), use minimum 24 inches (Average of d_f (pool) and d_f (riffle)
K	=	coefficient of permeability of filter medium (feet/day), use K = 3.5 for sand/woodchip mix
h_f	=	Depth of Pool (feet), minimum 18 inches
t_f	=	design filter bed drain time (days), use 1.67 days as recommended by MDE for sand mix filters

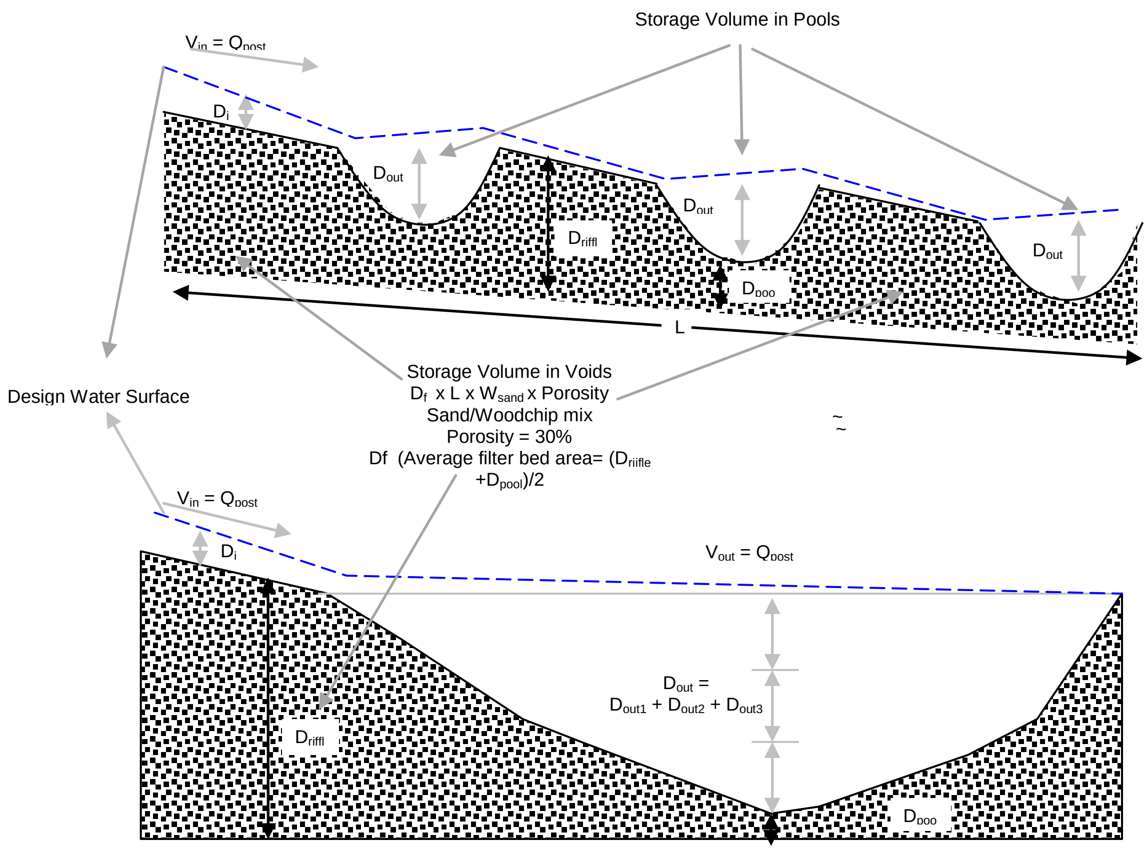
- For SPSC systems that meet the ESD criteria and for outfall retrofit and stream restoration projects, the required WQ_v for the contributing drainage area may be met by adjusting the depth of pools, width of sand/woodchip mix filter, or length of the facility to increase the filtering capacity. Partial treatment credit may be claimed for outfall retrofit and stream restoration projects. SPSC systems proposed as part of a new development or redevelopment that is not designed as an ESD device may not claim any water quality credit.

- In situations where the existing soil, underlying the proposed SPSC, is confirmed through "borings" to be highly infiltratable, and the SPSC meets the ESD criteria or is a retrofit project, the designer may utilize the State Manual's water quality sizing criteria for an infiltration basin in lieu of filtration. This is prescribed so the designer engineer is not forced, under certain circumstances, to replace highly infiltratable native soil with non-native filter bed material. In order to claim water quality credit, the design ponding depth/head, h_f, intended to drive the seepage through the filter shall be entirely above the seasonal high groundwater elevation.

- The proposed SPSC will satisfy peak management flow requirements if two conditions are met:

  - ☐ First, adequate storage volume within the pools and sand/woodchip voids shall be provided to meet the required storage volume/quantity management for the project.
  - ☐ Second, it must be demonstrated that the design renders the hydraulic power equivalent to the pre-development/desired hydraulic power through the proposed energy dissipation pools.

- To achieve the conditions above, the designer must compare the required peak management storage volume with the combined volume within the pools and the volume in the voids within the sand/woodchip mix. A 30 percent porosity (n=0.3) shall be used for the sand/woodchip mix to calculate the volume within the voids. The total provided storage shall exceed the required storage volume for the design peak management storm. Second, the selected design for the SPSC must be checked using the conservation of energy principles to ensure that the hydraulic power is adequately reduced to design/pre-development levels. This is achieved by equating the pre-development or reference condition hydraulic power to the post development hydraulic power and solving for the equivalent added stream length/volume of storage needed to render this power to the desired condition. The conservation of energy principles are then utilized to convert the energy loss within this horizontal length to an equivalent vertical drop. The vertical drop is then converted to multiple drops that are distributed along the system in a manner that result in the least site disturbances. The provided quantity/volume of pools is then compared with the calculated quantity/volume of pools. If the provided pool storage is less than the computed/required pool storage, then additional SPSC design measures or additional upland management strategies must be taken to reduce the inflow and in turn the hydraulic power. Refer to the figure below for a demonstration of the SPSC-provided volume of storage and input parameters for the conservation of energy computations. It should be noted that equating the geometric configuration of a multiple pool system to one pool with an area equal to the cumulative areas within the individual pools is a conservative measure and is used to simplify the hydraulic power routing computations. It is expected that cumulative roughness and headloss within the multiple pool configuration to be much higher than the individual pool configuration.



- These steps should be followed in checking the before/after hydraulic power:

  - Compute the pre-development/design and post development hydraulic powers by substituting the pre-development and post development discharges in terms of Q in the hydraulic power equation. The hydraulic power is expressed in the units of lb/second.

    Hydraulic Power = γ x Q x S, where

    γ is the unit weight of water = 62.4 lb/ft^3

    Q corresponds to Chapter 2 of State Manual CPV discharge

    S is the slope of the outfall channel in percent

  - Equate the pre-development/design and post development hydraulic powers and solve for the needed added stream length.
  - γ x Q_{pre} x $(\Delta E/L_{pre})$= γ x Q_{post} x $(\Delta E/L_{post})$

  - The elevation difference between the top and bottom of the project and the unit weight of water will remain constant, therefore, the channel protection requirement could be expressed in terms of a required additional stream channel length L_{add}, needed to render the post development hydraulic power equivalent to the pre-development hydraulic power.

- $L_{add} = L_{pre} \times (Q_{Post}/Q_{Pre}) - L_{pre}$

➢ The required headloss due to friction through the Step Pool Storm Conveyance system can be calculated using the Darcy-Weisbach equation. By substituting L_{add} for L, this headloss becomes equivalent to the energy loss within an added stream channel of length L_{add}. The friction factor can be calculated using established relationships between Darcy-Weisbach friction factor and the Manning friction coefficient listed in Chow, 1959. The Darcy –Weisbach headloss equation is as follows:

$$\textit{Friction head loss} = \frac{f L_{add} V_{out}^{\ 2}}{2 D_{out}\, g}$$

➢ By substituting the required headloss term in the Bernoulli conservation of energy equation, the total combined design depth in feet of all proposed pools shall be at least equal to the "D_{out}" term embedded in the Bernoulli conservation of energy equation depicted below. If the total combined depth in feet of all proposed pools is less than the calculated "D_{out}" term, then additional pools are required or alternatively the pools could be made deeper. Solve for the "D_{out}" term using trial and error techniques or available commercial solver functions/calculators, (i.e., Microsoft Excel). The general and solved forms of the Bernoulli conservation of energy equation are shown below.

General Form of the Bernoulli Equation

(Potential + Kinetic + Static) Energies $_{\text{SPSC entrance}}$ = (Potential + Kinetic + Static) Energies $_{\text{SPSC outlet}}$ + Headloss $_{\text{within SPSCsystem}}$

Solved Form of the Bernoulli Equation

$$D_{in} + \frac{9Q^2}{4gD_{in}^{\ 2}W_{in}^{\ 2}} + \Delta E = D_{out} + \frac{9Q^2}{4gD_{out}^{\ 2}W_{out}^{\ 2}} + \frac{9\, f L_{add}\, Q^2}{4gD_{out}^{\ 3}W_{out}^{\ 2}}$$

Where,

f = Darcy-Weisbach friction factor, the Chow 1959 equations below may be used to relate the friction factor to a manning roughness:

$$f = 8gRh^{-1/3}n^2 \qquad Chow, 1959$$

http://www.water.tkk.fi/wr/kurssit/Yhd-12.121/www_book/runoff_6.htm

L_{add} = additional channel length (feet) required to render the post development power to pre-development conditions

V_{in} = Design velocity at entrance riffle = V

D_{in} = Design depth at entrance riffle = D

W_{in} = Design width of riffle = W

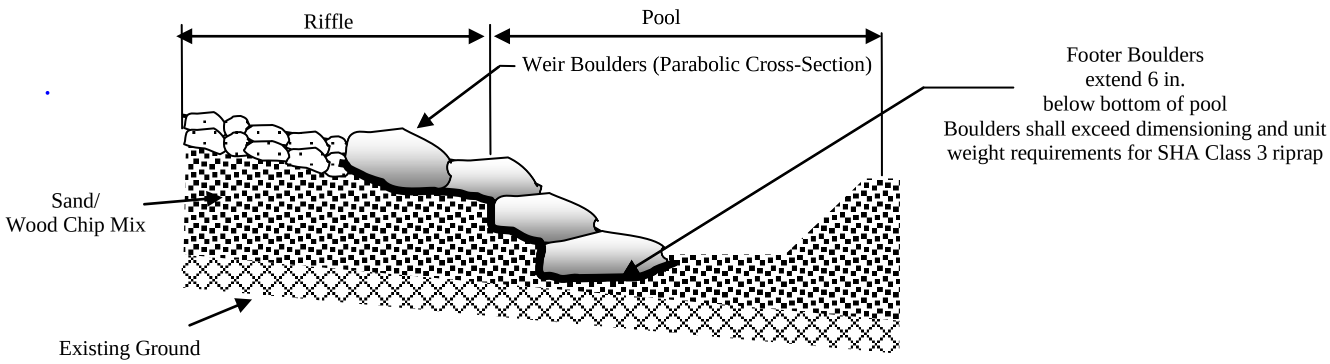
W_{out} = Width of the pool (feet)

V_{out} = typical velocity of flow (feet/second) in the pool, this term is unknown in the Bernoulli equation. Using flow continuity principals, this term could be expressed in terms of the CP_V design discharge, D_{out}, and W_{out}.

g = acceleration due to gravity = 32.174 ft/sec^2

D_{out} = Solve for combined depth of flow in all pools (feet) and compare to the total provided pool depth

8. Finalize the cross-section and profile design for the project
   - Develop a grading plan based on the preliminary profile and cross-section typical design.
   - Adjust the preliminary profile dimensions to accommodate site specific concerns/impacts. Minimum design parameters for hydraulic, water quality, and quantity management criteria should be rechecked based on adjustments to the riffle/pool channels to ensure that safe and adequate conveyance is still maintained.
   - The sand/woodchip mix filter bed shall have a minimum depth of 18 inches under the riffle channel and a minimum width of 4 feet and shall be placed as the substrate drainage material along the entire project length. The actual dimensions of the sand/woodchip mix filter bed will be determined based on the required water quality volume.
   - Typically, construction of the SPSC system shall begin at the downstream end and proceed upstream to the project outfall. The outlet pool is designed to be placed at the lowest point in the project reach. This is often in the receiving wetland or stream/floodplain, but can also be located in upland settings where the SPSC system discharges to another stormwater BMP or adequate storm conveyance system.
   - Footer boulders shall be placed at the interface of the pools and riffles as shown below. Additional boulders shall be placed on top of the footer boulders at the weir elevation upstream of the footer boulders to form the riffle channel parabolic shape. Boulders shall exceed the dimensioning and unit weight requirements for the Maryland State Highway Administration (SHA) Class 3 riprap.



- Continue the process of alternating pools and riffles/weirs up through the system to the entry pool. If the entry pool ties to an existing pipe outfall, additional armoring or scour protection of the pool may be needed to address the pipe exit velocities associated with supercritical hydraulic conditions. The designer may elect to use a larger size pool at the project entry to dissipate the outfall velocity and/or to address pretreatment concerns.
- If the SPSC is proposed below a pipe system, it is desirable that the top invert of the weir associated with the entry pool is set at or above the invert of the discharge pipe or culvert. It is the responsibility of the design engineer to check the adequacy of the upstream drainage system and drainage area.
- Vegetative stabilization must comply with Anne Arundel Soil Conservation/MDE stabilization specifications. Kentucky 31 tall fescue is not to be used in wetlands or wetland buffer systems.
- Course woodchips and compost (4 inch – 8 inch thick) should be used throughout the limit of disturbance for site stabilization provided that plantings will be installed during the first available planting season.
- All areas should be hydro-seeded.
- At the end of each day, exposed dirt shall be stabilized immediately.
- It is advisable that excess materials, i.e., cobbles and boulders, be placed at the edge of the cross-section for use during the maintenance phase to correct any physical instability.
- A direct maintenance access shall be provided to the system. All public systems must be fully contained within public right of way or easement with sufficient width to allow future maintenance and retrofit activities as needed.

9. <u>Setback requirements</u>
    - The minimum setback from the 100 year water surface elevation of the system to structures on slabs is 10 feet.
    - Systems located uphill of an existing house or structure shall be evaluated for possible adverse effects to the structure.

- The 100 year water surface elevation of a system located uphill of a building or structure that has a basement shall be no closer than 20 feet from the structure or the intersection of the structure foundation footing and the phreatic line associated with the overflow depth of the device, whichever is greater.
- The 100 year water surface elevation of a system located downhill of a building or structure that has a basement shall be no closer than 10 feet from the structure foundation or the intersection of the structure foundation footing and the phreatic line associated with the overflow depth of the device, whichever is greater.
- The 100 year water surface elevation of a system shall be located a minimum of 1 foot below the structure floor or basement floor. Certification to this effect from a professional engineer shall be shown on the plan.
- The 100 year water surface elevation of a system shall not be located within 25 feet of a retaining wall or the top of a slope that is 25 percent or greater. In no case shall the phreatic line associated with the overflow depth of the system intersect the existing or final ground surface of the retaining wall or slope.
- The 100 year water surface elevation of a system shall not be located within 50 feet of any residential water supply well.
- The designer shall consider the proximity of sanitary septic drain fields when locating a new system. These systems can raise the localized groundwater elevation and therefore impact existing septic drain fields. The designer shall ensure that constructed SPSC systems pose no impact to primary and secondary septic drain fields and shall consult the Anne Arundel County Health Department regulations in these instances.
- The 100 year water surface elevation of a system shall not be located within 10 feet horizontally from any public sanitary sewer manhole and clean out structures or house connections. Sewer manholes, clean outs, pump stations, and other sewer structures shall be located 1 foot above the 100 year storm elevation within the SPSC system.

10. <u>Sequence of construction and erosion and sediment control notes</u>
    - It is preferred that the SPSC system be installed at the end of the construction phase (when the upstream area is stabilized) so as not to contaminate the SPSC during upstream construction. However, if the site is constricted and the SPSC system needs to be installed earlier on in the sequence, then upstream flows must be directed around the SPSC system to avoid contamination.
    - Under no circumstance can the SPSC system be used as a sediment control device during construction unless approved by the Anne Arundel Soil Conservation District (AASCD). Upstream controls such as diversion pipes and pump-arounds are required during construction so as not to contaminate the SPSC system.

- The SPSC system shall not be finalized until all upstream construction is complete and all disturbed areas stabilized and erosion and sediment control measures have been removed at the discretion of the inspector.
- Special attention shall be paid to the application of perimeter reinforced or super silt fence along the SPSC system so as not overwhelm the silt fence with concentrated flow and develop erosion within the SPSC floodplain and behind the stone structures. If erosion from sheet flow to the system is observed during construction, a plan revision to address the upstream drainage area and an adequate design of the conveyance channel should be submitted for the problem location.
- SPSC sediment controls when possible shall have reinforced silt fence along the toe of the outlet for the bottom pool. A bypass for upstream runoff around the SPSC is needed until the drainage area is permanently stabilized. Riffles and pools shall be stabilized at the end of each work day.

11. Draft a planting plan
    - The planting plan and proposed species must be reviewed and approved by the County project manager/reviewer prior to installation. Additionally, any plant substitutions must be approved by the project manager/reviewer before the substitute species are installed.
    - For projects within the airport zone, a sample list of the Maryland Aviation Administration (MAA) approved native plants is attached at the end of this document. A selection of approved trees with approved understory of shrubs and herbaceous materials should be provided.
    - Pay special attention to use of native material, diversity, and dense placement of plant material within appropriate wetness zones throughout the site (MDE, 2000).
    - As a temporary stabilization measure, seed and mulch (compost) the entire site with annual rye throughout construction.
    - Spray down a minimum 4-8 inch layer of compost throughout the site avoiding areas of ponding water. The compost shall be derived from the natural composting process of plant material with no lime additives. The PH acceptable range shall be between 5 and 8.
    - As a permanent stabilization measure, seed the entire site with Red Fescue. Chewing Red Fescue may be alternatively used.
    - Existing trees to be protected shall be marked clearly on the project plan view and planting plan.
    - The designer has the option to use inverted root wads, in the pool areas to enhance the soil porosity and create habitat for the biological community. Root wads shall be embedded 6 feet below the invert of the pool and their size shall not exceed 10 percent of the pool volume. Root wads shall not be used in the two pools directly upstream of a cascade. The root wads shall be placed in the center of the pool in a vertical alignment. It is noted that the use of root wads is not a requirement and is an option. Root wads

are not intended to serve any bed or bank stabilization purpose and are primarily used to enhance habitat and increase roughness.

12. <u>Prepare a monitoring plan and schedule of completion</u>

- Prior to release of certification of completion, inspectors must ensure that adequate vegetative stabilization has occurred. Adequate vegetative stabilization requires 95 percent groundcover. In addition, all sediment accumulation having resulted from upstream construction must be removed to design elevations.
- A monitoring plan must be prepared to address the specific restoration goals for the project per Article 16-3-205(a). Clearly show the erosion control monitoring device on the sediment and erosion control plan.
- Structural stability and plants survivability are the two most pertinent components to monitor for private/developer built projects. These components shall be monitored for three years or as established in the plan review process. Enforcement of the monitoring conditions shall be tied to the asbuilt approval process and release of the stormwater management bond.
- The monitoring plan for SPSC shall include annual vegetation survey to document that planted species have 80 percent survivability and a biannual physical stability assessment. At the discretion of the project manager, annual benthic macro invertebrate monitoring using the Anne Arundel County approved protocols and storm event chemical monitoring for nutrients and sediments may be required. The monitoring plan shall also address all permit required project monitoring.
- Routine/biannual maintenance of County-owned SPSC systems is prescribed for a period of three years. This includes, but is not limited to, mulching and seeding of devoid areas, diseased plant replacement and replanting if necessary, removal of excessive debris and invasive species. This is done to ensure plant survivability, and to monitor and ensure the structural integrity of the construction project by performing any routine structural maintenance necessary.
- In the event that sediment accumulation exceeds 6 inches in the first year, the contractor shall spray down an additional layer of compost and replant the pool bottoms. Sediment deposition is expected in the pools to balance the energies within the system (upstream sediment input versus stable geomorphic design). Removal of accumulated sediment should be limited to when the accumulated sediment threatens the structural integrity of the system.
- Unless encountered with natural groundwater perch, the filtering capacity shall be physically checked. If the filtering capacity diminishes substantially (e.g. the design ponding depth is not recovered after 72 hours), the top few inches of discolored material within the pools shall be removed and shall be replaced with fresh material. The removed sediments should be disposed in an acceptable manner (i.e. landfill).

- Direct maintenance access shall be provided to all sandstone weirs and pools.
- A recorded maintenance agreement is required for all privately-owned SPSC systems.
- The operation and maintenance design detail and schedule shall be shown on the asbuilt plan. For privately-owned structures, the maintenance agreement shall be officially recorded and the recordation number shall be included on the approved grading plans.
- At a minimum, a maintenance plan shall include removal of exotic, invasive, and/or non-native plant species identified in the annual vegetation survey using methods approved by the County and by the Maryland Department of Agriculture.

13. Design checklist

SPSC Item	Check	Yes/No	Reviewer Comments
Hydrology	Delineate drainage area, landcovers, and soil to the most downstream point of the SPSC system.		
	Develop TR55/TR20 model run to calculate the pre-development and post-development peak discharges.		
	Utilize MDE standards and TR55 to calculate the required channel protection and other overbank quantity volume of storage to be controlled within the system.		
	Conduct a downstream investigation to check the adequacy of the outfall system.		
Hydraulics	Check the conveyance design (width, depth, slope) to ensure safe conveyance of the 100 year storm over the riffle/weir/cascade channels and that stable design dimensions for the cobbles and sandstone boulders are provided.		
	Check the calculated minimum pool depth to ensure that sufficient pool depth is provided to dissipate the upstream energies properly.		
	Check the post-development stream power for the 100 year storm to ensure that it is rendered equal to the pre-development stream power. (Note: this requires that sufficient SPSC length and number of pools be provided)		
	Does the storage volume within the pools and voids meet the required quantity management storage volume prescribed for the project and calculated using the MDE standards and TR55?		
Alignment	Does the alignment follow the natural drainage path and efforts are made to avoid impacts to natural resources such as trees and wetlands?		
Tree Protection	Have specimen trees been identified and a tree protection plan been developed?		
Downstream Tie-in	Does the SPSC system extend downstream to a point where the outfall is considered stable?		
	Has adequate downstream tie-in/transition been provided to address downstream instability and to ensure the outfall remains stable?		
Longitudinal Slope	Have the riffle segments been placed with a slope flatter than 5 percent?		
	Have the pool segments been placed with a slope flatter than 1 percent?		
	Have cascades been placed at no more than 1H:1V slope with double-lined boulders, and the height of any single cascade does not exceed 5 feet?		
Pool Design	Do the side slopes for the pool (from all unarmored segments) exceed 3H:1V?		
	Does the depth of the pool exceed the minimum calculated depth based on the upstream velocities? The design of the riffle and weir shall be modified such as not to result in pool depth exceeding 3 feet.		
	Does the length of the pool exceed the minimum required 10 feet and allow sufficient length to accommodate the 3H:1V slope on unarmored sides? Is the length of the pool at least twice as long as the length of the riffle?		

SPSC Item	Check	Yes/No	Reviewer Comments
Riffle Channel Design	Is the channel parabolic in shape?		
	Does the width, depth, and slope meet the design requirement and allow minimal entrenchment and safe conveyance of the 100 year storm?		
	Are the d_{50} cobble size adequate for accommodating the 100 year velocities? Did the designer include a cobble gradation table on the plan?		
Weir Design	Are the boulders forming the weir 3-4 times larger than the calculated d_{50}?		
	Are the footer boulders extended/anchored at least 2 feet below the lowest point of the scour pool?		
	Does the cross-section for the weir safely convey the 100 year storm?		
	Is filter fabric placed under the sandstone boulders?		
Cascade Design	Are the cascades armored with sandstone weir over filter fabric and the height does not exceed 5 feet at any given location?		
	Are three pools provided following the cascade, with adequate weirs separating each pool structure and designed in a manner to safely convey the 100 year storm?		
Cross-section Drawings	Has the designer provided a typical detail sections for the riffle, stone weirs and pools where needed and actual cross-sections along the alignment at frequent intervals to reflect changes in the grading? Note: the cross-sections shall be developed based on the geometric alignment and shall show the station numbers, existing grade, proposed grade, and sand mix/stone structure detail.		
	Has the designer shown the 100 year storm water surface elevation on the typical and actual cross-sections?		
Profile Drawings	Has the designer provided a longitudinal profile along the centerline of the alignment and shown invert and top elevations of all structures and the 100 year water surface elevation?		
Plan Sheets	Has proposed grading been provided, and are minimum/maximum dimensioning requirements met?		
	Has the 100 year water surface elevation been plotted on the plan?		
	Is the 100 year water surface elevation sufficiently contained within easements and is below all habitable structures?		
E&S	Has an approved erosion and sediment control plan by AASCD been implemented upstream and downstream of the SPSC system prior to excavation clearing and channel shaping?		
	Have flows from traps and basins been bypassed around the newly constructed SPSC system?		
Wetlands, Streams, Buffers, and 100 year Floodplain	Provide documentation from MDE/Army Corps of Engineers for approval of all impacts to all County Agencies.		
Maintenance	Have a permanent and direct maintenance access and public right of way been provided to all public facilities?		
	Has a maintenance agreement been signed and recorded for private SPSC structures?		

SPSC Item	Check	Yes/No	Reviewer Comments
Monitoring Plan	Has a monitoring/maintenance plan been developed for County-owned systems as prescribed in the design guidelines and is clearly shown on the plan?		
Planting	Have mulching and hydro-seeding been prescribed for the entire system?		
	Has the designer paid special attention to the use of native material, diversity, and dense placement of plant material within appropriate wetness zones throughout the site?		

14. Inspection checklist

SPSC Item	Check	Yes/No	Inspector Comments
Alignment	Does the alignment of the system match the alignment specified on the plan?		
Length	Has the contractor provided sufficient SPSC length to meet the minimum requirement on the plan?		
Elevation Difference	Does the elevation difference from structure to structure and from top to bottom of system match the design plan and profile?		
Number of Weirs	Does the number of weirs match the number specified on the plan and profile?		
Outfall Conditions and Tie-in	Is the connecting outfall physically stable with no signs of erosion and is the structure properly tied into the outfall as specified on the plans?		
Pools	Does the number of pools match the number specified on the plan and profile?		
	Does the depth in any given pool exceed the minimum required pool depth as shown on the design plans?		
Cascades	Cascades shall not exceed 5 feet in vertical height at any given location.		
	Cascades shall be parabolic in shape with adequate width and depth to accommodate safe conveyance of the 100 year storm as specified on the plan.		
	Cascades shall be followed by three consecutive pools.		
	Cascades shall be underlined by filter fabric.		
Weir Cross-section	Are the weirs curvilinear in the direction of the flow? i.e., are the boulders placed in a manner similar to a cross-vane that would direct the flow to the center of the pool and away from the banks?		
	Is the cross-section parabolic with adequate depth and width for safe 100 year conveyance as specified on the plans?		
	Are the sandstone boulders forming the weir 3 to 4 times larger than the d_{50} for the cobbles and underlined by filter fabric as specified on the plans?		
	Are footer boulders provided and extend to a depth that is 2 feet below the lowest point in the pool?		
Cobbles	Does the cobble size meet the d_{50} stone gradation requirements indicated on the gradation table?		
	Are the cobbles rounded? Are they silica/bank run		

SPSC Item	Check	Yes/No	Inspector Comments
	gravel?		
Filter Sand Mix	Has the contractor placed the required volume of filter sand mix below the system?		
	Does the filter sand mix include 20 percent wood chips by volume?		
Filter Fabric	Has filter fabric been applied under all sandstone boulder structures and as required on the plans?		
E&S	Have all the upstream erosion and sediment control measures been removed?		
	Have adequate conveyance systems been provided to address all lateral drainage? (Note: The presence of erosion lateral to the system suggests poor grading and the need for lateral conveyance systems to intercept the flow.)		
Plantings	Has mulch/compost been applied on the entire site?		
	Has the entire site been hydro-seeded with Red Fescue?		
	Has the site been planted with adequate number of shrubs and trees as specified in the plan? (Note: Pay special attention to use of native material, diversity, and dense placement of plant material within appropriate wetness zones throughout the site.)		
Maintenance Access	Has a direct vehicular maintenance access been provided as an entry location to the site? Are public facilities located within a deeded public parcel or a perpetual easement?		
For Private Structures	Has a maintenance agreement been prepared, signed, and recorded?		
For Public Structures: **The following items must be verified before the structure as-built is accepted by DPW and the bond is released**			
SPSC Item	**Check**	**Yes/No**	**Inspector Comments**
Filtering Capacity	For water quality ephemeral systems, do the pools drain to an acceptable level where the design ponding head for the filter is fully recovered in 72 hours after a rain event?		
Sedimentation	Has the contractor removed sedimentation (exceeding 6 inches) from the pools?		
Monitoring	Has the structure been monitored for at least 3 years? Specifically physical stability and plant survivability.		
	Have annual monitoring reports been submitted to I&P and IMD and were they favorable? If not, were deficiencies addressed?		
Plant Survivability	Has at least 80 percent of the planted shrubs and trees survived 3 years after installation?		
Physical stability	Are all sandstone boulders in place with no sign of bank or bed erosion throughout the length of the project?		
Invasive Species	Have all invasive plant species been removed from the system and the entire system re-seeded?		

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City of Wheat Ridge, Colorado, Department of Public Works, Engineering Division, Rock and Riprap Gradation, E-A02 Detail Code

Abbreviated List of Native Plants

Step Pool Storm Conveyances are designed with the intention that they will mimic natural processes. Vegetation plays an important role in these processes. It is highly encouraged on all projects and required on those in Anne Arundel County to use native vegetation appropriate for the conditions of the site.

The following is a sample, abbreviated list of native plants that may be used on SPSC structures within the airport zone. The list has been cross-checked for consistency with the Maryland Aviation Administration (MAA) approved plant list. This list may be subject to expansion to accommodate other native plant species and future updates to the MAA guidelines. It is the responsibility of the designer to check and propose native plant species that are consistent with MAA regulations for projects within the airport zone.

Common Name	Latin Name	Comments
American Holly	*Ilex opaca*	*(Male Only)*
Bald Cypress	*Taxodium distichum*	
Bayberry	*Myrica pensylvanica*	
Blue Flag Iris	*Iris versicolor*	
Christmas Ferns	*Polystichum acrostichoides*	
Cinnamon Fern	*Osmunda cinnamomea*	
Fringe Tree	*Chionanthus virginiana*	*(Male Only)*
Inkberry	*Ilex glabra*	*(Male Only)*
Little Bluestem	*Schizachyrium scoparium*	
Mountain Laurel	*Kalmia latifolia*	
Pitch Pine	*Pinus rigida*	
Switchgrass	*Panicum virgatum*	
Summersweet	*Clethra alinifolia*	
Sweetbay Magnolia	*Magnolia virginiana*	
Tussock Sedge	*Carex stricta*	
Virginia Sweetspire	*Itea virginica*	

For SPSC projects outside of the airport zone, the designer shall utilize the list of native plants as listed below:

Common Name	Latin Name
American Holly	*Ilex opaca*
Atlantic White Cedar	*Chamaecyparis thyoides*
Bald Cypress	*Taxodium distichum*
Northern Bayberry	Morella *pensylvanica*
Blue Flag Iris	*Iris versicolor*
Broomsedge	*Andropogon virginicus*
Christmas Fern	*Polystichum acrostichoides*
Cinnamon Fern	*Osmunda cinnamomea*
Common Winterberry	*Ilex laevigata*

Common Name	Latin Name
Cranberry	*Vaccinium macrocarpon*
Lowbush Blueberry v*accinium*	*Anguaticolium*
Water Lily	*Nymphea odorata*
Fringe Tree	*Chionanthus virginiana*
Golden Club	*Orontium aquaticum*
Highbush Blueberry	*Vaccinum corymbosum*
Inkberry	*Ilex glabra*
Little Bluestem	*Schizachyrium scoparium*
Mountain Laurel	*Kalmia latifolia*
Redhead Grass	*Potamogeton perfoliatus*
Eastern Redcedar	*Juniperus virginiana*
Royal Fern	*Osmunda regalis*
Serviceberry	*Amelanchier canadensis*
Switchgrass	*Panicum virgatum*
Smooth Alder	*Alnus serrulata*
Black Gum	*Nyssa sylvatica*
Sweet Pepperbush	*Clethra alinifolia*
Swamp Azalea	*Rhododendron viscosum*
Southern Bayberry	Morella canotiniensis
Sweetbay Magnolia	*Magnolia virginiana*
Tussock Sedge	*Carex stricta*
Virginia Chain Fern	*Woodwardia virginica*
Virginia Sweetspire	*Itea virginica*
Wax Myrtle	*Morella cerifera*
Yellow Pond Lilly	*Nuphar advena*
Riverbirch	*Batala Nigna*
American Hornbean	*Carpinus caroliniana*

The list above is not a complete list. A complete list of native plants can be found under www.aacounty.org/IP/Resources/AANativePlants.pdf. Special attention shall be placed on diversity and dense placement of plant material within appropriate wetness zones throughout the site (MDE, 2000). Additional information on native plants for the Chesapeake Bay region can be found at www.nps.gov/plants/pubs/chesapeake. For information concerning Native Plant Nurseries, please visit www.aacounty.org/IP/Forms.cfm and scroll down to the "Forestry Forms and Fact Sheets" section.

Summary of Revisions:

August 2010 Revision 1: (a) Added language to clarify when an SPSC system can and cannot be used as part of the ESD treatment train.

November 2010 Revision 2: (a) Replaced the d50 cobble size definition with the d_{100} definition indicating that the cobble design size is the minimum allowable cobble size to be used rather than median stone size. (b) Added a clarification on the minimum and maximum allowable length of pools and riffles. (c) Added a design checklist. (d) Added an inspection checklist. (e) Added guidance pertaining to sequence of construction and erosion and sediment control measures.

April 2011 Revision 3: The 2000 Maryland Stormwater Design Manual does not prescribe a groundwater separation requirement for filtering systems as is done with infiltration systems. Due to this, revision 3 eliminates the requirement for groundwater separation from the filtering system. However, to ensure that the filtering mechanism works as designed, the design water quality filter ponding depth in the pools, also known as seepage head, shall be available for storage during storm events and not inundated by seasonal groundwater. Further, construction inspection shall verify that pools do drain down within 72 hours to their design levels. Added horizontal and vertical setback requirements for SPSC systems. Added "Regenerative" to the practice name for consistency with EPA TMDL/WIP publications. Width/Depth ratio for Riffle/Weir section shall not be less than 10W:1D. Further, pool depths shall not exceed 3 feet. Modified the Erosion and Sediment Control and planting criteria.

Reviewed by Stewart Comstock, Debbie Cappuccitti, and Richard Trickett, MDE. Comments received from Stewart Comstock on 7/15/2011. Comments were addressed as part of revision 3.

October 2011, Revision 4. Some of the minimum and maximum allowable dimensions were changed to allow more energy dissipation and better channel connection with the floodplain. The changes were as follows:

- Pool length shall be at least two times longer than the riffle length.
- The weir/riffle cross-section shall be set no steeper than 10H:1V slope to allow for better connection with the floodplain
- Root wads may float and cause a debris jam that can undermine the stability of the stone structures. The use of root wads is optional and if used must be anchored at least 6 ft in the ground. Root wads shall not be used in the two pools directly upstream of a cascade.
- Added a cascade maximum height versus allowable slope design table.
- The footer rocks shall be anchored 2 feet below the lowest point in the pool.
- Changed the name of the instream weir to constructed instream riffle. The instream riffle slope is set to a maximum of 4% or 1H:25V.

December 2012 Revision 5: (a) A cobble stone gradation table was added to assist in defining the d_{50} design requirements. (b) Added allowance for increasing cross-section entrenchment up to 5H:1V. This allowance is limited to retrofit projects. (c) Drawing schematics updated with additional detail regarding cobble placement. (d) Text corrections pertaining to the instream riffle maximum allowable slope.

APPENDIX 6-2

USDA-NRCS ENGINEERING FIELD HANDBOOK

PART 650, CHAPTER 16

STREAMBANK AND SHORELINE PROTECTION

United States
Department of
Agriculture

**Natural
Resources
Conservation
Service**

Engineering
Field
Handbook

Chapter 16 Streambank and Shoreline Protection

Issued December 1996

Cover: Little Yellow Creek, Cumberland Gap National Park, Kentucky
(photograph by Robbin B. Sotir & Associates)

Preface

Chapter 16, Streambank and Shoreline Protection, is one of 18 chapters of the U.S. Department of Agriculture, Natural Resources Conservation Service, Engineering Field Handbook, previously referred to as the Engineering Field Manual. Other chapters that are pertinent to, and should be referenced in use with, Chapter 16 are:

Chapter 1:	Engineering Surveys
Chapter 2:	Estimating Runoff
Chapter 3:	Hydraulics
Chapter 4:	Elementary Soils Engineering
Chapter 5:	Preparation of Engineering Plans
Chapter 6:	Structures
Chapter 7:	Grassed Waterways and Outlets
Chapter 8:	Terraces
Chapter 9:	Diversions
Chapter 10:	Gully Treatment
Chapter 11:	Ponds and Reservoirs
Chapter 12:	Springs and Wells
Chapter 13:	Wetland Restoration, Enhancement, or Creation
Chapter 14:	Drainage
Chapter 15:	Irrigation
Chapter 17:	Construction and Construction Materials
Chapter 18:	Soil Bioengineering for Upland Slope Protection and Erosion Reduction

This is the second edition of chapter 16. Some techniques presented in this text are rapidly evolving and improving; therefore, additions to and modifications of chapter 16 will be made as necessary.

Acknowledgments

This chapter was prepared under the guidance of **Ronald W. Tuttle,** national landscape architect, United States Department of Agriculture, Natural Resource Conservation Service (NRCS), and **Richard D. Wenberg,** national drainage engineer (retired).

Robbin B. Sotir & Associates, Marietta, Georgia, was a major contributor to the inclusion of soil bioengineering and revision of the chapter. In addition to authoring sections of the revised manuscript, they supplied original drawings, which were adapted for NRCS use, and photographs.

Walter K. Twitty, drainage engineer (retired), NRCS, Fort Worth, Texas, and **Robert T. Escheman,** landscape architect, NRCS, Somerset, New Jersey, served a coordination role in the review and revision of the chapter. **Carolyn A. Adams,** director, Watershed Science Institute, NRCS, Seattle, Washington; **Leland M. Saele,** design engineer; **Gary E. Formanek,** agricultural engineer; and **Frank F. Reckendorf,** sedimentation geologist (retired), NRCS, Portland, Oregon, edited the manuscript to extend its applicability to most geographic regions. In addition these authors revised the manuscript to reflect new research on stream classification and design considerations for riprap, dormant post plantings, rootwad/boulder revetments, and stream barbs. **H. Wayne Everett,** plant materials specialist (retired), NRCS, Fort Worth, Texas, supplied the plant species information in the appendix. **Mary R. Mattinson,** editor, **John D. Massey,** visual information specialist, and **Wendy R. Pierce,** illustrator, NRCS, Fort Worth, Texas, provided editing assistance and desktop publishing in preparation for printing.

Chapter 16 Streambank and Shoreline Protection

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Chapter 16 Streambank and Shoreline Protection

650.1600 Introduction

(a) Purpose and scope

Streambank and shoreline protection consists of restoring and protecting banks of streams, lakes, estuaries, and excavated channels against scour and erosion by using vegetative plantings, soil bioengineering, and structural systems. These systems can be used alone or in combination. The information in chapter 16 does not apply to erosion problems on ocean fronts, large river and lake systems, or other areas of similar scale and complexity.

(b) Categories of protection

The two basic categories of protection measures are those that work by reducing the force of water against a streambank or shoreline and those that increase their resistance to erosive forces. These measures can be combined into a system.

Stormwater reduction or retention methods, grade reduction, and designs that reduce flow velocity fall into the first category of protection. Examples include permeable fence design, tree or brush revetments, jacks, groins, stream jetties, barbs, drop structures, increasing channel sinuosity, and log, rootwad, and boulder combinations. The second category includes channels lined with grass, concrete, riprap, gabions, cellular concrete, and other revetment designs. These measures can be used alone or in combination. Most designs that employ brushy vegetation, e.g., soil bioengineering, either alone or in combination with structures, protect from erosion in both ways.

Revetment designs do not reduce the energy of the flow significantly, so using revetments for spot protection may move erosion problems downstream or across the stream channel.

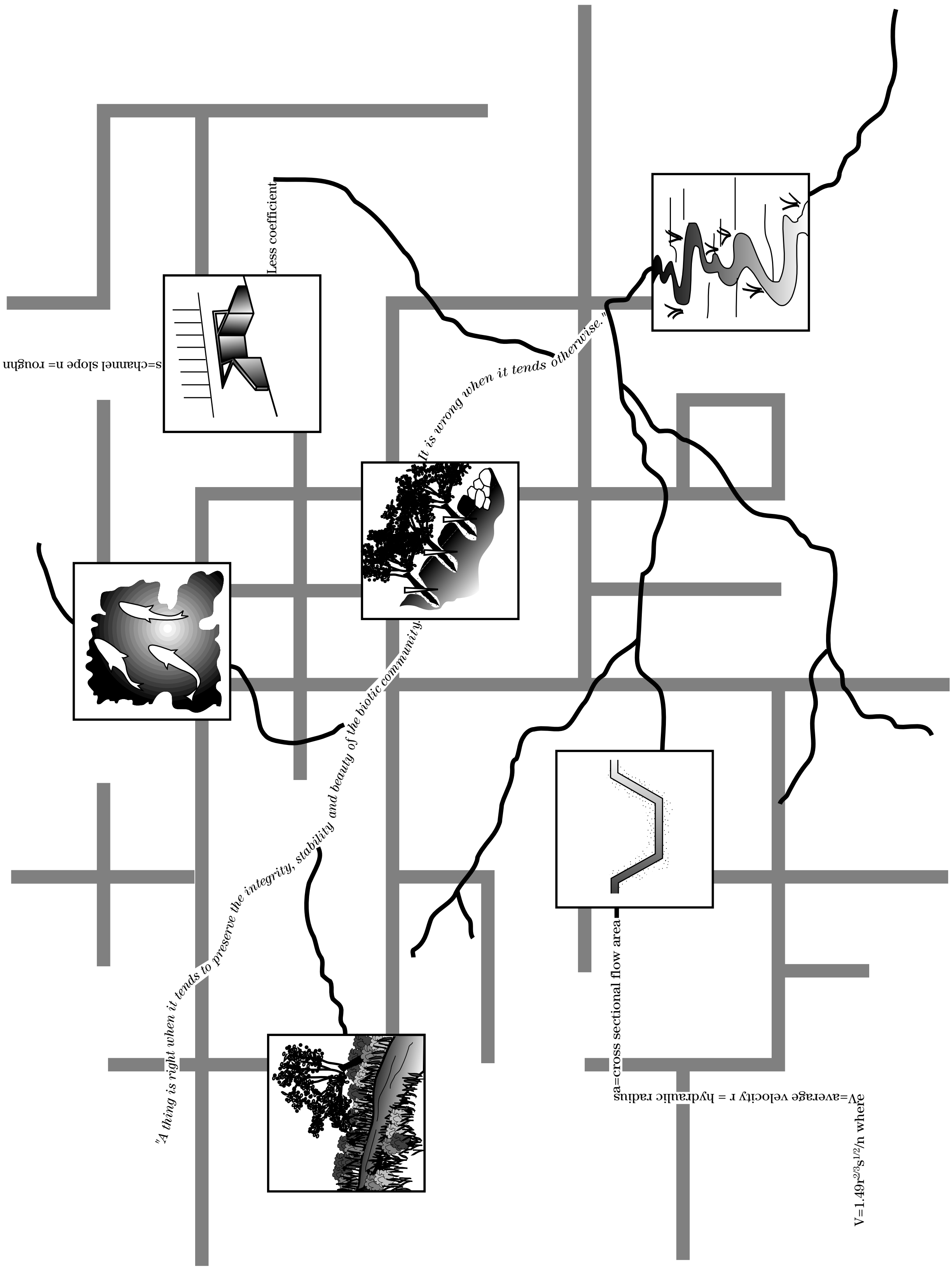
(c) Selecting streambank and shoreline protection measures

This document recognizes the need for intervention into stream corridors to affect rehabilitation; however, it is also acknowledged that this should be done on a selective basis. When selecting a site or stream reach for treatment, it is most effective to select areas within relatively healthy systems. Projects planned and installed in this context are more likely to be successful, and it is often critically important to prevent the decline of these healthier systems while an opportunity remains to preserve their biological diversity. Rehabilitation of highly degraded systems is also important, but these systems often require substantial investment of resources and may be so modified that partial success is often a realistic goal.

After deciding rehabilitation is needed, a variety of remedies are available to minimize the susceptibility of streambanks or shorelines to disturbance-caused erosive processes. They range from vegetation-oriented remedies, such as soil bioengineering, to engineered grade stabilization structures (fig. 16–1). In the recent past, many organizations involved in water resource management have given preference to engineered structures. Structures may still be viable options; however, in a growing effort to restore sustainability and ensure diversity, preference should be given to those methods that restore the ecological functions and values of stream or shoreline systems.

As a first priority consider those measures that
- are self sustaining or reduce requirements for future human support;
- use native, living materials for restoration;
- restore the physical, biological, and chemical functions and values of streams or shorelines;
- improve water quality through reduction of temperature and chronic sedimentation problems;
- provide opportunities to connect fragmented riparian areas; and
- retain or enhance the stream corridor or shoreline system.

Figure 16–1 Appropriate selection and application of streambank or shoreline protection measures should vary in response to specific objectives and site conditions (Aldo Leopold)



650.1601 Streambank protection

(a) General

The principal causes of streambank erosion may be classed as geologic, climatic, vegetative, and hydraulic. These causes may act independently, but normally work in an interrelated manner. Direct human activities, such as channel confinement or realignment and damage to or removal of vegetation, are major factors in streambank erosion.

Streambank erosion is a natural process that occurs when the forces exerted by flowing water exceed the resisting forces of bank materials and vegetation. Erosion occurs in many natural streams that have vegetated banks. However, land use changes or natural disturbances can cause the frequency and magnitude of water forces to increase. Loss of streamside vegetation can reduce resisting forces, thus streambanks become more susceptible to erosion. Channel realignment often increases stream power and may cause streambeds and banks to erode. In many cases streambed stabilization is a necessary prerequisite to the placement of streambank protection measures.

(b) Planning and selecting streambank protection measures

The list that follows, although not exhaustive, includes data commonly needed for planning purposes.

(1) Watershed data

When analyzing the source of erosion problems, consider the stream as a system that is affected by watershed conditions and what happens in other stream reaches. An analysis of stream and watershed conditions should include historical information on land use changes, hydrologic conditions, and natural disturbances that might influence stream behavior. It should anticipate the changes most likely to occur or that are planned for the near future:

- Climatic regime.
- Land use/land cover.
- History of land use, prior stream modifications, past stability problems, and previous treatments.
- Projected development over anticipated project life.

(2) Causes and extent of erosion problems

- If bank failure problems are the result of widespread bed degradation or headcutting, determine what triggered the problem.
- If bank erosion problems are localized, determine the cause of erosion at each site.

(3) Hydrologic/hydraulic data

- Flood frequency data (if not available, estimate using regional equations or other procedures).
- Estimates of stream-forming flow at 1- to 2-year recurrence interval and flow velocities.
- Estimates of width and depth at stream-forming flow conditions.
- Channel slope, width, depth, meander wavelength, and shape (width/depth, wetted perimeter).
- Sediment load (suspended and bedload).
- Water quality.

(4) Stream reach characteristics

- Soil and streambank materials at site.
- Potential streambank failures.
- Vegetative condition of banks.
- Channel alignment.
- Present stream width, depth, meander amplitude, belt width, wavelength, and sinuosity to determine stream classification.
- Identification of specific problems arising from flow deflection caused by sediment buildup, boulders, debris jams, bank irregularities, or constrictions.
- Bed material d_{50} based on a pebble count.
- Quality, amount, and types of terrestrial and aquatic habitat.
- Suspended load and bedload as needed, to determine if incoming sediment load can be transported through the restored reach.
- When selecting protective measures, analyze the needs of the entire watershed, the effects that stream protection may have on other reaches, surrounding wetlands, the riparian corridor, terrestrial habitat, aquatic habitat, water quality, and aesthetics. Reducing runoff and soil loss from the upland portions of the watershed using sound land treatment and management measures normally makes the streambank protection solution less expensive and more durable.

(5) Stream classification

Stream classification has evolved significantly over the past 100 years. William Davis (1899) first divided streams into three stages as youthful, mature and old age. Streams were later classified by their pattern as straight, meandering, or braided (Leopold & Wolman, 1957) or by stability and mode of sediment transport (Schumm, 1963 and 1977). Although all these systems served their intended purposes, they were not particularly helpful in establishing useful criteria for streambank protection and design. Rosgen (1985) developed a stream classification system that categorizes essentially all types of stream channels on the basis of measured morphological features. This system has been updated several times (Rosgen, 1992) and has broad applicability for communication among users and to predict a stream's behavior based on its appearance.

Predicting a stream's behavior based on appearance is also a feature of the Schumm, Harvey, and Watson (1984) channel evolution model developed for Oaklimeter Creek in Mississippi. This model discusses channel conditions extending from total disequilibrium to a new state of dynamic equilibrium. Such a model is useful in stream restoration work because streams can be observed in the field and their dominant process determined in the reach under consideration (i.e., active headcutting and transport of sediment, through aggradation and stabilization of alternate bars, and approaching a stage of dynamic equilibrium).

Rosgen's (1992) stream classification system goes beyond the channel evolution model as it is based on determining hydraulic geometry of stable stream reaches. This geometry is then extrapolated to unstable stream reaches to derive a template for potential channel design and reconstruction.

The present version of Rosgen's stream classification has several types (A, B, C, D, DA, E, F, and G), based on a hierarchical system. The first level of classification distinguishes between single or multiple thread channels. The streams are then separated based on degrees of entrenchment, width-to-depth ratio, and stream sinuosity. They are further subdivided by slope range and channel materials. Several stream subtypes are based on other criteria, such as average riparian vegetation, organic debris and channel blockages, flow regimes, stream size, depositional features, and meander pattern.

(6) Soils

A particular soil's resistance to erosion depends on its cohesiveness and particle size. Sandy soils have low cohesion, and their particles are small enough to be entrained by velocity flows of 2 or 3 feet per second. Lenses or layers of erodible material are frequent sources of erosion. Fines are selectively removed from soils that are heterogeneous mixtures of sand and gravel, leaving behind a layer of gravel that may protect or armor the streambed against further erosion. However, the hydraulic removal of fines and sand from a gravel matrix may cause it to collapse, resulting in sloughing of the streambank and its overlying material.

The resistance of cohesive soils depends on the physical and chemical properties of the soil as well as the chemical properties of the eroding fluid. Cohesive soils often contain montmorillonite, bentonite, or other expansive clays. Because unvegetated banks made up of expansive clays are subject to shrinkage during dry weather, tension cracks may develop parallel to and several feet below the top of the bank. These cracks may lead to slab failures on oversteepened banks, especially in places where bank support has been reduced by toe erosion. Tension cracks can also contribute to piping and related failures.

(7) Hydrologic, climatic, and vegetative conditions

Stream erosion is largely a function of the magnitude and frequency of flow events. Flow duration is of secondary importance except for flows that exceed stream-forming flow stage for extended periods. A streambank's position (outside curve or inside) can also be a major factor in determining its erosion potential.

Watershed changes that increase magnitude and frequency of flooding, such as urbanization, deforestation, and increased surface runoff, contribute to streambank erosion. Associated changes, such as loss of streamside vegetation from human or animal trampling, often compound the streambank erosion effect.

In cold climates where streams normally freeze or partly freeze during winter, erosion caused by ice is an additional problem. Streambanks are affected by ice scour in several ways:

- Streambanks and associated vegetation can be forcibly damaged during freezing or thawing action.

- Floating ice can cause gouging of streambanks.
- Acceleration of flow around and under ice rafts can cause damage to streambanks.

Erosion from ice may be minimized or reduced by vegetation for the following reasons:

- Streambank vegetation reduces damaging cycles of freeze-thaw by maintaining the temperature of bank materials, thus preventing ice from forming and encouraging faster thawing.
- Vegetation tends to be flexible and absorbs much of the momentum of drifting ice.
- Vegetation helps protect the bank from ice damage.
- Woody vegetation has deeply embedded roots that reinforce soils.
- Deeply rooted, woody vegetation helps to control erosion by adding strength to streambank materials, increasing flow resistance, reducing flow velocities in the vicinity of the bank, and retarding tension crack development.

(8) Hydraulic data

Stream power is a function of velocity, flow depth, and slope. Channelization projects that straighten or enlarge channels often increase one or more of these factors enough to cause widespread erosion and associated problems, especially if soils are easily erodible.

Headcuts often develop in the modified reach or at the transition from the modified reach to the unaltered reach. They move upstream, causing bed erosion and bank failure on the main stream and its tributaries. Returning the stream to its former meander geometry is generally the most reliable way to stop headcuts or prevent their development. Installing grade control structures that completely cross a stream and act as a very low head dam may initiate other channel instabilities by:

- inducing bank erosion around the ends of the structure;
- raising flood levels and causing out-of-bank flows to erode new channels;
- trapping sediment, thus decreasing channel capacity, inducing bank erosion and flood plain scour; and
- increasing width-to-depth ratio with subsequent lateral migration, increased bank erosion, and increased bar deposition or formation.

Grade control structures should be designed to maintain low channel width-to-depth ratios, maintain the sediment transport capacity of the channel, and provide for passing a wide range of flow velocities without creating backwater and causing sediment deposition. Vortex rock weirs, "W" rock weirs, and other rock/boulder structures that protect the channel without creating backwater should be considered instead of small rock and log dams.

Local obstructions to flow, channel constrictions, and bank irregularities cause local increases in the energy slope and create secondary currents that produce accelerations in velocity sufficient to cause localized streambank erosion problems. These localized problems often are treated best by eliminating the source of the problem and providing remedial bank protection. However, secondary cross currents are also a natural feature around the outside curves of meanders, and structural features may be required to modify these cross currents.

Streamflows that transport sustained heavy loads of sediment are less erosive than clear flows. This can easily be seen where dams are constructed on large sediment-laden streams. Once a dam is operational, the sediment drops out into the reservoir pool, so the water leaving the structure is clear. Several feet of degradation commonly occurs in the reach below the dam before an armor layer develops or hydraulic parameters are sufficiently altered to a stable grade. In watersheds that have high sediment yields, conservation treatments that significantly reduce sediment loads can trigger stream erosion problems unless runoff is also reduced.

(9) Habitat characteristics

The least-understood aspect of designing and analyzing streambank protection measures is often the impact of the protective measures on instream and riparian habitats. Commonly, each stage of the life cycle of aquatic species requires different habitats, each having specific characteristics. These diverse habitats are needed to meet the unique demands imposed by spawning and incubation, summer rearing, and overwintering. The productivity of most aquatic systems is directly related to the diversity and complexity of available habitats.

Fish habitat structures are commonly an integral part of stream protection measures, but applicability of habitat structures varies by classified stream type. Work by Rosgen and Fittante (1992) resulted in a guide for evaluating suitability of various proposed fish habitat structures for a wide range of morphological stream types. They divide structures into those for rearing habitat enhancement and those for spawning habitat enhancement. The structures for rearing habitat enhancement include low stage check dam, medium stage check dam, boulder placement, bank-placed materials, single wing deflector, channel constrictor, bank cover, floating log cover, submerged shelter, half log cover, and migration barrier. U-shaped gravel traps, log sill gravel traps, and gravel placement are for spawning habitat enhancement.

Since a multitude of interrelated factors influence the productivity of streams, the response of fish and wildlife populations to changes in habitat is often difficult to predict with confidence.

(10) Environmental data

Environmental goals should be set early in the planning process to ensure that full consideration is given to ecological stability and productivity during the selection and design of streambank protection measures. Special care should be given to consideration of terrestrial and aquatic habitat benefits of alternative types of protection and to maintenance needs on a site specific basis.

In general, the least disturbance to the existing stream system during construction and maintenance produces the greatest environmental benefits. Damages to the environment can be limited by:

- Using small equipment and hand labor.
- Limiting access.
- Locating staging areas outside work area boundaries.
- Avoiding or altering construction procedures during critical times, such as fish spawning or bird nesting periods.
- Coordinating construction on a stream that involves more than one job or ownership.
- Adopting maintenance plans that maximize riparian vegetation and allow wide, woody vegetative buffers.
- Scheduling construction activities to avoid expected peak flood season(s).

(11) Social and economic factors

Initial installation cost and long-term maintenance are factors to be considered when planning streambank and shoreline protection. Other factors include the suitability of construction material for the use intended, the cost of labor and machinery, access for equipment and crews at the site, and adaptations needed to adjust designs to special conditions and the local environment.

Some protection measures seem to have apparent advantages, such as low cost or ease of construction, but a more expensive alternative might best meet planned objectives when maintenance, durability of material, and replacement costs are considered. Effect upon resources and environmental values, such as aesthetics, wildlife habitat, and aquatic requirements, are also integral factors.

The need for access to the stream or shoreline and the effects of protection measures upon adjacent property and land uses should be analyzed.

Minor protective measures can be installed without using contract labor or heavy equipment. However, many of the protective measures presented in this chapter require evaluation, design, and implementation to be done by a knowledgeable interdisciplinary team because precise construction techniques and costly construction materials may be required.

(c) Design considerations for streambank protection

(1) Channel grade

The channel grade may need to be controlled before any permanent type of bank protection can be considered feasible unless the protection can be safely and economically constructed to a depth well below the anticipated lowest depth of bed scour. Control can be by natural or artificial means. Reconstructing stream channels to their historical stream type (i.e., stream geometry) has been successfully used to achieve grade control. Artificial measures typically include rock, gabions and reinforced concrete grade control structures.

(2) Discharge frequency

Maximum floods are rarely used for design of streambank protection measures. The design flood frequency should be compatible with the value or safety of the property or improvements being protected, the repair cost of the streambank protection, and the sensitivity and value of ecological systems within the planning unit. Bankfull discharge (stream-forming flow) of natural streams tends to have a recurrence interval of 1 to 2 years based on the annual flood series (Leopold and Rosgen, 1991). The discharge at this frequency is commonly used as a design discharge for stream restoration (Rosgen, 1992). For modified streams, the 1- to 2-year frequency discharge is also useful for design discharge because it is the flow that has the most impact upon the stability of the stream channel.

(3) Discharge velocities

Where the flow entering the section to be protected carries only clay, silt, and fine sand in suspension, the maximum velocity should be limited to that which is nonscouring on the least resistant material occurring in any appreciable quantity in the streambed and bank. The minimum velocity should be that required to transport the suspended material. The depth-area-velocity relationship of the upstream channel should be maintained through the protected reach. Where the flow entering the section is transporting bedload, the minimum velocity should be that which will transport the entering bedload material through the section.

The minimum design velocity should also be compatible with the needs of the various fish species present or those targeted for recovery. Velocity changes can reduce available habitat or create physical barriers that restrict fish passage. Further information on fish habitat is available in publications cited in the reference section.

Streambank protection measures on large, wide channels most likely will not significantly change streamflow velocity. On smaller streams, however, the protective measures can influence the velocity throughout the reach.

In calculating these velocities, the Manning's n values selected should represent the stream condition after the channel has matured, which normally requires several years. Erosion or sedimentation may occur if this is not anticipated.

(4) Freeboard

Freeboard should be provided to prevent overtopping of the revetment at curves and other points where high velocity flow contacts the revetment. In these areas a potential supercritical velocity can set up waves, and the climb on sloping revetments may be appreciable. Because an accurate method to determine freeboard requirements is not available for sloping revetments in critical zones, the allowance for freeboard should be based on sound judgment and experience. Under similar conditions, the freeboard required for a sloping revetment is always greater than that for a vertical revetment.

(5) Alignment

Changes in channel alignment affect the flow characteristics through, above, and below the changed reach. Straightening without extensive channel hardening does not eliminate a stream's tendency to meander. An erosion hazard may often develop at both ends of the channel because of velocity increases, bar formations, and current direction changes. Changes in channel alignment are not recommended unless the change is to reconstruct the channel to its former meander geometry.

Alignment of the reach must also be carefully considered in designing protective measures. Because of major changes in hydraulic characteristics, streambanks for channels having straight alignment generally require a continuous scour-resistant lining or revetment. To prevent scour by streamflow as the stream attempts to recreate its natural meander pattern, most banks must be sloped to a stable grade before the lining is applied. For nonrigid lining, the slope must be flat enough to prevent the lining material from sliding.

Curved revetments are subjected to increased forces because of the secondary currents acting against them. More substantial and permanent types of construction may be needed on curved channel sections because streambank failures at these vulnerable points could result in much greater damage than that along unobstructed straight reaches of channel.

(6) Stream type and hydraulic geometry

Stream rehabilitation should be considered in the context of the historically stable stream type and its geometry. If stream modification has caused shortened meander wavelength, amplitude, and radius of curvature, the stream being treated might be best stabilized by restoring the historical geometry. The width-to-depth ratio of the stream being treated may be too high to transport the sediment load, and a lower ratio may be needed in the design channel.

(7) Sediment load and bed material

To determine the potential for stream aggradation, the sediment load (bedload and suspended) for storm and snowmelt runoff periods must frequently be determined before reconstruction. The size distribution of the streambed and bar material also should be determined. These measurements are important above and below the reconstruction reach under consideration as well as in the main tributary streams above the reach. This information is used with appropriate shear stress equations to determine the size of material that would be entrained at bankfull discharge (stream-forming flow) for both the tributary streams and in the restored reach. The sediment transport rate must be sufficient to prevent aggradation of the newly restored channel. As shown by studies in Colorado (Andrews, 1983) on gravelbed rivers, it is anticipated that particles as large as the median diameter of the bed surface will be entrained by discharge equal to the bankfull stage (stream-forming flow) or less.

(8) Protection against failure

Measures should be designed to provide against loss of support at the revetment's boundaries. This includes upstream and downstream ends, its base or toe, and the crest or top.

(9) Undermining

Undermining or scouring of the foundation material by high velocity currents is a major cause of bank protection failure. In addition to protecting the lowest expected stable grade, additional depth must be provided to reach a footing that most likely will not be scoured out during floods or lose its stability through saturation. Deep scour can be expected where construction is on an erodible streambed and high velocity currents flow adjacent to it.

Methods used to provide protection against undermining at the toe are:

- Extending the toe trench down to a depth below the anticipated scour and backfilling with heavy rock.
- Anchoring a heavy, flexible mattress to the bottom of the revetment, which at the time of installation will extend some distance out into the channel. This mattress will settle progressively as scour takes place, protecting the revetment foundation.
- Installing a massive toe of heavy rock where excavation for a deep toe is not practical. This allows the rock forming the toe to settle in place if scour occurs. However, because of the forces of flow, the settlement direction of the rock is not always straight down.
- Driving sheet piling to form a continuous protection for the revetment foundation. Such piling should be securely anchored against lateral pressures. To provide for a remaining embedment after scour, piling should be driven to a depth equal to about twice the exposed height.
- Installing toe deflector groins to deflect high velocity currents away from the toe of the revetment.
- Installing submerged vanes to control secondary currents.

Since most of these measures have direct impacts on aquatic habitat and other stream functions and values, their use should be considered carefully when planning a streambank protection project.

(10) Ends of revetment

The location of the upstream and downstream ends of revetments must be selected carefully to avoid flanking by erosion. Wherever possible, the revetment should tie into stable anchorage points, such as bridge abutments, rock outcrops, or well-vegetated stable sections. If this is not practical, the upstream and downstream ends of the revetment must be positioned well into a slack water area along the bank where bank erosion is not a problem.

(11) Debris removal

Streambank protection may require the selective removal or repositioning of debris, such as fallen trees, sediment bars, or other obstructions. Because logs and other woody debris are the major habitat-forming components in many stream systems, a plan for debris removal should be developed in consultation with qualified fish and wildlife specialists. Small accumulations of debris and sediment generally do not cause problems and should be left undisturbed.

When planning streambank stabilization work, select access routes for equipment that minimize disturbance to the flood plain and riparian areas. All debris removal, grading, and material delivery and placement should be accomplished in a manner that uses the smallest equipment feasible and minimizes disturbance of riparian vegetation. Excavated material should be disposed of in such a way that it does not interfere with overbank flooding, flood plain drainage, or associated wetland hydrology. In high velocity streams it may be necessary to remove floating debris selectively from flood-prone areas or anchor it so that it will not float back into the channel.

Sediment bars, snags, trees, and other debris drifts that create secondary currents or deflect flow toward the banks may require selective removal or relocation in the stream channel. The entire plant structure does not always need to be dislodged when considering the removal of trees and snags; rooted stumps should be left in place to prevent erosion. Isolated or single logs that are embedded, lodged, or rooted in the channel and not causing flow problems should not be disturbed. Fallen trees may be used to construct bank protection systems. Trees and other large vegetation are important to aquatic, aesthetic and riparian habitat systems, and removal should be done judiciously and with great care.

(12) Vegetative systems

Vegetative systems provide many benefits to fish and wildlife populations as well as increasing the streambank's resistance to erosive forces. Vegetation near the channel provides shade to help maintain suitable water temperature for fish, provides habitat for wildlife and protection from predators, and contributes to aesthetic quality. Leaves, twigs, and insects drop into the stream, providing nutrients for aquatic life (fig. 16–2).

Figure 16–2 Vegetative system along streambank

Although woody brush is preferable for habitat reasons, suitable herbaceous ground cover can provide desirable bank protection in areas of marginal erosion. Perennial grasses and forbes, preferably those native to the area, should be used rather than annual grasses. Woody vegetation may also be used to control undesirable access to the stream.

Associated emergent aquatic plants serve multiple functions, including the protection of woody streambank or shoreline vegetation from wave or current wave action, which tend to undercut them.

Vegetation protects streambanks in several ways:

- Root systems help hold the soil particles together increasing bank stability.
- Vegetation may increase the hydraulic resistance to flow and reduce local velocities in small channels.
- Vegetation acts as a buffer against the hydraulic forces and abrasive effect of transported materials.
- Dense vegetation on streambanks can induce sediment deposition.
- Vegetation can redirect flow away from the bank.

(d) Protective measures for streambanks

Protective measures for streambanks can be grouped into three categories: vegetative plantings, soil bioengineering systems, and structural measures. They are often used in combination.

(1) Vegetative plantings

Conventional plantings of vegetation may be used alone for bank protection on small streams and on locations having only marginal erosion, or it may be used in combination with structural measures in other situations. Considerations in using vegetation alone for protection include:

- Conventional plantings require establishment time, and bank protection is not immediate.
- Maintenance may be needed to replace dead plants, control disease, or otherwise ensure that materials become established and self-sustaining.
- Establishing plants to prevent undercutting and bank sloughing in a section of bank below baseflow is often difficult.
- Establishing plants in coarse gravely material may be difficult.
- Protection and maintenance requirements are often high during plant establishment.

Woody vegetation, which is seeded or planted as rooted stock, is used most successfully above baseflow on properly sloped banks and on the flood plain adjacent to the banks. Vegetation should always be used behind revetments and jetties in the area where sediment deposition occurs, on the banks above baseflow, and on slopes protected by cellular blocks or similar type materials.

Many species of plants are suitable for streambank protection (see appendix 16B). Use locally collected native species as a first priority. Exotic or introduced species should be used only if there is no alternative. They should never be invasive species. Locally available erosion-resistant species that are suited to the soil, moisture, and climatic conditions of a particular site are desirable. Aesthetics may also play an important role in selecting plants for certain areas.

In many instances streambank erosion is accelerated by overgrazing, cultivating too close to the banks, or by overuse. In either case the treated area should be protected by adequate streamside buffers and appropriate management practices. If the stream is the source of livestock drinking water, access can be provided by establishing a ramp down to the water. Such ramps should be located where the bank is not steep and, preferably, in straighter sections or at the inside of curves in the channel where velocities are low. Providing watering facilities out of the channel (i.e., on the flood plain or terrace) for the livestock is often a preferred alternative to using ramps.

The visual impact, habitat value, and other environmental effects of material removal or relocation must also be considered before performing any work.

Protective measures reduce streambank erosion and prevent land losses and sediment damages, but do not directly stabilize the channel grade. However, if the channel is restored to a stable stream type, vegetative protective measures, such as soil bioengineering, can be used to stabilize the streambanks. Vegetation assists in bank stabilization by trapping sediment, reducing tractive stresses acting on the bank, redirecting the flow, and holding soil. The boundary shear stress provided by vegetation, however, is much less than that provided by structural elements.

(2) Soil bioengineering systems

Properly designed and constructed soil bioengineering systems have been used successfully to stabilize streambanks (figs. 16–3a, 16–3b, 16–3c, and 16–3d).

Soil bioengineering is a system of living plant materials used as structural components. Adapted types of woody vegetation (shrubs and trees) are initially installed in specified configurations that offer immediate soil protection and reinforcement. In addition, soil bioengineering systems create resistance to sliding or shear displacement in a streambank as they develop roots or fibrous inclusions. Environmental benefits derived from woody vegetation include diverse and productive riparian habitats, shade, organic additions to the stream, cover for fish, and improvements in aesthetic value and water quality.

Under certain conditions, soil bioengineering installations work well in conjunction with structures to provide more permanent protection and healthy function, enhance aesthetics, and create a more environmentally acceptable product. Soil bioengineering systems normally use unrooted plant parts in the form of cut branches and rooted plants. For streambanks, living systems include brushmattresses, live stakes, joint plantings, vegetated geogrids, branchpacking, and live fascines.

Major attractions of soil bioengineering systems are their natural appearance and function and the economy with which they can often be constructed. As discussed in chapter 18 of this Engineering Field Handbook, the work is normally done in the dormant months, generally September to March, which is the off season for many laborers. The main construction materials are live cuttings from suitable plant species. Species must be appropriate for the intended use and adapted to the site's climate and soil conditions.

Consult a plant materials specialist for guidance on plant selection. Ideally plant materials should come from local ecotypes and genetic stock similar to that within the vicinity of the stream. Species that root easily, such as willow, are required for measures, such as live fascines and live staking, or where unrooted cuttings are used with structural measures. Suitable plant materials are listed in appendix 16B. They may also be identified in Field Office Technical Guides for specific site conditions or by contacting Plant Materials Centers.

Many sites require some earthwork before soil bioengineering systems are installed. A steep undercut or slumping bank, for example, may require grading to a 3:1 or flatter slope. Although soil bioengineering systems are suitable for most sites, they are most successful where installed in sunny locations and constructed during the dormant season.

Rooted seedlings and rooted cuttings are excellent additions to soil bioengineering projects. They should be installed for species diversification and to provide habitat cover and food for fish and wildlife. Optimum establishment is usually achieved shortly after earth work, preferably in the spring.

Some of the most common and useful soil bioengineering structures for restoration and protection of streambanks are described in the following sections.

Figure 16–3a Eroding bank, Winooski River, Vermont, June 1938

Figure 16–3b Bank shaping prior to installing soil bioengineering practices, Winooski River, Vermont, September 1938

Figure 16–3c Three years after installation of soil bioengineering practices, 1941

Figure 16–3d Soil bioengineering system, Winooski River, Vermont, June 1993 (55 years after installation)

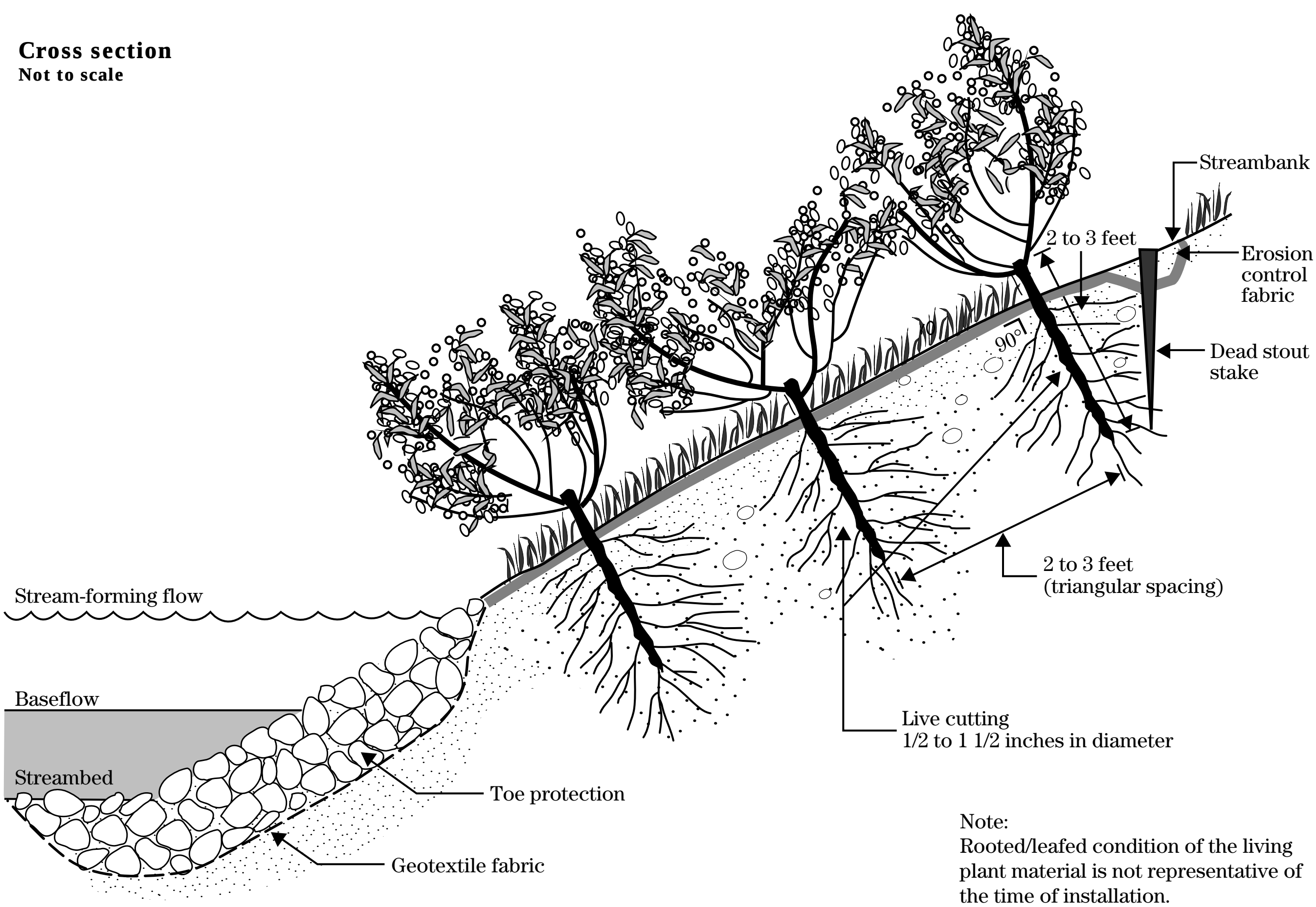
(i) Live stakes—Live staking involves the insertion and tamping of live, rootable vegetative cuttings into the ground (figs. 16–4 and 16–5). If correctly prepared, handled, and placed, the live stake will root and grow (fig. 16–6).

A system of stakes creates a living root mat that stabilizes the soil by reinforcing and binding soil particles together and by extracting excess soil moisture. Most willow species root rapidly and begin to dry out a bank soon after installation.

Applications and effectiveness

- Effective streambank protection technique where site conditions are uncomplicated, construction time is limited, and an inexpensive method is needed.
- Appropriate technique for repair of small earth slips and slumps that frequently are wet.
- Can be used to peg down and enhance the performance of surface erosion control materials.
- Enhance conditions for natural colonization of vegetation from the surrounding plant community.
- Stabilize intervening areas between other soil bioengineering techniques, such as live fascines.
- Produce streamside habitat.

Figure 16–4 Live stake details



Construction guidelines

Live material sizes—The stakes generally are 0.5 to 1.5 inches in diameter and 2 to 3 feet long. The specific site requirements and available cutting source determine sizes.

Live material preparation

- The materials must have side branches cleanly removed with the bark intact.
- The basal ends should be cut at an angle or point for easy insertion into the soil. The top should be cut square.
- Materials should be installed the same day that they are prepared.

Installation

- Erosion control fabric should be placed on slopes subject to erosive inundation.
- Tamp the live stake into the ground at right angles to the slope and diverted downstream. The installation may be started at any point on the slope face.
- The live stakes should be installed 2 to 3 feet apart using triangular spacing. The density of the installation will range from 2 to 4 stakes per square yard. Site variations may require slightly different spacing.
- Placement may vary by species. For example, along many western streams, tree-type willow species are placed on the inside curves of point bars where more inundation occurs, while shrub willow species are planted on outside curves where the inundation period is minimal.
- The buds should be oriented up.
- Four-fifths of the length of the live stake should be installed into the ground, and soil should be firmly packed around it after installation.
- Do not split the stakes during installation. Stakes that split should be removed and replaced.
- An iron bar can be used to make a pilot hole in firm soil.
- Tamp the stake into the ground with a dead blow hammer (hammer head filled with shot or sand).

Figure 16–5 Prepared live stake (Robbin B. Sotir & Associates photo)

Figure 16–6 Growing live stake

***(ii) Live fascines*—**Live fascines are long bundles of branch cuttings bound together in cylindrical structures (fig. 16–7). They should be placed in shallow contour trenches on dry slopes and at an angle on wet slopes to reduce erosion and shallow sliding.

Applications and effectiveness

- Apply typically above bankfull discharge (stream-forming flow) except on very small drainage area sites (generally less than 2,000 acres).
- Effective stabilization technique for streambanks. When properly installed, this system does not cause much site disturbance.
- Protect slopes from shallow slides (1 to 2 foot depth).
- Offer immediate protection from surface erosion.
- Capable of trapping and holding soil on a streambank by creating small dam-like structures, thus reducing the slope length into a series of shorter slopes.
- Serve to facilitate drainage where installed at an angle on the slope.
- Enhance conditions for colonization of native vegetation by creating surface stabilization and a microclimate conducive to plant growth.

Construction guidelines

Live materials—Cuttings must be from species, such as young willows or shrub dogwoods, that root easily and have long, straight branches.

Live material sizes and preparation

- Cuttings tied together to form live fascine bundles normally vary in length from 5 to 10 feet or longer, depending on site conditions and limitations in handling.
- The completed bundles should be 6 to 8 inches in diameter, with all of the growing tips oriented in the same direction. Stagger the cuttings in the bundles so that tops are evenly distributed throughout the length of the uniformly sized live fascine.
- Live stakes should be 2.5 feet long.

Inert materials—String used for bundling should be untreated twine.

Dead stout stakes used to secure the live fascines should be 2.5-foot long, untreated, 2 by 4 lumber. Each length should be cut again diagonally across the 4-inch face to make two stakes from each length (fig 16–8). Only new, sound lumber should be used, and any stakes that shatter upon installation should be discarded.

Installation

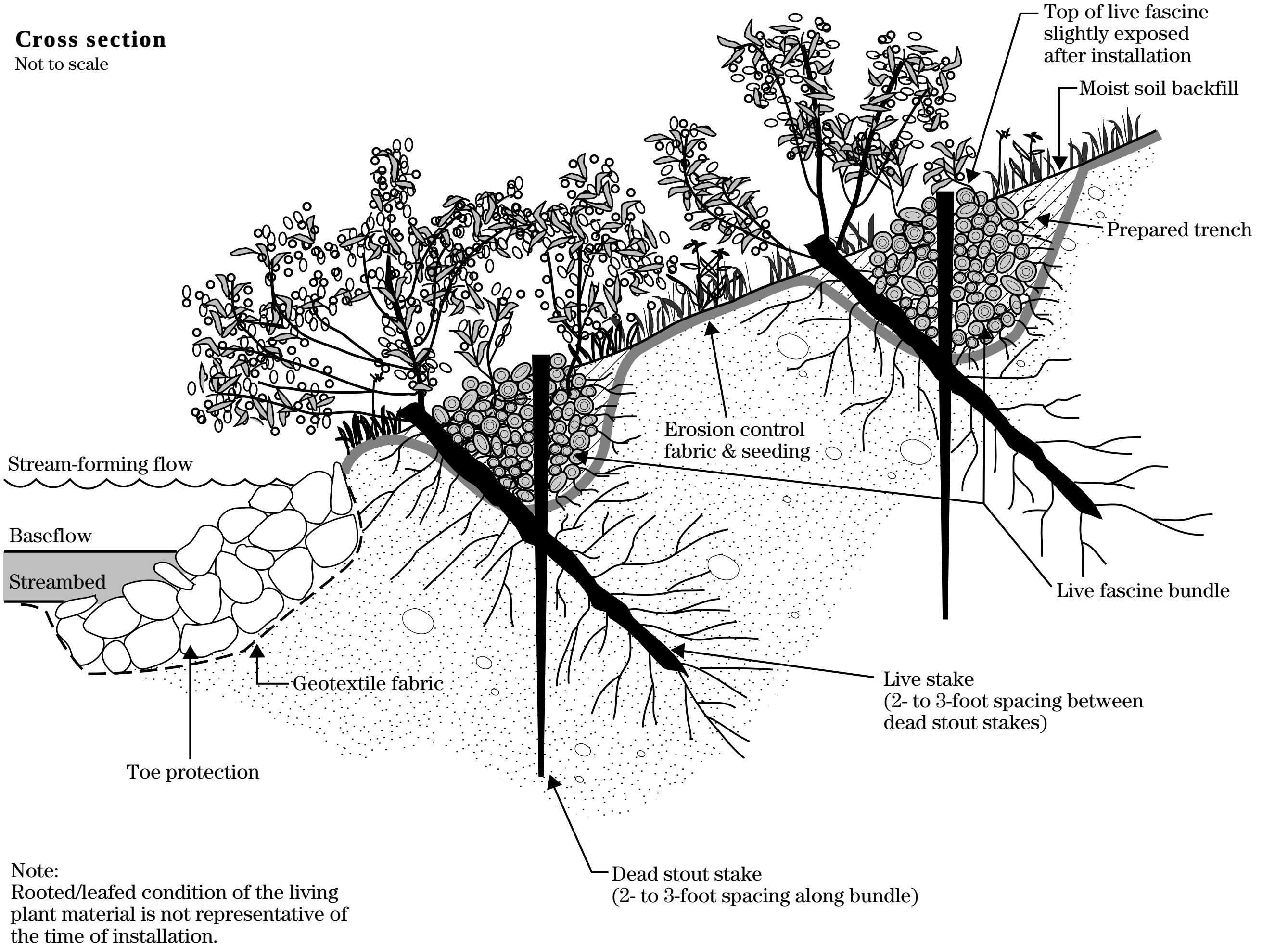
- Prepare the live fascine bundle and live stakes immediately before installation.
- Beginning at the base of the slope, dig a trench on the contour approximately 10 inches wide and deep.
- Excavate trenches up the slope at intervals specified in table 16–1. Where possible, place one or two rows over the top of the slope.
- Place long straw and annual grasses between rows.
- Install jute mesh, coconut netting, or other acceptable erosion control fabric. Secure the fabric.
- Place the live fascine into the trench (fig. 16–9a).
- Drive the dead stout stakes directly through the live fascine. Extra stakes should be used at connections or bundle overlaps. Leave the top of the dead stout stakes flush with the installed bundle.
- Live stakes are generally installed on the downslope side of the bundle. Tamp the live stakes below and against the bundle between the previously installed dead stout stakes, leaving 3 inches to protrude above the top of the ground (fig. 16–9b). Place moist soil along the sides of the bundles. The top of the live fascine should be slightly visible when the installation is completed. Figure 16–9c shows an established live fascine system 2 years after installation is completed.

Table 16–1 Live fascine spacing

Slope steepness	Soils		
	Erosive (feet)	Non-erosive (feet)	Fill (feet)
3:1 or flatter	3 – 5	5 – 7	3 – 5 1/
Steeper than 3:1 (up to 1:1)	3 1/	3 – 5	2/

1/ Not recommended alone.
2/ Not a recommended system.

Figure 16–7 Live fascine details



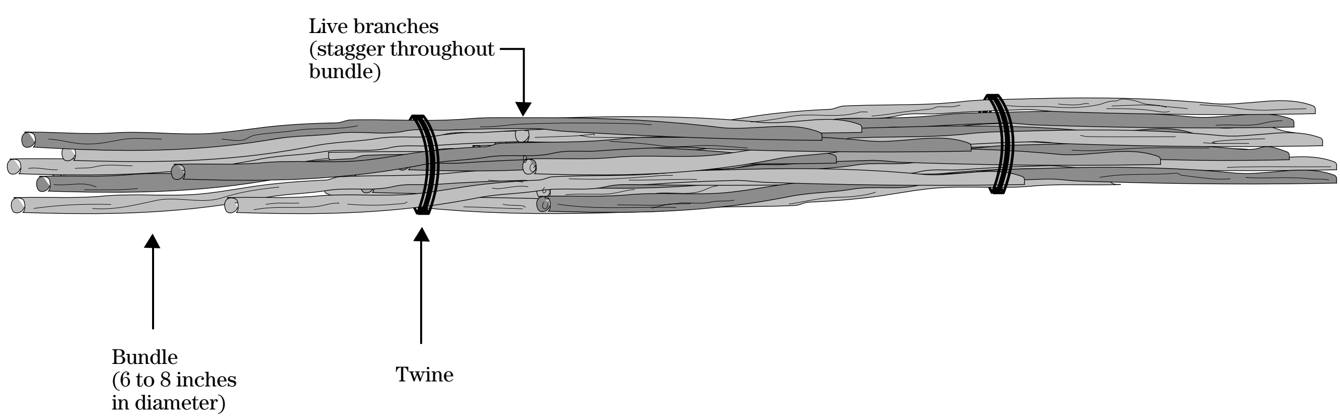


Figure 16–8 Preparation of a dead stout stake

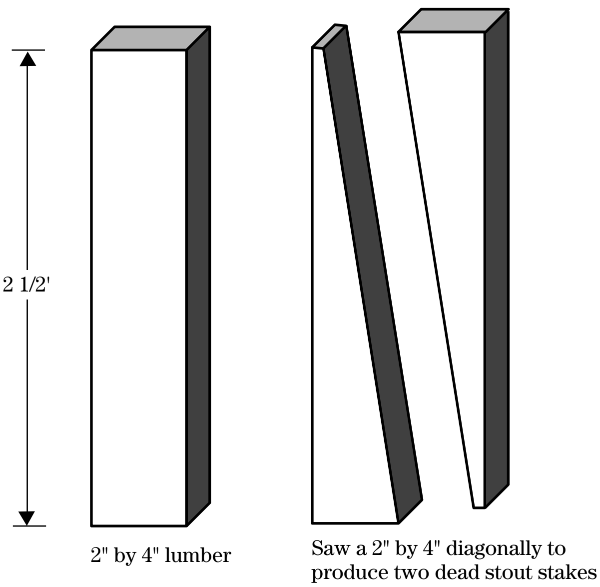


Figure 16–9a Placing live fascines (Robbin B. Sotir & Associates photo)

Figure 16–9b Installing live stakes in live fascine system (Robbin B. Sotir & Associates photo)

Figure 16–9c An established 2-year-old live fascine system (Robbin B. Sotir & Associates photo)

(iii) Branchpacking—Branchpacking consists of alternating layers of live branches and compacted backfill to repair small localized slumps and holes in streambanks (figs. 16–10, 16–11a, 16–11b, and 16–11c).

Applications and effectiveness

- Effective and inexpensive method to repair holes in streambanks that range from 2 to 4 feet in height and depth.
- Produces a filter barrier that prevents erosion and scouring from streambank or overbank flow.
- Rapidly establishes a vegetated streambank.
- Enhances conditions for colonization of native vegetation.
- Provides immediate soil reinforcement.
- Live branches serve as tensile inclusions for reinforcement once installed. As plant tops begin to grow, the branchpacking system becomes increasingly effective in retarding runoff and reducing surface erosion. Trapped sediment refills the localized slumps or hole, while roots spread throughout the backfill and surrounding earth to form a unified mass.
- Typically branchpacking is not effective in slump areas greater than 4 feet deep or 4 feet wide.

Construction guidelines

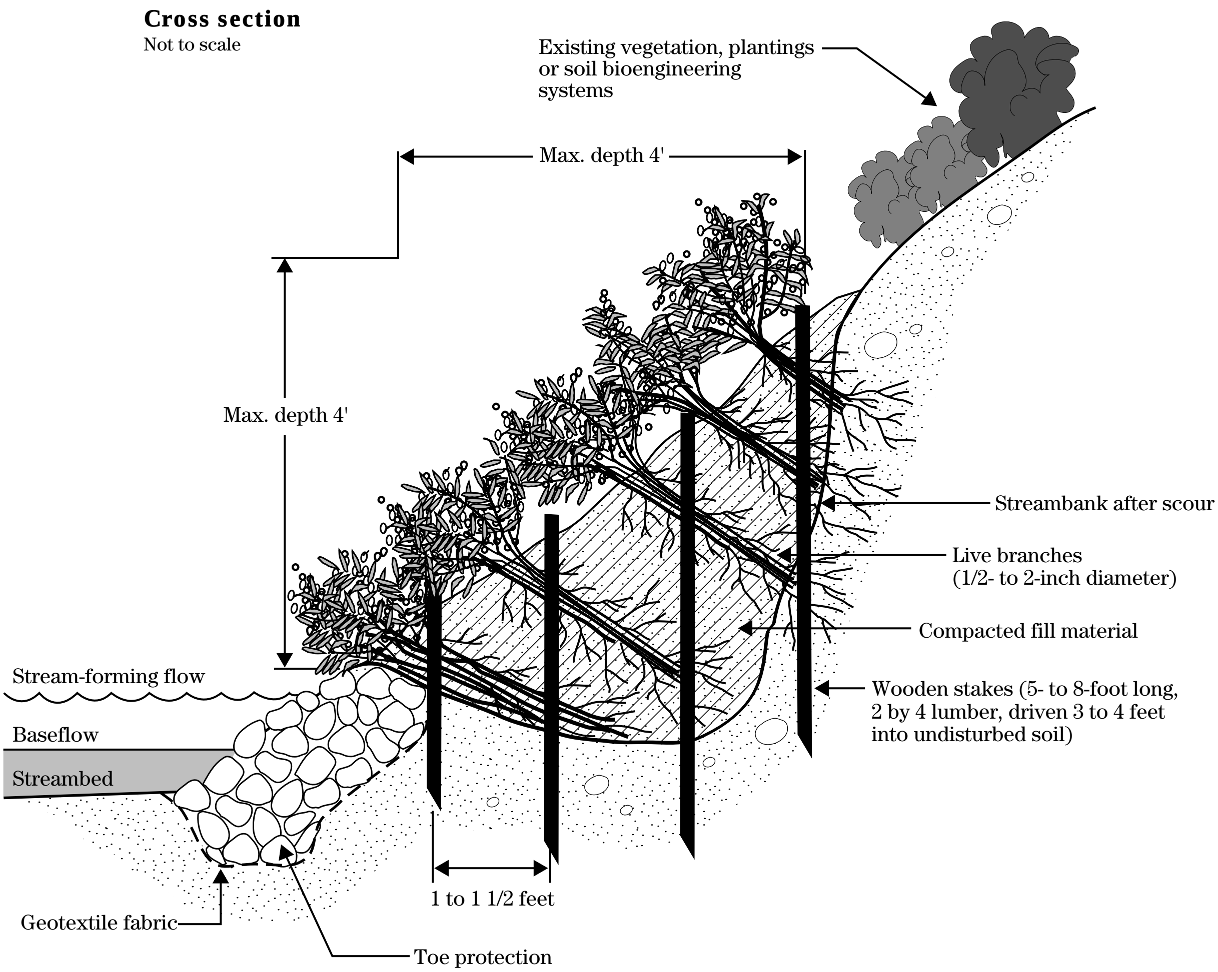
Live materials—Live branches may range from 0.5 to 2 inches in diameter. They should be long enough to touch the undisturbed soil of the back of the trench and extend slightly from the rebuilt streambank.

Inert materials—Wooden stakes should be 5 to 8 feet long and made from 3- to 4-inch diameter poles or 2 by 4 lumber, depending upon the depth of the particular slump or hole being repaired.

Installation

- Starting at the lowest point, drive the wooden stakes vertically 3 to 4 feet into the ground. Set them 1 to 1.5 feet apart.
- Place an initial layer of living branches 4 to 6 inches thick in the bottom of the hole between the vertical stakes, and perpendicular to the slope face (fig. 16–10). They should be placed in a criss-cross configuration with the growing tips generally oriented toward the slope face. Some of the basal ends of the branches should touch the undisturbed soil at the back of the hole.
- Subsequent layers of branches are installed with the basal ends lower than the growing tips of the branches.
- Each layer of branches must be followed by a layer of compacted soil to ensure soil contact with the branches.
- The final installation should conform to the existing slope. Branches should protrude only slightly from the filled installation.
- Water must be controlled or diverted if the original streambank damage was caused by water flowing over the bank. If this is not done, erosion will most likely occur on either or both sides of the new branchpacking installation.

Figure 16–10 Branchpacking details



Note:
Root/leafed condition of the living plant material is not representative of the time of installation
.

Figure 16–11a Live branches installed in criss-cross configuration (Robbin B. Sotir & Associates photo)

Figure 16–11b Each layer of branches is followed by a layer of compacted soil (Robbin B. Sotir & Associates photo)

Figure 16–11c A growing branchpacking system (Robbin B. Sotir & Associates photo)

(iv) Vegetated geogrids—Vegetated geogrids are similar to branchpacking except that natural or synthetic geotextile materials are wrapped around each soil lift between the layers of live branch cuttings (figs. 16–12, 16–13a, 16–13b, and 16–13c).

Applications and effectiveness
- Used above and below stream-forming flow conditions.
- Drainage areas should be relatively small (generally less than 2,000 acres) with stable streambeds.
- The system must be built during low flow conditions.
- Can be complex and expensive.
- Produce a newly constructed, well-reinforced streambank.
- Useful in restoring outside bends where erosion is a problem.
- Capture sediment, which rapidly rebuilds to further stabilize the toe of the streambank.
- Function immediately after high water to rebuild the bank.
- Produce rapid vegetative growth.
- Enhance conditions for colonization of native vegetation.
- Benefits are similar to those of branchpacking, but a vegetated geogrid can be placed on a 1:1 or steeper slope.

Construction guidelines

Live materials—Live branch cuttings that are brushy and root readily are required. They should be 4 to 6 feet long.

Inert materials—Natural or synthetic geotextile material is required.

Installation
- Excavate a trench that is 2 to 3 feet below streambed elevation and 3 to 4 feet wide. Place the geotextile in the trench, leaving a foot or two overhanging on the streamside face. Fill this area with rocks 2 to 3 inches in diameter.
- Beginning at the stream-forming flow level, place a 6- to 8-inch layer of live branch cuttings on top of the rock-filled geogrid with the growing tips at right angles to the streamflow. The basal ends of branch cuttings should touch the back of the excavated slope.
- Cover this layer of cuttings with geotextile leaving an overhang. Place a 12-inch layer of soil suitable for plant growth on top of the geotextile before compacting it to ensure good soil contact with the branches. Wrap the overhanging portion of the geotextile over the compacted soil to form the completed geotextile wrap.
- Continue this process of excavated trenches with alternating layers of cuttings and geotextile wraps until the bank is restored to its original height.
- This system should be limited to a maximum of 8 feet in total height, including the 2 to 3 feet below the bed. The length should not exceed 20 feet for any one unit along the stream. An engineering analysis should determine appropriate dimensions of the system.
- The final installation should match the existing slope. Branch cuttings should protrude only slightly from the geotextile wraps.

Figure 16–12 Vegetated geogrid details

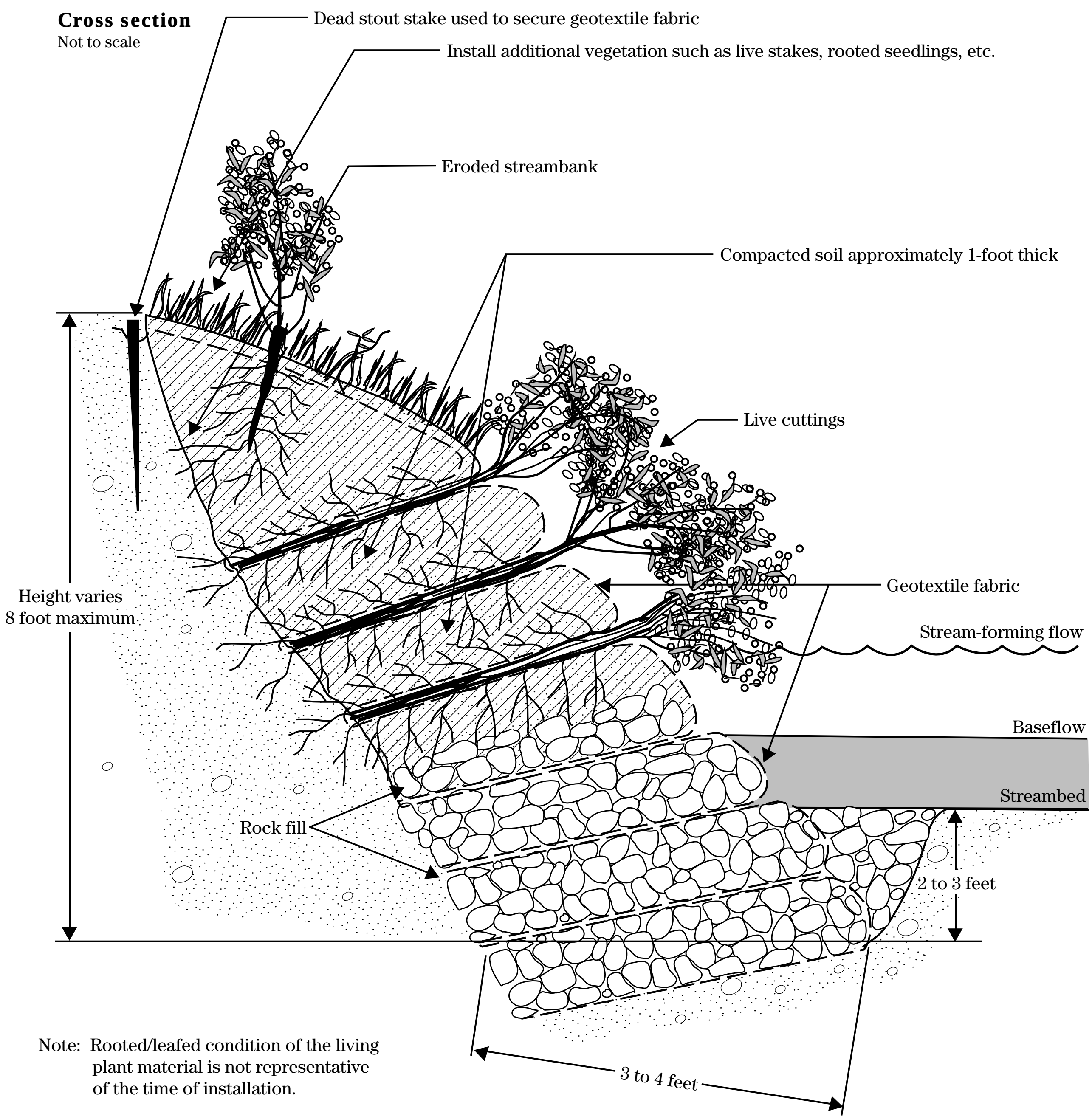


Figure 16–13a A vegetated geogrid during installation (Robbin B. Sotir & Associates photo)

Figure 16–13b A vegetated geogrid immediately after installation (Robbin B. Sotir & Associates photo)

Figure 16–13c Vegetated geogrid 2 years after installation (Robbin B. Sotir & Associates photo)

(v) Live cribwall—A live cribwall consists of a box-like interlocking arrangement of untreated log or timber members. The structure is filled with suitable backfill material and layers of live branch cuttings that root inside the crib structure and extend into the slope. Once the live cuttings root and become established, the subsequent vegetation gradually takes over the structural functions of the wood members (fig. 16–14).

Applications and effectiveness

- Effective on outside bends of streams where strong currents are present.
- Appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and reduce its steepness.
- Appropriate above and below water level where stable streambeds exist.
- Useful where space is limited and a more vertical structure is required.
- Effective in locations where an eroding bank may eventually form a split channel.
- Maintains a natural streambank appearance.
- Provides excellent habitat.
- Provides immediate protection from erosion, while established vegetation provides long-term stability.
- Supplies effective bank erosion control on fast flowing streams.
- Should be tilted back or battered if the system is built on a smooth, evenly sloped surface.
- Can be complex and expensive.

Construction guidelines

Live materials—Live branch cuttings should be 0.5 to 2.5 inches in diameter and long enough to reach the back of the wooden crib structure.

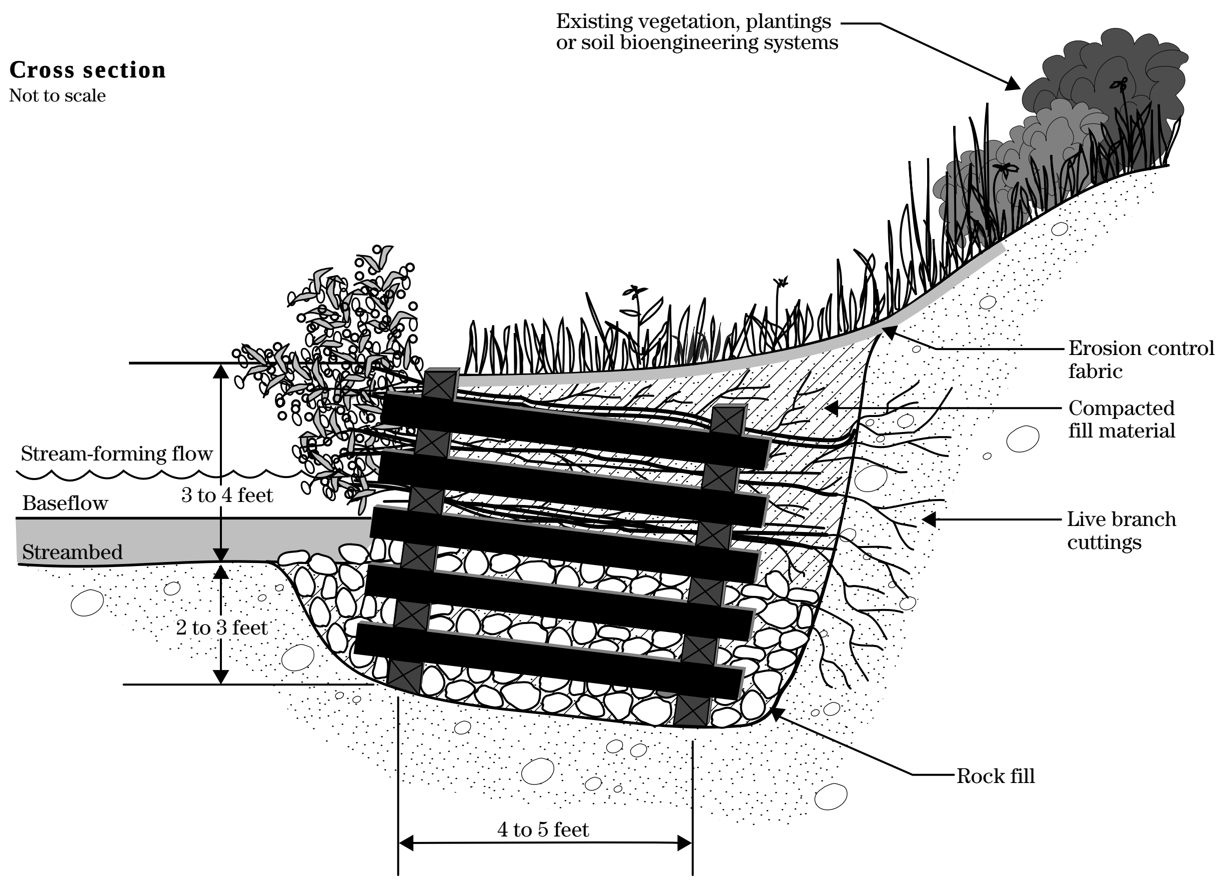
Inert materials—Logs or timbers should range from 4 to 6 inches in diameter or dimension. The lengths will vary with the size of the crib structure.

Large nails or rebar are required to secure the logs or timbers together.

Installation

- Starting at the base of the streambank to be treated, excavate 2 to 3 feet below the existing streambed until a stable foundation 5 to 6 feet wide is reached.
- Excavate the back of the stable foundation (closest to the slope) 6 to 12 inches lower than the front to add stability to the structure.
- Place the first course of logs or timbers at the front and back of the excavated foundation, approximately 4 to 5 feet apart and parallel to the slope contour.
- Place the next course of logs or timbers at right angles (perpendicular to the slope) on top of the previous course to overhang the front and back of the previous course by 3 to 6 inches. Each course of the live cribwall is placed in the same manner and secured to the preceding course with nails or reinforcement bars.
- Place rock fill in the openings in the bottom of the crib structure until it reaches the approximate existing elevation of the streambed. In some cases it is necessary to place rocks in front of the structure for added toe support, especially in outside stream meanders.
- Place the first layer of cuttings on top of the rock material at the baseflow water level, and change the rock fill to soil fill capable of supporting plant growth at this point. Ensure that the basal ends of some of the cuttings contact undisturbed soil at the back of the cribwall.
- When the cribwall structure reaches the existing ground elevation, place live branch cuttings on the backfill perpendicular to the slope; then cover the cuttings with backfill and compact.
- Live branch cuttings should be placed at each course to the top of the cribwall structure with growing tips oriented toward the slope face. Follow each layer of branches with a layer of compacted soil. Place the basal ends of the remaining live branch cuttings so that they reach to undisturbed soil at the back of the cribwall with growing tips protruding slightly beyond the front of the cribwall (figs. 16–15a, 16–15b, and 16–15c).
- The live cribwall structure, including the section below the streambed, should not exceed a maximum height of 7 feet. An engineering analysis should determine appropriate dimensions of the system.
- The length of any single constructed unit should not exceed 20 feet.

Figure 16–14 Live cribwall details



Note:
Rooted/leafed condition of the living plant material is not representative of the time of installation.

Figure 16–15a Pre-construction streambank conditions

Figure 16–15b A live cribwall during installation

Figure 16–15c An established live cribwall system

(vi) Joint planting—Joint planting or vegetated riprap involves tamping live stakes into joints or open spaces in rocks that have been previously placed on a slope (fig 16–16). Alternatively, the stakes can be tamped into place at the same time that rock is being placed on the slope face.

Applications and effectiveness

- Useful where rock riprap is required or already in place.
- Roots improve drainage by removing soil moisture.
- Over time, joint plantings create a living root mat in the soil base upon which the rock has been placed. These root systems bind or reinforce the soil and prevent washout of fines between and below the rock.
- Provides immediate protection and is effective in reducing erosion on actively eroding banks.
- Dissipates some of the energy along the streambank.

Construction guidelines

Live material sizes—The stakes must have side branches removed and bark intact. They should be 1.5 inches or larger in diameter and sufficiently long to extend well into soil below the rock surface.

Installation

- Tamp live stakes into the openings of the rock during or after placement of riprap. The basal ends of the material must extend into the backfill or undisturbed soil behind the riprap. A steel rod or hydraulic probe may be used to prepare a hole through the riprap.
- Orient the live stakes perpendicular to the slope with growing tips protruding slightly from the finished face of the rock (figs. 16–17a, 16–17b, and 16–17c).
- Place the stakes in a random configuration.

Figure 16–16 Joint planting details

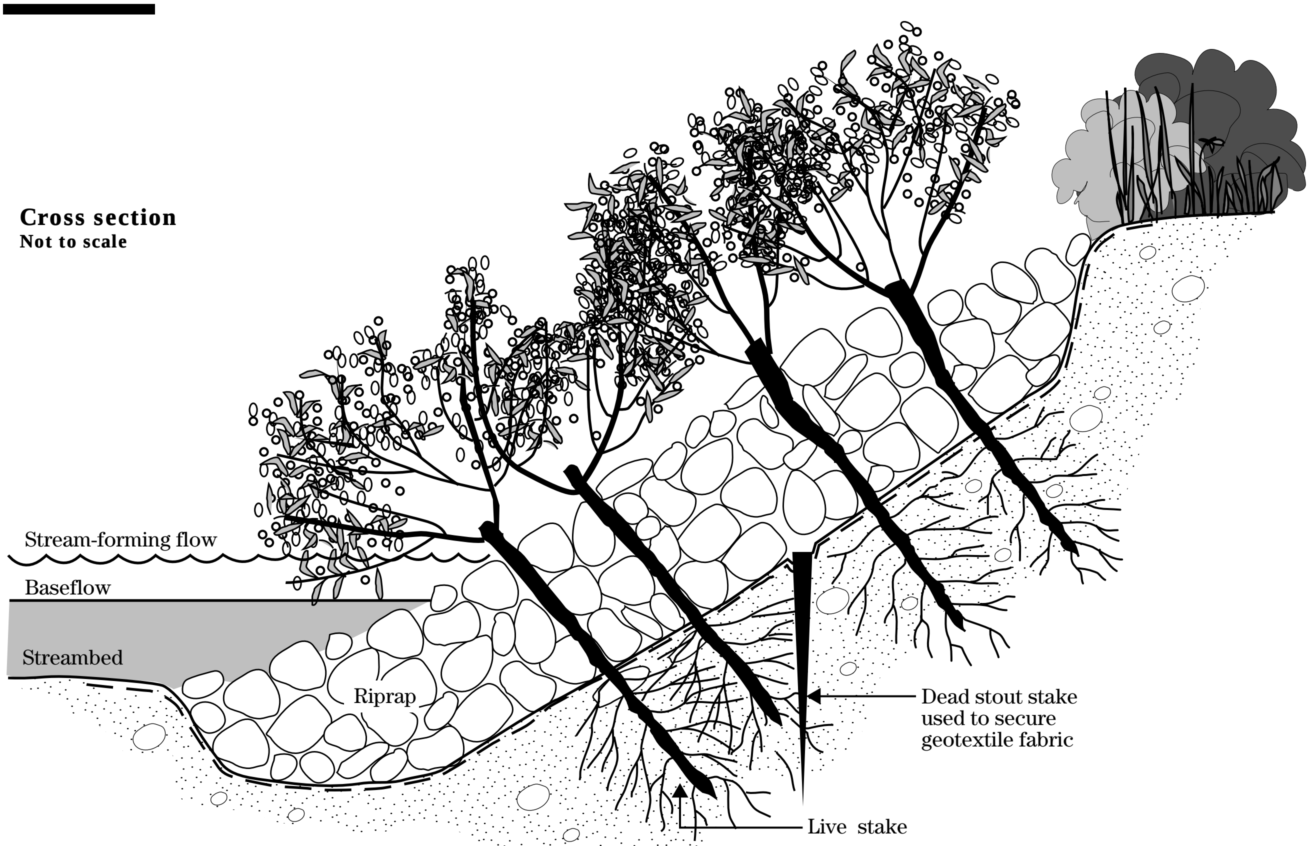


Figure 16–17a Live stake tamped into rock joints (joint planting) (Robbin B. Sotir & Associates photo)

Figure 16–17b An installed joint planting system (Robbin B. Sotir & Associates photo)

Figure 16–17c An established joint planting system (Robbin B. Sotir & Associates photo)

(vii) Brushmattress—A brushmattress is a combination of live stakes, live fascines, and branch cuttings installed to cover and stabilize streambanks (figs. 16–18, 16–19a through 16–19d). Application typically starts above stream-forming flow conditions and moves up the slope.

Applications and effectiveness

- Forms an immediate, protective cover over the streambank.
- Useful on steep, fast-flowing streams.
- Captures sediment during flood conditions.
- Rapidly restores riparian vegetation and streamside habitat.
- Enhances conditions for colonization of native vegetation.

Construction guidelines

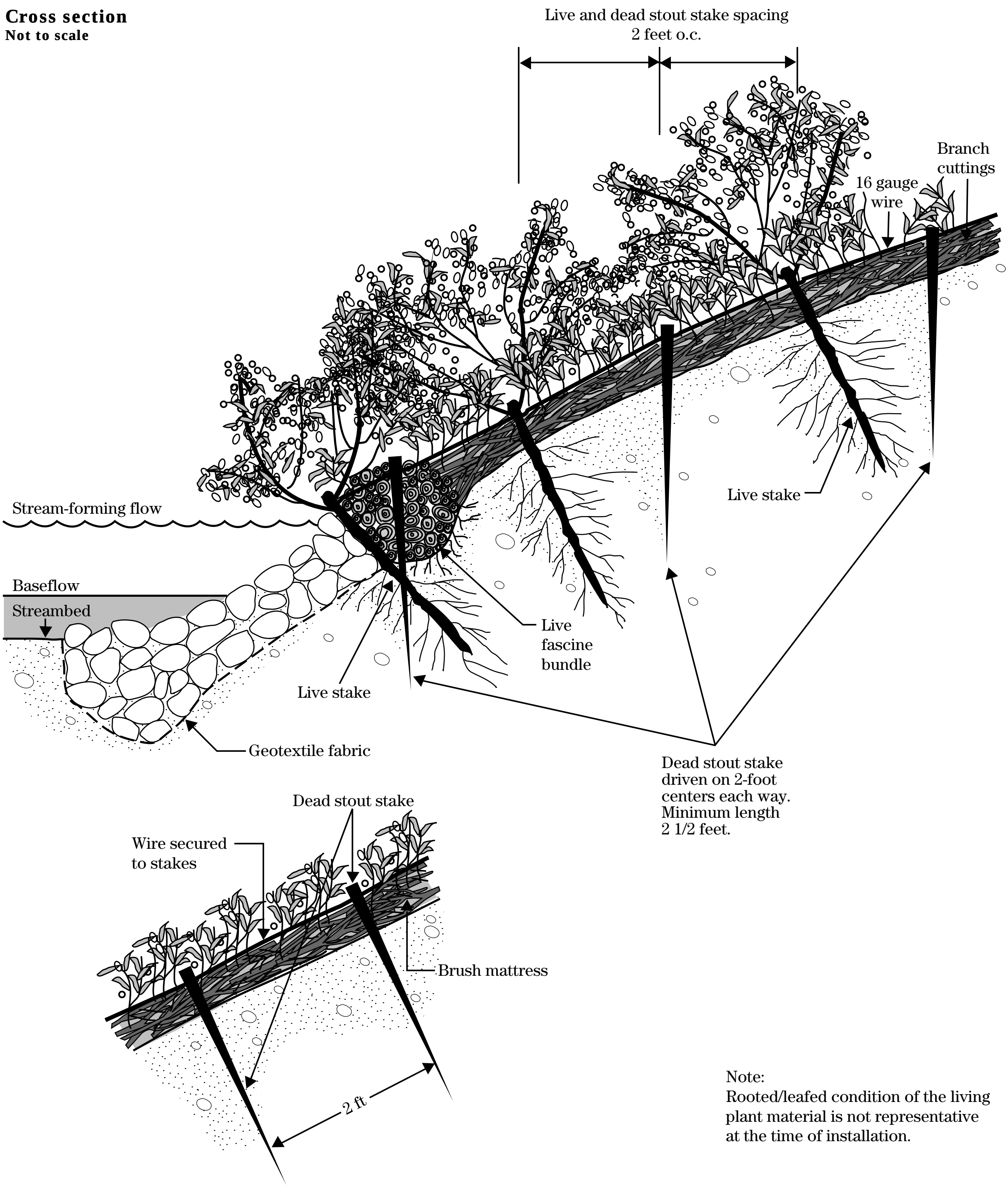
Live materials—Branches 6 to 9 feet long and approximately 1 inch in diameter are required. They must be flexible to enable installations that conform to variations in the slope face. Live stakes and live fascines are previously described in this chapter.

Inert materials—Untreated twine for bundling the live fascines and number 16 smooth wire are needed to tie down the branch mattress. Dead stout stakes to secure the live fascines and brushmattress in place.

Installation

- Grade the unstable area of the streambank uniformly to a maximum steepness of 3:1.
- Prepare live stakes and live fascine bundles immediately before installation, as previously described in this chapter.
- Beginning at the base of slope, near the stream-forming flow stage, excavate a trench on the contour large enough to accommodate a live fascine and the basal ends of the branches.
- Install an even mix of live and dead stout stakes at 1-foot depth over the face of the graded area using 2-foot square spacing.
- Place branches in a layer 1 to 2 branches thick vertically on the prepared slope with basal ends located in the previously excavated trench.
- Stretch No. 16 smooth wire diagonally from one dead stout stake to another by tightly wrapping wire around each stake no closer than 6 inches from its top.
- Tamp and drive the live and dead stout stakes into the ground until branches are tightly secured to the slope.
- Place live fascines in the prepared trench over the basal ends of the branches.
- Drive dead stout stakes directly through into soil below the live fascine every 2 feet along its length.
- Fill voids between brushmattress and live fascine cuttings with thin layers of soil to promote rooting, but leave the top surface of the brushmattress and live fascine installation slightly exposed.

Figure 16–18 Brushmattress details



Note:
Rooted/leafed condition of the living plant material is not representative at the time of installation.

Figure 16–19a Brushmattress during installation (Robbin B. Sotir & Associates photo)

Figure 16–19b An installed brushmattress system (Robbin B. Sotir & Associates photo)

Figure 16–19c Brushmattress system 6 months after installation (Robbin B. Sotir & Associates photo)

Figure 16–19d Brushmattress system 2 years after installation (Robbin B. Sotir & Associates photo)

(4) Structural measures

Structural measures include tree revetments; log, rootwad and boulder revetments; dormant post plantings; piling revetments with wire or geotextile fencing; piling revetments with slotted fencing; jacks or jack fields; rock riprap; stream jetties; stream barbs; and gabions.

(i) Tree revetment—A tree revetment is constructed from whole trees (except rootwads) that are usually cabled together and anchored by earth anchors, which are buried in the bank (figs. 16–20, 16–21a, and 16–21b).

Applications and effectiveness

- Uses inexpensive, readily available materials to form semi-permanent protection.
- Captures sediment and enhances conditions for colonization of native species.
- Has self-repairing abilities following damage after flood events if used in combination with soil bioengineering techniques.
- Not appropriate near bridges or other structures where there is high potential for downstream damage if the revetment dislodges during flood events.
- Has a limited life and may need to be replaced periodically, depending on the climate and durability of tree species used.
- May be damaged in streams where heavy ice flows occur.
- May require periodic maintenance to replace damaged or deteriorating trees.

Construction guidelines

- Lay the cabled trees along the bank with the basal ends oriented upstream.
- Overlap the trees to ensure continuous protection to the bank.
- Attach the trunks by cables to anchors set in the bank. Pilings can be used in lieu of earth anchors in the bank if they can be driven well below the point of maximum bed scour. The required cable size and anchorage design are dependent upon many variables and should be custom designed to fit specific site conditions.
- Use trees that have a trunk diameter of 12 inches or larger. The best type are those that have a brushy top and durable wood, such as douglas fir, oak, hard maple, or beech.
- Use vegetative plantings or soil bioengineering systems within and above structures to restore stability and establish a vegetative community. Tree species that will withstand inundation should be staked in openings in the revetment below stream-forming flow stage.

Figure 16–20 Tree revetment details

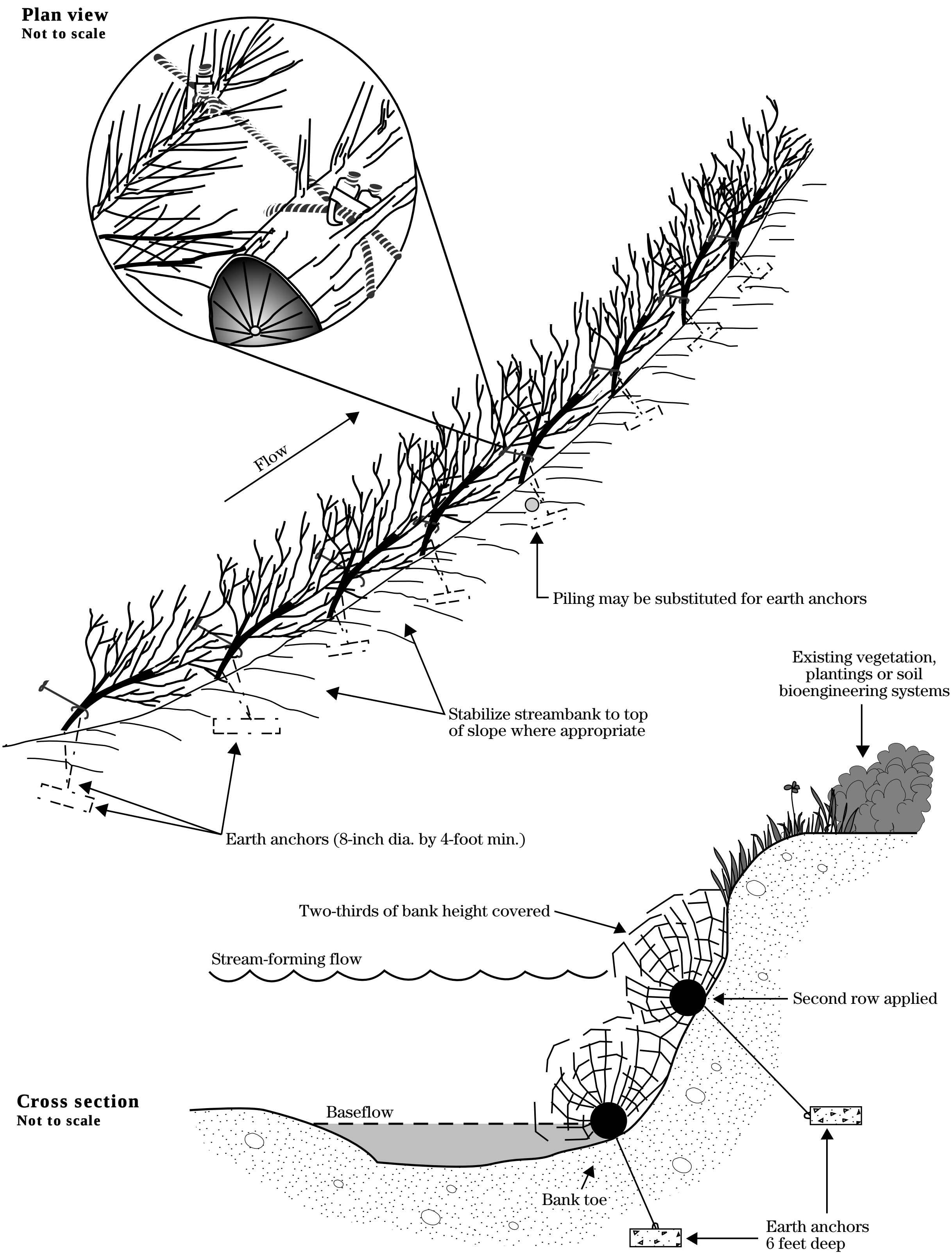


Figure 16–21a Tree revetment system with dormant posts

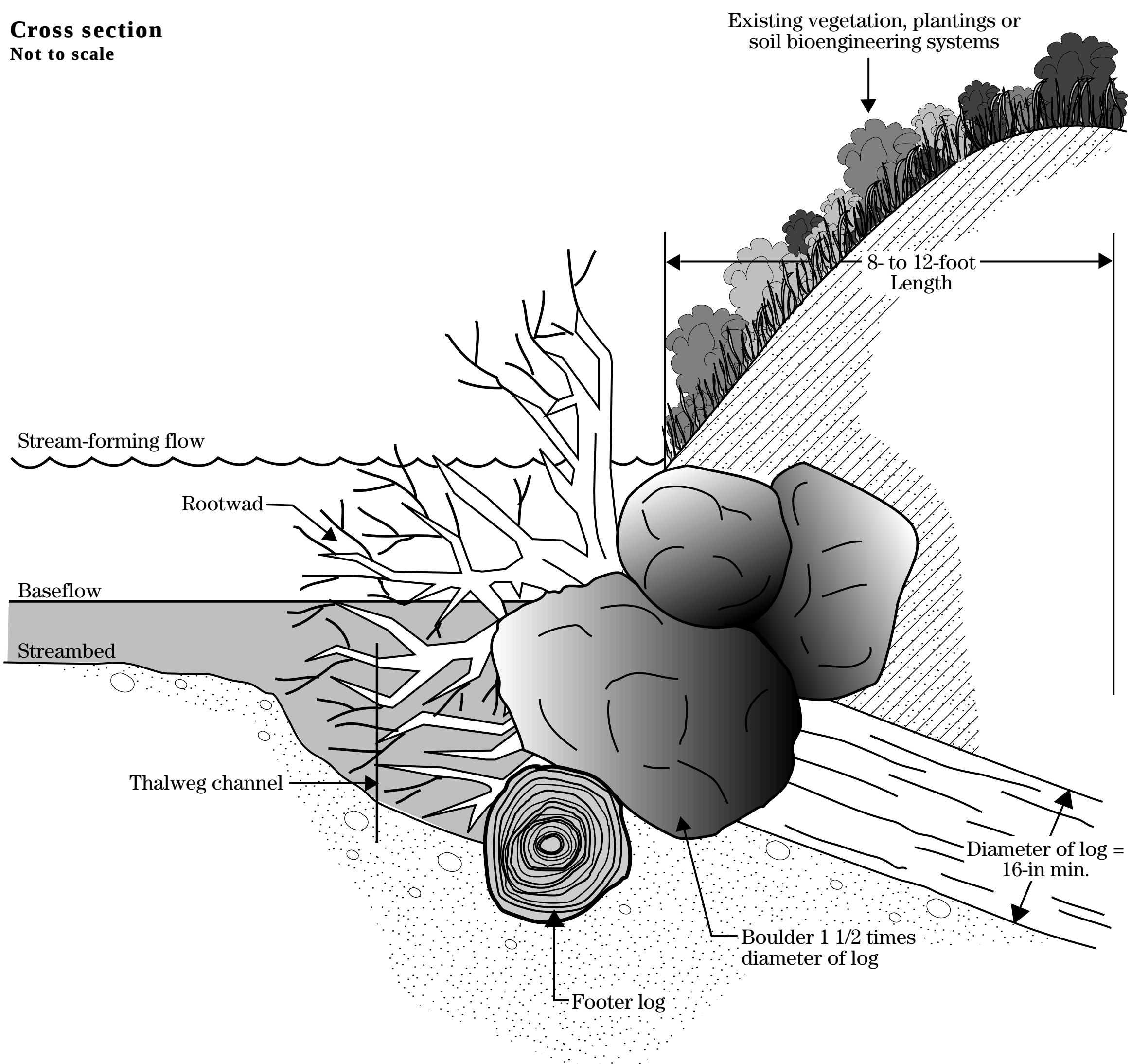
Figure 16–21b Tree revetment system with dormant posts, 2 years after installation

(ii) Log, rootwad and boulder revetments— These revetments are systems composed of logs, rootwads, and boulders selectively placed in and on streambanks (figs. 16–22 and 16–23). These revetments can provide excellent overhead cover, resting areas, shelters for insects and other fish food organisms, substrate for aquatic organisms, and increased stream velocity that results in sediment flushing and deeper scour pools. Several of these combinations are described in Flosi and Reynolds (1991), Rosgen (1992) and Berger (1991).

Applications and effectiveness

- Used for stabilization and to create instream structures for improved fish rearing and spawning habitat
- Effective on meandering streams with out-of-bank flow conditions.
- Will tolerate high boundary shear stress if logs and rootwads are well anchored.
- Suited to streams where fish habitat deficiencies exist.
- Should be used in combination with soil bioengineering systems or vegetative plantings to stabi-

Figure 16–22 Log, rootwad, and boulder revetment details (adapted from Rosgen 1993—Applied fluvial geomorphology short course)



lize the upper bank and ensure a regenerative source of streambank vegetation.
- Enhance diversity of riparian corridor when used in combination with soil bioengineering systems.
- Have limited life depending on climate and tree species used. Some species, such as cottonwood or willow, often sprout and accelerate natural colonization. Revetments may need eventual replacement if natural colonization does not take place or soil bioengineering methods are not used in combination.

Construction guidelines
Numerous individual organic revetments exist and many are detailed in the U.S. Forest Service publication, *Stream Habitat Improvement Handbook.* Chapter 16 only presents construction guidelines for a combination log, rootwad, and boulder revetment.
- Use logs over 16 inches in diameter that are crooked and have an irregular surface.
- Use rootwads with numerous root protrusions and 8- to 12-foot long boles.
- Boulders should be as large as possible, but at a minimum one and one-half the log diameter. They should have an irregular surface.
- Install a footer log at the toe of the eroding bank by excavating trenches or driving them into the bank to stabilize the slope and provide a stable foundation for the rootwad.
- Place the footer log to the expected scour depth at a slight angle away from the direction of the stream flow.
- Use boulders to anchor the footer log against flotation. If boulders are not available, logs can be pinned into gravel and rubble substrate with 3/4-inch rebar 54 inches or longer. Anchor rebar to provide maximum pull out resistance. Cable and anchors may also be used in combination with boulders and rebar.
- Drive or trench and place rootwads into the streambank so that the tree's primary brace roots are flush with the streambank. Place the rootwads at a slight angle toward the direction of the streamflow.
- Backfill and combine vegetative plantings or soil bioengineering systems behind and above rootwad. They can include live stakes and dormant post plantings in the openings of the revetment below stream-forming flow stage, live stakes, bare root, or other upland methods at the top of the bank.

Figure 16–23 Rootwad, boulder, and willow transplant revetment system, Weminuche River, CO (Rosgen, Wildland hydrology)

(iii) Dormant post plantings—Dormant post plantings form a permeable revetment that is constructed from rootable vegetative material placed along streambanks in a square or triangular pattern (figs. 16–24, 16–25a, 16–25b, 16–25c).

Applications and effectiveness

- Well suited to smaller, non-gravely streams where ice damage is not a problem.
- Quickly re-establishe riparian vegetation.
- Reduce stream velocities and causes sediment deposition in the treated area.
- Enhance conditions for colonization of native species.
- Are self-repairing. For example, posts damaged by beaver often develop multiple stems.
- Can be used in combination with soil bioengineering systems.
- Can be installed by a variety of methods including water jetting or mechanized stingers to form planting holes or driving the posts directly with machine mounted rams.
- Unsuccessfully rooted posts at spacings of about 4 feet can provide some benefits by deflecting higher streamflows and trapping sediment.

Construction guidelines

- Select a plant species appropriate to the site conditions. Willows and poplars have demonstrated high success rates.
- Cut live posts approximately 7 to 9 feet long and 3 to 5 inches in diameter. Taper the basal end of the post for easier insertion into the ground.
- Install posts into the eroding bank at or just above the normal waterline. Make sure posts are installed pointing up.
- Insert one-half to two-thirds of the length of post below the ground line. At least the bottom 12 inches of the post should be set into a saturated soil layer.
- Avoid excessive damage to the bark of the posts.
- Place two or more rows of posts spaced 2 to 4 feet apart using square or triangular spacing.
- Supplement the installation with appropriate soil bioengineering systems or, where appropriate, rooted plants.

Figure 16-24 Dormant post details

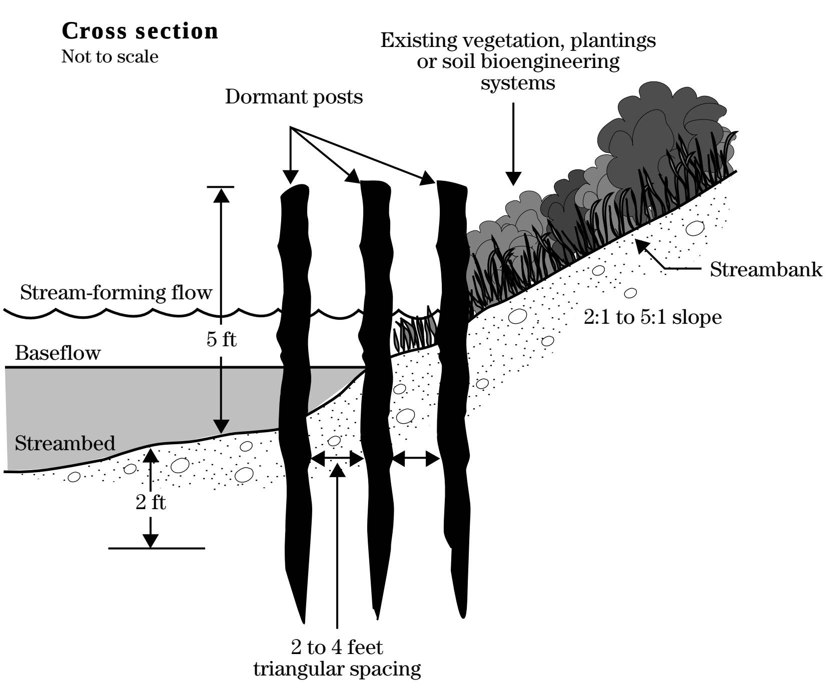


Figure 16–25a Pre-construction streambank conditions (Don Roseboom photo)

Figure 16–25b Installing dormant posts (Don Roseboom photo)

Figure 16–25c Established dormant post system (Don Roseboom photo)

(iv) Piling revetment with wire or geotextile fencing—Piling revetment is a continuous single or double row of pilings with a facing of woven wire or geogrid material (fig. 16–26). The space between double rows of pilings is filled with rock and brush.

Applications and effectiveness

- Particularly suited to streams where water next to the bank is more than 3 feet deep.
- Application is limited to a flow depth (and height of piling) of 6 feet.
- More economical than riprap construction in deep water because it eliminates the need to build a stable foundation under water for holding the riprap in place.
- Is easily damaged by ice flows or heavy flood debris and should not be used where these conditions occur.
- Do not use where the stream has fish or an abundance of riparian wildlife.
- Do not use without careful analysis of its long-term effects upon aesthetics, changes in flows where large amounts of debris will be collected, habitat damage caused by driving or installing pilings with water jets, and possible dangers for recreational uses (boating, rafting, swimming, or wading).

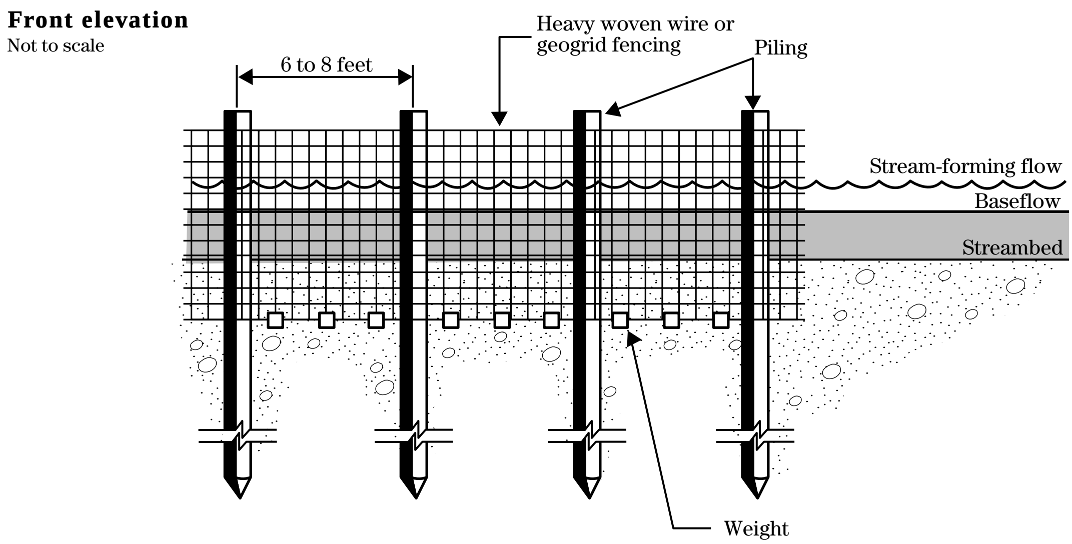
Construction guidelines

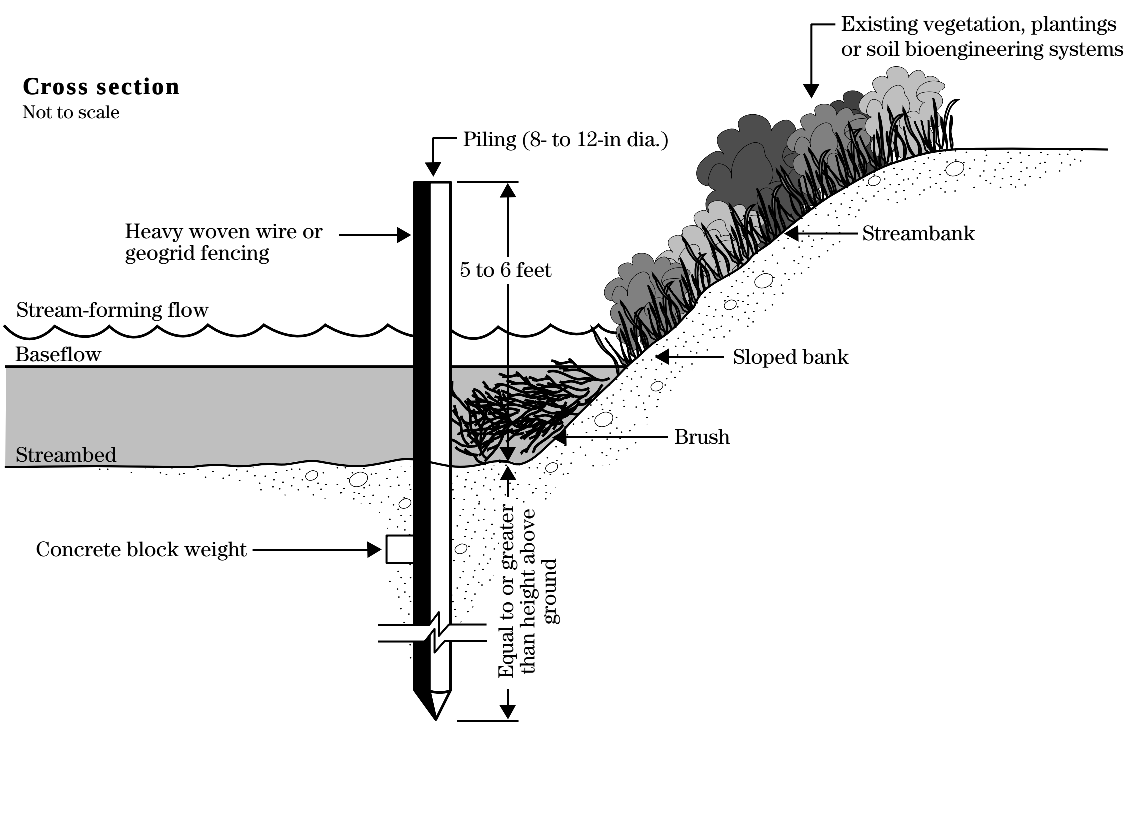
Inert materials—Used material, such as timbers, logs, railroad rails, or pipe, may be used for pilings. Logs should have a diameter sufficiently large to permit driving to the required depth. Avoid material that may produce toxicity effects in aquatic ecosystems.

Installation

- Beginning at the base of the streambank, near stream-forming flow stage, drive pilings 6 to 8 feet apart to a depth approximately half their length and below the point of maximum scour. If the streambed is firm and not subject to appreciable scour, the piling should be driven to refusal or to a depth of at least half the length of the piling.
- Additional rows of pilings may be installed at higher elevations on the streambank if required to protect the bank and if using vegetation or other methods is not practical.
- Fasten a heavy gauge of woven wire or geotextile material to the stream side of the pilings to form a fence. The purpose of this material is to collect debris while serving as a permeable wall to reduce velocities on the streambank.
- Double row piling revetment is typically constructed with 5 feet between rows. Fill the row space with rock and brush.
- If the streambed is subject to scour, extend the woven wire or geotextile material horizontally toward the center of the streambed for a distance at least equal to the anticipated depth of scour. Attach concrete blocks or other suitable weights at regular intervals to cause the fence to settle in a vertical position along the face of the pilings after scouring occurs.
- Place brush behind the piling to increase the system's effectiveness. Where piling revetments extend for several hundred feet in length, install permeable groins or tiebacks of brush and rock at right angles to the revetment at 50 foot intervals. This reduces currents developing between the streambank and the revetment.

Figure 16–26 Piling revetment details





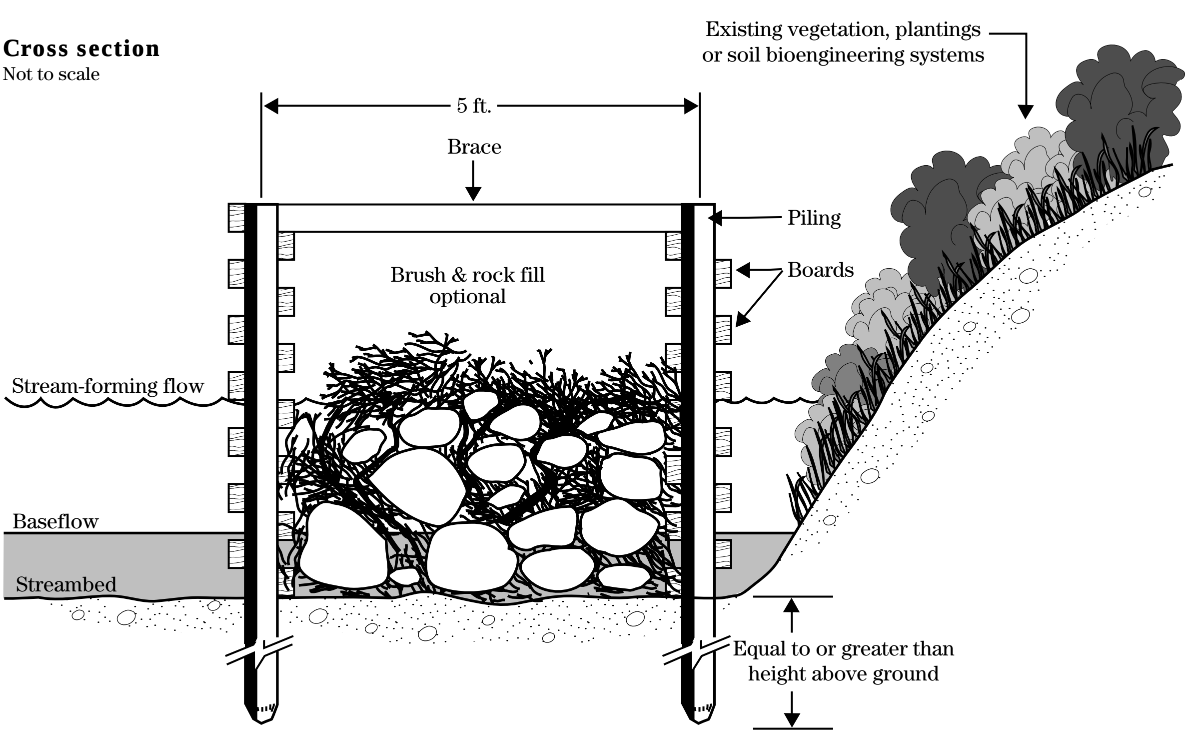
(v) Piling revetment with slotted board fencing —This type of revetment consists of slotted board fencing made of wood pilings and horizontal wood timbers (figs. 16–27 and 16–28). Variations include different fence heights, double rows of slotted fence, and use of woven wire in place of timber boards. The size and spacing of pilings, cross members, and vertical fence boards depend on height of fence, stream velocity, and sediment load.

Applications and effectiveness

- Most variations of slotted fencing include some bracing or tieback into the streambank to increase strength, reduce velocity against the streambank, and to trap sediment.
- Should not be constructed higher than 3 feet without an engineering analysis to determine sizes of the structural members.
- May be vulnerable to damage by ice or heavy flood debris; should not be used where these conditions occur.
- Usually complex and expensive.
- Most effective on streams that have a heavy sediment load of sand and silt.
- Can withstand a relatively high velocity attack force and, therefore, can be installed in sharper curves than jacks or other systems.
- Useful in deeper stream channels with large flow depths.
- Low slotted board fences, which do not control the entire flood flow, can be very effective for streambank toe protection where the toe is the weak part of the streambank.
- May not be appropriate where unusually hard materials are encountered in the channel bottom.

Figure 16–27 Slotted board fence details (double fence option)

Cross section
Not to scale



- Should not be used without careful consideration of its long-term effects upon aesthetics, changes in flows where large amounts of debris are collected, habitat damage caused by driving or installing pilings with water jets, and possible dangers for recreational uses (boating, rafting, swimming, or wading).

Construction guidelines
Inert materials—Slotted fencing is constructed of wood boards, wood pilings, and woven wire. Avoid materials that may produce toxicity effects in aquatic ecosystems.

Installation
- See *(iv) Piling revetment with wire or geotextile fencing* for general construction guidelines.
- Drive the timber piling to a depth below the channel bottom that is equal to the height of the slotted fence above the expected scour line when stream soils have a standard penetration resistance of 10 or more blows per foot. Increase the piling depth when penetration resistance is less than 10 blows per foot.
- Take great care during layout to tie in the upstream end adequately to prevent flanking and unraveling.

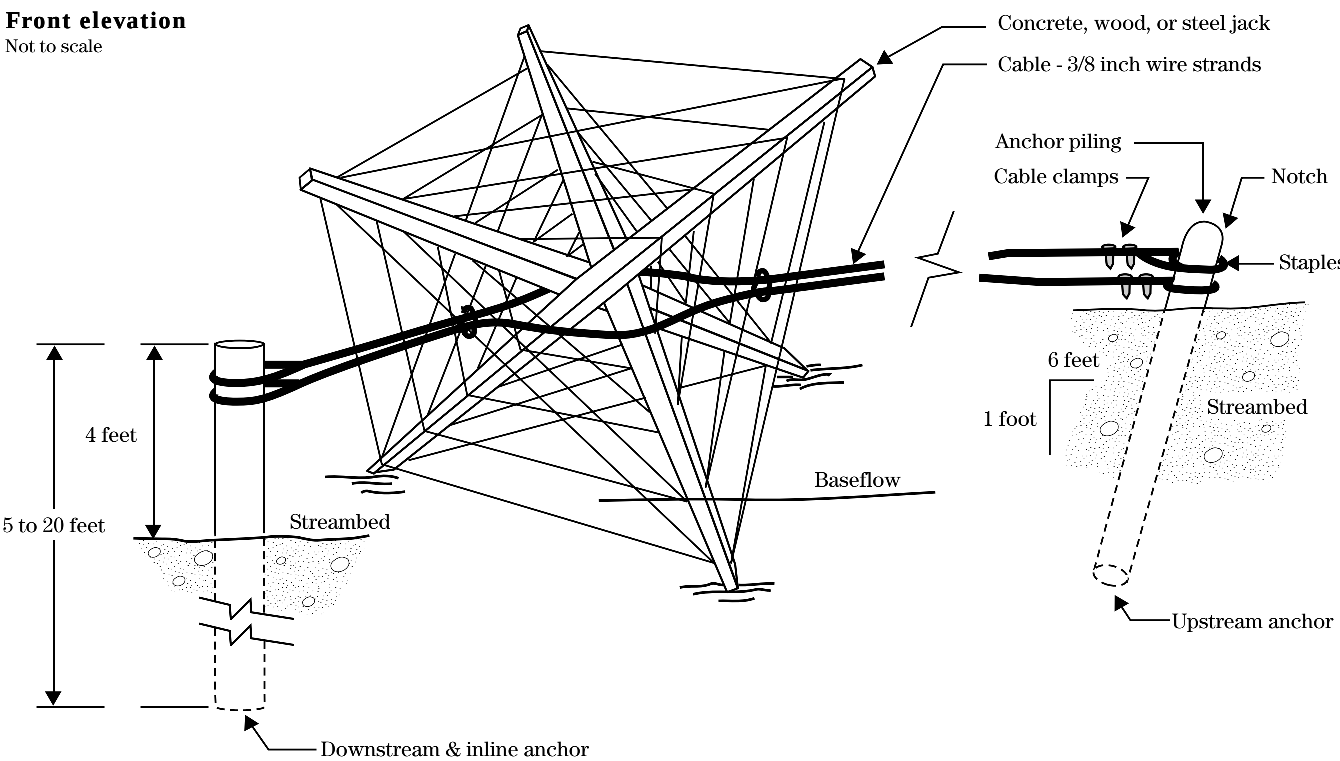
Figure 16–28 Slotted board fence system

(vi) Jacks or jack fields—Jacks are individual structures made of wood, concrete, or steel. The jacks are placed in rows parallel to the eroding streambank and function by trapping debris and sediment. They are often constructed in groups called jack fields (figs. 16–29, 16–30, and 16–31).

Applications and effectiveness

- May be an effective means of controlling bank erosion on sinuous streams carrying heavy bedloads of sand and silt during flood flows. This condition is generally indicated by the presence of extensive sandbar formations on the bed at low flow.
- Are complex systems requiring proper design and installation for effective results.
- Collect coarse and fine sediment, when functioning properly, and naturally revegetate as the systems, including cable, become embedded in the streambank.
- Do not use on high velocity, debris-laden streams.
- Somewhat flexible because of their physical configuration and installation techniques that allow them to adjust to slight changes in the channel grade.
- Most effective on long, radius curves.
- Not an effective alternative for redirecting flow away from the streambank.
- Do not use without careful analysis of its long-term effects upon aesthetics, changes in flows where large amounts of debris are collected, fish habitat damage, and possible dangers for recreational uses (boating, rafting, swimming, or wading).

Figure 16–29 Concrete jack details

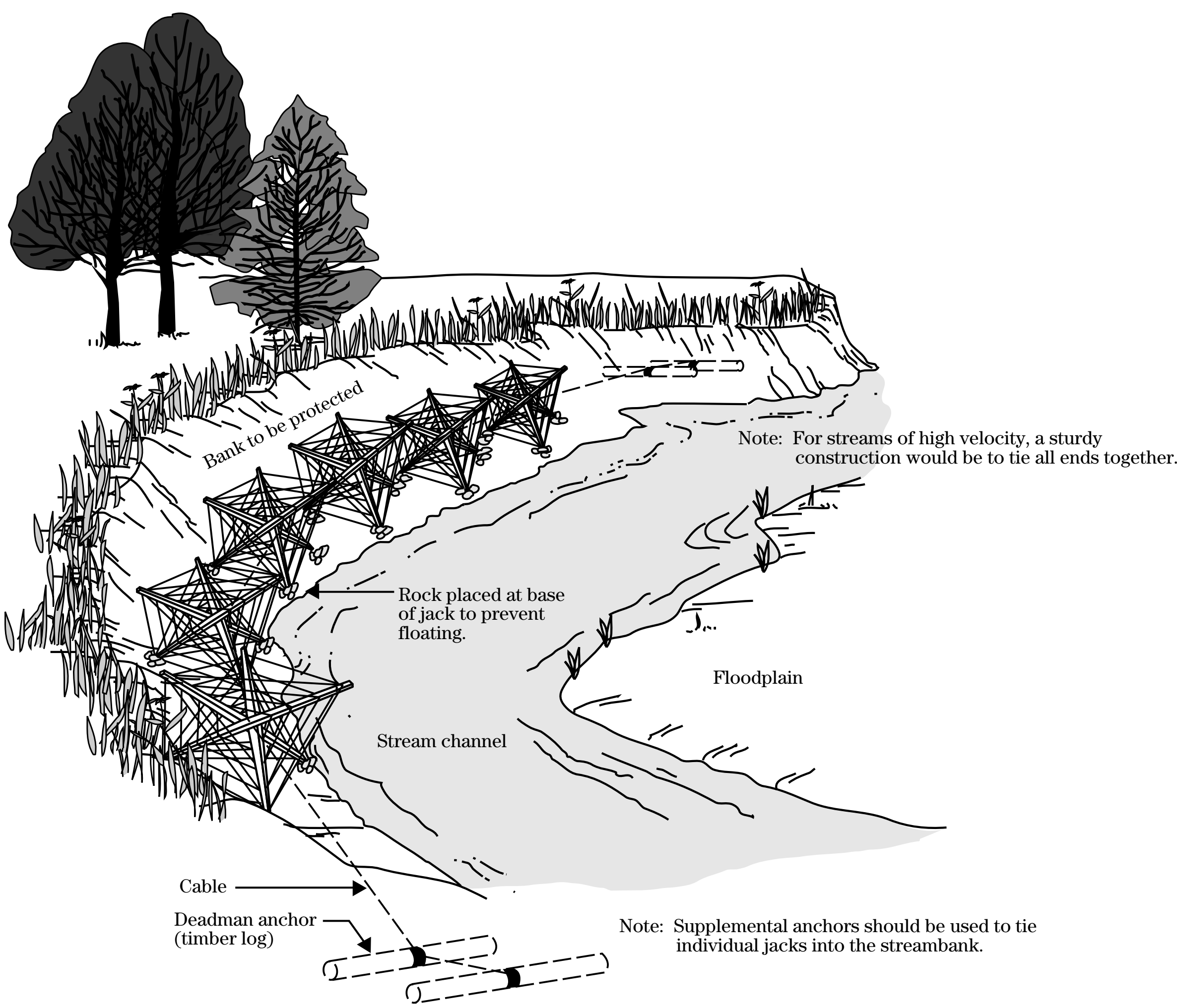


Construction guidelines

Inert materials—Jacks may be constructed of wood, steel, or concrete. Wooden jacks are constructed from three poles 10 to 16 feet long. They are crossed and wired together at the ends and midpoints with No. 9 galvanized wire. Cables used to anchor the wood jack systems should be 3/8-inch diameter or larger with a minimum breaking strength of 15,400 pounds. Wooden jack systems dimensioned in this chapter are limited to shallow flow depths of 12 feet or less.

Steel jacks are used in a manner similar to that of wood jacks; however, leg assemblies, cable size, anchor blocks, and anchor placement details vary. Concrete beams may be substituted for steel, but engineering design is required to determine different attachment methods, anchoring systems, and assembly configurations.

Figure 16–30 Wooden jack field



Installation

- Jack rows can be placed on a shelf 14 feet wide for one line and on two shelves, each 14 feet wide, for a double jack row. Grade the shelf to slope from 1 foot above the streambed at the side nearest the stream to 3 feet above the streambed at the side nearest the slope. This encourages a dry surface for construction and provides some additional elevation for protection from greater depths of flow. Alternatively, jacks can be constructed on the streambed or on the top of the bank and moved into place.
- Space jacks closely together with a maximum of one jack dimension between them to provide an almost continuous line of revetment.
- Anchor the jacks in place by a cable strung through and tied to the center of the jacks with cable clamps. The cable should be tied to a buried anchor or pilings, thereby securing all the jacks as a unit. Wooden jacks are weighted by rocks, which should be wired onto the jack poles. The first two pilings at the upstream end of the jack line should be driven no more than 12 feet apart to reduce the effect of increased water force from trash buildup.
- Bury anchors or drive anchor pilings to the design depth determined by an engineer. Depths may vary from 5 to 20 feet and must be specified based on individual site characteristics.
- On long curves, anchor jack rows at intermediate points along the curve to isolate damages to the jack row. Two 3/8-inch diameter wire cables tied to timber or steel pilings provide adequate anchors. Place anchors up the streambank rather than in the streambed.
- Consider pilings if streambed anchors are required. Space pilings 75 to 125 feet apart along the jack row, with closer spacing on shorter curves.
- Attach an anchored 3/8-inch diameter wire cable to one leg of each jack to prevent rotation and improve stability.
- Place jack rows perpendicular to the bank at regular intervals where jack rows are not close to existing banks. This prevents local scour. Extend bank protection far enough to prevent flanking action. Ensure the jack row is anchored to a hardpoint at the upstream end.
- Supplement the jack string or field with vegetative plantings. Dormant posts offer a compatible component in the system.

Figure 16–31 Concrete jack system several years after installation

(vii) Rock riprap—Rock riprap, properly designed and placed, is an effective method of streambank protection (figs.16–32 and 16–33). The cost of quarrying, transporting, and placing the stone and the large quantity of stone that may be needed must be considered. Gabion baskets, concrete cellular blocks, or similar systems (figs. 16–34, 16–35a, 16–35b; and 16–42, 16–43) can be an alternative to rock riprap under many circumstances.

Applications and effectiveness

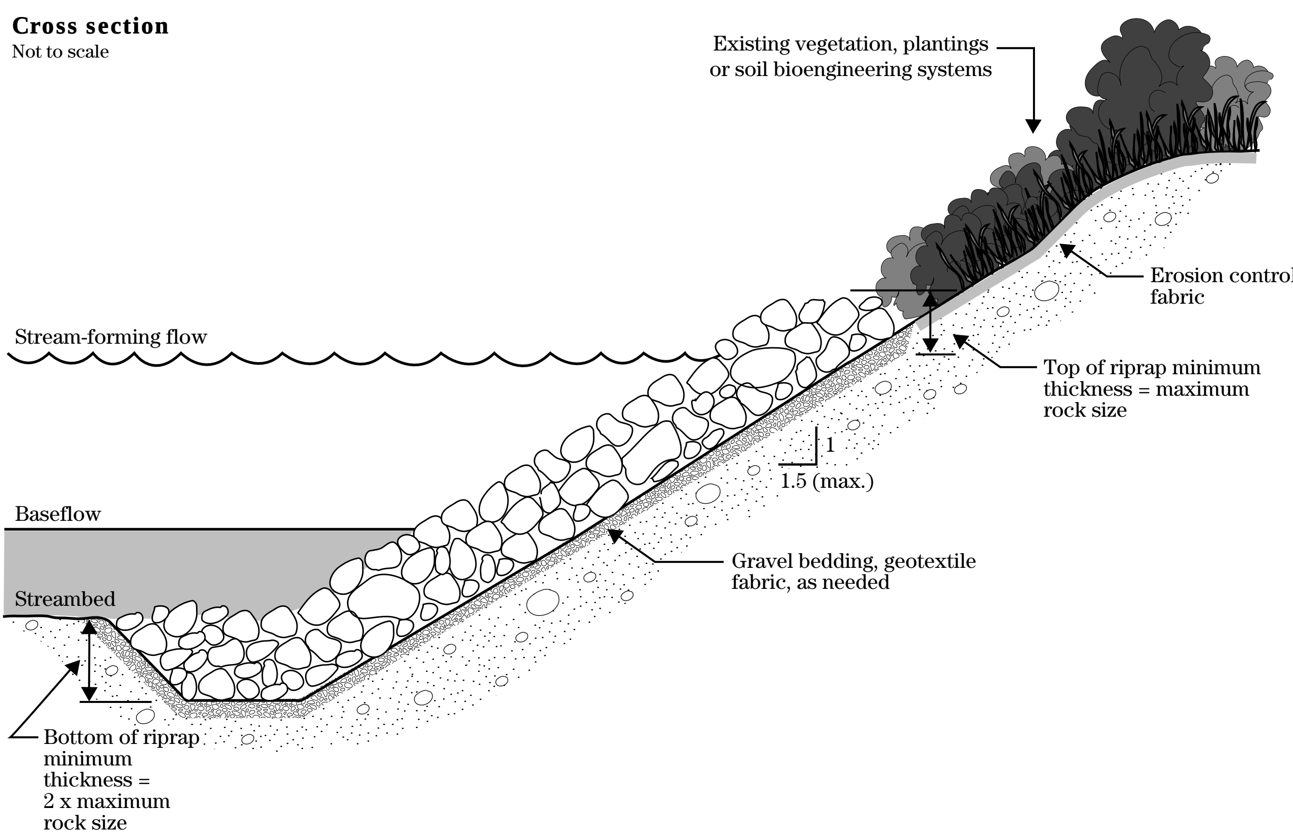
- Provides long-term stability.
- Has structural flexibility. It can be designed to self-adjust to eroding foundations.
- Has a long life and seldom needs replacement.
- Is inert so does not depend on specific environmental or climatic conditions for success.
- May be designed for high velocity flow conditions.

Construction guidelines

Inert materials—Cobbles and gravel obtained from the stream bed should not be used to armor streambanks unless the material is so abundant that its removal will not reduce habitat for benthic organisms and fish. Material forming an armor layer that protects the bed from erosion should not be removed. Use of stream cobble and gravel may require permission from state and local agencies.

Removing streambed materials tends to destroy the diversity of physical habitat necessary for optimum fish production, not only in the project area, but upstream and downstream as well. Construction activities often create channels of uniform depth and width in which water velocities increase. Following disruption of the existing streamflow by alteration of the stream channel, further damage results as the stream seeks to reestablish its original meander pattern.

Figure 16–32 Rock riprap details



Upstream, the stream may seek to adjust to the new gradient by actively eroding or grading its banks and bed. The eroded material may be deposited in the channel downstream from the alteration causing additional changes in flow pattern. The downstream channel will then also adjust to the new gradient and increased streamflow velocity by scour and bank erosion or further deposition.

Rock riprap on streambanks is affected by the hydrodynamic drag and lift forces created by the velocity of flow past the rock. Resisting the hydrodynamic effects are the force components resulting from the submerged weight of the rock and its geometry. These forces must be considered in any analytical procedure for determining a stable rock size. Channel alignment, surface roughness, debris and ice impact, rock gradation, angularity, and placement are other factors that must be considered when designing for given site conditions.

Numerous methods have been developed for designing rock riprap. Nearly all use either an allowable velocity or tractive stress methodology as the basis for determining a stable rock size. Table 16–2 lists several accepted procedures currently used in the NRCS. The table provides summary information and references where appropriate. Two of the more direct methods of obtaining a rock size are included in appendix 16A. All four methods listed in the table provide the user with a design rock size for a given set of input parameters. The first time user is advised to use more than one method in determining rock size. Availability of rock and experience of the designer continue to play important roles in determining the appropriate size rock for any given job.

Figure 16–33 Rock riprap revetment system

A well graded rock provides the greatest assurance of stability and long-term protection. Poorly graded rock results in weak areas where individual stones are subject to movement and subsequent revetment failure. Satisfactory gradation limits and thickness of the rock riprap can be determined from the basic stone size. Figure 16A–3 in appendix 16A can help determine rock gradation limits for any calculated basic rock size (D_{50}, D_{75}, and so forth).

The void space between rocks in riprap is generally many times greater than the void space in existing bank materials. A transition zone serves two purposes:

- Distributes the weight of rock to the underlying soil.
- Prevents movement and loss of fine grained soil into the large void spaces of the riprap.

The transition zone can be designed as a filter, bedding, or geotextile. The bank soils, bank seepage, and rock gradation and thickness are factors to consider when determining the transition material.

Bedding material is generally a pit run sand-gravel mixture. Bedding is suitable for those sites where bank materials are plastic and forces can be considered external, that is, forces acting on the bedding result only from the action of flow past or over the rock riprap. Bedding is not recommended for conditions where flow occurs through the rock (as on steep slopes), where subject to wave action, or where flow velocity exceeds 10 feet per second.

Table 16–2 Methods for rock riprap protection

Method (reference)	Basis for rock size	Procedure	Comments
Isbash Curve Appendix 16A (reprint from SCS Engineering Field Manual, chapter 16, 1969).	Allowable velocity—Curve developed from Isbash work.	Use design velocity and curve to determine basic rock size (D_{100}).	Use judgment to factor in site conditions. The basic stone weight is often doubled to account for debris.
FWS-Lane Appendix 16A (reprint from SCS Engineering Design Standards—Far West States, 1970).	Tractive stress—Monograph developed from Lane's work.	Enter monograph with channel hydraulic and physical data to solve for basic rock size (D_{75}).	Easy to use procedure. Generally results in a conservative rock size.
COE Method Corps of Engineers, EM 1110-2-1601, 7/91, Hydraulic Design of Flood Control Channels.	Allowable velocity—Basic equation developed by COE from study of models and comparison to field data.	Use equation or graphs and site physical and hydraulic data to determine basic rock size (D_{30}).	Detailed procedure can be used on natural or prismatic channels.
Federal Highway Administration Hydraulic Engineering Circular No. 11, Design of Riprap Revetment (1989).	Tractive Force Theory—Uses velocity as a primary design parameter.	Use equation with known site data and user determined stability factor to solve for basic rock size (D_{50}).	Stability factor requires user judgment of site conditions.

A filter is a graded granular material designed to prevent movement of the bank soil. A filter is recommended where bank materials are nonplastic, seepage forces exist, or where bedding is not adequate protection for the external forces as noted above. The site should be evaluated for potential seepage pressures from existing or seasonal water table, rapid fluctuations in streamflow (rapid drawdown), surface runoff, or other factors. In critical applications or where experience indicates problems with the loss of bank material under riprap, use chapter 26, part 633 of the NRCS National Engineering Handbook, January 1994, for guidance in designing granular filters.

Nonwoven geotextiles are widely used as a substitute for bedding and filter material. Availability, cost, and ease of placement are contributing factors. For guidance in selection of the proper geotextile, refer to NRCS Design Note 24, *Guide to Use of Geotextile.*

Installation

- Minimum thickness of the riprap should at least equal the maximum rock size at the top of the revetment. The thickness is often increased at the base of the revetment to two or more times the maximum rock size.
- The toe for rock riprap must be firmly established. This is important where the stream bottom is unstable or subject to scour during flood flows.
- Banks on which riprap is to be placed should be sloped so that the pressure of the stone is mainly against the bank rather than against the stone in the lower courses and toe. This slope should not be steeper than 1.5:1. The riprap should extend up the bank to an elevation at which vegetation will provide adequate protection.
- A filter or bedding must be placed between the riprap and the bank except in those cases where the material in the bank to be protected is determined to be a suitable bedding or filter material. The filter or bedding material should be at least 6 inches thick.
- A nonwoven geotextile may be used in lieu of a bedding or filter layer under the rock riprap. The geotextile material must maintain intimate contact with the subsurface. Geotextile that can move with changes in seepage pressure or external forces permits soil particle movement and can result in plugging of the geotextile. A 3-inch layer of bedding material over the geotextile prevents this movement.
- Hand-placing all rock in a revetment should seldom, if ever, be necessary. While the revetment may have a somewhat less finished look, it is adequate to dump the rock and rearrange it with a minimum of hand labor. However, the rock must be dumped in a manner that will not separate small and large stones or cause damage to the filter fabrics. The finished surface should not have pockets of finer materials that would flush out and weaken the revetment. Sufficient hand placing and chinking should be done to provide a well-keyed surface.

The Engineering Field Handbook, Chapter 17, Construction and Construction Materials, has additional information on riprap construction and materials.

Manufacturers have developed design recommendations for various flow and soil conditions. Their recommendations are good references in use of gabions, cellular blocks, and similar systems.

Figure 16–34 Concrete cellular block details

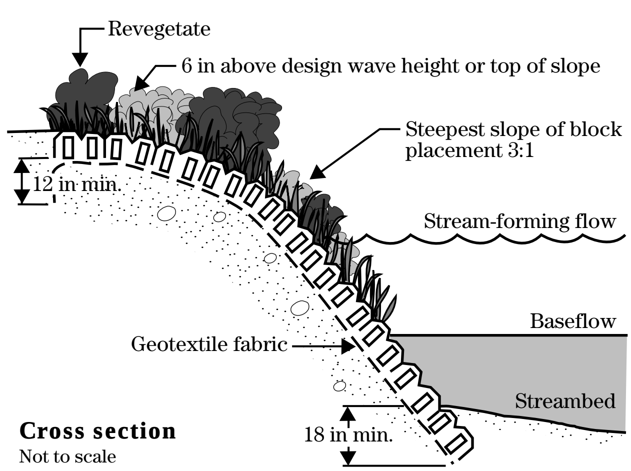


Figure 16–35a Concrete cellular block system before backfilling

Figure 16–35b Concrete cellular block system several years after installation

***(viii) Coconut fiber rolls*—**Coconut fiber rolls are cylindrical structures composed of coconut husk fibers bound together with twine woven from coconut (figs. 16–36, 16–37a, and 16–37b). This material is most commonly manufactured in 12-inch diameters and lengths of 20 feet. It is staked in place at the toe of the slope, generally at the stream-forming flow stage.

Applications and effectiveness

- Protect slopes from shallow slides or undermining while trapping sediment that encourages plant growth within the fiber roll.
- Flexible, product can mold to existing curvature of streambank.
- Produce a well-reinforced streambank without much site disturbance.
- Prefabricated materials can be expensive.
- Manufacturers estimate the product has an effective life of 6 to 10 years.

Construction guidelines

- Excavate a shallow trench at the toe of the slope to a depth slightly below channel grade.
- Place the coconut fiber roll in the trench.
- Drive 2 inch x 2 inch x 36 inch stakes between the binding twine and coconut fiber. Stakes should be placed on both sides of the roll on 2 to 4 feet centers depending upon anticipated velocities. Tops of stakes should not extend above the top of the fiber roll.
- In areas that experience ice or wave action, notch outside of stakes on either side of fiber roll and secure with 16-gauge wire.

Figure 16–36 Coconut fiber roll details

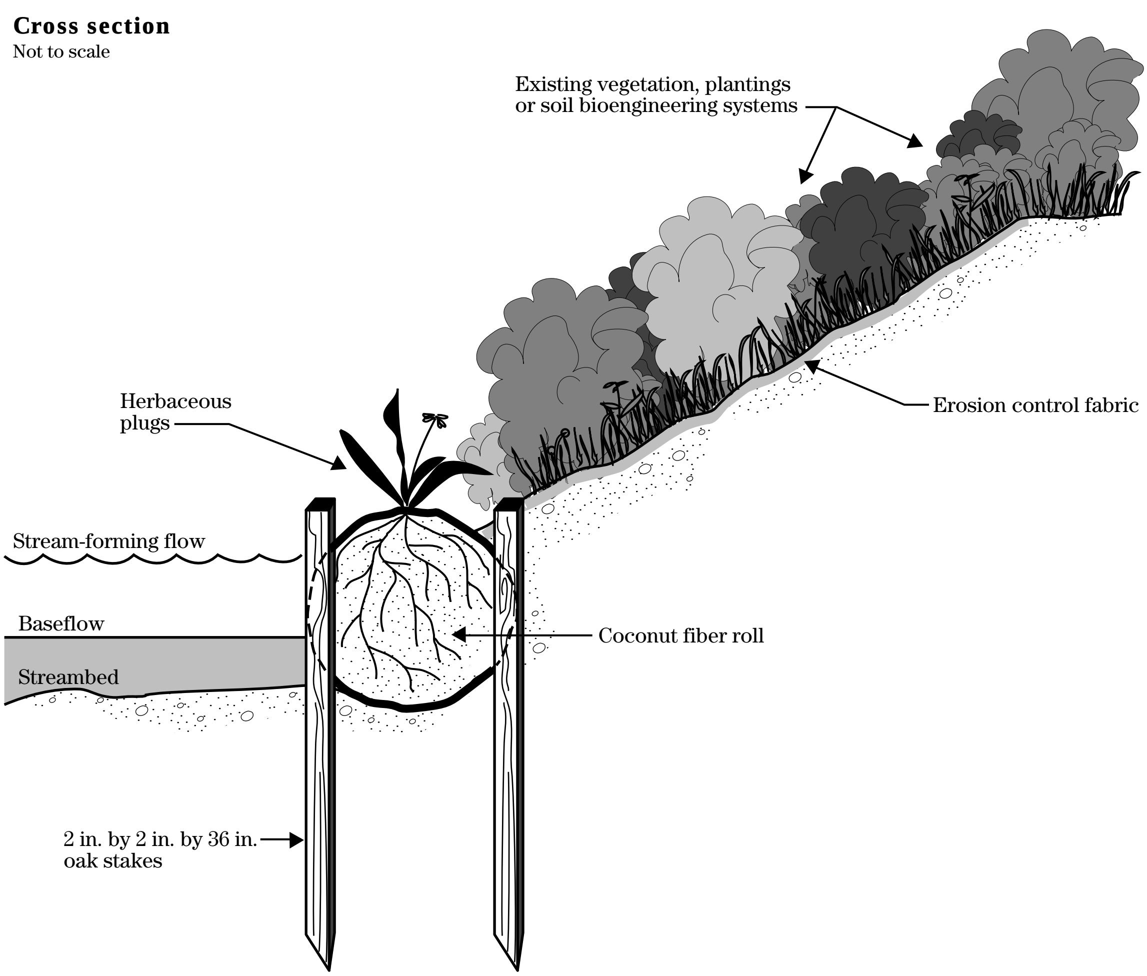


Figure 16–37a Coconut fiber roll

Figure 16–37b Coconut fiber roll system

- Backfill soil behind the fiber roll.
- If conditions permit, rooted herbaceous plants may be installed in the coconut fiber.
- Install appropriate vegetation or soil bioengineering systems upslope from fiber roll.

(ix) Stream jetties—Jetties are short dike-like structures that project from a streambank into a stream channel. They may consist of one or more structures placed at intervals along the bank to be protected. Most are constructed to the top of the bank and can be oriented either upstream, downstream, or perpendicular to the bank (figs. 16–38 and 16–39).

Jetties deflect or maintain the direction of flow through and beyond the reach of stream being protected. In function and design, jetties change the direction of flow by obstructing and redirecting the streamflow. Their design and construction require specialized skills. A fluvial geomorphologist, engineer, or other qualified discipline with knowledge of open channel hydraulics should be consulted for specific considerations and guidelines.

Applications and effectiveness

- Used successfully in a wide variety of applications in all types of rivers and streams.
- Effective in controlling erosion on bends in river and stream systems.
- Can be augmented with vegetation or soil bioengineering systems in some situations; i.e., deposited material upstream of jetties.
- May develop scour holes just downstream and off the end of the jetties.
- Can be complex and expensive.

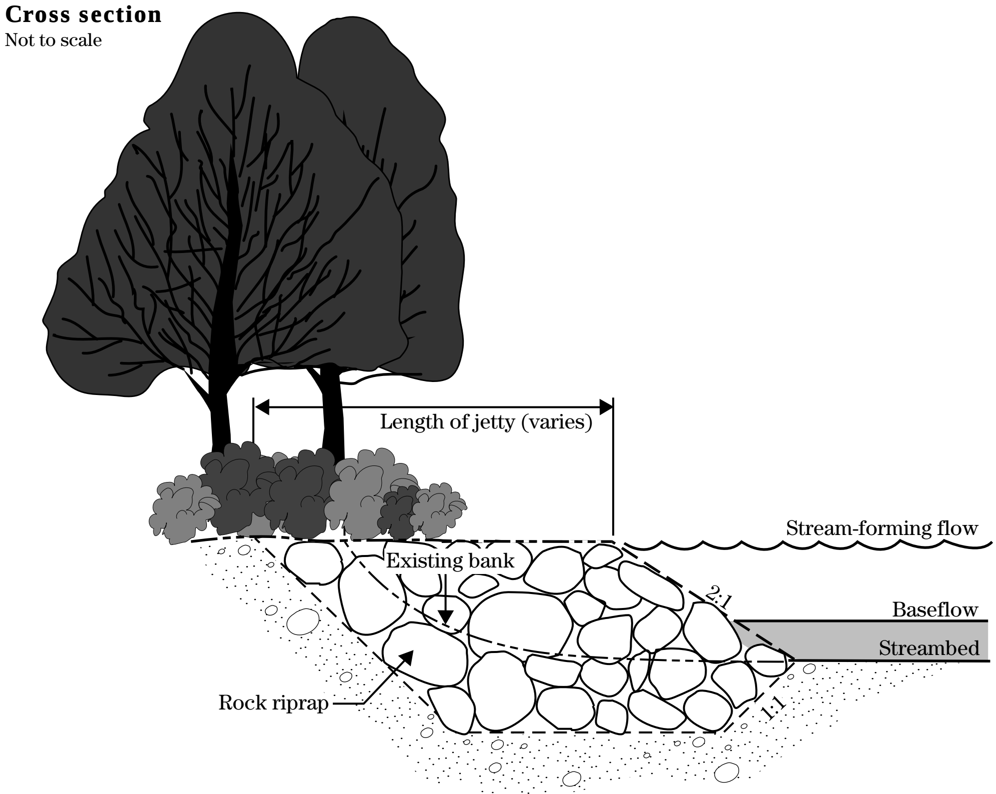
Construction guidelines

Inert materials—Rock filled jetties are the most common, however, other materials are used including timber, concrete, gabions, and rock protected earth.

Installation

- Use a D_{50} size rock equal to 1.5 to 2 times the d_{50} size determined from rock riprap design methods for bank full flow condition.
- Size and space jetties so that flow passing around and downstream from the outer end will intersect the next jetty before intersecting the eroding bank. The length varies but should not unduly constrict the channel. Rock jetties typically have 2:1 side slopes with an 8 to 12-foot top width and 2:1 end slope.
- Space jetties to account for such characteristics as stream width, stream velocity, and radius of curvature. Typical spacing is 2 to 5 times the jetty length.
- Construct jetties with a level top or a downward slope to the outer end (riverward). The top of the jetty at the bank should be equal to the bank height.
- Orient jetties either perpendicular to the streambank or angled upstream or downstream. Perpendicular and downstream orientation are the most common.
- Tie jetties securely back into the bank and bed to prevent washout along the bank and undercutting. Place rock a short distance on either side of the jetty along the bank to prevent erosion at this critical location. The base of the jetty should be keyed into the bed a minimum depth equal to the D_{100} rock size.

Figure 16–38 Stream jetty details



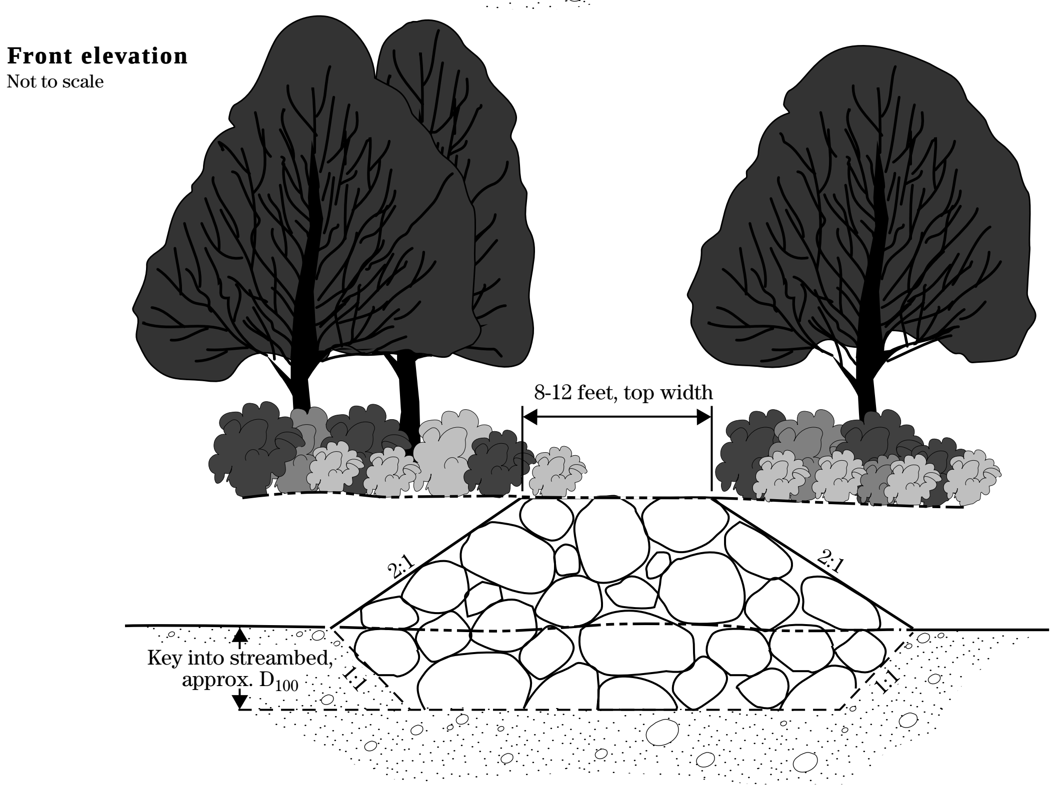


Figure 16–39a Stream jetty placed to protect railroad bridge

Figure 16–39b Long-established vegetated stream jetty, with deposition in foreground

(x) Stream barbs—Stream barbs are low rock sills projecting out from a streambank and across the stream's thalweg to redirect streamflow away from an eroding bank (figs.16–40 and 16–41). Flow passing over the barb is redirected so that the flow leaving the barb is perpendicular to the barb centerline. Stream barbs are always oriented upstream.

Application and effectiveness

- Used in limited applications and range of applicability is unclear.
- Effective in control of bank erosion on small streams.
- Require less rock and stream disturbance than jetties.
- Improve fish habitat (especially when vegetated).
- Can be combined with soil bioengineering practices.
- Can be complex and expensive.

Construction guidelines

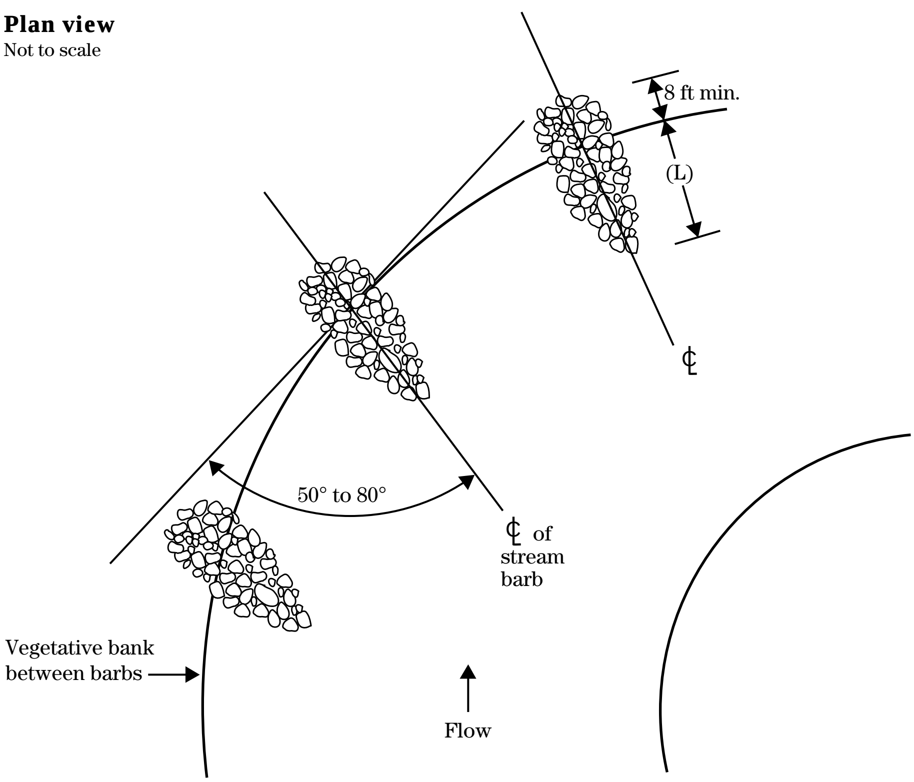
Inert materials—Stream barbs require the use of large rock.

Installation

- Use a D_{50} size rock equal to two times the d_{50} size determined from rock riprap design methods for bank full flow condition. The maximum rock size (D_{100}) should be about 1.5 to 2 times the D_{50} size. The minimum rock size should not be less than $.75D_{50}$.
- Key the barb into the stream bed to a depth approximately D_{100} below the bed.
- Construct the barb above the streambed to a height approximately equal to the D_{100} rock, but generally not over 2 feet. The width should be at least equal to 3 times D_{100}, but not less than a typical construction equipment width of 8 to 10 feet. Construction of barbs can begin at the streambank and proceed streamward using the barb to support construction equipment.
- Align the barb so that the flow off the barb is directed toward the center of the stream or away from the bank. The acute angle between the barb and the upstream bank typically ranges from 50 to 80 degrees.
- Ensure that, at a minimum, the barb is long enough to cross the stream flow low thalweg.
- Space the barbs apart from 4 to 5 times the barb’s length. The specific spacing is dependent on finding the point at which the streamflow leaving the barb intersects with the bank.

Figure 16–40 Stream barb details

Plan view
Not to scale



Cross section
Not to scale

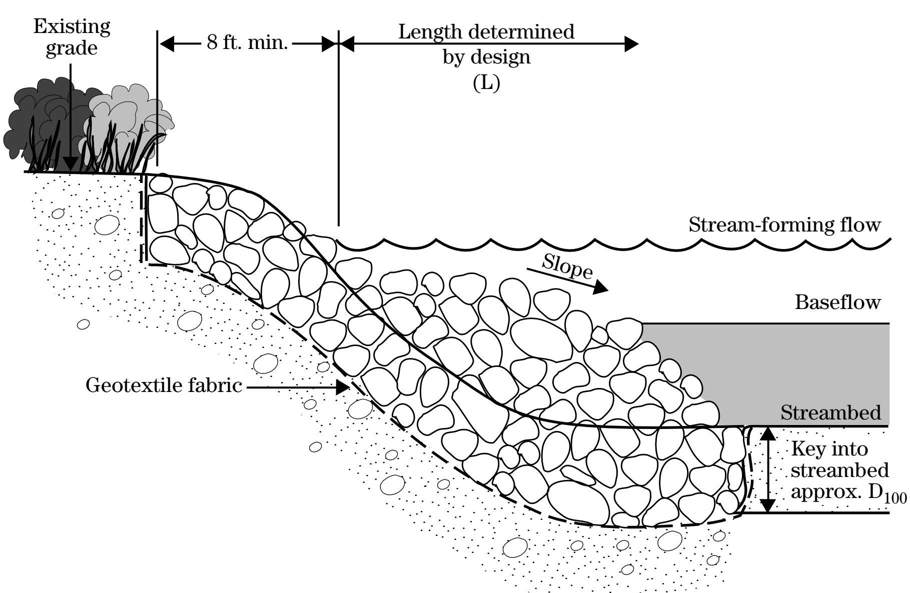


Figure 16–41 Stream barb system

(xi) Rock gabions—Rock gabions begin as rectangular containers fabricated from a triple twisted, hexagonal mesh of heavily galvanized steel wire. Empty gabions are placed in position, wired to adjoining gabions, filled with stones, and then folded shut and wired at the ends and sides. NRCS Construction Specification 64, Wire Gabions, provides detailed information on their installation.

Vegetation can be incorporated into rock gabions, if desired, by placing live branches on each consecutive layer between the rock-filled baskets (fig. 16–42 and 16–43). These gabions take root inside the gabion baskets and in the soil behind the structures. In time the roots consolidate the structure and bind it to the slope.

Applications and effectiveness

- Useful when rock riprap design requires a rock size greater than what is locally available.
- Effective where the bank slope is steep (typically greater than 1.5:1) and requires structural support.
- Appropriate at the base of a slope where a low wall may be required to stabilize the toe of the slope and reduce its steepness.
- Can be fabricated on top of the bank and then placed as a unit, below water if necessary.
- Lower initial cost than a concrete structure.
- Tolerate limited foundation movement.
- Have a short service life where installed in streams that have a high bed load. Avoid use where streambed material might abrade and cause rapid failure of gabion wire mesh.
- Not designed for or intended to resist large, lateral earth stresses. Should be constructed to a maximum of 5 feet in overall height, including the excavation required for a stable foundation.
- Useful where space is limited and a more vertical structure is required.
- Where gabions are designed as a structural unit, the effects of uplift, overturning, and sliding must be analyzed in a manner similar to that for gravity type structures.
- Can be placed as a continuous mattress for slope protection. Slopes steeper than 2:1 should be analyzed for slope stability.
- Gabions used as mattresses should be a minimum of 9 inches thick for stream velocities of up to 9 feet per second. Increase the thickness to a minimum of 1.5 feet for velocities of 10 to 14 feet per second.

Construction guidelines

Live material sizes—When constructing vegetated rock gabions, branches should range from 0.5 to 2.5 inches in diameter and must be long enough to reach beyond the back of the rock basket structure into the backfill or undisturbed bank.

Inert materials—Galvanized woven wire mesh or galvanized welded wire mesh baskets or mattresses may be used. The baskets or mattresses are filled with sound durable rock that has a minimum size of 4 inches and a maximum of 9 inches. Gabions can be coated with polyvinyl chloride to improve their service life where subject to aggressive water or soil conditions.

Installation

- Remove loose material from the foundation area and cut or fill with compacted material to provide a uniform foundation.
- Excavate the back of the stable foundation (closest to the slope) slightly deeper than the front to add stability to the structure. This provides additional stability to the structure and ensures that the living branches root well for vegetated rock gabions.
- Place bedding or filter material in a uniformly graded surface. Compaction of materials is not usually required. Install geotextiles so that they lie smoothly on the prepared foundation.
- Assemble, place, and fill the gabions with rock. Be certain that all stiffeners and fasteners are properly secured.
- Place the gabions so that the vertical joints are staggered between the gabions of adjacent rows and layers by at least one-half of a cell length.
- Place backfill between and behind the wire baskets.
- For vegetated rock gabions, place live branch cuttings on the wire baskets perpendicular to the slope with the growing tips oriented away from the slope and extending slightly beyond the gabions. The live cuttings must extend beyond the backs of the wire baskets into the fill material. Place soil over the cuttings and compact it.
- Repeat the construction sequence until the structure reaches the required height.

- Where abrasive bedloads or debris can snag or tear the gabion wire, a concrete cap should be used to protect those surfaces subject to attack. A concrete cap 6 inches thick with 3 inches penetration into the basket is usually sufficient. The concrete for the cap should be placed after initial settlement has occurred.
- A filter is nearly always needed between the gabions and the foundation or backfill to prevent soil movement through the baskets. Geosynthetics can be used in lieu of granular filters for many applications, however, when drainage is critical, the fabric must maintain intimate contact with the foundation soils. A 3-inch layer of sand-gravel between the gabions and the filter material assures that contact is maintained.
- At the toe and up and downstream ends of gabion revetments, a tieback into the bank and bed should be provided to protect the revetment from undermining or scour.

Figure 16–42 Vegetated rock gabion details

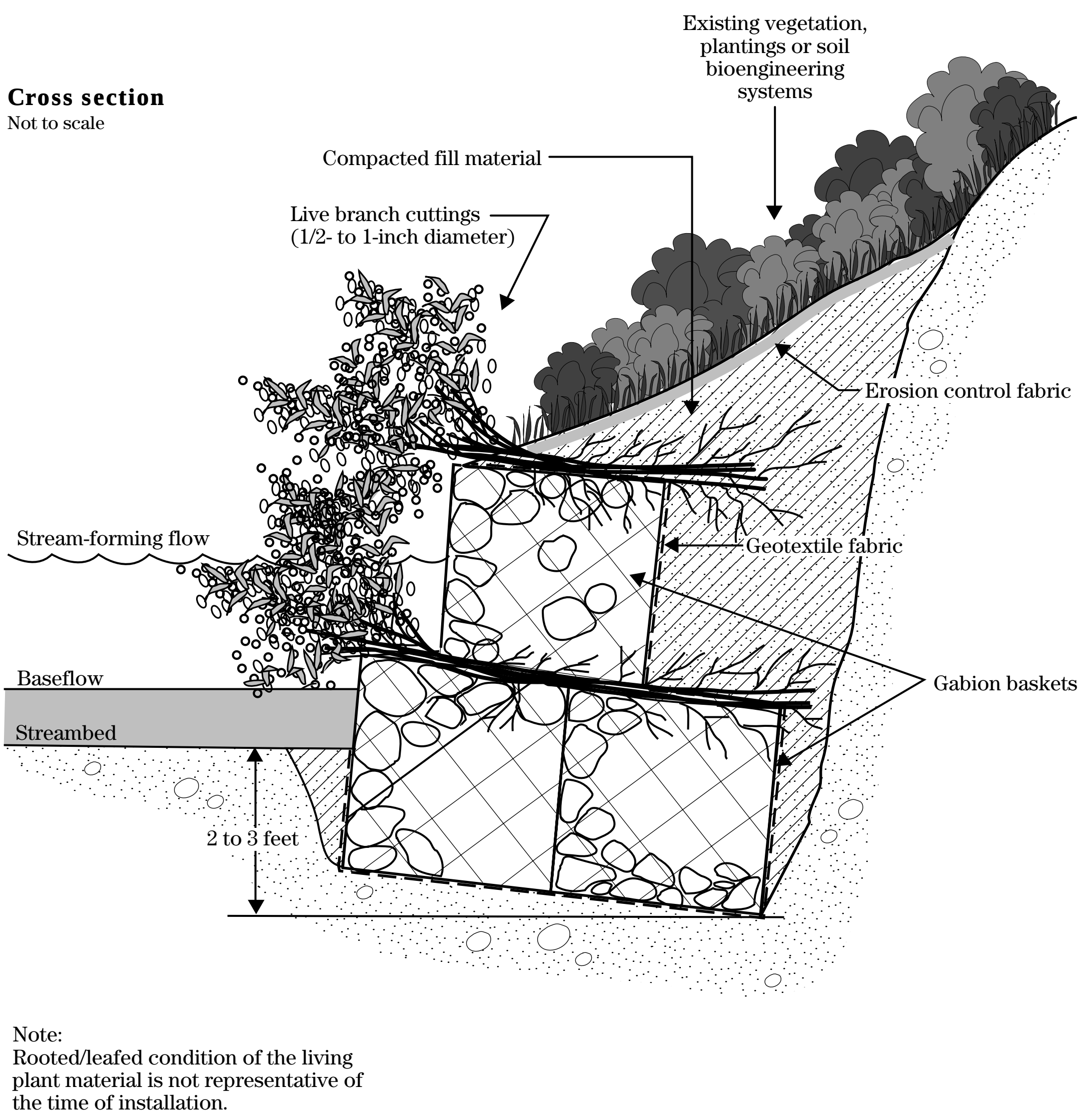


Figure 16–43 Vegetated rock gabion system (H.M. Schiechtl photo)

650.1602 Shoreline protection

(a) General

Shoreline erosion results primarily from erosive forces in the form of waves generally perpendicular to the shoreline. As a wave moves toward shore, it begins to drag on the bottom, dissipating energy. This eventually causes it to break or collapse. This major turbulence stirs up material from the shore bottom or erodes it from banks and bluffs. Fluctuating tides, freezing and thawing, floating ice, and surface runoff from adjacent uplands may also cause shorelines to erode.

(1) Types of shoreline protection

Systems for shoreline protection can be living or nonliving. They consist of vegetation, soil bioengineering, structures, or a combination of these.

(2) Planning for shoreline protection measures

The following items need to be considered for shoreline protection in addition to the items listed earlier in this chapter for planning streambank protection measures:

- Mean high and low water levels or tides.
- Potential wave parameters.
- Slope configuration above and below waterline.
- Nature of the soil material above and below water level.
- Evidence of littoral drift and transport.
- Causes of erosion.
- Adjacent land use.
- Maintenance requirements.

(b) Design considerations for shoreline protection

(1) Beach slope

Slopes should be determined above and below the waterline. The slope below waterline should be representative of the slope for a distance of at least 50 feet.

(2) Offshore depth and wave height

Offshore depth is a critical factor in designing shoreline protection measures. Structures that must be constructed in deep water, or in water that may become deep, are beyond the scope of this chapter. Other important considerations are the dynamic wave height acting in deep water (roughly, the total height of the wave is three times that visible) and the decreased wave action caused by shallow water. Effective fetch length also needs to be considered in determining wave height. Methods for computing wave height using fetch length are in NRCS Technical Releases 56 and 69.

(3) Water surface

The design water surface is the mean high tide or, in nontidal areas, the mean high water. This information may be obtained from tidal tables, records of lake levels, or from topographic maps of the reservoir site in conjunction with observed high and normal water lines along the shore.

(4) Littoral transport

The material being moved parallel to the shoreline in the littoral zone, under the influence of waves and currents should be addressed in groin design. It is important to determine that the supply of transport material is not coming from the bank being protected and the predominant direction of littoral transport. This information is used to locate structures properly with respect to adjacent properties and so that groins can fill most quickly and effectively. Another factor to be considered is that littoral transport often reverses directions with a change in season.

The rate of littoral transport and the supply are as important as the direction of movement. No simple ways to measure the supply are available. For the scope of this chapter, supply may be determined by observation of existing structures, sand beaches, auger samples of the sand above the parent material on the beach, and the presence of sandbars offshore. Other considerations are existing barriers, shoreline configuration, and inlets that tend to push the supply offshore and away from the area in question. The net direction of transport is an important and complex consideration.

(5) Bank soil type

Determining the nature of bank soil material aids in estimating the rate of erosion. A very dense, heavy clay can offer more resistance to wave action than noncohesive materials, such as sand. A thin sand lens can result in erosion problems since it may be washed out when subjected to high tides or wave action for extended periods of time. The resulting void will no longer support the bank above it, causing it to break away.

(6) Foundation material

The type of existing foundation may govern the type of protection selected. For example, a rock bottom will not permit the use of sheet piling. If the use of riprap is being considered on a highly erodible foundation, a filter will be needed to prevent fine material from washing through the voids. A soft foundation, such as dredge spoil, may result in excessive flotation or movement of the structure in any direction.

(7) Adjacent shoreline and structures

Structures that might have an effect on adjacent shoreline or other structures must be examined carefully. End sections need to be adequately anchored to existing measures or terminated in stable areas.

(8) Existing vegetation

The installation of erosion control structures can have a detrimental effect upon existing vegetation unless steps are taken to prevent what is often avoidable site disturbance. Existing vegetation should be saved as an integral part of the erosion control system being installed.

(c) Protective measures for shorelines

The analysis and design of shoreline protection measures are often complex and require special expertise. For this reason the following discussion is limited to revetments, bulkheads, and groins no higher than 3 feet above mean high water, as well as soil bioengineering and other vegetative systems used alone or in combination with structural measures. Consideration must be given to the possible effects that erosion control measures can have on adjacent areas, especially estuarine wetlands.

(1) Groins

Groins are somewhat permeable to impermeable finger-like structures that are installed perpendicular to the shore. They generally are constructed in groups called groin fields, and their primary purpose is to trap littoral drift. The entrapped sand between the groins acts as a buffer between the incoming waves and shoreline by causing the waves to break on the newly deposited sand and expend most of their energy there (figs. 16–44 and 16–45).

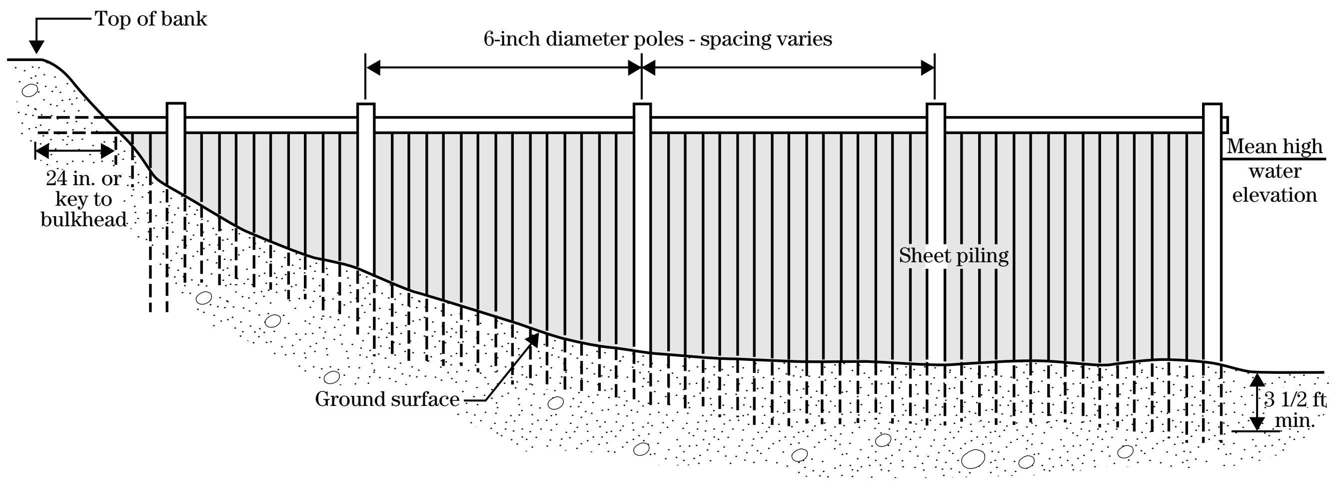
Applications and effectiveness

- Particularly dependent on site conditions. Groins are most effective in trapping sand when littoral drift is transported in a single direction.
- Filling the groin field with borrowed sand may be necessary, if the littoral transport is clay or silt rather than sand.
- Will not fill until all preceding updrift groins have been filled.

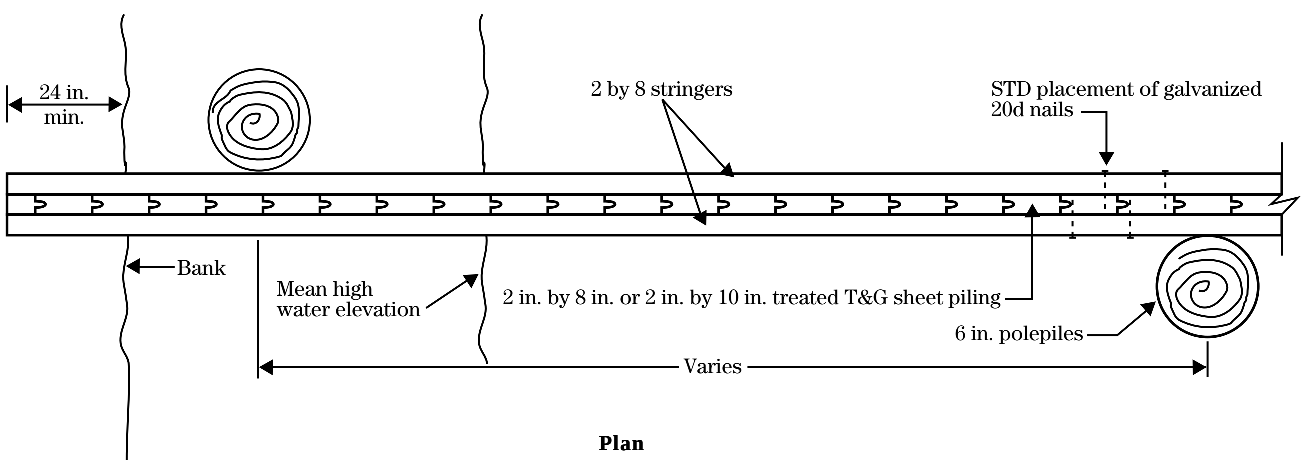
Construction guidelines

Inert materials—The most common type of structural groin is built of preservative-treated tongue and groove sheet piling.

Figure 16–44 Timber groin details



Cross section



Plan

Installation

- Groins must extend far enough into the water to retain desired amounts of sand. The distance between groins generally ranges from one to three times the length of the groin. When used in conjunction with bulkheads, the groins are usually shorter.
- Groins are particularly vulnerable to storm damage before they fill, so initially only the first three or four at the downdrift end of the system should be constructed.
- Install the second group of groins after the first has filled and the material passing around or over the groins has again stabilized the downdrift shoreline. This provides the means to verify or adjust the design spacing.
- Key the shoreward end of the groins into the shoreline bank for at least 2 feet or extend them to a bulkhead.
- Measure the groin height on the shoreline so that it will generally be at high tide or mean high water elevation plus 2 or 3 feet for wave surge height. Decrease the height seaward at a gradual rate to mean high water elevation.

Figure 16–45 Timber groin system

(3) Bulkheads

Bulkheads are vertical structures of timber, concrete, steel, or aluminum sheet piling installed parallel to the shoreline.

Applications and effectiveness

- Generally constructed where wave action will not cause excessive overtopping of the structure, which causes bank erosion to continue as though the bulkhead were not there.
- Scour at the base of the bulkhead also causes failure. The vertical face of the bulkhead redirects wave action to cause excessive scour at the toe of the structure unless it is protected.

Construction guidelines

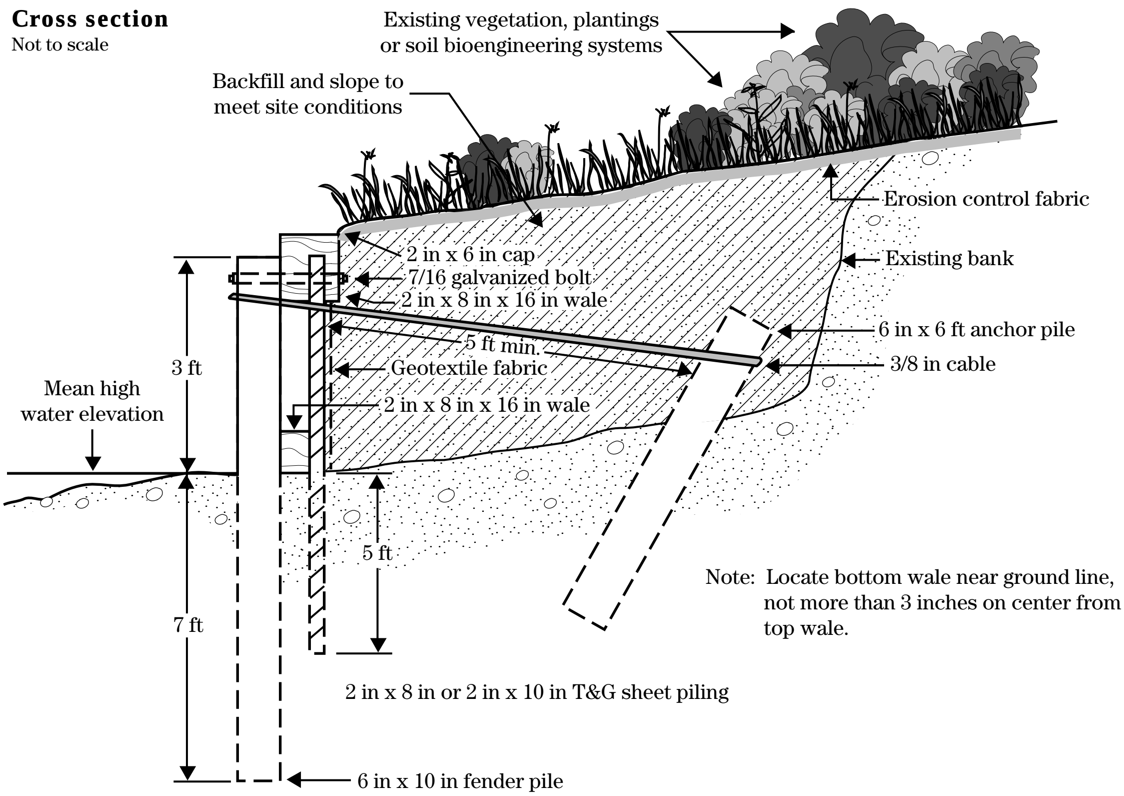
Inert materials—The most common materials used for bulkhead construction are timber (figs. 16–46 and 16–47), concrete (figs. 16–48 and 16–49), and masonry.

Installation

- Use environmentally compatible treated timber.
- Thickness and spacing of pilings, supports, cross member, and face boards must be engineered on a site-by-site basis.
- Pilings can be drilled, driven, or jetted depending on the foundation materials. Depth of piling must be at least equal to the exposed height below the point of maximum anticipated scour.
- Place stones or other appropriate materials at the base of the bulkhead to absorb wave energy.
- In salt water environments, use noncorrosive materials to the greatest extent possible.

Figure 16–46 Timber bulkhead system

Figure 16–47 Timber bulkhead details



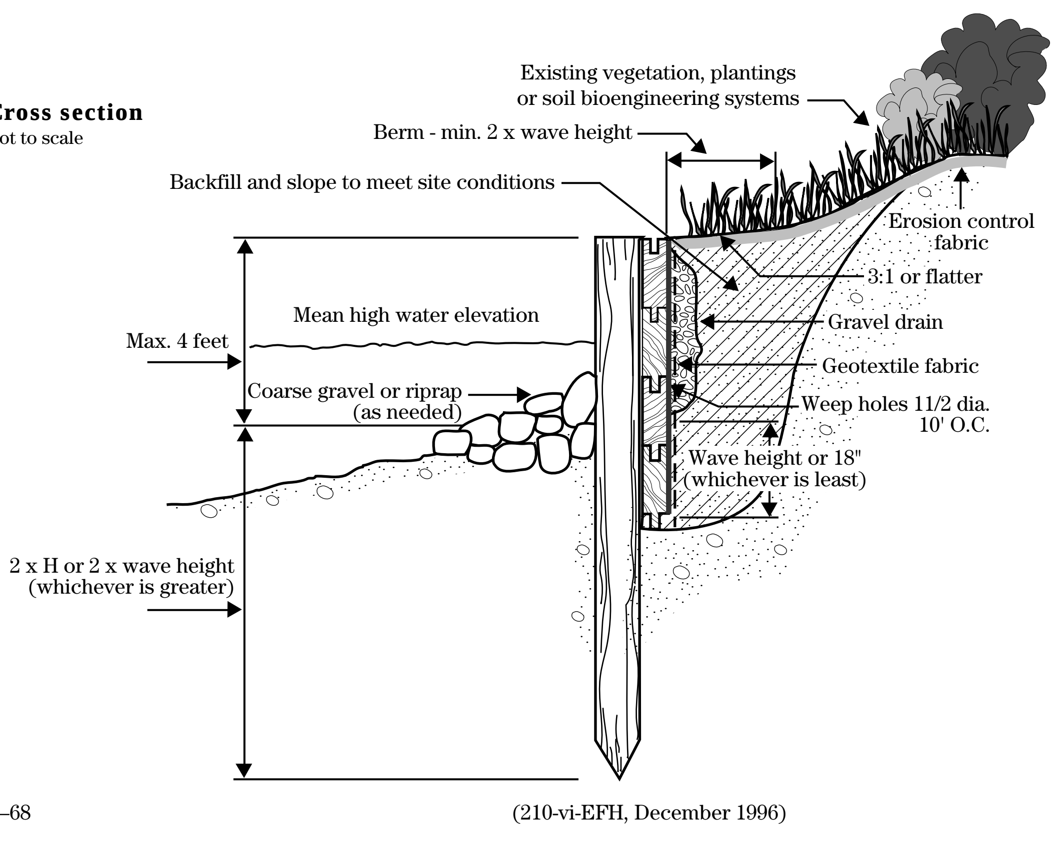
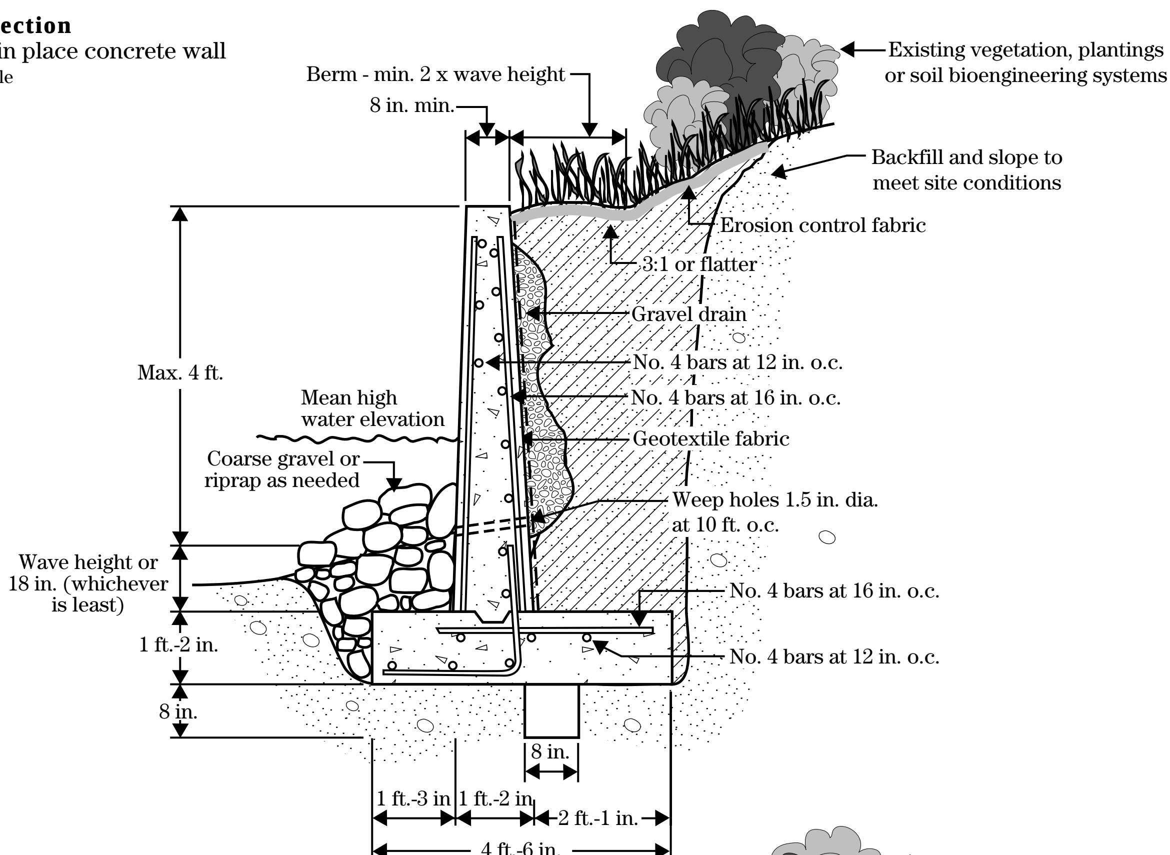


Figure 16–48 Concrete bulkhead details

Cross section
Poured in place concrete wall
Not to scale



Cross section
Concrete block wall
Not to scale

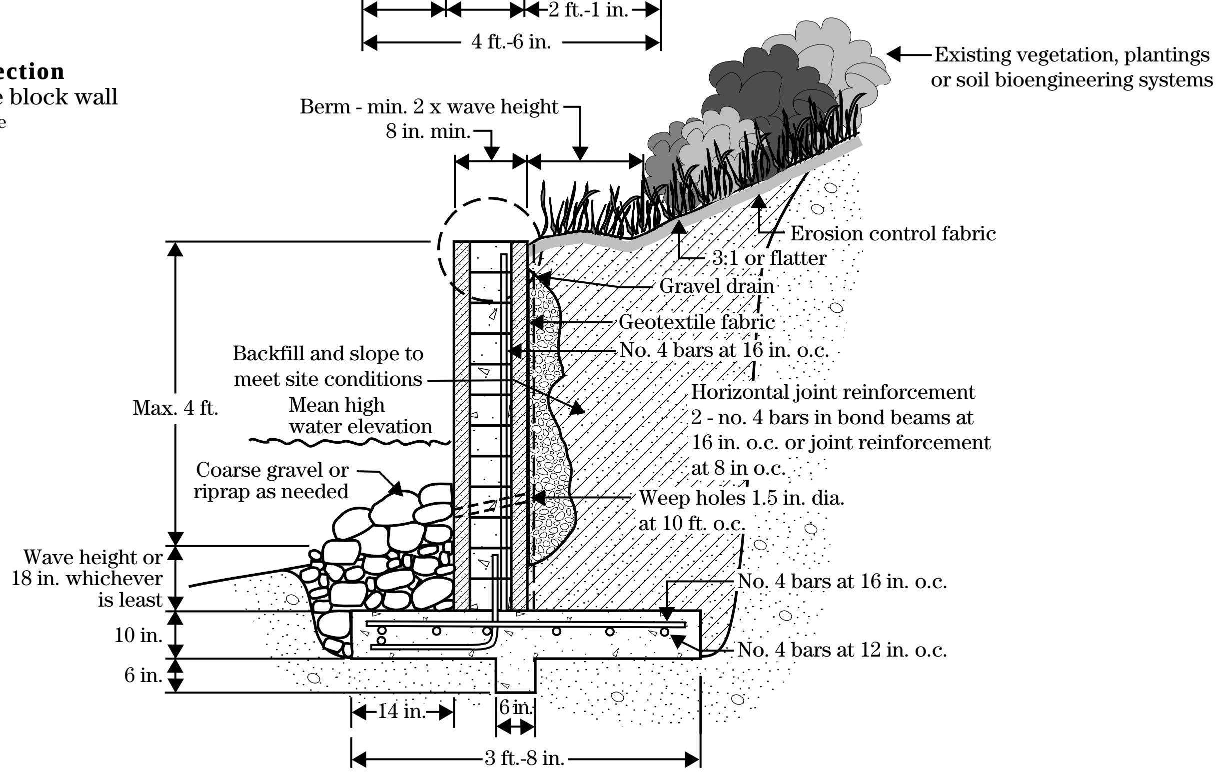


Figure 16–49 Concrete bulkhead system

(4) Revetments

Revetments are protective structures of rock, concrete, cellular blocks, or other material installed to fit the slope and shape of the shoreline (figs. 16–50 and 16–51).

Applications and effectiveness

- Flexible and not impaired by slight movement caused by settlement or other adjustments.
- Preferred to bulkheads where the possibility of extreme wave action exists.
- Local damage or loss of rock easily repaired.
- No special equipment required for construction.
- Subject to scour at the toe and flanking, thus filters are important and should always be considered.
- Complex and expensive.

Construction guidelines

- The size and thickness of rock revetments must be determined to resist wave action. NRCS Technical Release 69, *Rock Riprap for Slope Protection Against Wave Action*, provides guidance for size, thickness, and gradation.
- The base of the revetment must be founded below the scour depth or placed on nonerosive material.
- Angular stone is preferred for revetments. If rounded stone is used, increase the layer thickness by a factor of 1.5.
- Use a minimum thickness of 6-inch filter material under rock.
- If geotextile is used in place of granular filter, cover the geotextile with a minimum of 3inches of sand-gravel before placement of rock.

Figure 16–50 Concrete revetment (poured in place)

Figure 16–51 Rock riprap revetment

(5) Vegetative measures

If some vegetation exists on the shoreline, the shoreline problem may be solved with more vegetation. Determine if the vegetation disappeared because of a single, infrequent storm, or if plants are being shaded out by developing overstory trees and shrubs. In either case revegetation is a viable alternative. Consult local technical guides and plant material specialists for appropriate plant species and planting specifications. NRCS Technical Release 56, *Vegetative Control of Wave Action on Earth Dams*, provides additional guidance.

(6) Patching

A shoreline problem is often isolated and requires only a simple patch repair. Site characteristics that would indicate a patch solution may be appropriate include good overall protection from wave action, slight undercutting in spots with an occasional slide on the bank, and fairly good vegetative growth on the shoreline. The problems are often caused by boat wake or excessive upland runoff. Fill undercut areas with stone sandbags or grout-filled bags and repair with a grass transplant, reed clumps, branchpacking, vegetated geogrid, or vegetated riprap.

Slides that occur because of a saturated soil condition are best alleviated by providing subsurface drainage or a diversion. Leaning or slipping trees in the immediate slide area may need to be removed initially because of their weight and the forces they exert on the soil; however, once the saturated condition is remedied, disturbed areas should be revegetated with native trees, shrubs, grasses, and forbs to establish cover.

(7) Soil bioengineering systems

Soil bioengineering systems that are best suited to reducing erosion along shorelines are live stakes, live fascines, brushmattresses, live siltation, and reed clump constructions.

***(i) Live stake*—**Live stakes offer no stability until they root into the shoreline area, but over time they provide excellent soil reinforcement. To reduce failure until root establishment occurs, installations may be enhanced with a layer of long straw mulch covered with jute mesh or, in more critical areas, a natural geotextile fabric.

Refer to streambank protection section of this chapter for appropriate applications and construction guidelines.

***(ii) Live fascine*—**The live fascines previously described in this chapter work best in shoreline applications where the ground between them is also protected. Natural geotextiles, such as those manufactured from coconut husks, are strong, durable, and work well to protect the ground.

Construction guidelines

Live materials—Live cuttings as previously described for fabrication of live fascine bundles. Fabricate live fascine bundles approximately 8 inches in diameter. Live stakes should be about 3 feet long.

Inert materials—Dead stout stakes approximately 3 feet long to anchor well in loose sand. Jute mesh with long straw for low energy shorelines. Natural geotextile with long straw for higher energy shorelines.

Installation

The installation methods are similar to those discussed for live fascines, with the following variations:

- Excavate a trench approximately 10 inches wide and deep, beginning at one end of and parallel to the shoreline section to be repaired and extending to the other end.
- Spread jute mesh or geotextile fabric across the excavated trench and temporarily leave the remainder on the slope immediately above the trench.
- Place a live fascine bundle in the trench on top of the fabric and anchor with live and dead stout stakes.
- Spread long straw on the slope above the trench to the approximate location of the next trench to be constructed upslope.
- Pull the fabric upslope over the long straw and spread in the next excavated trench. Trenches should be spaced 3 to 5 feet apart and parallel to each other.
- Repeat the process until the system is in place over the treatment area.

***(iii) Brushmattress*—**Brushmattresses for shorelines perform a similar function as those for streambanks. Therefore, effectiveness and construction guidelines are similar to those given earlier in this chapter, with the following additions.

Applications and effectiveness

- May be effective in lake areas that have fluctuating water levels since they are able to protect the shoreline and continue to grow.
- Able to filter incoming water because they also establish a dense, healthy shoreline vegetation.

Installation

- After the trench at the bottom has been dug and the mattress branches placed, the trench should be lined with geotextile fabric.
- Secure the live fascine, press down the mattress brush, and place the fabric on top of the brush.
- At this point, install the live and dead stout stakes to hold the brush in place. A few dead stout stakes may be used in the mattress branch and partly wired down before covering the fabric. This helps in the final steps of covering and securing the brush and the fabric.

***(iv) Live siltation construction*—**Live siltation construction is similar to brushlayering except that the orientation of the branches are more vertical. Ideally live siltation systems are approximately perpendicular to the prevailing winds. The branch tips should slope upwards at 45 to 60 degrees. Installation is similar to brushlayering (see Engineering Field Handbook, chapter 18 for a more complete discussion of a brushlayer).

Live siltation branches that have been installed in the trenches serve as tensile inclusions or reinforcing units. The part of the brush that protrudes from the ground assists in retarding runoff and surface erosion from wave action and wind (figs. 16–52 and 16–53).

Applications and effectiveness

Live siltation systems provide immediate erosion control and earth reinforcement functions, including:

- Providing surface stability for the planting or establishment of vegetation.
- Trapping debris, seed, and vegetation at the shoreline.
- Reducing wind erosion and surface particle movement.
- Drying excessively wet sites through transpiration.
- Promoting seed germination for natural colonization.
- Reinforcing the soil with unrooted branch cuttings.
- Reinforcing the soil as deep, strong roots develop and adding resistance to sliding and shear displacement.

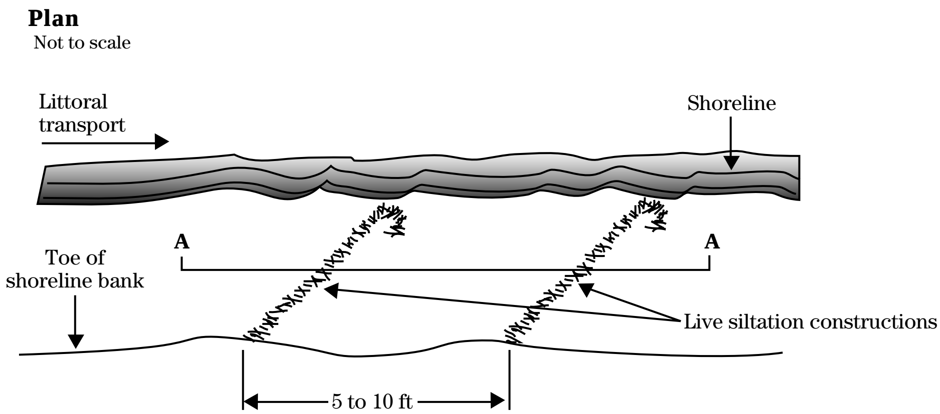
Construction guidelines

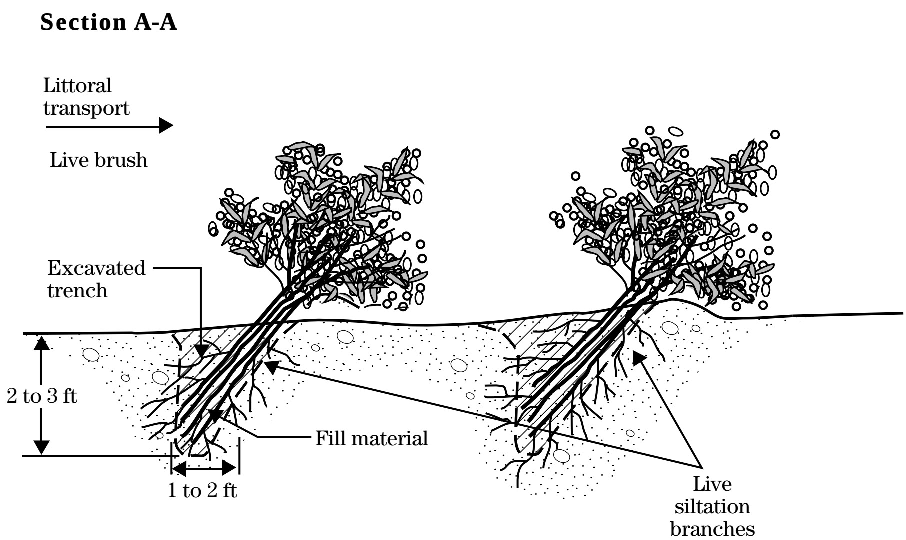
Live material—Live branch cuttings 0.5 to 1 inch in diameter and 4 to 5 feet long with side branches intact.

Installation

- Beginning at the toe of the shoreline bank to be treated, excavate a trench 2 to 3 feet deep and 1 to 2 feet wide, with one vertical side and the other angled toward the shoreline.
- Parallel live siltation rows should vary from 5 to 10 feet apart, depending upon shoreline conditions and stability required. Steep, unstable and high energy sites require closer spacing.

Figure 16–52 Live siltation construction details





Note: Rooted/leafed condition of the living plant material is not respresentative of the time of installation.

Figure 16–53 Live siltation construction system (Robbin B. Sotir & Associates photo)

(v) Reed clump—Reed clump installations consist of root divisions wrapped in natural geotextile fabric, placed in trenches, and staked down. The resulting root mat reinforces soil particles and extracts excess moisture through transpiration. Reed clump systems are typically installed at the water's edge or on shelves in the littoral zone (fig. 16–54 and 16–55).

Applications and effectiveness

- Reduces toe erosion and creates a dense energy-dissipating reed bank area.
- Offers relatively inexpensive and immediate protection from erosion.
- Useful on shore sites where rapid repair of spot damage is required.
- Retains soil and transported sediment at the shoreline.
- Reduces a long beach wash into a series of shorter sections capable of retaining surface soils.
- Enhances conditions for natural colonization and establishment of vegetation from the surrounding plant community.
- Grows in water and survives fluctuating water levels.

Construction guidelines

Live materials—The reed clumps should be 4 to 8 inches in diameter and taken from healthy water-dependent species, such as arrowhead, cattail, or water iris. They may be selectively harvested from existing natural sites or purchased from a nursery.

Wrap reed clumps in natural geotextile fabric and bind together with twine. These clumps can be fabricated several days before installation if they are kept moist and shaded.

Inert materials—Natural geotextile fabric, twine, and 3- to 3.5-foot-long dead stout stakes are required.

Installation

- Reed root clumps are either placed directly into fabric-lined trenches or prefabricated into rolls 5 to 30 feet long. With the growing tips pointing up, space clumps every 12 inches on a 2- to 3-foot-wide strip of geotextile fabric to fabricate the rolls. The growing buds should all be oriented in the same upright direction for correct placement into the trench.
- Wrap the fabric from both sides to overlap the top, leaving the reed clumps exposed and bound with twine between each plant.
- Beginning at and parallel to the water's edge, excavate a trench 2 inches wider and deeper than the size of the prefabricated reed roll or reed clumps.
- To place reed clumps directly into trenches, first line the trench with a 2- to 3-foot-wide strip of geotextile fabric before spreading a 1-inch layer of highly organic topsoil over it at the bottom of the trench. Next, center the reed clumps on 12-inch spacing in the bottom of the trench. Fill the remainder of the trench between and around reed clumps with highly organic topsoil, and compact. Wrap geotextile fabric from each side to overlap at the top and leave the reed clumps exposed before securing with dead stout stakes spaced between the clumps. Complete the installation by spreading previously excavated soil around the exposed reed clumps to cover this staked fabric.
- To use the prefabricated reed clump roll, place it in the excavated trench, secure it with dead stout stakes, and backfill as described above.
- Repeat the above procedure by excavating additional parallel trenches spaced 3 to 6 feet apart toward the shoreline. Place the reed clumps from one row to the next to produce a staggered spacing pattern.

Figure 16–54 Reed clump details

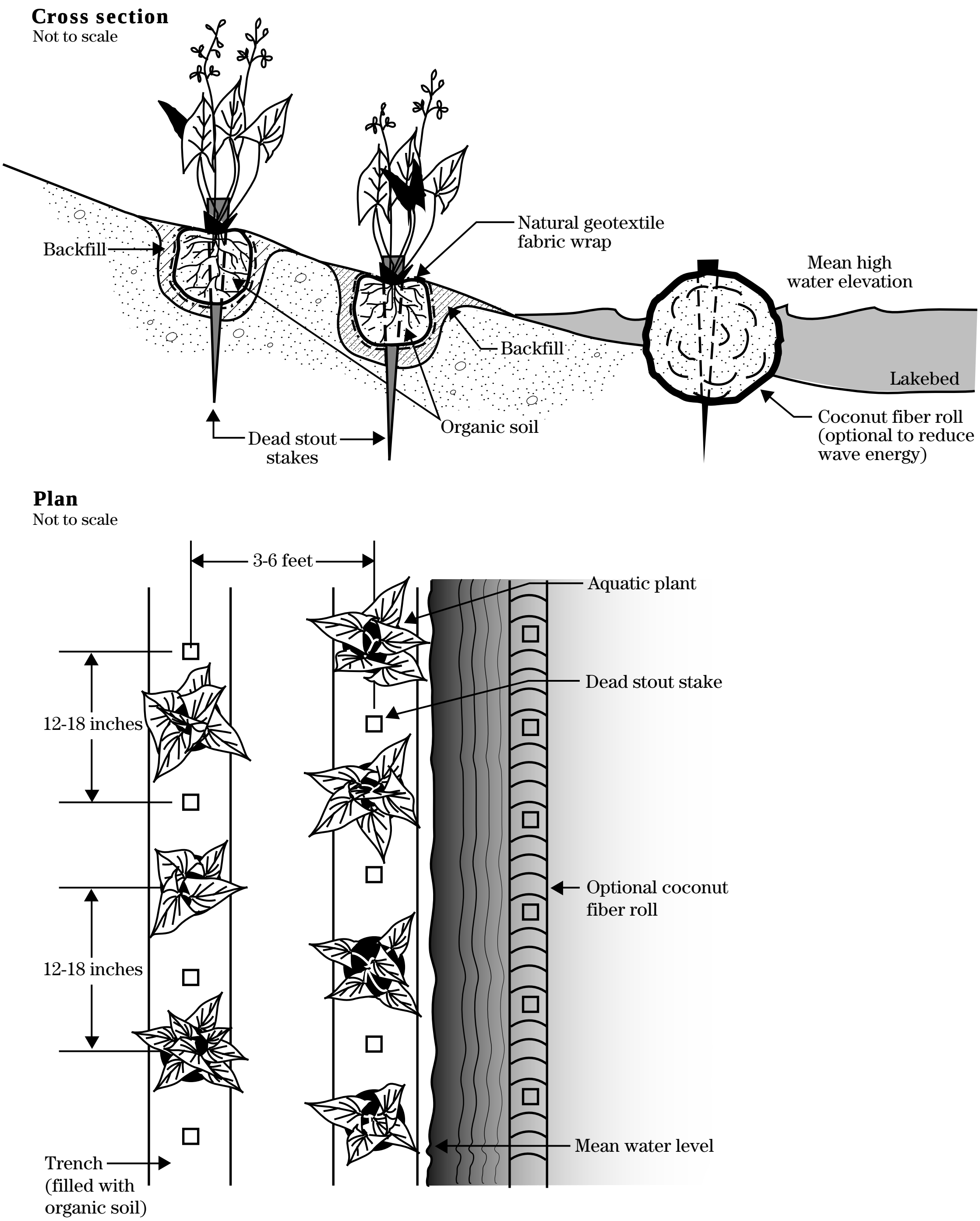


Figure 16–55a Installing dead stout stakes in reed clump system (Robbin B. Sotir & Associates photo)

Figure 16–55b Completing installation of reed clump system (Robbin B. Sotir & Associates photo)

Figure 16–55c Established reed clump system (Robbin B. Sotir & Associates photo)

(8) Coconut fiber roll

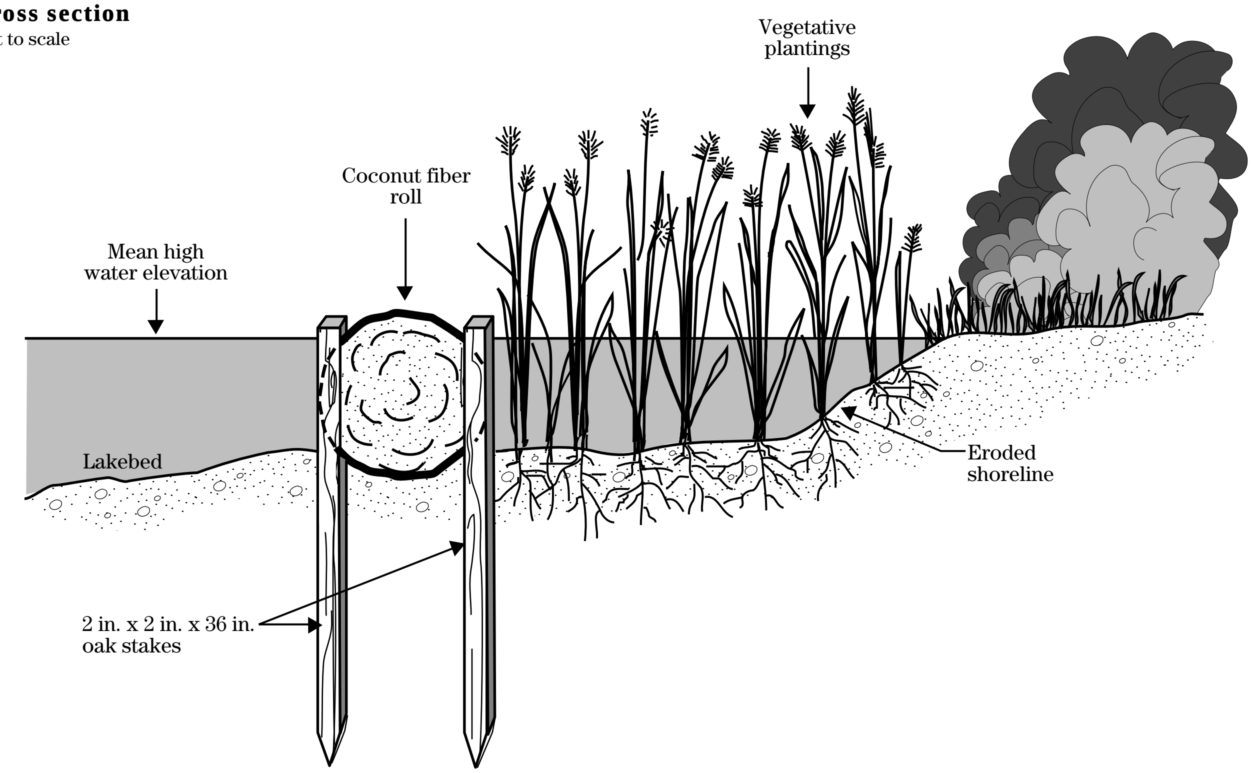
Coconut fiber rolls are cylindrical structures composed of coconut fibers bound together with twine woven from coconut (figs. 16–56 and 16–57). This material is most commonly manufactured in 12-inch diameters and lengths of 20 feet. The fiber rolls function as breakwaters along the shores of lakes and embayments. In addition to reducing wave energy, this product can help contain substrate and encourage development of wetland communities.

Applications and effectiveness

- Effective in lake areas where the water level fluctuates because it is able to protect the shoreline and encourage new vegetation.
- Flexible, can be molded to the curvature of the shoreline.
- Prefabricated materials can be expensive.
- Manufacturers estimate the product has an effective life of 6 to 10 years.

Figure 16–56 Coconut fiber roll details

Cross section
Not to scale



Installation

- Fiber roll should be located off shore at a distance where the top of the fiber roll is exposed at low tide. In nontidal areas, the fiber roll should be placed where it will not be overtopped by wave action.
- Drive 2 inch x 2 inch stakes between the binding twine and the coconut fiber. Stakes should be placed on 4-foot centers and should not extend above the fiber roll.
- If desired, rooted cuttings can be installed between the coconut fiber roll and the shoreline.

Figure 16–57 Coconut fiber roll system

650.1603 References

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Glossary

Bankfull discharge Natural streams—The discharge that fills the channel without overflowing onto the flood plain.

Modified or entrenched streams—The streamflow volume and depth that is the 1- to 3-year frequency flow event.

The discharge that determines the stream's geomorphic planform dimensions.

Bar A streambed deposit of sand or gravel, often exposed during low-water periods.

Baseflow The ground water contribution of streamflow.

Bole Trunk of a tree.

Branchpacking Live, woody, branch cuttings and compacted soil used to repair slumped areas of streambanks.

Brushmattress A combination of live stakes, fascines, and branch cuttings installed to cover and protect streambanks and shorelines.

Bulkhead Generally vertical structures of timber, concrete, steel, or aluminum sheet piling used to protect shorelines from wave action.

Channel A natural or manmade waterway that continuously or intermittently carries water.

Cohesive soil A soil that, when unconfined, has considerable strength when air dried and significant strength when wet.

Current The flow of water through a stream channel.

Dead blow hammer A hammer filled with lead shot or sand.

Deadman A log or concrete block buried in a streambank to anchor revetments.

Deposition The accumulation of soil particles on the channel bed, banks, and flood plain.

Discharge The volume of water passing through a channel during a given time, usually measured in cubic feet per second.

Dormant season The time of year when plants are not growing and deciduous plants shed their leaves.

Duration of flow Length of time a stream floods.

Erosion control fabric Woven or spun material made from natural or synthetic fibers and placed to prevent surface erosion.

Erosion The wearing away of the land by the natural forces of wind, water, or gravity.

Erosive (erodible) A soil whose particles are easily detached and entrained in a fluid, either air or water, passing over or through the soil. The most erodible soils tend to be silts and/or fine sands with little or no cohesion.

Failure Collapse or slippage of a large mass of streambank material.

Filter A layer of fabric, sand, gravel, or graded rock placed between the bank revetment or channel lining and soil to prevent the movement of fine grained sizes or to prevent revetment work from sinking into the soil.

Fines Silt and clay particles.

Flanking Streamflow between a structure and the bank that creates an area of scour.

Flow rate Volume of flow per unit of time; usually expressed as cubic feet per second.

Footer log A log placed below the expected scour depth of a stream. Foundation for a rootwad and boulders.

Gabion A wire mesh basket filled with rock that can be used in multiples as a structural unit.

Geotextile Any permeable textile used with foundation soil, rock, or earth as an integral part of a product, structure, or system usually to provide separation, reinforcement, filtration, or drainage.

Groin A structure built perpendicular to the shoreline to trap littoral drift and retard erosion.

Ground water Water contained in the voids of the saturated zone of geologic strata.

Headcutting The development and upstream movement of a vertical or near vertical change in bed slope, generally evident as falls or rapids. Headcuts are often an indication of major disturbances in a stream system or watershed.

Joint planting The insertion of live branch cuttings in openings or interstices of rocks, blocks, or other inert revetment units and into the underlying soil.

Littoral drift The movement of littoral drift either transport parallel (long shore transport) or perpendicular (on-shore transport) to the shoreline.

Littoral The sedimentary material of shorelines moved by waves and currents.

Littoral zone An indefinite zone extending seaward from the shoreline to just beyond the breaker zone.

Live branch cuttings Living, freshly cut branches from woody shrub and tree species that readily propagate when embedded in soil.

Live cribwall A rectangular framework of logs or timbers filled with soil and containing live woody cuttings that are capable of rooting.

Live fascine Bound, elongated, cylindrical bundles of live branch cuttings that are placed in shallow trenches, partly covered with soil, and staked in place.

Live siltation construction Live branch cuttings that are placed in trenches at an angle from shoreline to trap sediment and protect them against wave action.

Live stake Live branch cuttings that are tamped or inserted into the earth to take root and produce vegetative growth.

Noncohesive soil Soil, such as sand, that lacks significant internal strength and has little resistance to erosion.

Piling (sheet) Strips or sheets of metal or other material connected with meshed or interlocking members to form an impermeable diaphragm or wall.

Piling A long, heavy timber, concrete, or metal support driven or jetted into the earth.

Piping The progressive removal of soil particles from a soil mass by percolating water, leading to the development of flow channels or tunnels.

Reach A section of a stream's length.

Reed clump A combination of root divisions from aquatic plants and natural geotextile fabric to protect shorelines from wave action.

Revetment (armoring) A facing of stone, interlocking pavers, or other armoring material shaped to conform to and protect streambanks or shorelines.

Riprap A layer, facing, or protective mound of rubble or stones randomly placed to prevent erosion, scour, or sloughing of a structure of embankment; also, the stone used for this purpose.

Rootwad A short length of tree trunk and root mass.

Scour Removal of underwater material by waves or currents, especially at the base or toe of a streambank or shoreline.

Sediment deposition The accumulation of sediment.

Sediment load The amount of sediment in transport.

Sediment Soil particles transported from their natural location by wind or water.

Seepage The movement of water through the ground, or water emerging on the face of a bank.

Slumping (sloughing) Shallow mass movement of soil as a result of gravity and seepage.

Stream-forming flow The discharge that determines a stream's geomorphic planform dimensions. Equivalent to the 1- to 3-year frequency flow event (see Bankfull discharge).

Streambank The side slopes within which streamflow is confined.

Streambed (bed) The bottom of a channel.

Streamflow The movement of water within a channel.

Submerged vanes Precast concrete or wooden elements placed in streambeds to deflect secondary currents away from the streambank.

Thalweg The deepest part of a stream channel where the fastest current is usually found.

Toe The break in slope at the foot of a bank where it meets the streambed.

Vegetated geogrid Live branch cuttings placed in layers with natural or synthetic geotextile fabric wrapped around each soil lift.

Vegetated structural revetments Porous revetments, such as riprap or interlocking pavers, into which live plants or cuttings can be placed.

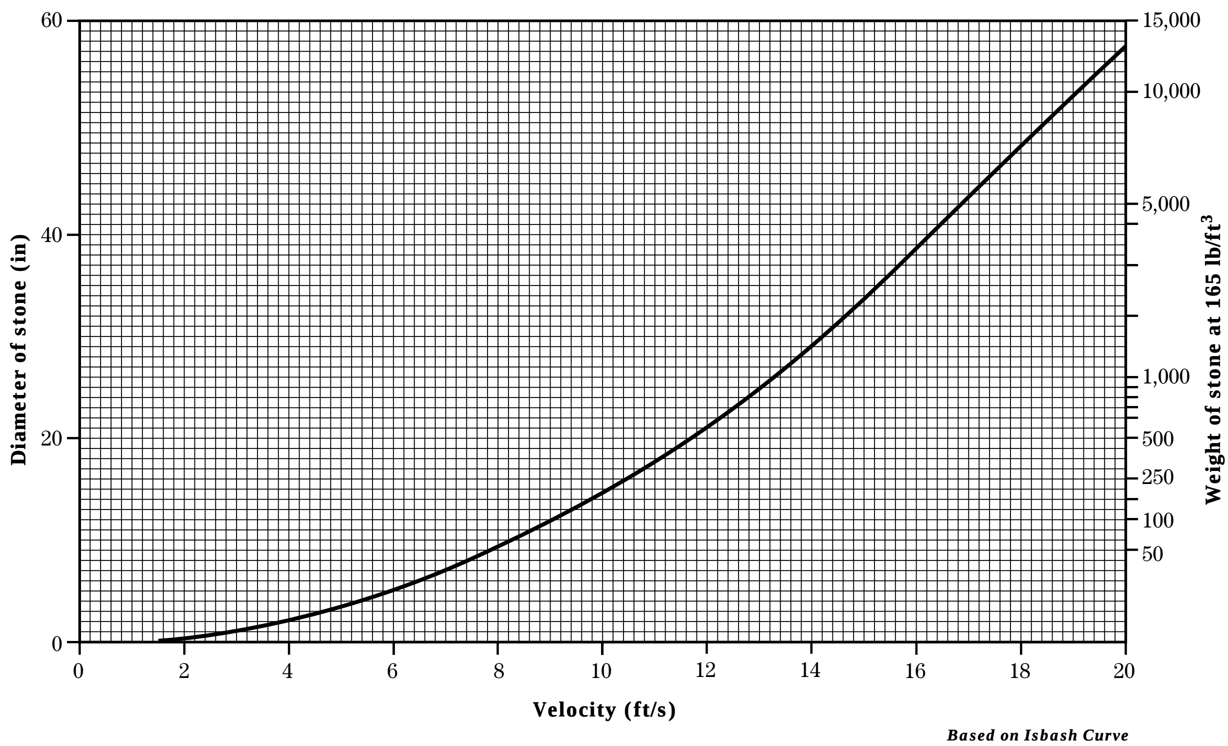
Vegetated structures A retaining structure in which live plants or cuttings have been integrated.

Appendix 16A Size Determination for Rock Riprap

Isbash Curve

The Isbash Curve, because of its widespread acceptance and ease of use, is a direct reprint from the previous chapter 16, Engineering Field Manual. The curve was developed from empirical data to determine a rock size for a given velocity. See figure 16A–1. The user can read the D_{100} rock size (100 percent of riprap ≤ this size) directly from the graph in terms of weight (pounds) or dimension (inches). Less experienced users should use this method for quick estimates or comparison with other methods before determining a final design.

Figure 16A–1 Rock size based on Isbash Curve



Procedure

1. Determine the design velocity.
2. Use velocity and fig. 16A-1 (Isbash Curve) to determine basic rock size.
3. Basic rock size is the D_{100} size.

Figure 16A–2 Rock size based on Far West States (FWS)-Lane method

$D_s = \frac{3.5}{CK} w D S$ $\quad D_s = D_{75}$ size rock in inches

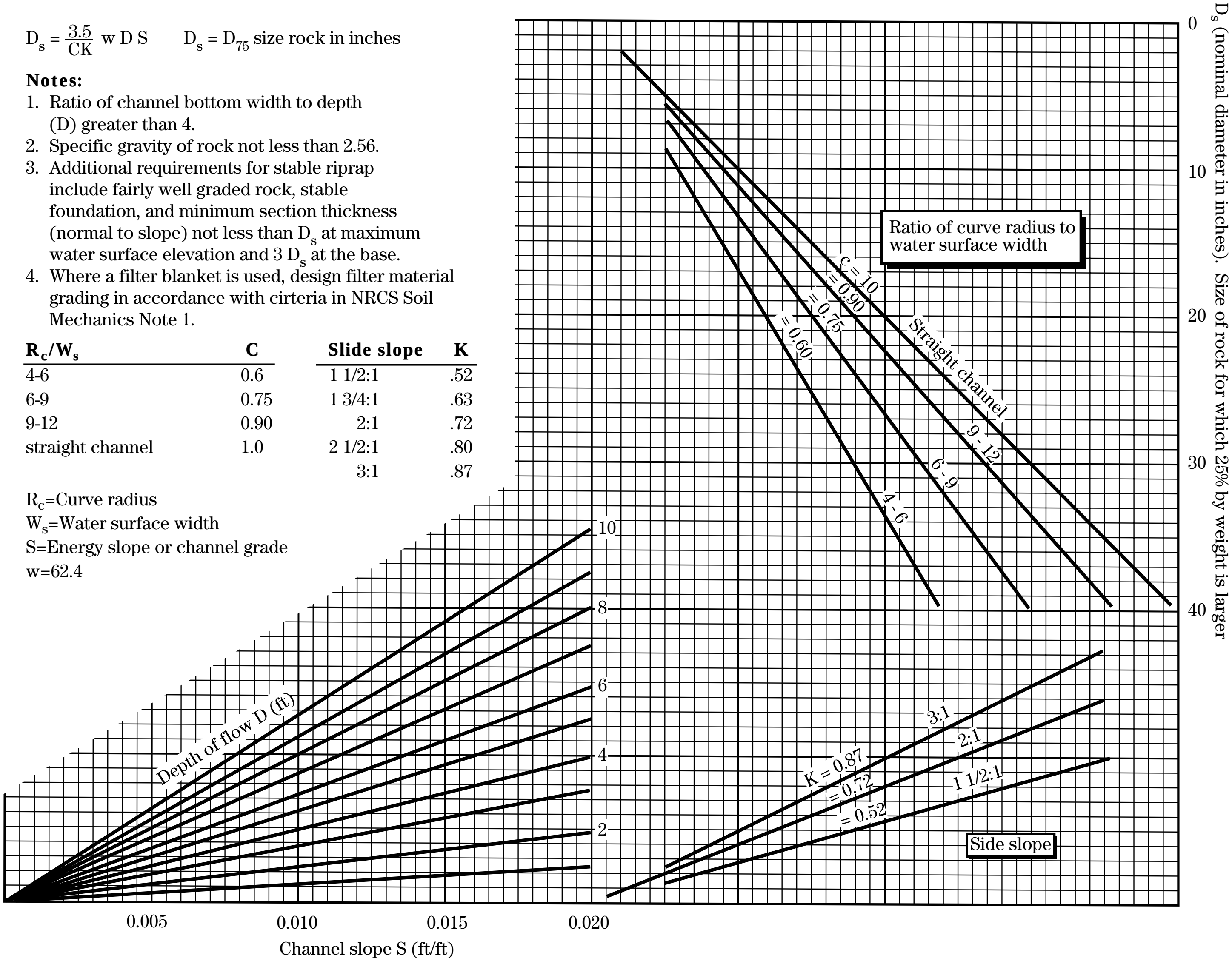
Notes:

1. Ratio of channel bottom width to depth (D) greater than 4.
2. Specific gravity of rock not less than 2.56.
3. Additional requirements for stable riprap include fairly well graded rock, stable foundation, and minimum section thickness (normal to slope) not less than D_s at maximum water surface elevation and 3 D_s at the base.
4. Where a filter blanket is used, design filter material grading in accordance with cirteria in NRCS Soil Mechanics Note 1.

R_c/W_s	C
4-6	0.6
6-9	0.75
9-12	0.90
straight channel	1.0

Slide slope	K
1 1/2:1	.52
1 3/4:1	.63
2:1	.72
2 1/2:1	.80
3:1	.87

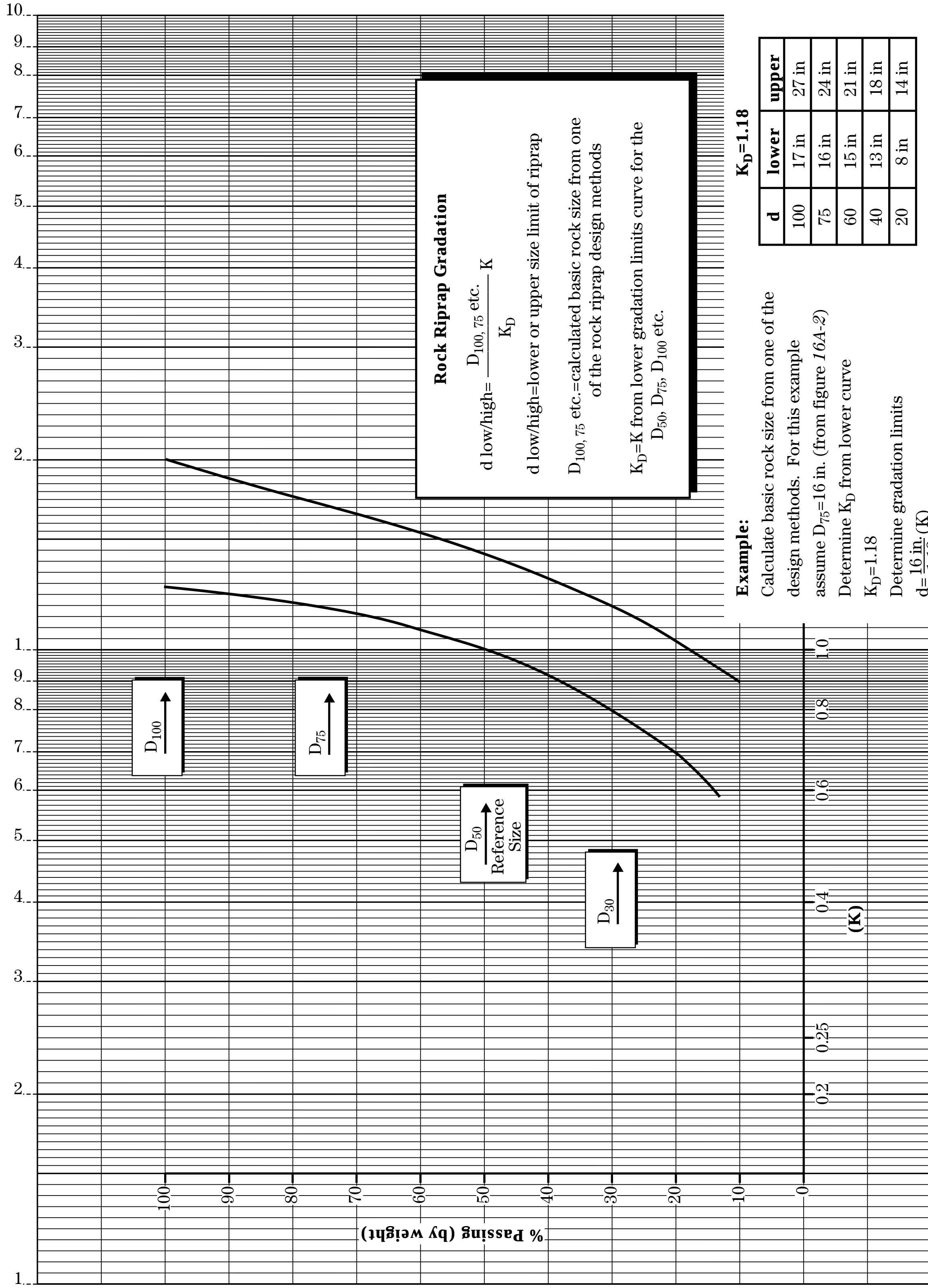
R_c=Curve radius
W_s=Water surface width
S=Energy slope or channel grade
w=62.4



Procedure

1. Determine the average channel grade or energy slope.
2. Enter fig. 16A-2 with energy slope, flow depth, and site physical characteristics to determine basic rock size.
3. Basic rock size is the D_{75} size.

Figure 16A–3 Gradation limits curve for determining suitable rock gradation



Rock Riprap Gradation

$$d\ \text{low/high} = \frac{D_{100,\,75}\ \text{etc.}}{K_D}\ K$$

d low/high=lower or upper size limit of riprap

$D_{100,\,75}$ etc.=calculated basic rock size from one of the rock riprap design methods

K_D=K from lower gradation limits curve for the D_{50}, D_{75}, D_{100} etc.

Example:
Calculate basic rock size from one of the design methods. For this example assume D_{75}=16 in. (from figure *16A-2*)
Determine K_D from lower curve
K_D=1.18
Determine gradation limits
$d = \frac{16\ \text{in.}}{1.18}$ (K)

K_D=1.18

d	lower	upper
100	17 in	27 in
75	16 in	24 in
60	15 in	21 in
40	13 in	18 in
20	8 in	14 in

Appendix 16B Plants for Soil Bioengineering and Associated Systems

The information in appendix 16B is from the Natural Resources Conservation Service's data base for Soil Bioengineering Plant Materials (biotype). The plants are listed in alphabetical order by scientific name. Further subdivision of the listing should be considered to account for local conditions and identify species suitable only for soil bioengineering systems.

Table header definitions (in the order they occur on the tables):

Scientific name—Genus and species name of the plant.

Common name—Common name of the plant.

Region of occurrence—Region(s) of occurrence using the regions of distribution in PLANTS (Plant List of Attributes, Nomenclature, Taxonomy, and Symbols, 1994). Region code number or letter:

- 1 Northeast—ME, NH, VT, MA, CT, RI, WV, KY, NY, PA, NJ, MD, DE, VA, OH
- 2 Southeast—NC, SC, GA, FL, TN, AL, MS, LA, AR
- 3 North Central—MO, IA, MN, MI, WI, IL, IN
- 4 North Plains—ND, SD, MT (eastern) WY (eastern)
- 5 Central Plains—NE, KS, CO (eastern)
- 6 South Plains—TX, OK
- 7 Southwest—AZ, NM
- 8 Intermountain—NV, UT, CO (western)
- 9 Northwest—WA, OR, ID, MT (western) WY (western)
- 0 California—Ca
- A Alaska—AK
- C Caribbean—PR, VI, CZ, SQ
- H Hawaii—HI, AQ, GU, IQ, MQ, TQ, WQ, YQ

Commercial availability—Answers whether the plant is available from commercial plant vendors.

Plant type—Short description of the type of plant: tree, shrub, grass, forb, legume, etc.

Root type—Description of the root of the plant: tap, fibrous, suckering, etc.

Rooting ability from cutting—Subjective rating of cut stems of the plant to root without special hormone and/or environmental surroundings provided.

Growth rate—Subjective rating of the speed of growth of the plant: slow, medium, fast, etc.

Establishment speed—Subjective rating of the speed of establishment of the plant.

Spread potential—Subjective rating of the potential for the plant to spread: low, good, etc.

Plant materials—The type of vegetation plant parts that can be used to establish a new colony of the species.

Notes—Other important or interesting characteristics about the plant.

Soil preference—Indication of the type of soil the plant prefers: sand, loam, clay, etc.

pH preference—Lists the pH preference(s) of the plant.

Drought tolerance—Subjective rating of the ability of the plant to survive dry soil conditions.

Shade tolerance—Subjective rating of the ability of the plant to tolerate shaded sites.

Deposition tolerance—Subjective rating of the ability of the plant to tolerate deposition of soil or organic debris around or over the roots and stems.

Flood tolerance—Selective rating of the ability of the plant to tolerate flooding events.

Flood season—Time of the year that the plant can tolerate flooding events.

Minimum water depth—The minimum water depth required by the plant for optimal growth.

Maximum water depth—The maximum water depth the plant can tolerate and not succumb to drowning.

Wetland indicator—A national indicator from National List of Plant Species that Occur in Wetlands: 1988 National Summary.

Table 16B–1 Woody plants for soil bioengineering and associated systems

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Acer circinatum	vine maple	9,0	yes, but in limited quantities	shrub to small tree	fibrous, rooting at nodes	fair to good	slow	slow	good	plants	Branches often touch& root at ground level. Often occurs with conifer overstory. Occurs British Columbia to CA.
Acer glabrum	dwarf maple	4,5,7, 8,9,0, A	yes	small tree		poor				plants	usually dioecious, grows in poor soils.
Acer negundo	boxelder	1,2,3, 4,5,6, 7,8,9, 0	yes	small to medium tree	fibrous, moderately deep, spreading, suckering	poor	fast	fast	fair	plants, rooted cuttings	Use in sun & part shade. Survived deep flooding for one season in Pacific NW.
Acer rubrum	red maple	1,2,3, 6	yes	medium tree	shallow	poor	fast when young	medium	good	plants	Not tolerant of high pH sites. Occurs on and prefers sites with a high water table and/or an annual flooding event.
Acer saccharinum	silver maple	1,2,3, 4,5,6, 8	yes	medium tree	shallow, fibrous	poor	fast when young	medium	fair	plants	Plants occur mostly east of the 95th parallel. Survived 2 years of flooding in MS.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Alnus pacifica	pacific alder			tree		poor	most alders are fast			plants	A species for forested wetland sites in the Pacific northwest. Plant on 10- to 12-foot spacing.
Alnus rubra	red alder	9,0,A	yes	medium tree	shallow, spreading, suckering	poor to fair	fast	fast	good	plants	Usually grows west of the Cascade Mtns, within 125 milesof the ocean & below 2,400 feet elevation. A nitrogen source. Short lived species. May be seedable. Susceptible to caterpillers.
Alnus serrulata	smooth alder	1,2,3, 5,6	yes	large shrub	shallow, spreading	poor	slow	medium	fair	plants	Thicket forming. Survived 2 years of flooding in MS. Roots have relation with nitrogen-fixing actinomycetes, susceptible to ice damage, needs full sun.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Alnus viridis ssp.sinuata	sitka alder	9,0,A	yes, but very limited quantities	shrub to small tree	shallow	poor	rapid first year, moderate thereafter	medium	fair to good	plants	A nitrogen source. Occurs AK to CA.
Amelanchier alnifolia var cusickii	cusick's serviceberry	9	yes	shrub		poor	medium	medium	medium	plants	Usually seed propagated. Occurs in eastern WA, northern ID, & eastern OR. A different variety is Pacific serviceberry A. alnifolia var semiintegrifolia. Host to several insect & disease pests.
Amelanchier utahensis	utah serviceberry	9		small to large shrub						plants	Occurs in southeast OR, south ID, NV, & UT.
Amorpha fruitcosa	false indigo	1,2,3, 4,5,6, 7,8,0	yes	shrub		poor	medium	fast	poor	plants, seed	Supposedly root suckers. Has been seeded directly on roadside cut and fill sites in MD.
Aronia arbutifolia	red chokeberry	1,2,3, 6	yes	shrub		poor	fast	fast		plants, seed	Rhizomatous. May produce fruit in second year.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Asimina triloba	pawpaw	1,2,3, 5,6	yes	small tree	tap and root suckers	poor to fair	fast		poor	root cuttings, plants	Does produce thickets where native & can be propagated by layering & root cuttings. Occurs NY to FL & TX.
Baccharis glutinosa	seepwillow	6,7,8, 0	yes	medium shrub	deep & wide-spreading, fibrous	good				plants	Thicket forming.
Baccharis halimifolia	eastern baccharis	1,2,6	yes	medium shrub	fibrous	good	fair	fast	fair	fascines, cuttings, plants,	Resistant to salt spray; unisexual plants. Occurs MA to FL & TX.
Baccharis pilularis	coyotebush	9,0		medium evergreen shrub	fibrous	good			fair	fascines, stakes, brush mats, layering, cuttings	Pioneer in gullies, many forms prostrate & spreading. May be seedable. Colony-forming to 1 foot high in CA coastal bluffs.
Baccharis salicifolia	water wally	6,7,8, 0		medium evergreen shrub	fibrous, deep, wide-spreading	good			fair	fascines, brush mats, stakes, layering, cuttings	Was B. glutinosa. Thicket forming, unisexual plants.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Baccharis viminea	mulefat baccharis	6,7,8, 0		medium ever-green shrub	fibrous	good				fascines, stakes, brush mats, layering, cuttings	May be B. salicifolia.
Betula nigra	river birch	1,2,3, 5,6	yes	medium to large tree		poor	fast when young	fast	poor	plants	Plants coppice when cut. Survived 1 year of flooding in MS. Hybridizes with B papyrifera.
Betula occidentalis	water birch	4,5,7, 8,9,0, A	yes	medium tree	fibrous, spreading					plants	Occurs on the Pacific Coast to CO.
Betula papyrifera	paper birch	1,3,4, 5,9,A	yes	medium tree	shallow, fibrous	poor	fast when young	fast	poor	plants	Not tolerant of more than a few days inundation in a New England trial. Short lived but the most resistant to borers of all birches.
Betula pumila	low birch	1,3,4, 8,9		small to large shrub	fibrous	poor				plants	Occurs Newfound-land to NJ & MN.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Carpinis caroliniana	american hornbeam	1,2,3, 6	yes, limited sources	small tree		poor	slow	slow	poor	plants	Not tolerant of flooding in TN Valley trial. Occurs MD to FL & west to southern IL & east TX. A northern form occurs from New England to NC & west to MN & AR.
Carya aquatica	water hickory	1,2,3, 6	yes	tall tree	tap to shallow lateral	poor	slow	fast	poor	plants	A species for forested wetland sites.
Carya cordiformis	bitternut hickory	1,2,3, 5,6	yes	tree	tap & dense laterals	poor	slow		poor	plants	Roots & stumps coppice. Not tolerate flooding in a MO trial. Occurs Quebec to FL & LA. Transplants with difficulty.
Carya ovata	shagbark hickory	1,2,3, 4,5,6	yes	medium tree	tap	poor	slow	slow	poor	plants	Hard to transplant. Occurs Quebec to FL & TX.
Catalpa bignonioides	southern catalpa	1,2,3, 5,6,7	yes	tree		poor	fair	fair	poor	plants	Occurs in SW GA to LA; naturalized in New England, OH, MI, & TX.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Celtis laevigata	sugarberry	1,2,3, 5,6,7, 9,0	yes	medium tree	relatively shallow	poor	medium	slow	low	plants	Very resistant to witches-broom. Occurs FL, west to TX & southern IN. Also in Mexico. Leaf fall allelopathic.
Celtis occidentalis	hackberry	1,2,3, 4,5,6, 8	yes	medium tree	medium to deep fibrous	poor	medium to fast	slow	low	plants	Survived 2 years of flooding in MS. Not tolerate more than a few days inundation in a MO trial. Susceptible to witches-broom. Occurs Quebec to NC & AL.
Cephalanthus occidentalis	buttonbush	1,2,3, 5,6,7, 8,0	yes	large shrub		fair to good	slow	medium	poor	brush mats, layering, plants	Survived 3 years of flooding in MS. Will grow in sun or shade.
Cercis canadensis	redbud	1,2,3, 5,6,7, 8	yes	small tree	tap	poor	slow	slow	poor	plants	Juvenile wood & roots will root.
Chilopsis linearis	desert willow	6,7,8, 0	yes	shrub	fibrous		medium	medium	low	plants	Occurs TX to southern CA & into Mexico. 'Barranco,' 'Hope,' & 'Regal' cultivars were releasedin New Mexico.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Chionanthus virginicus	fringetree	1,2,3, 6	yes	small tree		poor	slow		poor	plants	Susceptible to severe browsing & scale. Occurs PA to FL & west to TX.
Clematis ligusticifolia	western clematis	1,2,4, 5,6,7, 8,9,0	yes	vine	shallow & fibrous	poor	fast	fast	good	plants	Produces new plants from layering in sandy soils at 7- to 8-inch precip & 1,000-foot elevation.
Clethera alnifolia	sweet pepperbush	1,2,6	yes	shrub		poor	slow			plants	Has rhizomes; salt tolerant on coastal sites. Occurs ME to FL.
Cornus amomum	silky dogwood	1,2,3, 4,5,6	yes	small shrub	shallow, fibrous	fair	fast	medium	poor	fascines, stakes, brush mats, layering, cuttings, plants	Pith brown, tolerates partial shade. 'Indigo' cultivar was released by MI PMC.
Cornus drummondii	roughleaf dogwood	1,2,3, 4,5,6	yes	large shrub	root suckering, spreading	fair			fair	fascines, stakes, layering, brush mats, cuttings, plants	Root suckers too. Pith usually brown. Occurs Saskatchewan to KS & NE, south to MS, LA, & TX.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Cornus florida	flowering dogwood	1,2,3, 5,6	yes	small tree	shallow, fibrous	poor	fair	fair	poor	plants	Hard to transplant as bare root; coppices freely. Not tolerant of flooding in TN Valley trial.
Cornus foemina	stiff dogwood	1,2,3, 4,5,6		medium shrub		fair	fast			fascines, plants	Formerly C. racemosa Occurs VA to FL & west to TX. Pith white.
Cornus racemosa	gray dogwood	1,2,3, 4,5,6	yes	medium to small shrub	shallow, fibrous	fair	medium		fair	fascines, stakes, brush mats, layering, cuttings, plants	Forms dense thickets. Pith usually brown, tolerates city smoke. Occurs ME & MN to NC & OK.
Cornus rugosa	roundleaf dogwood	1,3		medium to small shrub	shallow, fibrous	fair to good				fascines, cuttings, plants	Pith white. Use in combination with species with root_abil = good to excellent. Occurs Nova Scotia to VA & ND.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Cornus sericea ssp sericea	red-osier dogwood	1,3,4, 5,7,8, 9,0,A	yes	medium shrub	shallow	good	fast	medium	fair	fascines, stakes, brush mats, layering, cuttings, plants	Forms thickets by rootstocks & rooting of branches. Survived 6 years of flooding in MS. Pith white, tolerates partial shade. Formerly C. stolonifera. 'Ruby' cultivar was released by NY PMC.
Cornus stricta	swamp dogwood			shrub		poor				plants	May be same as C. foemina.
Crataegus douglasii	douglas hawthorn	3,8,9, 0,A	yes	small tree	tap to fibrous	poor to fair	slow		poor	cuttings, plants	Forms dense thickets on moist sites. Grown from seed or grafted. Occurs British Columbia to CA & MN.
Crataegus mollis	downy hawthorn	1,2,3, 4,5,6	yes	tree	tap	poor to fair				plants	Occurs Ontario & MN to AL, AR & MS. 'Homestead' cultivar was released by ND PMC.
Cyrilla racemiflora	titi	1,2,6, C		small tree		poor				plants	Semievergreen, a good honey plant. Occurs VA to FL & on to South America. Prefers organic sites.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Diospyros virginiana	persimmon	1,2,3, 5,6	yes	medium tree	tap	poor	slow	fair	poor	plants	Forms dense thickets on dry sites. Stoloniferous & tap rooted. Occurs CT toFL & TX.
Elaeagnus commutata	silverberry	1,3,4, 8,9,A	yes	small tree	shallow, fibrous	poor to fair	fast	fast	fair	plants	Grows well in limestone & alkaline soils.
Forestiera acuminata	swamp privet	1,2,3, 6	yes	large shrub to small tree		fair	slow		poor	plants	Thicket forming. Survived 3 years of flooding in MS.
Fraxinus caroliniana	carolina ash	1,2,6		large tree	fibrous	poor	fast	fast		plants	Easily transplanted. Occurs in swamps VA to TX.
Fraxinus latifolia	oregon ash	9,0	yes	medium tree	moderately shallow, fibrous	poor	fast when young	medium	fair	plants	May be grown from seed but usually grafted. Usually occurs west of the Cascade Mtns.
Fraxinus pennsylvanica	green ash	1,2,3, 4,5,6, 8,9	yes	medium tree	shallow, fibrous	poor	fast	fast	good	plants	Survived 3 years of flooding in MS. 'Cardan' cultivar was released by ND PMC.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Gleditsia triacanthos	honeylocust	1,2,3, 4,5,6, 7,8,9	yes	medium tree	deep & wide-spread	poor to fair	fast	fast	medium	plants	Survived deep flooding for 100 days 3 consecutive years. Has been used in reg_occ 7,8,9. Native ecotypes have thorns!
Hibiscus aculeatus	hibiscus	2,6	yes	shrub		poor				plants	
Hibiscus laevis	halberd-leaf marshmallow		yes	shrub		poor				plants	Was H. militaris.
Hibiscus moscheutos	common rose mallow	1,2,3, 5,6,7, 0	yes	shrub		poor				plants	
Hibiscus moscheutos ssp.lasiocarpos	hibiscus		yes	shrub		poor				plants	
Holodiscus discolor	oceanspray	9,0	yes, from contract growers.	shrub		poor to fair	medium to rapid	fast	poor	plants	Often pioneers on burned areas. Occurs from British Columbia to CA to ID. Usually grown from seed or cuttings.
Ilex coriacea	sweet gallberry	1,2,6, C	yes	small to large shrub		poor				plants	Evergreen.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Ilex decidua	possomhaw	1,2,3, 5,6	yes	large shrub to small tree		poor	slow			plants	Survived 3 years of flooding in MS.
Ilex glabra	bitter gallberrry	1,2,6	yes	small shrub		poor	slow			plants	Evergreen, sprouts after fire. Stoloniferous! Occurs eastern US & Canada.
Ilex opaca	american holly	1,2,3, 6	yes	small tree	tap root & prolific laterals	poor	slow	medium	poor	plants	Easy to transplant when young.
Ilex verticillata	winterberry	1,2,3, 6	yes	small to large shrub		poor	slow			plants	Prefers seasonally flooded sites. Plants dioecious.
Ilex vomitoria	yaupon	1,2,6	yes	large shrub		poor				plants	Root suckers.
Juglans nigra	black walnut	1,2,3, 4,5,6	yes	medium tree	tap & deep & wide-spread laterals	poor	fair	fair	poor	plants	Though drought tolerant, will not grow on poor or dry soil sites. Not tolerate flooding in TN Valley trial.
Juniperus virginiana	eastern redcedar	1,2,3, 4,5,6	yes	large tree	tap & dense fibrous laterals	poor	slow	medium	good	plants	Not tolerate flooding in TN Valley trial.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Leucothoe axillaris	leucothoe	1,2	yes	small to large shrub		poor	slow			plants	Evergreen.
Lindera benzoin	spicebush	1,2,3, 5,6	yes	shrub		poor	slow			plants	Prefers acid soils. Dioecious.
Liquidambar styraciflua	sweetgum	1,2,3, 6	yes	large tree	tap to fibrous	poor	slow		fair	plants	A species for forested wetland sites.
Liriodendron tulipifera	tulip poplar	1,2,3, 5,6	yes	large tree	deep & wide-spreading	poor	fast	fast		plants	Hard to transplant.
Lonicera involucrata	black twinberry	3,7,8, 9,0,A	yes	small to large shrub	fibrous & shallow	good	fast	fast	poor to fair	fascines, stakes, cuttings, plants	
Lyonia lucida	fetterbush	1,2		small to large shrub		poor				plants	Evergreen.
Magnolia virginiana	sweetbay	1,2,6	yes	small tree		poor	slow			plants	Occurs in swamps from MA to FL and west to east TX.
Myrica cerifera	southern waxmyrtle	1,2,6, c	yes	small shrub	fibrous	poor	medium	slow	slow	plants	Evergreen. Occurs east TX & OK, east to FL & north to NJ.
Nyssa aquatica	swamp tupelo	1,2,3, 6	yes	large tree	shallow, fibrous	poor		slow		plants	Trees from the wild do not transplant well.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Nyssa ogeeche	ogeeche lime	2		large shrub to small tree	sparse, fibrous	poor	slow	medium	poor	plants	Largest fruit of all Nyssa. Vegetative reproduction not noted. Only grows close to perennial wetland sites.
Nyssa sylvatica	blackgum	1,2,3, 6	yes	tall tree	sparse, fibrous, very long, decending	poor	medium	slow	fair	plants	A species for forested wetland sites. Difficult to transplant but plant in sun or shade on 10- to 12-foot spacing.
Ostrya virginiana	hophorn-beam	1,2,3, 4,5,6	yes	small tree		poor	slow	slow		plants	Difficult to transplant. Tolerated flooding for up to 30 days during 1 growing season.
Persea borbonia	redbay	1,2,6	yes	small to large evergreen tree		poor	slow	slow		plants	
Philadelphus lewesii	lewis mockorange	9,0	yes	large shrub	fibrous	poor	fast	medium to fast	medium	plants	Usually grown from seed.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Physocarpus capitatus	pacific ninebark	8,9,0, A	yes	large shrub	fibrous	good				fascines, brush mats, layering, cuttings, plants	Usually occurs west of the Cascade Mtns.
Physocarpus malvaceus	mallow ninebark	8,9	yes	small shrub	shallow but with rhizomes	fair				cuttings, plants	Propagated by seed or cuttings. Usually occurs east of the Cascade Mtns.
Physocarpus opulifolius	common ninebark	1,2,3, 4,5,6, 8,9	yes	medium shrub	shallow, lateral	fair	slow	slow	poor	fascines, brush mats, layering, cuttings, plants	Use in combination with other species with rooting ability good to excellent.
Pinus taeda	loblolly pine	1,2,3, 6	yes	medium tree	short tap changes to shallow spreading laterals	poor	fast	fast	poor	plants	
Planera aquatica	water elm	1,2,3, 5,6		small tree		poor	fairly fast			plants	Occurs KY to FL, west to IL & TX.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Platanus occidentalis	sycamore	1,2,3, 5,6	yes	large tree	fibrous, wide-spreading	poor	fast	fast	medium	plants	A species for forested wetland sites. Tolerates city smoke & alkali sites. Plant on 10- to12-foot spacing. Trans-plants well.
Platanus racemosa	California sycamore	0		tall tree						plants	A species for forested wetlands sites in CA.
Populus angustifolia	narrowleaf cottonwood	4,5,6, 7,8,9, 0		large tree	shallow	v good				fascines, stakes, poles, brush mats, layering, cuttings, plants	Under development in ID for riparian sites.
Populus balsamifera	balsam poplar	1,2,3, 4,5,8, 9,O,A	yes	tall tree	deep, fibrous	v good	fast	fast		fascines, stakes, poles, brush mats, layering, cuttings, plants	

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Populus deltoides	eastern cottonwood	1,2,3, 4,5,6, 7,8,9	yes	tall tree	shallow, fibrous, suckering	v good	fast	fast	poor	fascines, stakes, poles, brush mats, layering, cuttings, root suckers, plants	Short lived. Endures heat & sunny sites. Survived over 1 year of flooding in MS. Hybridizes with several other poplars. Plant roots may be invasive. May be sensitive to aluminum in the soil.
Populus fremontii	fremont cottonwood	6,7,8, 0		tree	shallow, fibrous	v good	fast			fascines, stakes, poles, brush mats, layering, cuttings, plants	Tolerates saline soils. Dirty tree.
Populus tremuloides	quaking aspen	1,2,3, 4,5,7, 8,9,0, A	yes	medium tree	shallow, profuse suckers, vigorous under-ground runners	poor to fair	fast	fast	fair	layering, root cuttings, plants	Short lived. A pioneer species on sunny sites. Normal propagation is by root cuttings. Not tolerant of more than a few days inundation in a New England trial. Use rooted plant materials.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Populus trichocarpa	black cottonwood	4,7,8, 9,0,A	yes	large tree	deep & wide-spread, fibrous	v good	fast	fast	good	fascines, stakes, poles, brush mats, layering, cuttings, plants	A species for forested wetland sites. Was P. trichophora. Usually grown from cuttings. Under development in ID for riparian sites. Plant on 10- to 12-foot spacing. May be P. balsimifera
Prunus angustifolia	wild plum	1,2,3, 5,6	yes	small shrub	fibrous, spreading, suckering	poor	medium	fast	good	plants, root cuttings	Thicket forming. 'Rainbow' cultivar released by Knox City, TX, PMC.
Prunus virginiana	common chokecherry	1,2,3, 4,5,6, 7,8,9, 0,A	yes	large shrub	shallow, suckering	poor	medium	medium	fair	plants	A species for forested wetland sites. Has hydrocyanic acid in most parts, especially the seeds. Usually grown from seed. Thicket forming. Plant on 5- to 8-foot spacing. Reportedly poisonous to cattle.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Quercus alba	white oak	1,2,3, 5,6	yes	large tree	tap to deep, well-developed fibrous	poor	slow	slow	slow	plants	Did not survive more than a few days flooding in a trial in New England. Difficult to transplant larger specimens.
Quercus bicolor	swamp white oak	1,2,3, 5,6	yes	medium tree	somewhat shallow	poor	fast	medium	fair	plants	Survived 2 years of flooding in MS.
Quercus garryana	oregon white oak	9,0	yes	shrub to large tree	deep tap & well-developed laterals	poor	slow	slow	fair	plants	Usually grows west of the Cascade Mtns, in the Columbia River Gorge to the Dalles & to Yakima, WA. Propagated from seed sown in fall.
Quercus laurifolia	swamp laurel oak	1,2,6		tree	tap	poor	fast	fast		plants	Often used as a street tree in the southeast US.
Quercus lyrata	overcup oak	1,2,3, 6	yes	medium tree	tap deteriorates to dense shallow laterals	poor	slow	slow	slow	plants	Often worthless as a lumber species.
Quercus macrocarpa	bur oak	1,2,3, 4,5,6, 9	yes	large tree	deep tap & well-developed laterals	poor	medium	fast	poor	plants	Survived 2 years of flooding in MS. 'Boomer' cultivar released by TX PMC.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Quercus michauxii	swamp chestnut oak	1,2,3, 6		medium tree	tap & deep laterals	poor	fair	fair	poor	plants	
Quercus nigra	water oak	1,2,3, 6		medium tree	shallow & spreading	poor	fast on good sites	slow	poor	plants	Easily transplanted.
Quercus pagoda	cherrybark oak			tree		poor				plants	
Quercus palustris	pin oak	1,2,3, 5,6	yes	large tree	well-developed fibrous laterals after taproot disinte-grates	poor	fast	fast	fair	plants	A species for forested wetland sites. Survived 2 years of flooding in MS. Plant on 10- to 12-foot spacing.
Quercus phellos	willow oak	1,2,3, 6	yes	medium to large tree	shallow, fibrous	poor	fast	medium	fair	plants	Easily transplanted.
Quercus shumardii	shumard oak	1,2,3, 5,6	yes	large tree	shallow	poor	medium	slow	low	plants	
Rhododendron atlanticum	coast azalea	1,2		small shrub		poor	fast		good by stolons	plants	Mat forming from suckers & stolons. Occurs from DE to SC.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Rhododendron viscosum	swamp azalea	1,2		shrub		poor	slow			plants	Has stoloniferous forms. Occurs from ME to SC. Highly susceptible to insects & diseases.
Rhus copallina	flameleaf sumac	1,2,3, 4,5,6	yes	medium shrub	fibrous, suckering	poor to fair	fast	fast	fair	root cuttings, root suckers, plants	Thicket forming.
Rhus glabra	smooth sumac	1,2,3, 4,5,6, 7,8,9	yes	large shrub	fibrous, suckering	poor to fair	fast	fast	fair to good	root cuttings, root suckers, plants	Thicket forming.
Robinia pseudoacacia	black locust	1,2,3, 4,5,6, 7,8,9, 0	yes	medium tree	shallow	poor	medium to fast	fast	good	root cuttings, plants	Normal propagation is by root cuttings or seed. Not tolerant of flooding in TN Valley trial. Escaped in regions 5,7,8,9,0. Reported toxic to livestock.
Rosa gymnocarpa	baldhip rose	9,0		shrub		fair to good				cuttings, plants	A browsed species.
Rosa nutkana	nootka rose	7,8,9, 0,A		shrub		fair to good				cuttings, plants	A browsed species.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Rosa palustris	swamp rose	1,2,3, 5		small shrub	shallow	good				fascines, plants	
Rosa virginiana	virginia rose	1,2,3	yes	small shrub	rhizomatous & fibrous	good	fair	fast	fair	plants	
Rosa woodsii	woods rose	3,4,5, 6,7,8, 9,0,A		shrub		fair to good				cuttings, plants	A browsed species.
Rubus allegheniensis	allegheny blackberry	1,2,3, 5,6,0		small shrub	fibrous	good				plants	Normal propagation is by root cuttings.
Rubus idaeus ssp. strigosus	red raspberry	1,2,3, 4,5,6, 7,8,9, A		small shrub	fibrous	good				plants	Was R. strigosus. Normal propagation is by root cuttings.
Rubus spectabilis	salmonberry	9,0,A		small shrub	fibrous	good				plants	Normal propagation is by root cuttings. Use in combination with other species. Rooting ability is good to excellent.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Salix X cottetii	dwarf willow	not native	yes	small shrub	shallow	v good	medium	fast	poor	fascines, stakes, brush mats, layering, cuttings, plants	Not a native species. Plant plants on 2' to 6' spacing. 'Bankers' cultivar released by Kentucky PMC.
Salix amygdaloides	peachleaf willow	1,2,3, 4,5,6, 7,8,9	yes	large shrub to small tree	shallow to deep	v good	fast	fast		fascines, stakes, poles, brush mats, layering, cuttings, plants	Often roots only at callus cut. May be short-lived. Under development in ID for riparian sites. Not tolerant of shade. Hybridized with several other willow species.
Salix bebbiana	bebb's willow	1,3,4, 5,7,8, 9,A		small shrub to large tree	fibrous					cuttings, plants	Does not form suckers. Usually east of the Cascade Mtns & in ID & MT.
Salix bonplandiana	pussy willow	7	yes	medium shrub to large tree	fibrous	v good				fascines, stakes, poles, brush mats, layering, cuttings, plants	Eaten by livestock when young.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Salix boothii	booth willow	8,9		shrub							Under development in Idaho for riparian sites.
Salix discolor	pussy willow	1,2,3, 4,9	yes	large shrub	shallow, fibrous, spreading	v good	rapid			fascines, stakes, poles, layering, cuttings, plants	Use on sunny to partial shade sites.
Salix drummondiana	drummond's willow	7,8,9, 0	yes	shrub		good				fascines, cuttings, plants	Usually east of the Cascade Mtns. Under development in ID for riparian sites. 'Curlew' cultivar released by WA PMC.
Salix eriocephala	erect willow	7,8,9, 0	yes	large shrub	fibrous	v good		fast		fascines, stakes, poles, layering, cuttings, plants	A botanic discrepancy in the name, it may be S. ligulifolia! 'Placer' cultivar released by OR PMC.
Salix exigua	coyote willow	1,2,3, 4,5,6, 7,8,9, 0,A	yes	medium shrub	shallow, suckering, rhizomatous	good	fast			fascines, stakes, poles, brush mats, layering, cuttings, plants	Relished by livestock. Under development in ID for riparian sites. 'Silvar' cultivar released by WA PMC.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Salix geyeriana	geyer's willow	7,8,9, 0		small to large shrub						cuttings, plants	Occurs east of the Cascade Mtns at higher elevations. Relished by livestock. Under development in ID for riparian sites.
Salix gooddingii	goodding willow	6,7,8, 0		small shrub to large tree	shallow to deep	good to excel	fast	fast		fascines, stakes, poles, brush mats, layering, cuttings, plants	Not tolerate alkaline sites. Some say this is western black willow.
Salix hookeriana	hooker willow	9,0	yes	large shrub to small tree	fibrous, dense	v good	rapid when young, medium thereafter	medium		fascines, stakes, poles, brush mats, layering, cuttings, plants	May have salt tolerance. Can compete well with grasses. 'Clatsop' cultivar was released by OR PMC.
Salix humilis	prairie willow	1,2,3, 4,5,6		medium shrub	fibrous, spreading	good		medium		fascines, stakes, poles, brush mats, layering, cuttings, plants	Thicket forming.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Salix interior	sandbar willow	1,3,4, 5,7,8, 9,A	yes	large shrub	shallow to deep	exce	medium	medium	fair	fascines, stakes, poles, brush mats, layering, cuttings, plants	Thicket forming. This species has been changed to S. exigua. Use in combination with species with rooting ability good to excellent.
Salix lasiolepis	arroyo willow	6,7,8, 9,0	yes	tall shrub to small tree	fibrous	v good	rapid when young, medium there-after	medium		fascines, stakes, poles, brush mats, layering, cuttings, plants	Roots only on lower 1/3 of cutting or at callus. 'Rogue' cultivar released by OR PMC.
Salix lemmonii	lemmon's willow	8,9,0	yes	medium shrub	fibrous	v good		fast		fascines, stakes, poles, brush mats, layering, cuttings, plants	Occurs at high elevations, east of the Cascade Mtns. Under development in ID for riparian sites. 'Palouse' cultivar released by WA PMC.
Salix lucida	shining willow	1,3,4, 5,7,8, 9,0		medium to tall shrub	fibrous, spreading	v good	rapid			fascines, stakes, poles, brush mats, layering, cuttings, plants	

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Salix lucida ssp. lasiandra	pacific willow	4,7,8, 9,0,A	yes	large shrub to small tree	fibrous	v good	medium to slow	medium to slow		fascines, stakes, poles, brush mats, layering, cuttings, plants	A species for forested wetlands sites. There are several subspecies of S. lucida. Under development in ID for riparian sites. Susceptible to several diseases and insects. Plant on 10- to 12-foot spacing. 'Nehalem' cultivar released by OR PMC.
Salix lutea	yellow willow	1,4,5, 7,8,9, 0		medium to tall shrub	fibrous	v good				fascines, stakes, poles, brush mats, layering, cuttings, plants	Usually browsed by livestock. Under development in ID for riparian sites.
Salix nigra	black willow	1,2,3, 5,6,7, 8	yes	small to large tree	dense, shallow, sprouts readily	good to excel	fast	fast	good	fascines, stakes, poles, brush mats, layering, cuttings, root cuttings, plants	May be short lived. Survived 3 years of flooding in MS. Needs full sun. Susceptible to several diseases & insects.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Salix pentandra	laural willow	not native	yes	large shrub to small tree	fibrous, spreading	good	fast	medium	poor	fascines, stakes, poles, brush mats, layering, cuttings, plants	From Europe, sparingly escaped in the East. Insects may defoliate it regularly.
Salix purpurea	purpleosier willow	1,2,3, 5	yes	medium tree	shallow	excel	fast	fast	poor	fascines, stakes, poles, brush mats, layering, cuttings, plants	Tolerates partial shade. 'Streamco' cultivar released by NY PMC.
Salix scouleriana	scouler's willow	4,7,8, 9,0,A		large shrub to small tree	shallow	v good	fast			fascines, stakes, poles, brush mats, layering, cuttings, plants	Pioneers on burned sites. Occurs on both sides of the Cascade Mtns in low to high elevations. Often roots only at callus.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Salix sitchensis	sitka willow	9,0,A	yes	very large shrub		v good	rapid when young, medium thereafter	medium		fascines, stakes, poles, brush mats, layering, cuttings, plants	Occurs on both sides of the Cascade Mtns. Vigorous shoots branch freely; lends itself to bioengineering uses; excellent survival in trials. 'Plumas' cultivar released by OR PMC.
Sambucus canadensis	american elder	1,2,3, 4,5,6, 8,9	yes	medium shrub	fibrous & stoloniferous	good	fast	fast	poor	fascines, cuttings, plants	Softwood cuttings root root easily in spring or summer. Pith white.
Sambucus cerulea	blue elderberry	6,7,8, 9,0	yes	large shrub	fibrous	poor	v fast	v fast	poor	plants	
Sambucus cerulea ssp. mexicana	mexican elder	6,7,8, 0,H		large shrub		good				fascines, plants	Was S. mexicana. Evergreen. Softwood cuttings root easily in spring or summer.
Sambucus racemosa	red elderberry	1,2,3, 4,7,8, 9,0,A	yes	medium shrub		good	medium	slow		fascines, brush mats, layering, cuttings, plants	Softwood cuttings root easily in spring or summer. Pith brown. This may be S. callicarpa.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Sambucus racemosa ssp. pubens	red elder	1,2,3, 4,9,A		medium shrub	deep laterals	fair to good				fascines, plants	Occurs west of the Cascade Mtns, usually within 10 miles of the ocean & on the coastal bays & estuaries. Softwood cuttings root easily in spring or summer. Pith brown. Use in combination with species with rooting ability good to excellent.
Spiraea alba	meadow-sweet spirea	1,2,3, 4	yes	short dense tree	dense shallow, lateral	fair to good		medium		plants	Propagation by leafy softwood cuttings in mid-summer under mist.
Spiraea betulifolia	shinyleaf spirea	1,2,4, 9		shrub						plants	Usually grown from seed. Occurs east of the Cascade Mtns at medium to high elevations.
Spiraea douglasii	douglas spirea	2,3,9, 0	yes	small dense shrub	fibrous, suckering	good	rapid	fast	excellent	fascines, brush mats, layering, cuttings, division of suckers, plants	Resists fire & prolific sprouter (forms thickets). Propagation by leafy softwood cuttings in midsummer under mist. 'Bashaw' cultivar released by WA PMC.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occurrence	Commercial availability	Plant type	Root type	Rooting ability from cutting	Growth rate	Establishment speed	Spread potential	Plant materials type	Notes
Spiraea tomentosa	hardhack spirea	1,2,3, 5		small shrub	dense, shallow	poor to fair				plants	Propagation by leafy softwood cuttings in mid-summer under mist. A weed in New England pastures. Use rooted materials.
Styrax japonica	Japanese snowbell	1,2,3, 5,6	yes	large shrub		poor				plants	
Symphoricarpos albus	snowberry	1,3,4, 5,7,8, 9,0,A	yes	small shrub, dense colony forming	shallow, fibrous, freely suckering	good	rapid	slow	fair	fascines, brush mats, layering, cuttings, plants	Plant in sun to part shade, especially on wet sites.
Taxodium distichum	baldcypress	1,2,3, 5,6	yes	medium tree	tap with laterals for knees for aeration	poor	medium	fast	poor	plants	Plant on 10- to 12-foot spacing. Tolerates upland sites in region 6 with 32" rainfall.
Tsuga canadensis	eastern hemlock	1,2,3	yes	large tree	shallow fibrous	poor	slow	slow	low	plants	

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

Scientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Ulmus americana	american elm	1,2,3, 4,5,6, 8	yes	large tree	tap on dry sites to shallow fibrous on moist sites	poor	medium	medium	poor	plants	A species for forested wetland sites. Survived near 2 years of flooding in MS. Plant on 10- to 12-foot spacing; tolerates full shade.
Viburnum dentatum	arrowwood	1,2,3, 6	yes	medium to tall shrub	shallow, fibrous	good	fast	slow		layering, cuttings, plants	Thicket forming; tolerates city smoke. Use rooted plant materials.
Viburnum lantanoides	hubblebush viburnam	1,2,3		medium shrub	shallow, fibrous	good				fascines, stakes, brush mats, layering, cuttings, plants	Was V. alnifolium. Thicket forming. Branch tips root at soil.
Viburnum lentago	nannyberry	1,2,3, 4,5,9	yes	large shrub	shallow	fair to good	fast	fast		fascines, cuttings, stakes, plants	Thicket forming; tolerates city smoke. Tolerates full shade. Older branches often root when they touch soil. Use in combination with species with rooting ability good to excellent.

Table 16B–1 Woody plants for soil bioengineering and associated systems—Continued

cientific name	Common name	Region occur-ence	Commer-cial avail-ability	Plant type	Root type	Rooting ability from cutting	Growth rate	Estab-lishment speed	Spread potential	Plant materials type	Notes
Viburnum nudum	swamp haw	1,2,6		large shrub		poor				plants	D. Wymann says it is more adapted to the South than V. cassinoides.
Viburnum trilobum	american cranberry-bush	1,3,4, 5,9	yes	medium shrub		poor	medium	slow		layering, plants	Use rooted plant materials. Fruits are edible.

Table 16B–2 Woody plants with fair to good or better rooting ability from unrooted cuttings

Scientific name	Common name	Scientific name	Common mame
Acer circinatum	vine maple	*Salix bonplandiana*	pussy willow
Baccharis glutinosa	seepwillow	*Salix discolor*	pussy willow
Baccharis halimifolia	eastern baccharis	*Salix drummondiana*	drummond's willow
Baccharis pilularis	coyotebush	*Salix eriocephala*	erect willow
Baccharis salicifolia	water wally	*Salix exigua*	coyote willow
Baccharis viminea	mulefat baccharis	*Salix gooddingii*	goodding willow
Cephalanthus occidentalis	buttonbush	*Salix hookeriana*	hooker willow
Cornus amomum	silky dogwood	*Salix humilis*	prairie willow
Cornus drummondii	roughleaf dogwood	*Salix interior*	sandbar willow
Cornus foemina	stiff dogwood	*Salix lasiolepis*	arroyo willow
Cornus racemosa	gray dogwood	*Salix lemmonii*	lemmon's willow
Cornus rugosa	roundleaf dogwood	*Salix lucida*	shining willow
Cornus sericea ssp sericea	red-osier dogwood	*Salix lucida ssp. lasiandra*	pacific willow
Lonicera involucrata	black twinberry	*Salix lutea*	yellow willow
Physocarpus capitatus	pacific ninebark	*Salix nigra*	black willow
Physocarpus opulifolius	common ninebark	*Salix pentandra*	laural willow
Populus angustifolia	narrowleaf cottonwood	*Salix purpurea*	purpleosier willow
Populus balsamifera	balsam poplar	*Salix scouleriana*	scouler's willow
Populus deltoides	eastern cottonwood	*Salix sitchensis*	sitka willow
Populus fremontii	fremont cottonwood	*Sambucus canadensis*	american elder
Populus trichocarpa	black cottonwood	*Sambucus cerulea ssp. mexicana*	mexican elder
Rosa gymnocarpa	baldhip rose	*Sambucus racemosa*	red elderberry
Rosa nutkana	nootka rose	*Sambucus racemosa ssp. pubens*	red elder
Rosa palustris	swamp rose	*Spiraea alba*	meadowsweet spirea
Rosa virginiana	virginia rose	*Spiraea douglasii*	douglas spirea
Rosa woodsii	woods rose	*Symphoricarpos albus*	snowberry
Rubus allegheniensis	allegheny blackberry	*Viburnum dentatum*	arrowwood
Rubus idaeus ssp.strigosus	red raspberry	*Viburnum lantanoides*	hubblebush viburnam
Rubus spectabilis	salmonberry	*Viburnum lentago*	nannyberry
Salix X cottetii	dwarf willow		
Salix amygdaloides	peachleaf willow		

Table 16B–3 Woody plants with poor or fair rooting ability from unrooted cuttings

Scientific name	Common name	Scientific name	Common mame
Acer glabrum	dwarf maple	*Fraxinus pennsylvanica*	green ash
Acer negundo	boxelder	*Gleditsia triacanthos*	honeylocust
Acer rubrum	red maple	*Hibiscus aculeatus*	hibiscus
Acer saccharinum	silver maple	*Hibiscus laevis*	halberd-leaf marshmallow
Alnus pacifica	pacific alder	*Hibiscus moscheutos*	common rose mallow
Alnus rubra	red alder	*Hibiscus moscheutos ssp. lasiocarpos*	hibiscus
Alnus serrulata	smooth alder	*Holodiscus discolor*	oceanspray
Alnus viridis ssp.sinuata	sitka alder	*Ilex coriacea*	sweet gallberry
Amelanchier alnifolia var cusickii	cusick's serviceberry	*Ilex decidua*	possomhaw
Amorpha fruitcosa	false indigo	*Ilex glabra*	bitter gallberrry
Aronia arbutifolia	red chokeberry	*Ilex opaca*	american holly
Asimina triloba	pawpaw	*Ilex verticillata*	winterberry
Betula nigra	river birch	*Ilex vomitoria*	yaupon
Betula papyrifera	paper birch	*Juglans nigra*	black walnut
Betula pumila	low birch	*Juniperus virginiana*	eastern redcedar
Carpinis caroliniana	american hornbeam	*Leucothoe axillaris*	leucothoe
Carya aquatica	water hickory	*Lindera benzoin*	spicebush
Carya cordiformis	bitternut hickory	*Liquidambar styraciflua*	sweetgum
Carya ovata	shagbark hickory	*Liriodendron tulipifera*	tulip poplar
Catalpa bignonioides	southern catalpa	*Lyonia lucida*	fetterbush
Celtis laevigata	sugarberry	*Magnolia virginiana*	sweetbay
Celtis occidentalis	hackberry	*Myrica cerifera*	southern waxmyrtle
Cercis canadensis	redbud	*Nyssa aquatica*	swamp tupelo
Chionanthus virginicus	fringetree	*Nyssa ogeeche*	ogeeche lime
Clematis ligusticifolia	western clematis	*Nyssa sylvatica*	blackgum
Clethera alnifolia	sweet pepperbush	*Ostrya virginiana*	hophornbeam
Cornus florida	flowering dogwood	*Persea borbonia*	redbay
Cornus stricta	swamp dogwood	*Philadelphus lewesii*	lewis mockorange
Crataegus douglasii	douglas' hawthorn	*Physocarpus malvaceus*	mallow ninebark
Crataegus mollis	downy hawthorn	*Physocarpus opulifolius*	common ninebark
Cyrilla racemiflora	titi	*Pinus taeda*	loblolly pine
Diospyros virginiana	persimmon	*Planera aquatica*	water elm
Dlaeagnus commutata	silverberry	*Platanus occidentalis*	sycamore
Forestiera acuminata	swamp privet	*Populus tremuloides*	quaking aspen
Fraxinus caroliniana	carolina ash	*Prunus angustifolia*	wild plum
Fraxinus latifolia	oregon ash		

Table 16B–3 Woody plants with poor or fair rooting ability from unrooted cuttings—Continued

Scientific name	Common name	Scientific name	Common mame
Prunus virginiana	common chokecherry	*Rhododendron atlanticum*	coast azalea
Quercus alba	white oak	*Rhododendron viscosum*	swamp azalea
Quercus bicolor	swamp white oak	*Rhus copallina*	flameleaf sumac
Quercus garryana	oregon white oak	*Rhus glabra*	smooth sumac
Quercus laurifolia	swamp laurel oak	*Robinia pseuodoacacia*	black locust
Quercus lyrata	overcup oak	*Sambucus cerulea*	blue elderberry
Quercus macrocarpa	bur oak	*Spiraea tomentosa*	hardhack spirea
Quercus michauxii	swamp chestnut oak	*Styrax americanus*	Japanese snowbell
Quercus nigra	water oak	*Taxodium distichum*	bald cypress
Quercus pagoda	cherrybark oak	*Tsuga canadensis*	eastern hemlock
Quercus palustris	pin oak	*Ulmus americana*	american elm
Quercus phellos	willow oak	*Viburnum nudum*	swamp haw
Quercus shumardii	shumard oak	*Viburnum trilobum*	american cranberrybush

Table 16B–4 Grasses and forbs useful in conjunction with soil bioengineering and associated systems

Scientific name	Common name	Warm season or non-competitive	Soil preference	pH preference	Drought tolerance	Shade tolerance	Deposition tolerance	Flood tolerance	Flood season	Min. h_2o	Max. h_2o	Wetland indicator 1/
Agrostis alba	redtop											
Ammophila breviligulata	American beachgrass		sands	5.5	fair	poor	good			0		1,facu- 2,upl 3,upl*
Andropogon gerardii	big bluestem	yes	loams	6.0	good	poor	poor	fair		0		1,fac 2,fac 3,fac- 4,facu 5,fac- 6,facu 7,fac- 8,facu 9facu
Arundo donax	giant reed		sandy	7.0	good	poor		poor		0	1"	1,facu- 2,facw 3,facw 6,fac+ 7,facw 8,facw 0,facw C,ni H,ni
Elymus virginicus	wildrye	yes noncompetitive	loams	6.0	fair	good	fair	good		0		1,facw-
Eragrostis trichodes	sand lovegrass	yes	sands	6.0	good	poor	poor	poor		0		
Festuca rubra	red fescue	noncompetitive	loams	6.5	good	good	poor	fair		0		1,facu

Table 16B–4 Grasses and forbs useful in conjunction with soil bioengineering and associated systems—Continued

Scientific name	Common name	Warm season or non-competitive	Soil preference	pH preference	Drought tolerance	Shade tolerance	Deposition tolerance	Flood tolerance	Flood season	Min. h_2o	Max. h_2o	Wetland indicator 1/
Hemarthria altissima	limpograss		sandy		poor	poor	poor	good		0	1'	1,facw 2,facw 6,facw
Panicum amarulum	coastal panicgrass	yes	sands to loams	5.5	good	poor	fair	good		0		1,facu- 2,fac 6,facu-
Panicum clandestinum	deertongue	yes										
Panicum virgatum	switchgrass	yes	loams to sands	6.0	good	poor	fair	good	all	0		1,fac 2,fac+ 3,fac+ 4,fac 5,fac 6,facw 7,fac+ 8,fac 9,fac+ H,ni
Paspalum vaginatum	seashore paspalum		sandy			poor		good		1/2'	1'	2,obl 6,facw* C,ni H,ni
Pennisetum purpureum	elephant-grass					poor				0	2'	2,facu+ C,ni H,ni

Table 16B–4 Grasses and forbs useful in conjunction with soil bioengineering and associated systems—Continued

Scientific name	Common name	Warm season or non-compe-titive	Soil prefer-ence	pH prefer-ence	Drought tolerance	Shade toler-ance	Deposi-tion tol-erance	Flood toler-ance	Flood season	Min. h_2o	Max. h_2o	Wetland indicator 1/
Poa pratensis	Kentucky bluegrass		loam	6.5	poor	poor	poor	fair		0		1,facu
Schizachyrium scoparium	little bluestem	yes	sands to loams	6.5	good	poor	poor	poor		0		1,facu
Sorghastrum nutans	Indiangrass	yes	sands to	6.5	fair	poor	poor	poor		0		1,upl
Spartina pectinata	prairie cordgrass	yes	sands to loams	6.0	good	fair	fair	fair		0	1"	1,obl 2,obl 3,facw+ 4,facw 5,facw 6,facw+ 7,facw 8,obl 9,obl
Zizaniopsis miliacea	giant cutgrass		loam	4.3-6.0	poor	poor		good	all	1/2'	2'	1,obl 2,obl 3,obl 6,obl

Table 16B–4 Grasses and forbs useful in conjunction with soil bioengineering and associated systems—Continued

Scientific name	Common name	Warm season or non-competitive	Soil preference	pH preference	Drought tolerance	Shade tolerance	Deposition tolerance	Flood tolerance	Flood season	Min. h_2o	Max. h_2o	Wetland indicator 1/

1/ Wetland indicator terms (from USDI Fish and Wildlife Service's National List of Plant Species That Occur in Wetlands, 1988):

Region code number or letter:
- **1** Northeast (ME, NH, VT, MA, CT, RI, WV, KY, NY, PA, NJ, MD, DE, VA, OH)
- **2** Southeast (NC, SC, GA, FL, TN, AL, MS, LA, AR)
- **3** North Central (MO, IA, MN, MI, WI, IL, IN)
- **4** North Plains (ND, SD, MT (eastern), WY (eastern))
- **5** Central Plains (NE, KS, CO (eastern))
- **6** South Plains (TX, OK)
- **7** Southwest (AZ, NM)
- **8** Intermountain (NV, UT, CO (western))
- **9** Northwest (WA, OR, ID, MT (western), WY (western))
- **0** California (Ca)
- **A** Alaska (AK)
- **C** Caribbean (PR, VI, CZ, SQ)
- **H** Hawaii (HI, AQ, GU, IQ, MQ, TQ, WQ, YQ)

Indicator categories (estimated probability):
- **fac** Facultative—Equally likely to occur in wetlands or nonwetlands (34-66%).
- **facu** Facultative upland—Usually occur in nonwetlands (67-99%), but occasionally found in wetlands (1-33%)
- **facw** Facultative wetland—Usually occur in wetlands (67-99%), but occasionally found in nonwetlands.
- **obl** Obligate wetland—Occur almost always (99%) under naturl conditions in wetlands.
- **upl** Obligate upland—Occur in wetlands in another region, but occur almost always (99%) under natural conditions in nonwetlands im¸QæB¸regioK¸QpC Ûh”DGed-¸'e¸` Qpec%Cs BMeQ nMt Mccur %n wetlands in any region, it is not on the National List.

Frequency of occurrence:
- **–** (negative sign) indicates less frequently found in wetlands.
- **+** (positive sign) indicates more frequently found in wetlands.
- ***** (asterisk) indicates wetlands indicators were derived from limited ecological information.
- **ni** (no indicator) indicates insufficient information was available to determine an indiator status.

7.0 Rooftop Disconnection

Photo courtesy of Montgomery County, Maryland

Definition: Rooftop Disconnection involves managing runoff close to its source by intercepting, infiltrating, filtering, treating or reusing it as it moves from the rooftop to the drainage system. Rooftop Disconnection practices can be used to reduce the volume of runoff that enters the combined or separate storm sewer systems.

Rooftop Disconnection reduces a portion of the Resource Protection Volume (RPv). In order to meet requirements for larger storm events, Rooftop Disconnection must be combined with additional practices.

Rooftop impervious areas may be disconnected from the drainage system and flow to other BMPs for management, including:

- Sheet flow to a filter strip or open space (see ***Specification 9.***)
- Infiltration by small infiltration practices such as dry wells or french drains (see ***Specification 1.***)
- Filtration by rain gardens or stormwater planters (see ***Specification 2.***)
- Storage and reuse with a rain barrel, cistern or other storage system (see ***Specification 5.***)

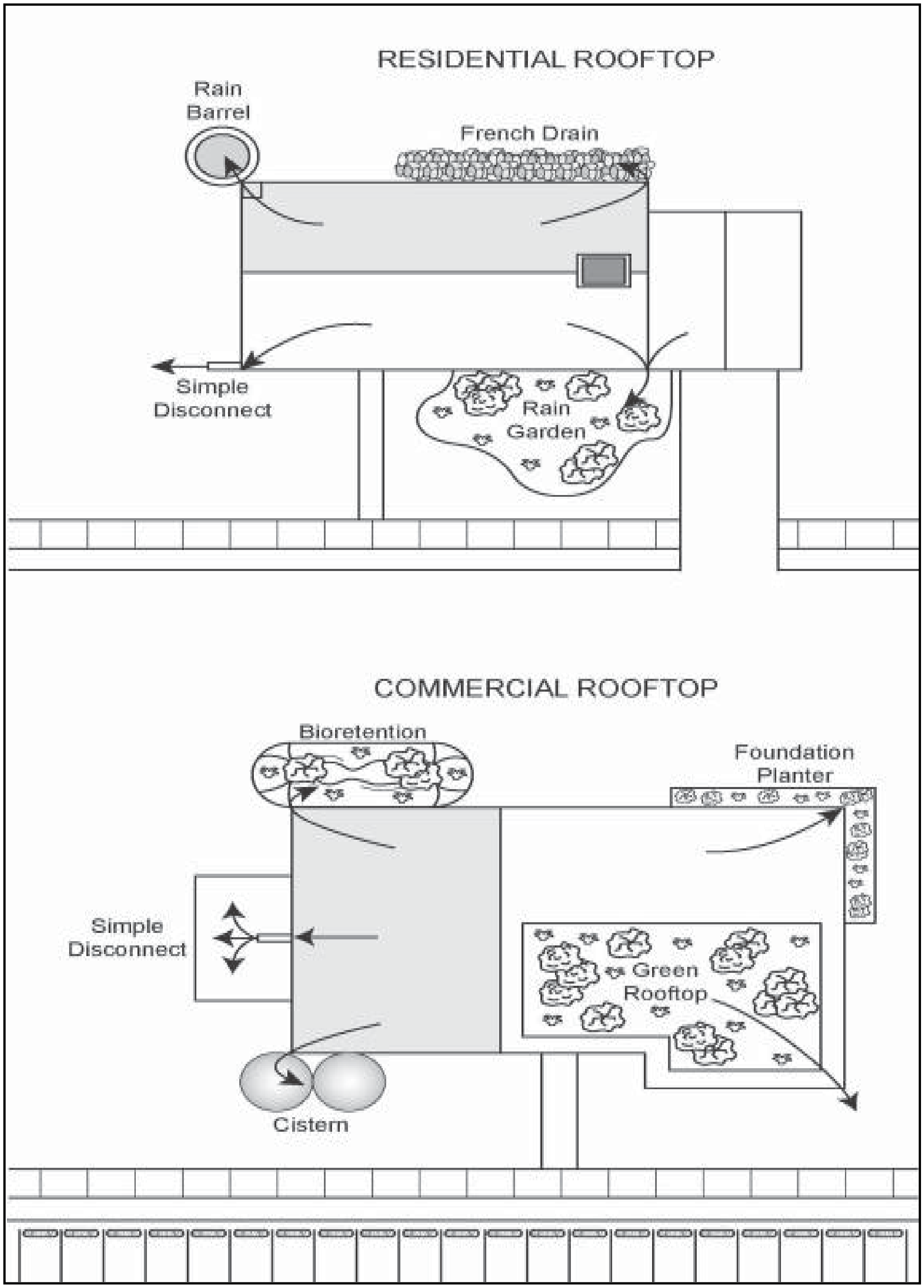


Figure 7.1. Rooftop Disconnection with Alternative Runoff Reduction Practices.

7.1 Rooftop Disconnection Stormwater Credit Calculations

Rooftop Disconnection receives a variable retention volume credit (Rv) depending upon the soil type (**Table 7.1**). Retention volume credit for Rooftop Disconnection directed toward a compost amended soil area will be determined based upon the soil type adjustment after soil amendments. Pollutant reduction credits are based upon the load reduced through retention.

Table 7.1 Rooftop Disconnection Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv -A/B Soil or Compost Amended C Soil	25% Annual Runoff Reduction
RPv - C/D Soil	10% Annual Runoff Reduction
Cv	10% of RPv Allowance
Fv	1% of RPv Allowance
Pollutant Reduction	
TN Reduction	100% of Load Reduction
TP Reduction	100% of Load Reduction
TSS Reduction	100% of Load Reduction

To receive the credits above, Rooftop Disconnection must be designed in accordance with the criteria detailed in ***Section 7.6 Rooftop Disconnection Design Criteria.***

7.2 Rooftop Disconnection Design Summary

Table 7.2 summarizes design criteria for Rooftop Disconnection. For more detail, consult Sections 7.3 through 7.7. Sections 7.8 and 7.9 describe Rooftop Disconnection construction and maintenance criteria.

Table 7.2 Rooftop Disconnection Design Summary

Feasibility (Section 7.3)	• Minimum disconnection area dimensions = 15ft. x 15 ft. • Unreinforced grade <2%; turf reinforced grade <5% • All soil types eligible • Maximum 1,000 sq.ft. rooftop per disconnection • Grade <1%, setback from foundation minimum of 5 ft.
Conveyance (Section 7.4)	• Safely convey RPv, Cv, Fv • Provide turf reinforcement as necessary
Pretreatment (Section 7.5)	• Downspout energy dissipater required prior to disconnection area
Design Dimensions (Section 7.6)	• Maximum 1,000 sq.ft. rooftop per disconnection • Maximum rooftop = twice disconnection area • Disconnection area trapezoidal • Minimum width at point of discharge to disconnection area = 15 ft.
Other Design Elements (Section 7.6)	• No impervious areas within disconnection area • Use sensitive area protection to prevent compaction during construction
Landscaping (Section 7.7)	• Disconnection area must be vegetated

7.3 Rooftop Disconnection Feasibility Criteria

Rooftop Disconnection is ideal for use on commercial, institutional, municipal, multi-family residential and single-family residential buildings. Key constraints with Rooftop Disconnection include available space, soil permeability, and soil compaction. For Rooftop Disconnection the following feasibility criteria exist:

Required Space. To account for runoff reduction, the available pervious disconnection area at the point of discharge must be at least 15 feet wide and 15 feet long for any downspout, regardless of rooftop area collected. The pervious disconnection area length may be increased as needed to increase the runoff reduction credit, but the width must be kept at a minimum of 15 feet. When the disconnection occurs on a private residential lot, its existence and purpose should be noted on the deed of record. A sample Record Plan note is as follows: “A minimum unobstructed pervious, vegetated area of fifteen feet wide by fifteen feet long should be provided at each downspout conveying roof runoff to allow for runoff reduction”.

Site Topography. Rooftop Disconnection is best applied when the grade of the receiving pervious area is less than 2%, or less than 5% with turf reinforcement. The slope of the receiving areas must be graded away from any building foundations. Turf reinforcement may include appropriate reinforcing materials that are confirmed by the designer to be non-erosive for the specific characteristics and flow rates anticipated at each individual application, and acceptable to the plan approving authority.

Soils. Rooftop Disconnection can be used on any post-construction Hydrologic Soil Group. For sites in Hydrologic Soil Group (HSG) C or D, soil amendments such as compost may be used to upgrade the HSG and increase the runoff reduction credit. Also, the erodibility of soils must be considered when designing disconnection practices.

Contributing Drainage Area. The maximum impervious rooftop area treated may not exceed 1,000 sq. ft. per disconnection.

Setbacks. If the grade of the receiving area is less than 1%, downspouts must be extended 5 ft. away from building. Note that the downspout extension of 5 feet is intended for simple foundations. The use of a dry well or french drain adjacent to an in-ground basement or finished floor area should be carefully designed and coordinated with the design of the structure's water-proofing system (foundation drains, etc.), or avoided altogether.

7.4 Rooftop Disconnection Conveyance Criteria

Rooftop disconnection areas must be designed to safely convey all design storm events (RPv, Cv, Fv) over the receiving area without causing erosion. In some applications, turf reinforcement matting or other appropriate reinforcing materials may be needed to prevent erosion of the pervious area anticipated during larger design storms.

7.5 Rooftop Disconnection Pretreatment Criteria

Pretreatment is not needed for Rooftop Disconnection; however, a transition area must be provided between the downspout discharge point and the disconnection area. A downspout energy dissipater shall be located at the discharge point of the downspout. If the grade of the receiving area is less than 1%, downspouts must be extended 5 ft. away from building.

7.6 Rooftop Disconnection Design Criteria

The maximum impervious rooftop area treated may not exceed 1,000 sq. ft. per disconnection. The contributing rooftop area may be no more than twice the disconnection area (i.e. disconnection of a 1,000 square foot rooftop requires at least 500 square feet of pervious disconnection area). The disconnection area must be trapezoidal. The minimum width at the point of discharge from the downspout to the disconnection area is 15 feet.

Table 7.3 Rooftop Disconnection Area Design Dimensions

Rootop Area (sq.ft.)	Pervious Disconnection Width (ft.) *at point of discharge*	Pervious Disconnection Width (ft.) *at downstream*	Pervious Disconnection Length (ft.)
Up to 250	15	15	15
250 - 500	15	16	16
500 - 750	15	21	21
750 - 1,000	15	25	25

Impervious areas may not be constructed within the area designated as the pervious disconnection area. The pervious disconnection area must be stabilized from erosion with vegetation (see Table 7.3 Recommended vegetation for pervious disconnection areas).

During site construction, care must be taken not to compact the receiving pervious area. To help prevent soil compaction, heavy vehicular and foot traffic should be kept out of the receiving pervious area both during and after construction. This can be accomplished by clearly delineating the pervious areas to receive disconnected runoff on all development plans and protecting them in accordance with sensitive area protection details prior to the start of land disturbing activities. If compaction occurs, the soils must be amended or aerated post-construction to increase permeability.

7.7 Rooftop Disconnection Landscaping Criteria

All pervious disconnection areas receiving rooftop runoff must be stabilized to prevent erosion or transport of sediment to receiving practices or drainage systems. Several types of grasses appropriate for Rooftop Disconnection areas are listed in **Table 7.3.** Designers should ensure that the maximum flow velocities do not exceed the values listed in the table for the selected grass species and the specific site slope.

Table 7.4. Recommended vegetation for pervious disconnection areas.

Vegetation Type	Slope (%)	Maximum Velocity (ft/s)	
		Erosion resistant soil	Easily Eroded Soil
Kentucky Bluegrass	0-5	7	5
	5-10	6	4
	>10	5	3
Tall Fescue Grass Mixture	0-5	6	4
	5-10	4	3
Annual and Perennial Rye	0-5	4	3
Sod		4	3
Source: USDA, TP-61, 1954; City of Roanoke Virginia Stormwater Design Manual, 2008.			

7.8 Rooftop Disconnection Construction Sequence

Construction Sequence for Rooftop Disconnection. For Rooftop Disconnection to a pervious area, the pervious area can be within the limits of disturbance during construction; however, the following procedures must be followed during construction:

- Before site work begins, the receiving pervious disconnection area boundaries must be clearly marked and protected in accordance with sensitive area protection details.
- Construction traffic in the disconnection area must be limited to avoid compaction. The material stockpile area shall not be located in the disconnection area.
- Construction runoff must be directed away from the proposed disconnection area.
- If existing topsoil is stripped during grading, it shall be stockpiled for later use.
- The disconnection area may require light grading to achieve desired elevations and slopes. This grading must be done with tracked vehicles to prevent compaction.
- Topsoil and or compost amendments must be incorporated evenly across the disconnection area, stabilized with seed, and protected from erosion with biodegradable erosion control matting.
- Stormwater may not be diverted into any compost amended areas until the turf cover is well established and no longer subject to erosion.

Construction Review. Construction review is critical to ensure compliance with design standards. Construction reviewers should evaluate the performance of the disconnection after the first big storm to look for evidence of gullies, undercutting or sparse vegetative cover. Spot repairs should be made, as needed.

Post Construction Verification. Post construction verification may be provided through visual inspection by the construction reviewer. When proper construction of the disconnection area is questioned, the construction reviewer may request for **s**pot grade elevations to be surveyed at the beginning and end of the delineated disconnection area, including spot grades at intervals necessary to determine that the design criteria has been met. Verify that no impervious surface exists within the pervious disconnection area.

7.9 Rooftop Disconnection Maintenance Criteria

Maintenance of Rooftop Disconnection areas involves the regular lawn or landscaping maintenance in the filter path from the roof to the street. In some cases, runoff from a Rooftop Disconnection may be directed to a more natural, undisturbed setting (i.e., where lot grading and clearing is “fingerprinted” and the proposed filter path is protected).

An Operation and Maintenance Plan for the project will be approved by the Department or the Delegated Agency prior to project closeout. The Operation and Maintenance Plan will specify the property owner’s primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed. The Operation and Maintenance Plan must ensure that downspouts remain disconnected and pervious filtering/infiltrating areas are not converted to impervious surface or disturbed.

Rooftop Disconnection areas that are, or will be, owned and maintained by a joint ownership such as a homeowner’s association must be located in common areas, community open space, community-owned property, jointly owned property, or within a recorded easement dedicated to public use. When the disconnection occurs on a private residential lot, its existence and purpose must be noted on the deed of record. The developer shall provide subsequent homeowners with a simple document that explains the purpose and routine maintenance needs for Rooftop Disconnection.

Operation and Maintenance Plans should clearly outline how vegetation in the Rooftop Disconnection pervious area will be managed in the future. Maintenance of Rooftop Disconnection is driven by annual maintenance reviews that evaluate the condition and performance of the practice. Based on maintenance review results, specific maintenance tasks may be required.

Sample Operation and Maintenance Plan Notes include:

1. The [OWNER/HOMEOWNER/LOT OWNER/PROPERTY MAINTENANCE CORPORATION] is responsible for maintaining the Rooftop Disconnection area in a pervious, vegetated state having minimum dimensions as shown on the approved Sediment and Stormwater Plan, but in no case less than fifteen feet wide by fifteen feet long. Turf vegetation shall be maintained at a minimum height of three inches.
2. Rooftop disconnection areas shall not be converted to an impervious surface.

3. Energy dissipaters (splash blocks) shall be maintained at each downspout discharge point.
4. The Department or its Delegated Agency shall have access to private property for the purposes of maintenance reviews of the Rooftop Disconnection area

7.10 References

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Virginia DCR Stormwater Design Specification No. 1: Rooftop (Impervious Surface) Disconnection, Version 1.9, March 1, 2011

8.0 Vegetated Channels

Definition: Vegetated open channels that are designed to convey the design storm volume (RPv and Cv, may also convey the Fv as designed).

Design variants include:

- 8-A Bioswale
- 8-B Grassed Channel

Vegetated channels systems shall not be designed to provide stormwater detention. Vegetated channels can provide a modest amount of runoff filtering and volume attenuation within the stormwater conveyance system resulting in the delivery of less runoff and pollutants than a traditional system of curb and gutter, storm drain inlets and pipes. The performance of vegetated channels will vary depending on the underlying soil permeability. Their runoff reduction performance can be boosted when compost amendments are added to the bottom of the channel. Vegetated channels are a preferable alternative to both curb and gutter and storm drains as a stormwater conveyance system, where development density, topography, soils, and water table permit.

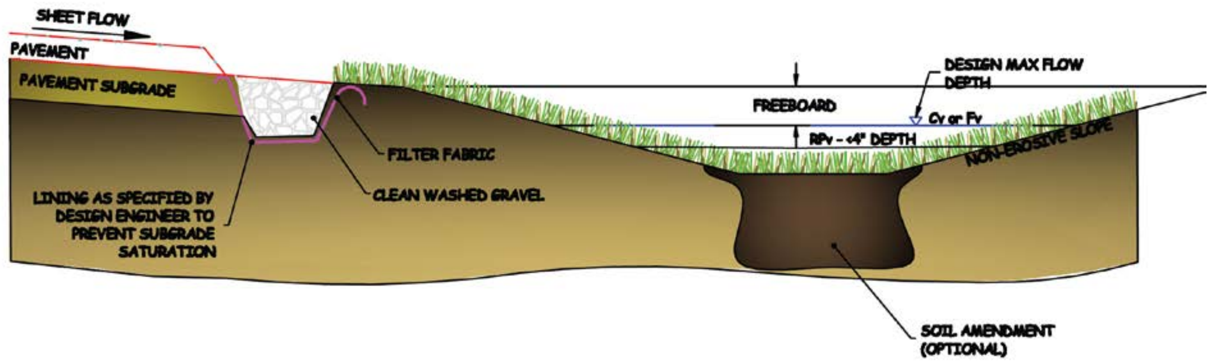

Figure 8.1. Typical Section for Bioswale / Grassed Channel

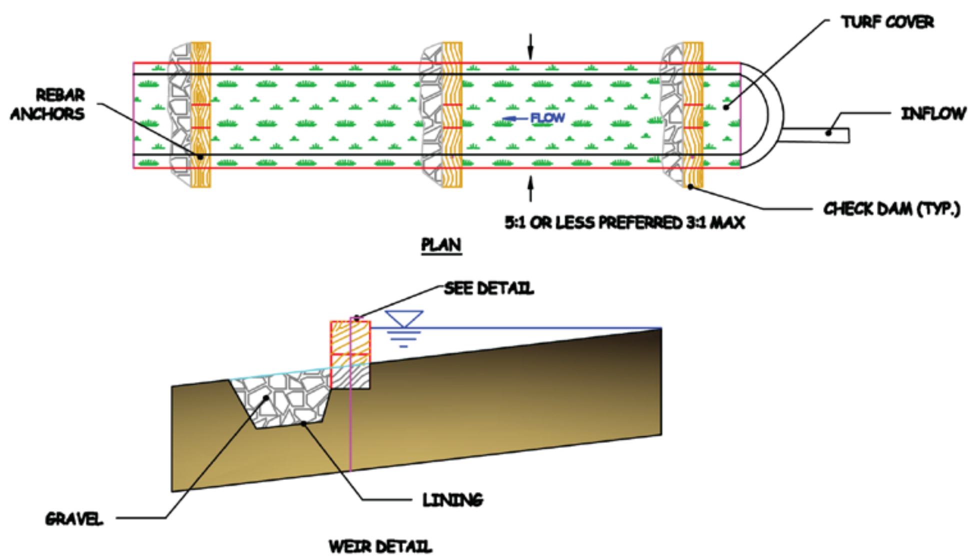

Figure 8.2. Example Check Dam

8.1 Vegetated Channel Stormwater Credit Calculations

Vegetated channels receive a variable annual runoff reduction volume credit depending upon the specific type employed (**Table 8.1**). No additional pollutant removal credit is awarded.

Table 8.1 Vegetated Channel Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv -A/B Soil or Compost Amended C Soil	Bioswale : 50% Annual Runoff Reduction Grassed Channel: 20% Annual Runoff Reduction
RPv - C/D Soil	Bioswale: 25% Annual Runoff Reduction Grassed Channel: 10% Annual Runoff Reduction
Cv	10% of RPv Allowance
Fv	1% of RPv Allowance
Pollutant Reduction	
TN Reduction	100% of Load Reduction
TP Reduction	100% of Load Reduction
TSS Reduction	100% of Load Reduction

8.2 Vegetated Channel Design Summary

Table 8.2 summarizes design criteria for vegetated channels, and Table 8.3 summarizes the materials specifications for these practices. For more detail, consult Sections 8.3 through 8.7. Section 6.8 describes practice construction and maintenance criteria.

Table 8.2 Vegetated Channel Design Summary

Feasibility (Section 8.3)	• Can convey runoff from hotspots, but does not qualify as hotspot treatment • Must not intersect groundwater table • Recommended longitudinal slopes <4% • Longitudinal slope <1% on C/D soils should be designed as *Wetland Swale*
Conveyance (Section 8.4)	• Must safely convey the Cv storm event. • The area of inundation from the Fv storm event must be calculated and its impact to the vegetated channel accounted for in the design.
Pretreatment (Section 8.5)	• All runoff directed to the practice from source areas where sediment loading is anticipated must receive pretreatment • Sediment forebay required for concentrated flow into vegetated channels • Several pretreatment options may be used.
Sizing (Total Storage) (Section 8.6)	• For a Bioswale sizing is based upon the conveyance of the design storm flow at a depth of 4” or less and a residence time of 9 minutes (see Equations 8.1-8.5) • For a Grassed Channel a maximum design storm depth of 4” is required, and the hydraulic residence time for concentrated flow entering the Grassed Channel should be a minimum of 5 minutes. Lateral flow entering the Grassed Channel as sheet flow may be excluded from residence time calculations • Design storm flow depth and residence time based on 50% of RPv peak flow rate
Geometry and Dimensions (Section 8.6)	• Design Flow Depth: 4” for the Resource Protection Volume (RPv) • Width: 2’ Minimum width • Side Slopes: 3:1 or flatter side slopes • Longitudinal slopes <4% unless using check dams
Landscaping (Section 8.7)	• Plant based on velocity limits (Tables 8.5) • Maintain vegetation in the drainage area to limit sediment loads to the practice.

Table 8.3. Vegetated Channel Materials Specifications

Component	Specification
Grass	A dense cover of water-tolerant, erosion-resistant grass. The selection of an appropriate species or mixture of species is based on several factors including climate, soil type, topography, and sun or shade tolerance. Grass species should have the following characteristics: • Deep root system to resist scouring • High stem density with well-branched top growth • Water-tolerance • Resistance to being flattened by runoff • An ability to recover growth following inundation • Salt tolerant for any channel receiving runoff from roadways
Check Dams	• Check dams must be constructed of a non-erosive material such as wood, gabions, riprap, or concrete. All check dams should be underlain with filter fabric (or other support material such as stone) conforming to local design standards. • Wood used for check dams should consist of pressure treated logs or timbers, or water-resistant tree species such as cedar, hemlock, swamp oak or locust. • Computation of check dam material is necessary, based on the surface area and depth used in the design computations.
Energy Dissipation	When conveyance velocity within the vegetated channel exceeds standard allowances, an energy dissipation device must be placed. Most commonly, energy dissipation will be required at the outlet of a piped stormwater conveyance system.
Erosion Control Fabric	Biodegradable erosion control netting or mats that are durable enough to last at least 12 months must be used, conforming to *Delaware Erosion and Sediment Control Handbook*.

8.3 Vegetated Channel Feasibility Criteria

Vegetated channels are primarily applicable for land uses such as roads, highways, and residential development. Some key feasibility issues for vegetated channels include the following:

Contributing Drainage Area. The maximum contributing drainage area to a vegetated channel should be 10 acres, and preferably less. The design criteria for maximum channel velocity and depth are applied along the entire length (See Section 8.6). It is this criteria that will determine the maximum drainage area to a specific vegetated channel.

Available Space. Vegetated channel footprints can fit into relatively narrow corridors between utilities, roads, parking areas, or other site constraints. Vegetated channels can be incorporated into linear development applications (e.g., roadways) by utilizing the space typically required for an open section drainage feature. The footprint required will likely be greater than that of a typical conveyance channel, but the benefit of the runoff reduction may reduce the footprint requirements for stormwater management elsewhere on the development site.

Site Topography. Vegetated channels should be used on sites with longitudinal slopes of less than 4%. Check dams can be used to reduce the effective slope of the channel and lengthen the contact time to enhance filtering and/or infiltration. Longitudinal slopes of less than 2% are ideal and may eliminate the need for check dams. However, channels designed with longitudinal slopes of less than

1% should be monitored carefully during construction to ensure a continuous grade, in order to avoid flat areas with pockets of standing water. Sites with longitudinal slopes less than 1% on HSG 'C' or 'D' soils should be designed as a *Wetland Swale*.

Land Uses. Vegetated channels can be used in residential, commercial, or institutional development settings.

The linear nature of vegetated channels makes them well-suited to treat highway or low- and medium-density residential road runoff, if there is adequate right-of-way width and distance between driveways. Typical applications of vegetated channels include the following, as long as drainage area limitations and design criteria can be met:

- Within a roadway right-of-way
- Along the margins of small parking lots
- Oriented from the roof (downspout discharge) to the street
- Disconnecting small impervious areas

Vegetated channels are not recommended when residential density exceeds more than 4 dwelling units per acre, due to a lack of available land and the frequency of driveway crossings along the channel.

Vegetated channels may provide pre-treatment for other stormwater treatment practices.

Hotspot Land Use. Vegetated channels can typically be used to convey runoff from stormwater hotspots, but do not qualify as a hotspot treatment mechanism. For a list of designated stormwater hotspot operations, consult ***Appendix 4***.

Available Hydraulic Head. A minimum amount of hydraulic head is needed to implement vegetated channels in order to ensure positive drainage and conveyance through the channel. The hydraulic head for vegetated channels is measured as the elevation difference between the channel inflow and outflow point.

Hydraulic Capacity. Vegetated channels are typically designed as on-line practices which must be designed with enough capacity to (1) convey runoff from the Conveyance Event (Cv) and Flooding Event (Fv) design storms at non-erosive velocities, and (2) contain the Cv flow within the banks of the swale. This means that the channel's surface dimensions are more often determined by the need to pass the Cv storm event, which can be a constraint in the siting of vegetated channels within existing rights-of-way (e.g., constrained by sidewalks).

Depth to Water Table. Designers should ensure that the bottom of vegetated channels is above the seasonally high groundwater table.

Soils. Soil conditions do not constrain the use of vegetated channels. However, vegetated channels situated on low-permeability soils may incorporate compost amendments in order to improve performance.

Utilities. Interference with underground utilities should be avoided, particularly water and sewer lines. Approval from the applicable utility company or agency is required if utility lines will run below the vegetated channel.

Floodplains. Vegetated channels should be constructed outside the limits of the 100-year floodplain.

Avoidance of Irrigation or Baseflow. Vegetated channels should be located so as to avoid inputs of springs, irrigation systems, chlorinated wash-water, or other dry weather flows.

8.4 Vegetated Channel Conveyance Criteria

- The bottom width and slope of a vegetated channel should be designed such that the design storm flow depth does not exceed 4-inches. Vegetated channels shall convey the Cv and Fv at non-erosive velocities (less than 3 feet-per-second) for the soil and vegetative cover provided. Additionally tractive force calculations may be provided to show that a channel is capable of supporting velocities in excess of 3 fps in a non-erosive condition. Check dams may be provided to reduce flow velocities. If check dams are employed, flow depths should be calculated through the check dams to ensure that the maximum flow depth of 4-inches is not violated for the RPv.

- The bottom width and slope of a Bioswale should be designed such that the design storm flow depth, 50% of RPv peak flow rate, does not exceed 4-inches, and the residence time of the flow within the channel must exceed 9 minutes. Bioswales shall convey the Cv and Fv at non-erosive velocities (less than 3 fps) for the soil and vegetative cover provided. Additionally tractive force calculations may be provided to show that a channel is capable of supporting velocities in excess of 3 fps in a non-erosive condition. The analysis should evaluate the flow profile through the channel at normal depth, as well as the flow depth over top of the check dams.

8.5 Vegetated Channel Pretreatment Criteria

Pretreatment is required for vegetated channels to dissipate energy, trap sediments and slow down the runoff velocity to below maximum allowable velocity.
The selection of a pre-treatment method depends on whether the channel will experience sheet flow or concentrated flow. Several options are as follows:

- ***Grass Filter Strip*** (sheet flow): Grass filter strips extend from the edge of the pavement to the bottom of the vegetated channel at a slope of 5:1 or flatter. Alternatively, provide a combined 5 feet of grass filter strip at a maximum 5% (20:1) cross slope and 3:1 or flatter side slopes on the vegetated channel.
- ***Gravel or Stone Flow Spreaders*** (concentrated flow). The gravel flow spreader may be located at curb cuts, downspouts, or other concentrated inflow points, and should have a 2 to 4 inch elevation drop from a hard-edged surface into the gravel or stone flow spreader. The gravel should extend the entire width of the opening and create a level stone weir at the bottom or treatment elevation of the channel.
- ***Initial Sediment Forebay*** (channel flow). This reinforced or otherwise stabilized cell is located at the upper end of the vegetated channel segment with a 2:1 length to width ratio and a storage volume equivalent to at least 15% of the Resource Protection event volume (RPv). Typically used when a concentrated flow from a pipe or other conveyance system enters a vegetated channel.

8.6 Vegetated Channel Design Criteria

Channel Geometry. Design guidance regarding the geometry and layout of vegetated channels is provided below:

- Vegetated channels should be designed with a trapezoidal or parabolic cross section. A parabolic shape is preferred for aesthetic, maintenance, and hydraulic reasons.
- The bottom width of the channel should be at a minimum of 2 feet wide to ensure that an adequate surface area exists along the bottom of the channel for filtering. If a channel will be wider than 8 feet, the designer should incorporate benches, check dams, level spreaders or multi-level cross sections to prevent braiding and erosion along the channel bottom.
- Vegetated channel side slopes should be no steeper than 3H:1V for ease of mowing and routine maintenance. Flatter slopes are encouraged, where adequate space is available, to enhance pre-treatment of sheet flows entering the channel.

Channel Slope. Design guidance regarding the channel slope of vegetated channels is provided below:

- Vegetated channels with slopes greater than 4% require special design considerations, such as drop structures to accommodate greater than 12-inch high check dams (and therefore a flatter effective slope), in order to ensure non-erosive flows.
- Longitudinal slopes of less than 2% may eliminate the need for check dams.
- Vegetated channels designed with longitudinal slopes of less than 1% should be monitored carefully during construction to ensure a continuous grade, in order to avoid flat areas with pockets of standing water.
- Sites with longitudinal slopes less than 1% on HSG ‘C’ or ‘D’ soils should be designed as a *Wetland Swale*.

Check dams. Check dams may be used for pre-treatment, to break up slopes, and to increase the hydraulic residence time in the channel. Design requirements for check dams are as follows:

- In typical spacing, the ponded water at a downhill check dam should not touch the toe of the upstream check dam.
- The maximum desired check dam height is 12 inches (for maintenance purposes). Design with check dams with a height greater than 12 inches may be submitted with design calculations showing that the surrounding soils can withstand the tractive forces applied from the increased hydraulic pressure head.
- Armoring may be needed at the downstream toe of the check dam to prevent erosion.
- Check dams must be firmly anchored into the side-slopes to prevent outflanking; check dams must also be anchored into the channel bottom so as to prevent hydrostatic head from pushing out the underlying soils.
- Check dams must be designed with a center weir sized to pass the Cv design storm peak flow.
- Each check dam should have a weep hole or similar drainage feature so it can dewater after storms.
- Check dams should be composed of wood, concrete, stone, or other non-erodible material. Check dams may be configured with elevated driveway culverts, however an underdrain (or similar physical structure) must be provided to meet the weep hole requirement above.
- Check dams for vegetated channels should be spaced to reduce the effective slope to less than 2%, as indicated below in Table 8.4.

Table 8.4. Typical Check Dam (CD) Spacing to Achieve Effective Channel Slope

Channel Longitudinal Slope	Spacing [1] of 12-inch High (max.) Check Dams [3, 4] to Create an Effective Slope of 2%	Spacing [1] of 12-inch High (max.) Check Dams [3, 4] to Create an Effective Slope of 0 to 1%
0.5%	–	200 ft. to –
1.0%	–	100 ft. to –
1.5%	–	67 ft. to 200 ft.
2.0%	–	50 ft. to 100 ft.
2.5%	200 ft.	40 ft. to 67 ft.
3.0%	100 ft.	33 ft. to 50 ft.
3.5%	67 ft.	30 ft. to 40 ft.
4.0%	50 ft.	25 ft. to 33 ft.
4.5% [2]	40 ft.	20 ft. to 30 ft.
5.0% [2]	40 ft.	20 ft. to 30 ft.

Notes:
[1] The spacing dimension is half of the above distances if a 6-inch check dam is used.
[2] Vegetated channels with slopes greater than 4% require special design considerations, such as drop structures to accommodate greater than 12-inch high check dams (and therefore a flatter effective slope), in order to ensure non-erosive flows.
[3] All check dams require a stone energy dissipater at the downstream toe.
[4] Check dams require weep holes at the channel invert. Channels with slopes less than 2% will require multiple weep holes (at least 3) in each check dam.

Material Specifications. All vegetated channels shall require a biodegradable erosion control matting conforming to *Delaware Erosion and Sediment Control Handbook* that is durable enough to last at least 12 months. Recommended material specifications for vegetated channels are shown in **Table 8.3**.

Enhancement using Soil Amendments. Soil compost amendments serve to increase the runoff reduction capability of a vegetated channel. The following design criteria apply when soil amendments are used:

- The soil amendments should extend over the length and width of the channel bottom, and the compost should be incorporated to a depth as outlined in *Post Construction Stormwater BMP Standards and Specifications for Soil Amendments*.
- The amended area will need to be rapidly stabilized with perennial, salt tolerant grass species if adjacent to a roadway.
- For vegetated channels on steep slopes, it may be necessary to install a protective biodegradable stabilization matting to protect the compost-amended soils. Care must be taken to consider the erosive characteristics of the amended soils when selecting appropriate turf reinforcement matting.

Sizing. Unlike other stormwater practices, vegetated channels are designed based on a peak rate of flow. Designers must demonstrate channel conveyance and treatment capacity in accordance with the following guidelines:

- Hydraulic capacity should be verified using Manning's Equation or an accepted equivalent method, such as tractive forces and vegetal retardance.
  - Design storm flow depth based on 50% of RPv peak flow rate should be maintained at 4 inches or less.
  - Manning's "n" value for vegetated channels should be 0.2 for flow depths up to 4 inches, decreasing to 0.03 above 4 inches of flow depth.
  - Peak flow rates for the Cv and Fv storms must be non-erosive (less than 3 fps), or subject to a site-specific analysis of the channel lining material and vegetation. Examples of site-specific analysis ranges can be found in **Table 8.5** below (see ***Section 8.7 Vegetated Channel Landscaping Criteria***);
  - The Cv peak flow rate must be contained within the channel banks.
  - If the Fv storm event is not contained within the channel, the area of inundation must be shown.
- Calculations for peak flow depth and velocity should reflect any increase in flow along the length of the channel, as appropriate. If a single flow is used, the flow at the outlet should be used.
- Hydraulic residence times (the time for runoff to travel the full length of the channel) for both Bioswales and Grassed Channels are computed based upon 50% of the RPv peak flow rate.
    - For Bioswales, the hydraulic residence time should be a minimum of 9 minutes for the design storm (Mar et al., 1982; Barrett et al., 1998; Washington State Department of Ecology, 2005). If flow enters the channel at several locations, a 9 minute minimum

hydraulic residence time should be demonstrated for each entry point, using Equations 8.1 – 8.5 below.

- For Grassed Channels, the hydraulic residence time for concentrated flow entering the Grassed Channel should be a minimum of 5 minutes for the design storm.
- Lateral flow entering the Grassed Channel as sheet flow may be excluded from residence time calculations, but should be accounted for in the channel depth and velocity calculations.
- For Grassed Channels, in-line culverts (such as driveway crossings) that do not introduce any new flow can be excluded from concentrated flow pre-treatment requirements and residence time calculations.
- For Grassed Channels, pipe length should not be included in residence time calculations.
- For Grassed Channels with in-line culverts, the proportion of grassed channel flow length should be a minimum of 80% of the total flow length.

The bottom width of the vegetated channel is therefore sized to maintain the appropriate flow geometry as follows:

Equation 8.1: Manning's Equation

$$V = \left[\left(\frac{1.49}{n}\right) D^{2/3} s^{1/2}\right]$$

Where:

V = flow velocity (ft./sec.)
n = roughness coefficient (0.2, or as appropriate)
D = flow depth (ft.) (NOTE: D approximates hydraulic radius for shallow flows)
s = channel slope (ft./ft.)

Equation 8.2: Continuity Equation

$$Q = V(WD)$$

Where:

Q = design storm peak flow rate (cfs)
V = design storm flow velocity (ft./sec.)
W = channel width (ft.)
D = flow depth (ft.)
(NOTE: channel width (W) x depth (D) approximates the cross sectional flow area for shallow flows.)

Combining **Equations 8.1 and 8.2**, and re-writing them provides a solution for the minimum width:

Equation 8.3: Minimum Width

$$W = {(nQ)}/{(1.49 D^{5/3} s^{1/2})}$$

Solving **Equation 8.2** for the corresponding velocity provides:

Equation 8.4: Corresponding Velocity

$$V = Q / WD$$

The width, slope, or Manning's "*n*" value can be adjusted to provide an appropriate channel design for the site conditions. However, if a higher density of grass is used to increase the Manning's "*n*" value and decrease the resulting channel width, it is important to provide material specifications and construction oversight to ensure that the denser vegetation is actually established. **Equation 8.5** can then be used to ensure adequate hydraulic residence time.

Equation 8.5: Bioswale Length for Hydraulic Residence Time of 9 minutes (540 seconds)

$$L = 540V$$

Where:

L = minimum swale length (ft.)
V = flow velocity (ft./sec.)

8.7 Vegetated Channel Landscaping Criteria

All vegetated channels must be stabilized to prevent erosion or transport of sediment to receiving practices or drainage systems. Several appropriate types of grasses appropriate for vegetated channels are listed in **Table 8.5.** Designers should choose plant species that can withstand both wet and dry periods and relatively high velocity flows for planting within the channel. Designers should ensure that the maximum flow velocities do not exceed the values listed in the table for the selected grass species and the specific site slope.

Table 8.5. Recommended vegetation for vegetated channels.

Vegetation Type	Slope (%)	Maximum Velocity (ft/s)	
		Erosion resistant soil	Easily Eroded Soil
Bermuda Grass	0-5	8	6
	5-10	7	5
	>10	6	4
Kentucky Bluegrass	0-5	7	5
	5-10	6	4
	>10	5	3
Tall Fescue Grass Mixture	0-5	6	4
	5-10	4	3
Annual and Perennial Rye	0-5	4	3
Source: USDA, TP-61, 1954			

Vegetation not contained in Table 8.5 will be evaluated on a case-by-case basis.

If roadway salt will be applied to the contributing drainage area, vegetated channels should be planted with salt-tolerant plant species.

Landscape design shall specify proper grass species based on specific site, soils and hydric conditions present along the channel.

Vegetated channels should be seeded at such a density to achieve a 70% vegetated cover for project completion and 90% vegetated cover after the second growing season. Taller and denser grasses are preferable, although the species is less important than good stabilization and dense vegetative cover.

Vegetated channels should be seeded and not sodded. Seeding establishes deeper roots and sod may have muck soil that is not conducive to infiltration. Vegetated channels should be protected by a biodegradable erosion control matting to provide immediate stabilization of the channel bed and banks.

8.8 Vegetated Channel Construction Sequence

Design Notes. Channel invert and tops of banks are to be shown in plan and profile views. A cross sectional view of each configuration should be shown. Completed limits of grading should be shown. The transition at the entrance and outfall is to be clearly shown on plan and profile views.

Vegetated Channel Installation. The following is a typical construction sequence to properly install vegetated channels, although steps may be modified to reflect different site conditions or design variations. Vegetated channels should be installed at a time of year that is best to establish turf cover without irrigation.

Step 1: Protection during Site Construction. Ideally, vegetated channels should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment. However, this is seldom practical, given that the channels are a key part of the drainage system at most sites. In these cases, temporary erosion and sediment controls such as dikes, silt fences and other erosion control measures should be integrated into the swale design throughout the construction sequence. Specifically, barriers should be installed at key check dam locations, and erosion control matting should be used to protect the channel.

Step 2. Installation may only begin after the entire contributing drainage area has been stabilized with vegetation. Any accumulation of sediments that does occur within the channel must be removed during the final stages of grading to achieve the design cross-section. Erosion and sediment controls for construction of the channel should be installed as specified in the erosion and sediment control plan. Stormwater flows must not be permitted into the channel until the bottom and side slopes are fully stabilized.

Step 3. Grade the vegetated channel to the final dimensions shown on the plan. Excavators or backhoes should work from the sides to grade and excavate the vegetated channels to the appropriate design dimensions. Excavating equipment should have scoops with adequate reach so they do not have to sit inside the footprint of the vegetated channel area.

Step 4 (Optional). Apply soil amendments in accordance with *Post Construction Stormwater BMP Standards and Specification for Soil Amendments*, if specified.

Step 5. Install check dams and internal pre-treatment features as shown on the plan. The top of each check dam should be constructed level at the design elevation.

Step 6. Seed the bottom and banks of the vegetated channel, and install erosion control matting.

Step 7. Plant landscaping materials as shown in the landscaping plan, and water them weekly during the first 2 months. The construction contract should include a care and replacement warranty to ensure that vegetation is properly established and survives during the first growing season following construction.

Step 8. Conduct the final construction inspection and develop a punch list for facility acceptance.

Vegetated Channel Construction Inspection. Inspections during construction are needed to ensure that the vegetated channel is built in accordance with these specifications.

Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of vegetated channel installation:

- Make sure the desired coverage of turf or erosion control matting has been achieved following construction, both on the channel beds and their contributing side-slopes.
- Inspect check dams and pre-treatment structures to make sure they are at correct elevations, are properly installed, and are working effectively.
- Check that outfall protection/energy dissipation measures at concentrated inflow and outflow points are stable.

The real test of a vegetated channel occurs after its first big storm. The post-storm inspection should focus on whether the desired sheet flow, shallow concentrated flows or fully concentrated flows assumed in the plan actually occur in the field. Minor adjustments are often needed as part of this post-storm inspection (e.g., spot re-seeding, gully repair, added armoring at inlets, or realignment of outfalls and check dams).

8.9 Vegetated Channel Maintenance Criteria

An Operation and Maintenance Plan for the project will be approved by DNREC or the Delegated Agency prior to project closeout. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize DNREC or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed. Vegetated channels that are, or will be, owned and maintained by a joint ownership such as a homeowner's association must be located in common areas, community open space, community-owned property, jointly owned property, or within a recorded easement dedicated to public use.

Operation and Maintenance Plans should clearly outline how vegetation in the vegetated channel will be managed or harvested in the future. The Operation and Maintenance Plan should schedule a cleanup at least once a year to remove trash and debris.

Maintenance of vegetated channels is driven by annual maintenance reviews that evaluate the condition and performance of the practice. Based on maintenance review results, specific maintenance tasks may be required.

Table 8.6. Suggested Maintenance Activities and Schedule for Vegetated Channels

Maintenance Activity	Schedule
• Mow vegetated channels during the growing season to maintain minimum grass heights in the 4" to 6" range.	As needed
• Ensure that the contributing drainage area, inlets, and facility surface are clear of debris. • Ensure that the contributing drainage area is stabilized. Perform spot-reseeding if where needed. • Remove accumulated sediment and oil/grease from inlets, pre-treatment devices, flow diversion structures, and overflow structures. • Repair undercut and eroded areas at inflow and outflow structures.	Quarterly
• Add reinforcement planting to maintain 90% turf cover. Reseed any salt-killed vegetation. • Remove any accumulated sand or sediment deposits behind check dams. • Inspect upstream and downstream of check dams for evidence of undercutting or erosion, and remove and trash or blockages at weep holes. • Examine channel bottom for evidence of erosion, braiding, excessive ponding or dead grass. • Check inflow points for clogging and remove any sediment. • Inspect side slopes and pretreatment areas for evidence of any rill or gully erosion and repair. • Look for any bare soil or sediment sources in the contributing drainage area and stabilize immediately.	Annual inspection

Annual inspections are used to trigger maintenance operations such as sediment removal, spot re-vegetation and inlet stabilization. Example maintenance inspection checklists for vegetated channels can be found in ***Article 5***.

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9.0 Sheet Flow to Filter Strip or Open Space

Definition:

Filter strips are vegetated areas that treat sheet flow delivered from adjacent impervious and managed turf areas by slowing runoff velocities and allowing sediment and attached pollutants to settle and/or be filtered by the vegetation. The two design variants of filter strips are *Vegetated Filter Strips* and *Conserved Open Space*. The design, installation, and management of these design variants are quite different, as outlined in this specification.

In both instances, stormwater must enter the filter strip or conserved open space as sheet flow. If the inflow is from a pipe or channel, an engineered level spreader must be designed in accordance with the criteria contained herein to convert the concentrated flow to sheet flow.

Applicable practices include:

- 9-A. Sheet Flow to Vegetated Filter Strip
- 9-B. Sheet Flow to Vegetated Conserved Open Space

Sheet flow practices reduce a portion of the Resource Protection Volume (RPv). In order to meet requirements for larger storm events, sheet flow practices must be combined with additional practices.

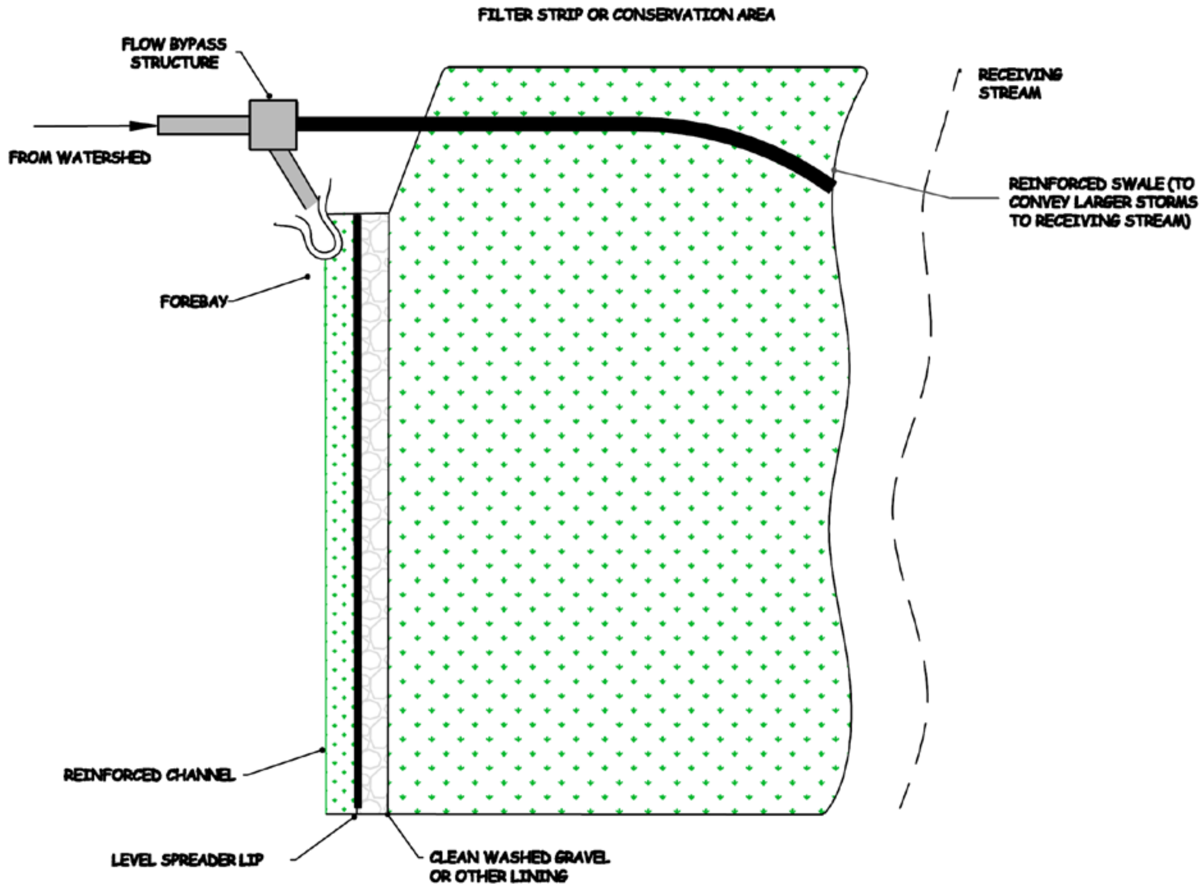

Figure 9.1. Sheet Flow To Vegetated Filter Strip or Conserved Open Space

9.1 Sheet Flow Stormwater Credit Calculations

Sheet flow practices receive varying retention volume credit (Rv) depending upon the specific type employed (**Table 9.1**). No additional pollutant removal credit is awarded.

9.1(a) Sheet Flow to Vegetated Filter Strip Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv -A/B Soil or Compost Amended C Soil	Turf: 25% Annual Runoff Reduction Forest: 40% Annual Runoff Reduction
RPv - C/D Soil	Turf: 10% Annual Runoff Reduction Forest: 20% Annual Runoff Reduction
Cv	10% of RPv Allowance
Fv	1% of RPv Allowance
Pollutant Reduction	
TN Reduction	100% of Load Reduction (max. 20% Removal Efficiency)
TP Reduction	100% of Load Reduction (max. 20% Removal Efficiency)
TSS Reduction	100% of Load Reduction (max. 80% Removal Efficiency)

9.1(b) Sheet Flow to Vegetated Open Space Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv -A/B Soil or Compost Amended C Soil	Turf: 50% Annual Runoff Reduction Forest: 65% Annual Runoff Reduction
RPv - C/D Soil	Turf: 20% Annual Runoff Reduction Forest: 40% Annual Runoff Reduction
Cv	10% of RPv Allowance
Fv	1% of RPv Allowance
Pollutant Reduction	
TN Reduction	100% of Load Reduction
TP Reduction	100% of Load Reduction
TSS Reduction	100% of Load Reduction

*For annual reduction practices, the annual reduction percentage is converted to an event runoff

The sheet flow practices described above must be designed using the guidance detailed in ***Section 9.6 Sheet Flow Design Criteria.***

9.2 Sheet Flow Design Summary

Table 9.2 summarizes design criteria for sheetflow practices. For more detail, consult Sections 9.3 through 9.7. Sections 9.8 and 9.9 describe practice construction and maintenance criteria.

Table 9.2 Sheet Flow Design Summary

	Filter Strips	**Sheet Flow to Open Space**
Feasibility (Section 9.3)	Typically <5,000 sf impervious cover	Hydrologically Connected areas
	• Max. 8% slopes • Appropriate for all soils except fill, but runoff reduction dependent on soil type. • Cannot receive hotspot runoff • Does not include jurisdictional wetlands	• Max. 1% slope • Appropriate for all soils except fill, but runoff reduction dependent on soil type. • Cannot receive hotspot runoff • Does not include jurisdictional wetlands
Conveyance (Section 9.4)	• Must receive sheet flow. • Can be achieved by receiving a relatively short flow path (<150' pervious or <75' impervious surfaces), or • Can use an engineered level spreader for concentrated flows (Section 9.6)	
Pretreatment (Section 9.5)	Not required	
Minimum Dimensions (Section 9.6)	Length dependent on slope and practice option (See Tables 9.3 and 9.4)	Area dependent on slope and impervious cover in CDA
Other Design Elements (Section 9.6)	• Gravel diaphragm at the top of the slope for sheet flow applications. • Engineered level spreader for concentrated flow • Permeable berm at the toe of slope of filter strips • Compost amendments when applied on C soils to increase soil permeability	
Landscaping (Section 9.7)	• Achieve 90% coverage with herbaceous materials for vegetated filter strips and vegetated open space. • Create an invasive species plan, and damage no native species for all conservation areas. • Requires 80% tree canopy for forested filter strips and conserved open space. • Specific criteria for reforestation. • Maximum velocity versus species type in Table 9.5.	

9.3 Sheet Flow Feasibility Criteria

Sheet Flow to a Filter Strip or Open Space can be employed on commercial, institutional, municipal, multi-family residential and single-family residential buildings. Key constraints include available space, soil permeability, soil compaction.

Vegetated Filter Strips
Filter strips are best suited to treat runoff from small segments of impervious cover (usually less than 5,000 sq. ft.) adjacent to road shoulders, small parking lots and rooftops. Filter strips may also be used as pretreatment for another stormwater practice such as a bioswale, bioretention, or infiltration areas. If sufficient pervious area is available at the site, larger areas of impervious cover can be treated by filter strips, using an engineered level spreader to recreate sheet flow. Filter strips are also well suited to treat runoff from turf-intensive land uses, such as the managed turf areas of sports fields, golf courses, and parkland. Filter strips tend to have more linear configurations and greater cross-slopes than areas that qualify as “Conserved Open Space”.

Forested Filter Strips

Forested filter strips are a subset of Vegetated Filter Strips in which the vegetation cover consists mostly of established tree species with an organic duff layer having greater hydrologic storage capacity than a non-forested filter strip. Runoff through a forested filter strip would be more likely to occur as interflow than as true surface runoff.

Conserved Open Space
The most common design applications of Conserved Open Space are on sites that are hydrologically connected to a protected stream buffer, wetland buffer, floodplain, forest conservation area, or other protected lands. Conserved Open Space is an ideal component of the "outer zone" of a stream buffer, which normally receives runoff as sheet flow. Care should be taken to locate all energy dissipaters or flow spreading devices outside of the protected area. Conserved Open Space generally has a less linear configuration and flatter cross-slope than Vegetated Filter Strips. Runoff reduction in Conserved Open Space is achieved mainly through storage and/or extended residence time. These areas therefore require minimal slope or even slight sump conditions to allow shallow ponding to occur. Similar to Vegetated Filter Strips, Conserved Open Space can be either in the form of turf vegetation or preserved forested areas.

Both Vegetated Filter Strips and Conserved Open Space must meet the following requirements:

- ***Slopes.*** Maximum slope for Vegetated Filter Strips is 8%, in order to maintain sheet flow through the practice. Maximum slope for Conserved Open Space is 1%. In addition, the overall contributing drainage area must likewise be relatively flat to ensure sheet flow draining into the filter. Where this is not possible, alternative measures, such as an engineered level spreader, can be used.

- ***Soils.*** Vegetated Filter Strips and Conserved Open Space are appropriate for all soil types, except fill material. As it applies to this practice, fill is defined as any placed soil that requires compaction to meet a design grade or elevation. The runoff reduction rate, however, is dependent on the underlying Hydrologic Soil Groups (see **Table 9.1** above) and whether soils receive compost amendments.
- ***Hotspot Land Uses.*** Vegetated Filter Strips and Conserved Open Space should not receive hotspot runoff, since the infiltrated runoff could cause groundwater contamination.
- ***Proximity of Underground Utilities.*** Underground pipes and conduits that cross a Vegetated Filter Strip or Conserved Open Space are acceptable.
- ***Jurisdictional Wetlands.*** Restrictions may apply when these practices are located adjacent to jurisdictional wetlands that are sensitive to increased inputs of stormwater runoff (e.g., bogs and fens).

9.4 Sheet Flow Conveyance Criteria

Vegetated Filter Strips and Conserved Open Space are used to treat very small drainage areas of a few acres or less. The limiting design factor is the length of flow directed to the filter. As a rule, flow tends to concentrate after 75 feet of flow length for impervious surfaces, and 150 feet for pervious surfaces (Claytor, 1996). When flow concentrates, it moves too rapidly to be effectively treated, unless an engineered level spreader is used.

9.5 Sheet Flow Pretreatment Criteria

Pretreatment is not needed for Sheet Flow to Vegetated Filter Strips or Conserved Open Space.

9.6 Sheet Flow Design Criteria

For Vegetated Filter Strips, the following minimum lengths apply (length is measured in direction of flow):

Table 9.3 Minimum Length of Filter Strips

Slope of Filter Strip	Minimum Length
<- 3%	25 feet
3% - 8%	50 feet
The first 10 feet of filter must be 2% or less in all cases.	

For Conserved Open Space, the following minimum area a

Table 9.4 Minimum Area of Conserved Open Space

Slope of Open Space	Minimum Area
1% Max	1:1 equivalent to impervious area in CDA

The following accessory structures may be necessary or required as part of a filter strip or conserved open space:

Gravel Diaphragms

A gravel diaphragm at the top of the slope is required for both filter strips and conserved open space. The gravel diaphragm is created by excavating a 2-foot wide and 1-foot deep trench that runs on the same contour at the top of the filter strip. The diaphragm serves two purposes. First, it acts as a pretreatment device, settling out sediment particles before they reach the practice. Second, it acts as a level spreader, maintaining sheet flow as runoff flows over the filter strip.

- The flow should travel over the impervious area and to the practice as sheet flow and then drop at least 3 inches onto the gravel diaphragm. The drop helps to prevent runoff from running laterally along the pavement edge, where grit and debris tend to build up (thus allowing by-pass of the Filter Strip).
- A layer of filter fabric should be placed between the gravel and the underlying soil trench.
- If the contributing drainage area is steep (6% slope or greater), then larger stone should be used in the diaphragm.
- If the contributing drainage area is solely turf (e.g., sports field), then the gravel diaphragm may be eliminated.

Engineered Level Spreaders

The design of engineered level spreaders should conform to the following design criteria based on recommendations of Hathaway and Hunt (2006), in order to ensure non-erosive sheet flow into the vegetated area. At times, it may be necessary to include a bypass structure (see **Figure 9.1** above) that diverts the design storm to the level spreader, and bypasses the larger storm events around the Vegetated Filter Strip or Conserved Open Space through an improved channel. An alternative approach would be to direct the entire flow through a stilling basin energy dissipator and then a level spreader such that the entire Conveyance Event (Cv) storm for the) is discharged as sheet flow through the buffer.

Key design elements of the engineered level spreader, as provided in **Figures 9.3 and 9.4**, include the following:

- The length of the level spreader should be determined by the type of filter area and the design flow:
  - 13 feet of level spreader length per every 1 cubic foot per second (cfs) of inflow for discharges to a filter strip or turf conservation area;
  - 40 feet of level spreader length per every 1 cfs of inflow when the spreader discharges to a forested conservation area (Hathaway and Hunt, 2006).
  - The minimum level spreader length is 13 feet and the maximum is 130 feet.
  - For the purposes of determining the level spreader length, the peak discharge shall be determined using the Rational Equation with an intensity of 2.7-inch/hour.

- The level spreader lip should be concrete, wood or pre-fabricated metal, with a well-anchored footer, or other accepted rigid, non-erodible material.
- The ends of the level spreader section should be tied back into the slope to avoid scouring around the ends of the level spreader; otherwise, short-circuiting of the facility could create erosion.
- The width of the level spreader channel on the up-stream side of the level lip should be three times the diameter of the inflow pipe, and the depth should be 9 inches or one-half the culvert diameter, whichever is greater.

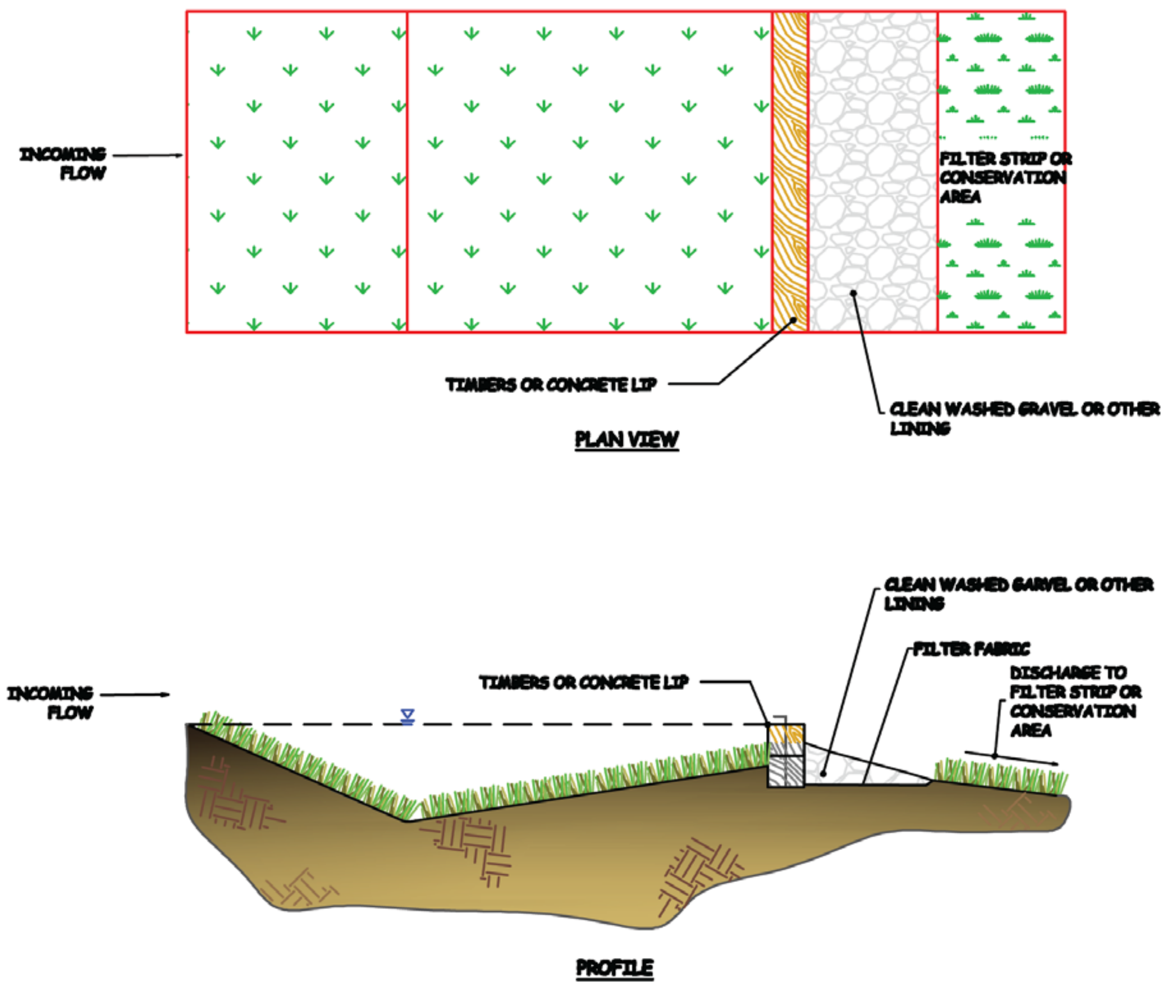

Figure 9.3: Example Level Spreader

Permeable Berm
Vegetated Filter Strips should be designed with a permeable berm at the toe of the filter strip to create a shallow ponding area. Runoff ponds behind the berm and gradually flows through outlet pipes in the berm or through a gravel lens in the berm with a perforated pipe. During larger storms, runoff may overtop the berm (Cappiella *et al.*, 2006). The permeable berm should have the following properties:

- A wide and shallow trench, 6 to 12 inches deep, should be excavated at the upstream toe of the berm, parallel with the contours.
- Media for the berm should consist of 40% excavated soil, 40% sand, and 20% pea gravel.
- The berm 6 to 12 inches high should be located downgradient of the excavated depression and should have gentle side slopes to promote easy mowing (Cappiella *et al*., 2006).
- Stone may be needed to armor the top of berm to handle extreme storm events.
- A permeable berm is not needed when vegetated filter strips are used as pretreatment to another stormwater practice.

Compost Soil Amendments
Compost soil amendments can enhance the runoff reduction capability of a Vegetated Filter Strip or Conserved Open Space when located on hydrologic soil group C, subject to the following design requirements:

- The compost amendments should extend over the full length and width of the vegetated area.
- The amount of approved compost material and the depth to which it must be incorporated is outlined in **Specification 14, Soil Amendments**.
- The amended area must be raked to achieve the most level slope possible without using heavy construction equipment, and stabilized with perennial grass and/or herbaceous species prior to receiving runoff discharges..
- If slopes exceed 3%, an erosion control matting should be installed in accordance with the **Delaware ESC Handbook** to assist with stabilization of the site.
- Compost amendments should not be incorporated until the gravel diaphragm and/or engineered level spreader are installed (see below).

9.7 Impermeable Surface Disconnection Landscaping Criteria

Vegetated Filter Strips. Vegetated Filter Strips should be planted at such a density to achieve a 90% grass/herbaceous cover after the second growing season. Vegetated Filter Strips should be seeded, not sodded. Seeding establishes deeper roots, and sod may have muck soil that is not conducive to infiltration (Wisconsin DNR, 2007). The vegetation may consist of turf grasses, meadow grasses, other herbaceous plants, shrubs, and trees, as long as the primary goal of at least 90% coverage with grasses and/or other herbaceous plants is achieved. Designers should choose vegetation that stabilizes the soil and is salt tolerant. Vegetation at the toe of the filter, where temporary ponding may occur behind the permeable berm, should be able to withstand both wet and dry periods. The planting areas can be divided into zones to account for differences in inundation and slope.

Forested Filter Strips. No grading or clearing of native vegetation is allowed within the Forested Filter Strip. Forested Filter Strips must have at least 80% tree canopy coverage. An invasive species management plan should be developed and approved as part of plan review.

Conserved Open Space. No grading or clearing of native vegetation is allowed within the Conserved Open Space. An invasive species management plan should be developed and approved as part of plan review.

Vegetated Conservation Area. In addition to the constraints listed for Conserved Open Space in section 9.3 above, turf conservation areas must have at least 90% coverage with grasses and/or other herbaceous plants, although tree coverage in portions is acceptable.

Forested Conservation Area. In addition to the constraints listed for Conserved Open Space in section 9.3 above, Forested Conservation Areas must have at least 80% tree canopy coverage.

Re-vegetated Conserved Open Space. At some sites, the proposed Conserved Open Space may not meet the coverage requirements above, may be previously disturbed, or may be overrun with invasive plants and vines. In these situations, a landscape architect or horticulturalist should prepare a re-vegetation or restoration plan for the Conserved Open Space to achieve the coverage requirements for a turf or aforested conservation area. The entire area can be planted with herbaceous cover for a vegetated conservation area, or with native trees and shrubs for an aforested conservation area. For aforested conservation areas:

- Trees and shrubs with deep rooting capabilities are recommended for planting to maximize soil infiltration capacity (PWD, 2007).
- Over-plant with seedlings for fast establishment and to account for mortality.
- Plant larger stock at desired spacing intervals (25 to 40 feet for large trees) using random spacing (Cappiella *et al*., 2006).
- Plant ground cover or a herbaceous layer to ensure rapid vegetative cover of the surface area.

(*NOTE: The runoff reduction allowance for Re-vegetated Conserved Open Space shall be determined on a case-by-case basis following Departmental review of the proposed landscaping plan.*)

Stabilization. All Vegetated Filter Strips and re-vegetated Conserved Open Space must be stabilized to prevent erosion or transport of sediment to receiving practices or drainage systems. Several types of grasses appropriate for filter strips or turf conservation areas are listed in **Table 9.5.** Designers should ensure that the maximum flow velocities do not exceed the values listed in the table for the selected grass species and the specific site slope.

Table 9.5. Recommended vegetation for filter strips and turf conservation areas.

Vegetation Type	Slope (%)	Maximum Velocity (ft/s)	
		Erosion resistant soil	Easily Eroded Soil
Bermuda Grass	0-5	8	6
	5-10	7	5
	>10	6	4
Kentucky Bluegrass	0-5	7	5
	5-10	6	4
	>10	5	3
Tall Fescue Grass Mixture	0-5	6	4
	5-10	4	3
Annual and Perennial Rye	0-5	4	3
Sod		4	3
Source: USDA, TP-61, 1954; City of Roanoke Virginia Stormwater Design Manual, 2008.			

9.8 Sheet Flow Construction Sequence

Construction Sequence for Vegetated Filter Strips
Vegetated Filter Strips can be within the limits of disturbance during construction. The following procedures should be followed during construction:

- Before site work begins, filter strip boundaries should be clearly marked.
- Only vehicular traffic used for filter strip construction should be allowed within the filter strip boundary.
- If existing topsoil is stripped during grading, it shall be stockpiled for later use.
- Construction runoff should be directed away from the proposed filter strip site, using perimeter silt fence, or, preferably, a diversion dike.
- Construction of the gravel diaphragm or engineered level spreader shall not commence until the contributing drainage area has been stabilized and perimeter erosion and sediment (E&S) controls have been removed and cleaned out.
- Filter strips require light grading to achieve desired elevations and slopes. This should be done with tracked vehicles to prevent compaction. Topsoil and or compost amendments should be incorporated evenly across the filter strip area, stabilized with seed, and protected by biodegradable erosion control matting or blankets.
- Stormwater should not be diverted into the filter strip until the turf cover is dense and well established.

Construction Sequence for Vegetated Conserved Open Space
No major disturbance may occur within the Conserved Open Space during or after construction (i.e., no clearing or grading is allowed except temporary disturbances associated with incidental

utility construction, restoration operations, or management of nuisance vegetation). The Conserved Open Space area shall not be stripped of topsoil. Some light grading may be needed at the boundary using tracked vehicles to prevent compaction.

The Conserved Open Space must be fully protected during the construction stage of development and kept outside the limits of disturbance on the Sediment & Stormwater Plan.

- The perimeter of the Conserved Open Space shall be protected by super silt fence, chain link fence, orange safety fence, or other measures to prevent compaction and sediment discharge.
- The limits of disturbance should be clearly shown on all construction drawings and identified and protected in the field by acceptable signage, silt fence, snow fence or other protective barrier.
- Construction of the gravel diaphragm or engineered level spreader shall not commence until the contributing drainage area has been stabilized and perimeter E&S controls have been removed and cleaned out.
- Stormwater should not be diverted into the conserved open space until the gravel diaphragm and/or level spreader are installed and stabilized.

Construction Inspection. Construction inspection is critical to ensure compliance with design standards. Inspectors should evaluate the performance of the filter strip or open space after the first big storm to look for evidence of gullies, outflanking, undercutting or sparse vegetative cover. Spot repairs should be made, as needed.

Post Construction Verification Documentation. The following items shall be included in the Post Construction Verification Documentation for Sheet Flow Practices:

- Dimensions of Vegetated Filter Strips (length and width).
- Area of Conserved Open Space.
- Cross-slope.
- Volume dimensions of any pre-treatment component.
- Elevations of any structural components, such as gravel diaphragms or engineered level spreaders.

9.9 Sheet Flow Maintenance Criteria

An Operation and Maintenance Plan for the project will be approved by the Department or the Delegated Agency prior to project closeout. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed. Sheet Flow Practices that are, or will be, owned and maintained by a joint ownership such as a homeowner's association must be located in common areas, community open space, community-owned property, jointly owned property, or within a recorded easement dedicated to public use.

Operation and Maintenance Plans should clearly outline how vegetation in the Sheet Flow Practice will be managed or harvested in the future. Maintenance of Sheet Flow Practices is driven by annual maintenance reviews that evaluate the condition and performance of the practice. Based on maintenance review results, specific maintenance tasks may be required.

Table 9.6. Sheet Flow to Filter Strip or Open Space Maintenance Items and Frequency

Frequency	Maintenance Items
During establishment, as needed (first year)	• Inspect the site after storm event that exceeds 0.5 inches of rainfall. • Stabilize any bare or eroding areas in the contributing drainage area including the Wet Pond perimeter area • Water trees and shrubs planted in the Wet Pond vegetated perimeter area during the first growing season. In general, water every 3 days for first month, and then weekly during the remainder of the first growing season (April - October), depending on rainfall.
Quarterly or after major storms (>1 inch of rainfall)	• Remove debris and blockages • Repair undercut, eroded, and bare soil areas
Twice a year	• Mowing of the Wet Pond vegetated perimeter area and embankment
Annually	• Shoreline cleanup to remove trash, debris and floatables • A full maintenance review • Open up the riser to access and test the valves • Repair broken mechanical components, if needed
One time –during the second year following construction	• Wet Pond vegetated perimeter and aquatic bench reinforcement plantings
Every 5 to 7 years	• Forebay sediment removal
From 5 to 25 years	• Repair pipes, the riser and spillway, as needed • Remove sediment from Wet Pond area outside of forebays

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10.0 Detention Practices

Definition: Detention Practices are storage practices that are explicitly designed to provide stormwater detention for the Conveyance Event, Cv (10-year) and Flooding Event, Fv (100-year). Design variants include:

- 10-A Dry Detention Pond
- 10-B Dry Extended Detention Basin
- 10-C Underground Detention Facilities

Dry Detention Ponds and Dry Extended Detention Basins are widely applicable for most land uses and are best suited for larger drainage areas. An outlet structure restricts stormwater flow so it backs up and is stored within the basin. The temporary ponding reduces the maximum peak discharge to the downstream channel, thereby reducing the effective shear stress on the bed and banks of the receiving stream. Dry Detention Ponds receive some credit for pollutant removal, while Dry Extended Detention Basins receive both runoff reduction and pollutant removal credits.

The key difference between Dry Detention Ponds and Dry Extended Detention Basins is that, in addition to management of the Cv and Fv, a Dry Extended Detention Basin provides up to a 24-hour detention of all or a portion of the Resource Protection Volume (RPv). An under-sized outlet structure restricts stormwater flow so it backs up and is stored within the basin. The temporary ponding enables particulate pollutants to settle out and reduces the maximum peak discharge to the downstream channel, thereby reducing the effective shear stress on banks of the receiving stream. Extended detention differs from a Dry Detention Pond's stormwater detention, since it is designed to achieve a minimum drawdown time, rather than a maximum peak rate of flow. Dry Detention Ponds, which are designed only to manage the larger Conveyance Event and Flooding Event will often detain smaller storm events for only a few minutes or hours.

Underground Detention Facilities include vaults and tanks. Underground Detention Vaults are box-shaped underground stormwater storage facilities typically constructed with reinforced concrete. Underground Detention Tanks are underground storage facilities typically constructed with large diameter metal or plastic pipe. Both serve as an alternative to surface dry detention for stormwater quantity control, particularly for space-limited areas where there is not adequate land for a dry detention basin or multi-purpose detention area. Prefabricated concrete vaults are available from commercial vendors. In addition, several pipe manufacturers have developed packaged detention systems. Underground detention vaults do not receive any runoff reduction or pollutant removal credit, and should be considered only for management of larger storm events.

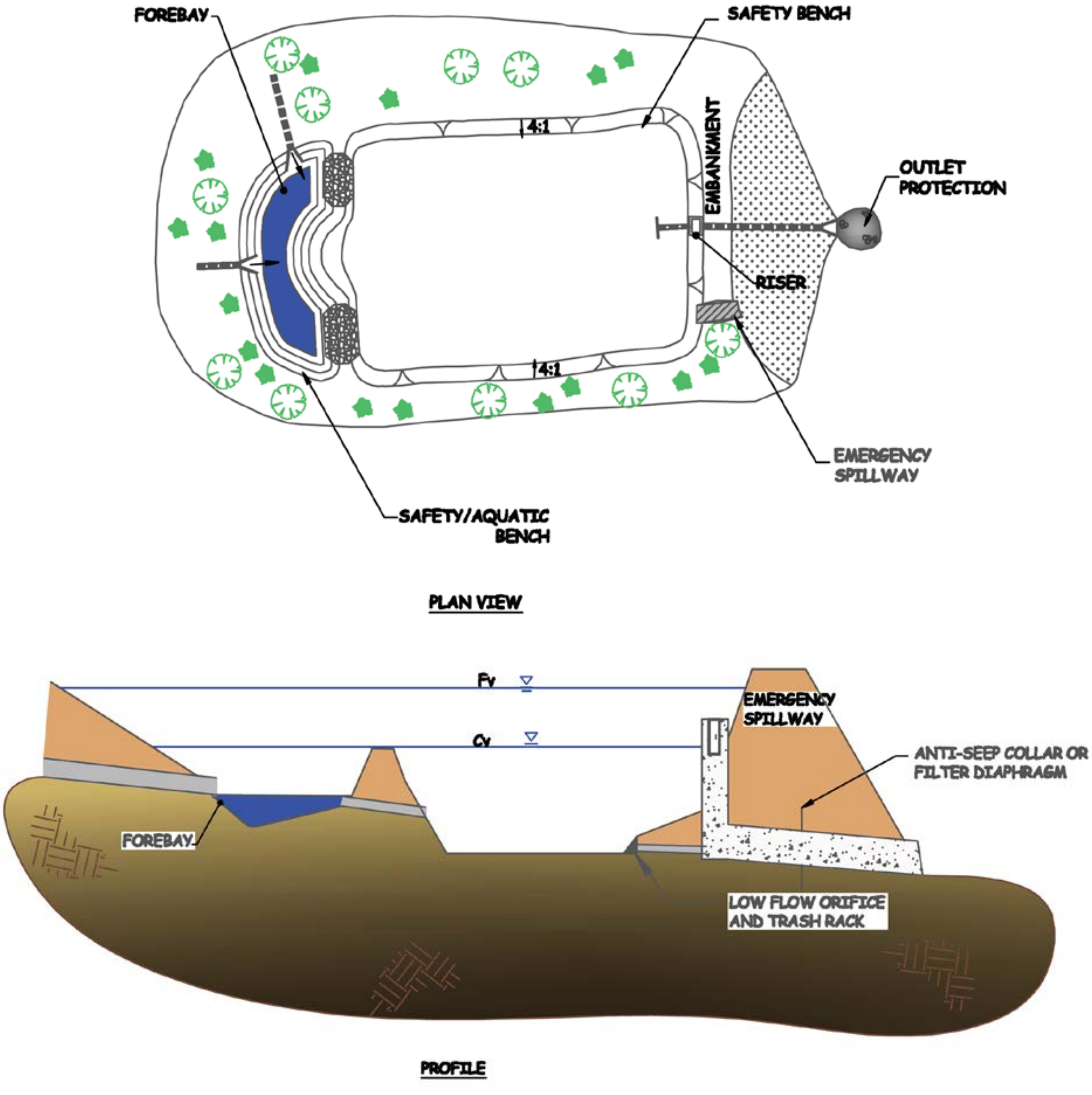


Figure 10.1. Example of a Dry Detention Pond (10-A)

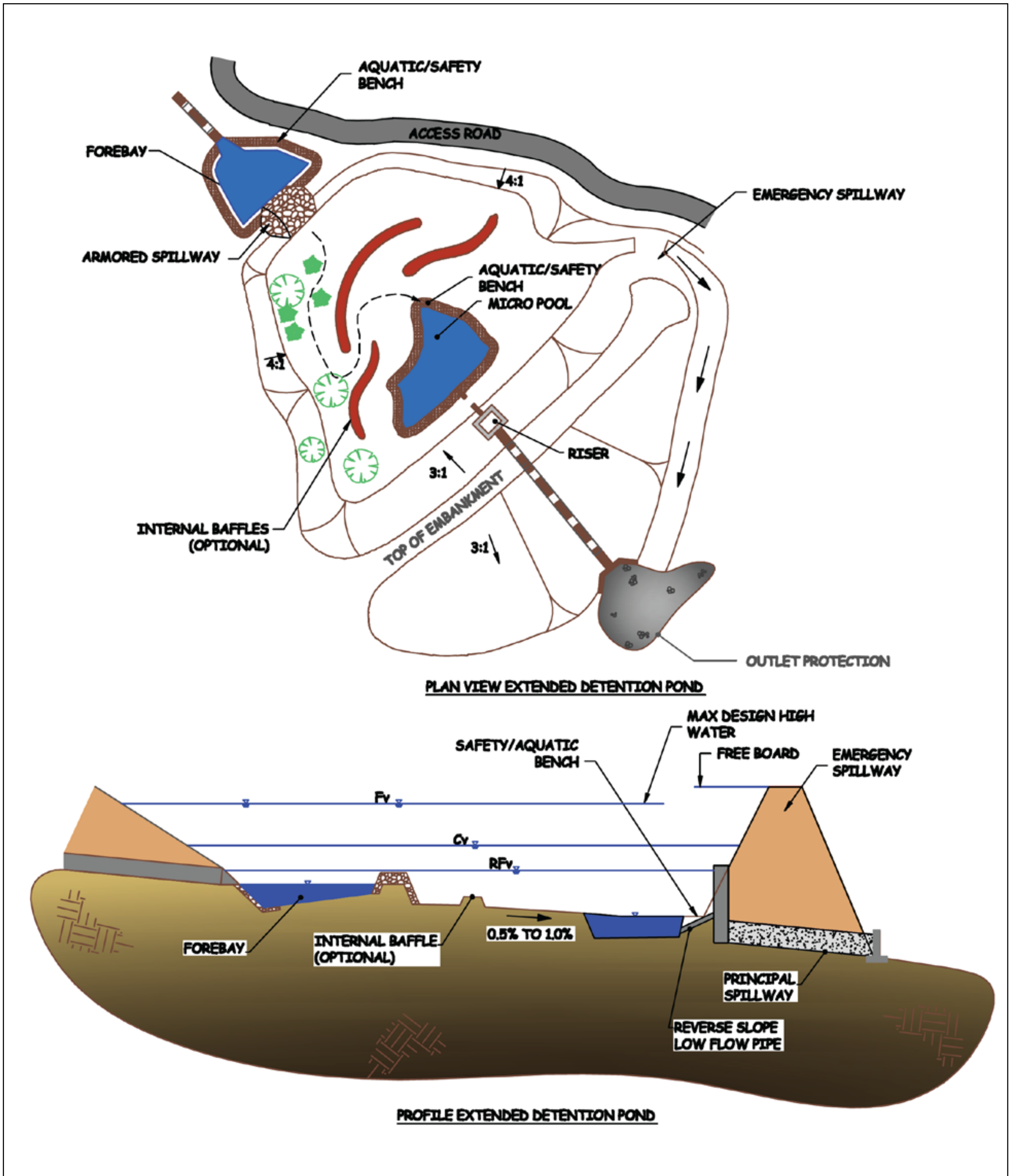


Figure 10.2. Example of a Dry Extended Detention Basin (10-B)

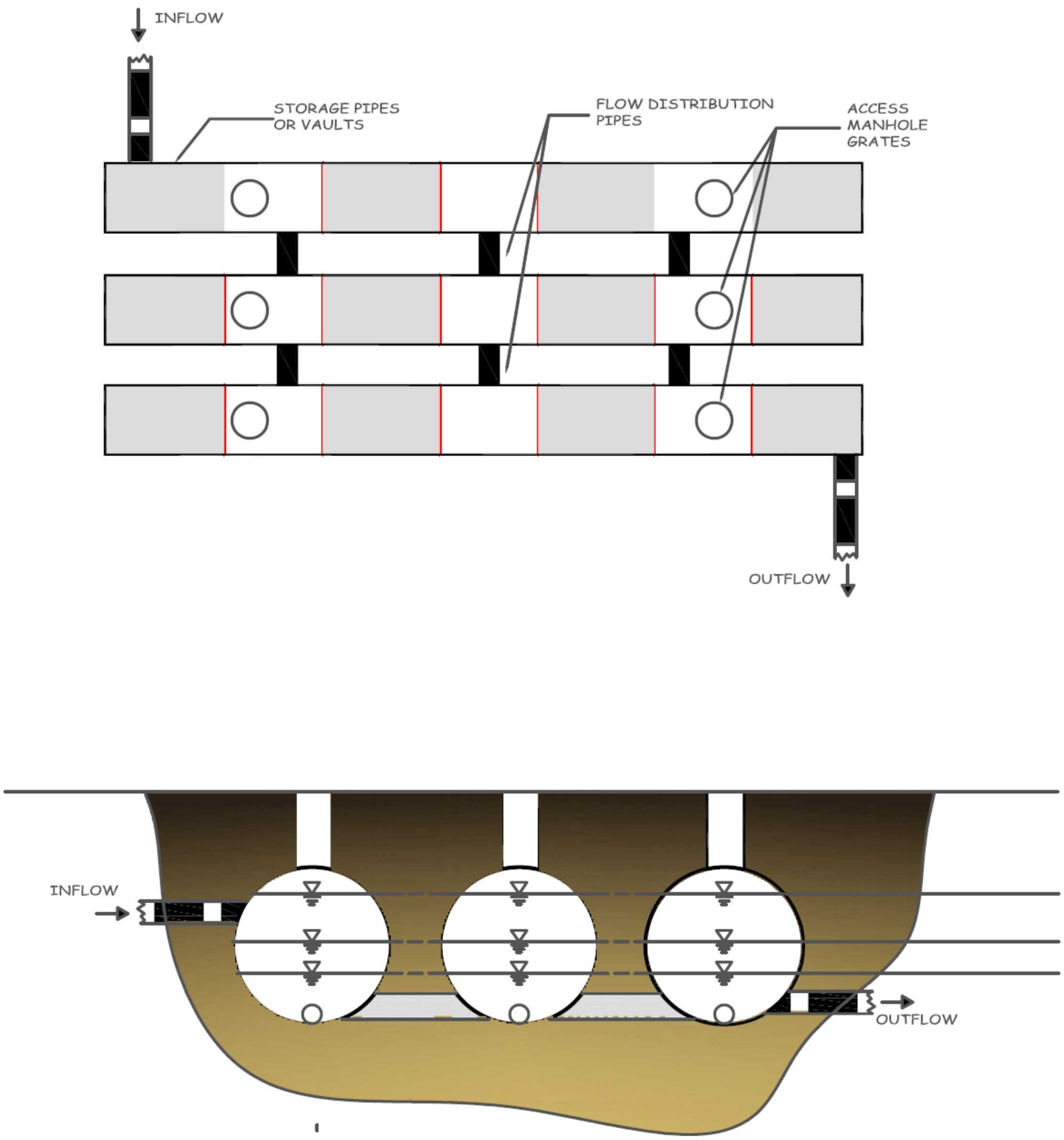


Figure 10.3. Example of an Underground Detention Facility (10-C)

10.1 Detention Practices Stormwater Credit Calculations

Both Dry Detention Ponds and Dry Extended Detention Basins receive a pollutant removal credit, while Dry Extended Detention Basins receive partial runoff reduction credit as well. Underground Detention Facilities receive no credit for runoff reduction or pollutant removal.

Table 10.1 Dry Detention Pond Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv -A/B Soil	0%
RPv - C/D Soil	0%
Cv	0%
Fv	0%
Pollutant Reduction	
TN Reduction	5%
TP Reduction	10%
TSS Reduction	10%

Table 10.2 Dry Extended Detention Basin Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv -A/B Soil	10%
RPv - C/D Soil	10%
Cv	1%
Fv	0%
Pollutant Reduction	
TN Reduction	20%
TP Reduction	20%
TSS Reduction	60%

Since Detention Practices are designed for larger storm events, rather than the RPv, the credits above are “fixed” credits – they are not based on the relative size of the practice. To receive these credits, the practice must be designed using the guidance detailed in ***Section 10.6. Detention Practices Design Criteria.***

10.2 Detention Practices Design Summary

Table 10.3 summarizes design criteria for Detention Practices. For more detail, consult Sections 10.3 through 10.7. Sections 10.8 and 10.9 describe practice construction and maintenance criteria.

Table 10.3 Dry Detention Pond (10-A) and Dry ED Basin (10-B) Design Summary

Feasibility (Section 10.3)	• 1%-3% of CDA for footprint • Recommended minimum CDA = 10 acres • Setbacks in accordance with local codes • Minimum 2' separation to groundwater or bedrock • Geotechnical investigations required • Soil tests on HSG A and B soils to determine infiltration rates • No utilities within embankments • 10' horizontal clearance from utilities • Permit required if located on perennial streams • Community and environmental concerns
Conveyance (Section 10.4)	• Designed in accordance with NRCS Small Pond Code 378 Appendix B • Use accepted hydrologic and hydraulic routing computations • Principal spillway designed to release flow rates from Cv • Principal spillway must be accessible by dry land, include anti-floatation, anti-vortex devices, trash racks, and contain watertight joints. • Dry ED design must include an orifice to drain the Rpv over 12- to 24-hours • Minimize tree clearing at outlets • Non-clogging outlets (>3" or internal orifice control) • Outlets non-erosive for the Fv (100-year storm) event. • Emergency spillway cut in fill must be lined • If no emergency spillway, 3 square feet minimum for principal spillway • Provide inlet protection
Pretreatment (Section 10.5)	• Forebays at major inlets – those contributing >10% runoff volume • Forebays sized for 10% of RPv • Exit velocity from forebay non-erosive • Direct maintenance access provided
Sizing (Section 10.6)	• Store volume equivalent to RPv (1-year, 2.7") • Detain RPv minimum 24 hours, not to exceed 48 hours
Geometry/ Features (Section 10.6)	• Flow evenly distributed across the pond bottom • Minimum longitudinal slope: HSG A/B – 1%, HSG C/D – 2% • Side slopes no steeper than 3:1 • Irregular shape and long flow path increase performance
Safety (Section 10.6)	• Prevent entry to principal spillway by small children • Restrict entry to principal spillway and lock maintenance access points • 1' freeboard above the Fv elevation; 2' freeboard if no emergency spillway •
Maintenance (Section 10.6)	• Accessible for annual maintenance • Minimum 15' wide maintenance access provided • Maintenance set aside area provided
Landscaping (Section 10.7)	• No woody vegetation within 15' of toe of embankment or 25' of pipes • Landscaping plan required

Table 10.4 Underground Detention Facilities (10-C) Design Summary

Feasibility (Section 10.3)	• Could be classified as Class V Injection Well • 1%-3% of CDA for footprint • Sufficient head room to facilitate maintenance • Setbacks in accordance with local codes • Minimum 2’ separation to groundwater or bedrock • Anti-flotation analysis for watertight systems • Geotechnical investigations required • Structural analysis required • 10’ horizontal clearance from utilities
Conveyance (Section 10.4)	• Use accepted hydrologic and hydraulic routing computations • Non-clogging outlets (>3” or internal orifice control) • Outlets non-erosive for the Fv (100-year storm) event. • Minimize tree clearing at outlets • Internal or external high flow bypass to safely pass the Fv (100-year storm) event.
Pretreatment (Section 10.5)	• Pretreatment structure to capture debris, trash, and coarse sediment • Separate vault to capture minimum 0.1” of runoff per impervious acre
Sizing (Section 10.6)	• Store volume equivalent to RPv (1-year, 2.7”)
Safety/ Maintenance Access (Section 10.6)	• Prevent access by small children • Restrict access to principal spillway and lock maintenance access points • 1’ freeboard above the Fv elevation • Maintenance access provided over the inlet pipe and outflow structure
Materials (Section 10.6)	• Watertight joints • Cast-in-place wall sections designed as retaining walls • Anti-floatation analysis required using FS=1.2

10.3 Detention Practices Feasibility Criteria

The following feasibility issues need to be evaluated when Detention Practices are considered:

EPA Requirements for Class V Injection Wells. Certain types of practices in this category, particularly Underground Detention Facilities, may be classified as Class V Injection Wells, which are subject to regulations under the Federal Underground Injection Control (UIC) program. In general, if the facility allows stormwater runoff to come in direct contact with groundwater it would meet this criterion. Facilities with a minimum 2’ vadose zone separation from the groundwater table would not meet the criterion. Designers are advised to contact the DNREC Groundwater Discharges Section for additional information regarding UIC regulations and possible permitting requirements.

Space Required. A typical Detention Practice requires a footprint of 1% to 3% of its contributing drainage area, depending on the depth of the Dry Detention Pond, Dry Extended Detention Basin, or Underground Detention Facility (i.e., the deeper the practice, the smaller footprint needed).

Contributing Drainage Area. A minimum contributing drainage area of 10 acres is recommended for Dry Detention Ponds in order to keep the required orifice size from becoming a maintenance problem. Designers should be aware that small "pocket" ponds will typically (1) have very small orifices that will be prone to clogging, (2) experience fluctuating water levels such that proper stabilization with vegetation is very difficult, and (3) generate more significant maintenance problems. When the contributing drainage area of the Detention Practice is less than 10 acres, alternative outlet configurations should be used to eliminate the possibility of clogging of the outlet.

Underground Detention Systems can be located downstream of other structural stormwater controls providing treatment of the design storm. For treatment train designs where upland practices are utilized for treatment of the RPv, designers can use a site-adjusted curve number (CN) that reflects the volume reduction of upland practices and likely reduce the size and cost of detention (see ***Section 10.6. Detention Practice Design Criteria***).

Available Hydraulic Head. The depth of a Dry Detention Pond or Dry ED Basin is usually determined by the amount of hydraulic head available at the site (dimension between the surface drainage and the bottom elevation of the site). The bottom elevation is normally the invert of the existing downstream conveyance system to which the Detention Practice discharges. The needed hydraulic head for a Dry Detention Pond or Dry ED Basin to function properly will be determined by the size of the developed drainage area and the available surface area of the basin. An Underground Detention Facility will require sufficient head room to facilitate maintenance of the underground facility.

Minimum Setbacks. Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines, structures, and wells. When not specified in local code, Detention Practices should be set back at least 20 feet from property lines, 25 feet down-gradient from building foundations, 100 feet from septic system fields, and 150 feet from public or private water supply wells.

Depth-to-Water Table and Bedrock. Dry Detention Ponds or Dry Extended Detention Basins are not allowed if the seasonal high water table or bedrock will be within 2 feet of the floor of the pond. Non-watertight Underground Detention Facilities must also maintain a separation of two feet from the bottom of the facility to the elevation of seasonal high water or bedrock. For watertight Underground Detention Facilities, an anti-flotation analysis is required to check for buoyancy problems in seasonal high water table areas.

Geotechnical Tests. At least one soil boring must be taken at a low point within the footprint of any proposed detention practice to establish the water table and bedrock elevations and evaluate soil suitability. A geotechnical investigation is required for all underground BMPs, including underground storage systems.

Soils. The permeability of soils is seldom a design constraint for Detention Practices. Soil investigation must be conducted in accordance with Department Soil Investigation Procedures at proposed Dry Detention Pond and Dry Extended Detention Basin sites to determine soil suitability. Infiltration through the bottom of the pond is typically encouraged unless it may potentially migrate laterally thorough a soil layer and impair the integrity of the embankment or other structure.

Structural Stability. Underground Detention Facilities must meet structural requirements for overburden support and traffic loading as determined by a licensed design professional, and based upon manufacturer's recommendations where applicable.

Utilities. For a Dry Detention Pond or Dry ED Basin, no utility lines shall be permitted to cross any part of an embankment. All utilities must have a minimum 10' horizontal clearance from Detention Practices unless protective measures are provided for the utility line.

Perennial Streams. Locating Dry Detention Ponds on perennial streams will require both a Section 401 and Section 404 permit from the appropriate state or federal regulatory agency.

Community and Environmental Concerns. Dry Detention Ponds and Dry ED Basins can generate the following community and environmental concerns that need to be addressed during design:

- **Aesthetic Issues.** Properly designed, constructed and maintained Dry Detention Ponds and Dry ED Basins can serve as usable active open space in a community. It is important that the design include necessary cross slope on the pond bottom, and the pond is constructed in accordance with that design so that the bottom can be maintained free of wet areas. Dry Detention Ponds and Dry ED Basins may also be landscaped with native vegetation to become an attractive habitat within a community.
- **Existing Forests.** Construction of a Dry Detention Pond or Dry ED Basin may involve extensive clearing of existing forest cover. Designers can expect a great deal of neighborhood opposition if they do not make a concerted effort to save mature trees during Dry Detention Pond and Dry ED Basin design and construction.
- **Safety Risk.** Because Dry Detention Ponds and Dry ED Basins do not maintain a permanent pool of water, they can be very attractive during runoff event when they are holding water. Gentle side slopes and personnel grating should be provided to avoid potentially dangerous situations, especially where Dry Detention Ponds and Dry ED Basin are located near residential areas.
- **Mosquito Risk.** Improperly functioning Dry Detention Ponds and Dry ED Basins that do not completely drain or take greater than 48 hours to drain, have the potential to breed mosquitoes. Mosquito problems can be minimized through simple design features and maintenance operations described in MSSC (2005).

10.4 Detention Practice Conveyance Criteria

Dry Detention Ponds and Dry ED Basins, including their conveyance systems, constructed to meet regulatory stormwater management requirements in the State of Delaware shall be designed and constructed in accordance with the USDA NRCS Small Pond Code 378 and this document. Designers must use accepted USDA NRCS hydrologic and hydraulic routing calculations to determine the required storage volume and an appropriate outlet design for Detention Practices.

Principal Spillway. For both Dry Detention Ponds and Dry Extended Detention Basins, the control structure must include orifices or outlets designed to release the required flow rates from the Cv (10-year frequency storm). The principal spillway may be composed of a structure-pipe configuration or a weir-channel configuration. A structure-pipe spillway shall be designed with anti-flotation, anti-vortex and trash rack devices on the structure. The outfall pipe and all connections to the outfall structure shall be made watertight. When reinforced concrete pipe is used for the principal spillway pipe to increase its longevity, “O-ring” gaskets (ASTM C361) shall be used to create watertight joints. When the principal spillway is composed of a weir wall discharging to a channel, the channel below the weir must be reinforced (with riprap, for example) to prevent scour of the channel.

Non-Clogging Low Flow Orifice. For Dry Extended Detention Basins, the control structure must include a low-flow orifice that will slowly release the RPv over a 24-hour period. A low flow orifice must be provided that is adequately protected from clogging by either an acceptable external trash rack or by internal orifice protection that may allow for smaller diameters. Orifices less than 3 inches in diameter may require extra attention during design, to minimize the potential for clogging.

Adequate Outfall Protection. The design must specify an outfall that will be stable for the flooding event (Fv). The channel immediately below the Dry Detention Pond or Dry ED Basin outfall must be modified to prevent erosion and conform to natural dimensions in the shortest possible distance. This is accomplished by placing appropriately sized riprap over stabilization geotextile in accordance with HEC-14 Hydraulic Design of Energy Dissipators for Culverts and Channels and Delaware Erosion and Sediment Control Handbook Specification 3.3.11 Riprap Stilling Basin or 3.3.10 Riprap Outlet Protection, which can reduce flow velocities from the principal spillway to non-erosive levels (3.5 to 5.0 fps) based upon the channel lining material.

When the discharge is to a manmade pipe or channel system, the system must be adequate to convey the required design storm peak discharge. Care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance. Excessive use of rip-rap should be avoided. The final release rate of the facility shall be modified if any increase in flooding or stream channel erosion would result at a downstream structure, highway, or natural point of restricted streamflow.

Emergency Spillway. Dry Detention Ponds and Dry ED Basins must be constructed with overflow capacity to pass the maximum design storm event (Fv) if the Fv is being routed through the pond or basin rather than bypassing. An emergency spillway designed to convey the Fv should be cut in natural ground or, if cut in fill, must be lined with stabilization geotextile and riprap. When the maximum design storm will be passing through the principal spillway, the principal spillway outlet pipe must have a minimum cross sectional area of 3 square feet.

Inflow Points Stabilization. Inflow points into the Dry Detention Pond or Dry ED Basin must be stabilized to ensure that non-erosive conditions exist during storm events up to the conveyance storm (i.e., the 10-year storm event). A forebay (See **10.5 Detention Practices Pretreatment Criteria**) shall be provided at each inflow location, unless the inlet provides less than 10% of the total design storm inflow to the Dry Detention Pond or Dry ED Basin.

Dam Safety Permits. The designer should determine whether or not the embankment meets the criteria to be regulated as a dam by the Delaware Dam Safety Regulations. In the event that the embankment is a regulated dam, the designer should verify that the appropriate Dam Safety Permit has been approved by the Department's Dam Safety Program.

Bypass. For Underground Detention Facilities, an internal or external high flow bypass or overflow shall be included in the design to safely pass the Flooding event (Fv).

10.5 Detention Practices Pretreatment Criteria

Pretreatment Forebay. A forebay must be located at each major inlet to a Dry Detention Pond or Dry Extended Detention Basin to trap sediment and preserve the capacity of the main treatment cell. The following criteria apply to forebay design:

- A major inlet is defined as an individual storm drain inlet pipe or open channel serving at least 10% of the Dry Detention Pond or Dry ED Basin's contributing runoff volume.
- The preferred forebay configuration consists of a separate cell, formed by an acceptable barrier such as a concrete weir, riprap berm, gabion baskets, etc. Riprap berms are the preferred barrier material.
- The forebay must be sized to contain ten percent of the volume of runoff from the contributing drainage impervious area from the Resource Protection event. The relative size of individual forebays will be proportional to the percentage of the total inflow to the Dry Detention Pond or Dry ED Basin. The storage volume within the forebay may be included in the calculated required storage volume for the Dry Detention Pond or Dry ED Basin.
- The forebay should be designed in such a manner that it acts as a level spreader to distribute runoff evenly across the entire bottom surface area of the main storage cell.
- Exit velocities from the forebay shall be non-erosive or an armored overflow shall be provided. Direct maintenance access for appropriate equipment shall be provided to the each forebay

Underground Detention Pretreatment. A pretreatment structure to capture sediment, coarse trash and debris must be placed upstream of any inflow points to Underground Detention Facilities. A separate sediment sump or vault chamber sized to capture a minimum of 0.1 inches per impervious acre of contributing drainage area shall be provided at the inlet for Underground Detention Facilities.

10.6 Detention Practices Design Criteria

Detention Practice Sizing. In order to receive the credits outlined in Section 10.1, Detention Practices must be sized to store a volume equivalent to the Resource Protection storm (i.e., the runoff volume from the 1-year, 2.7” Type II storm event). Further, Dry Extended Detention Basins must also be sized to detain the RPv for a minimum period of 24 hours, not to exceed 48 hours.

Detention Practices can be designed to capture and treat the remaining stormwater discharged from upstream practices to improve water quality . Detention Practices should be sized to control peak flow rates from the Conveyance Event and Flooding Event as required in accordance with the Delaware Sediment and Stormwater Regulations and accompanying Technical Document.
For treatment train designs where upland practices are utilized for treatment of the RPv, designers can use a site-adjusted CN that reflects the volume reduction of upland practices to compute the Cv and Fv that must be treated by the Detention Practice.

Dry Detention Pond and Dry Extended Detention Basin Internal Design Features. The following apply to Dry Detention Pond and Dry Extended Detention Basin design:

- ***Flow Distribution.*** Dry Detention Ponds and Dry ED Basin shall be constructed in a manner whereby flows are evenly distributed across the pond bottom, to avoid scour, promote attenuation, filtering, and, where possible, infiltration.
- ***Internal Slope.*** The minimum longitudinal slope through a pond constructed on HSG A/B soils should be 1%. The minimum longitudinal slope through a pond constructed on HSG C/D soils should be 2%.
- ***Side Slopes.*** Side slopes within the Dry Detention Pond or Dry ED Basin should have a gradient of 3H:1V to 4H:1V. The mild slopes promote better establishment and growth of vegetation and provide for easier maintenance and a more natural appearance. In no case shall the side slopes be designed and constructed steeper than 3H:1V.
- ***Long Flow Path.*** Dry Detention Pond and Dry ED Basin designs should have an irregular shape and a long flow path from inlet to outlet to increase water residence time, treatment pathways, pond performance, and to eliminate short-cutting. In terms of flow path geometry, there are two design considerations: (1) the overall flow path through the pond, and (2) the length of the shortest flow path (Hirschman et al., 2009):

- The *overall flow path* can be represented as the length-to-width ratio *OR* the flow path ratio. These ratios must be at least 2L:1W (3L:1W preferred). Internal berms, baffles, or topography can be used to extend flow paths and/or create multiple pond cells.
- The *shortest flow path* represents the distance from the closest inlet to the outlet. The ratio of the shortest flow to the overall length must be at least 0.4. In some cases – due to site geometry, storm sewer infrastructure, or other factors – some inlets may not be able to meet these ratios. However, the drainage area served by these “closer” inlets should constitute no more than 20% of the total contributing drainage area.

- ***Non-clogging Low Flow (Extended Detention) Orifice.*** The low flow ED orifice shall be adequately protected from clogging by an acceptable external trash rack. The preferred method is a hood apparatus over the orifice that reduces gross pollutants such as floatables and trash, as well as oil and grease and sediment.

  Orifices less than 3 inches in diameter may require extra attention during design, to minimize the potential for clogging. As an alternative, internal orifice protection may be used (i.e., an orifice internal to a perforated vertical stand pipe with 0.5-inch orifices or slots that are protected by wirecloth and a stone filtering jacket).

Safety Features. The following safety features apply to Detention Practices:

- The principal spillway opening as well as all inlets and outlets must be designed and constructed to prevent entry by small children. Personnel safety grates shall be installed on the inlets of all stormwater pipes 12” in diameter or larger that are not straight from the inlet to the open outlet, regardless of the length of the pipe.
- Detention practices must incorporate an additional 1 foot of freeboard above the emergency spillway, or 2 feet of freeboard if the design has no emergency spillway, for the maximum water elevation for the Fv, unless more stringent Dam Safety requirements apply.
- The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges.
- Fencing of the perimeter of Dry Detention Ponds and Dry ED Basins is discouraged. The preferred method to reduce risk is to manage the contours of the pond to eliminate drop-offs or other safety hazards.
- Maintenance access to Underground Detention Facilities should be locked at all times. The Operation and Maintenance Plan will specify how access to the Underground Detention Facility will be accomplished.

Maintenance Access. All Detention Practices shall be designed so as to be accessible to annual maintenance. A minimum 15’ wide maintenance access shall be provided from public open space or public right-of-way to the Detention Practice and around the perimeter of the Detention Practice. Adequate maintenance access must also be provided for all Underground Detention

Facilities. Access must be provided over the inlet pipe and outflow structure with access steps. Access openings can consist of a standard 30” diameter frame, grate and solid cover, or a hinged door or removable panel.

Maintenance Set-Aside Area. Adequate land area adjacent to the Dry Detention Pond or Dry ED Basin should be provided for in the Operation and Maintenance Plan as a location for disposal of sediment removed from the pond when maintenance is performed

- The maintenance set-aside area shall accommodate the volume of 0.1 inches of runoff from the Dry Detention Pond or Dry ED Basin’s contributory drainage area.
- The maximum depth of the set aside volume shall be one foot.
- The slope of the set aside area shall not exceed 5%; and
- The area and slope of the set aside area may be modified if an alternative area or method of disposal is approved by the Department or Delegated Agency.

Detention Vault and Tank Materials: Designers should consider longevity in selecting materials for construction of Underground Detention Facilities. All construction joints and pipe joints shall be water tight. Cast-in-place wall sections must be designed as retaining walls. The maximum depth from finished grade to the vault invert should be 20 feet. Manufacturer’s specifications should be consulted for proprietary Underground Detention Facilities.

Anti-floatation Analysis for Underground Detention: For watertight Underground Detention Facilities, anti-flotation analysis is required to check for buoyancy problems in the high water table areas. Anchors shall be designed to counter the pipe and structure buoyancy by at least a 1.2 factor of safety.

10.7 Detention Practices Landscaping Criteria

No landscaping criteria apply to Underground Detention Facilities.

Vegetated Perimeter. A vegetated area should be provided around the perimeter of the Detention Practice that extends at least 25 feet outward from the top of bank of the Dry Detention Pond or Dry ED Basin. Permanent structures (e.g., buildings) should not be constructed within the vegetated perimeter area. Where possible, existing trees should be preserved in the vegetated perimeter area during construction. The full width of the vegetated perimeter should be located in common open space, not within recorded lots.

The soils in the vegetated perimeter area are often severely compacted during the construction process, to ensure stability. The density of these compacted soils can be so great that it effectively prevents root penetration and, therefore, may lead to premature mortality or loss of vigor. As a rule of thumb, planting holes should be three times deeper and wider than the diameter of the root ball for ball-and-burlap stock, and five times deeper and wider for container-grown stock. Organic matter such as locally generated compost may be used to amend compacted soil to improve soil structure, help establish vegetation, and reduce runoff.

For more guidance on planting trees and shrubs in vegetated perimeter areas, consult Cappiella et al (2006).

Woody Vegetation. Woody vegetation may not be planted or allowed to grow within 15 feet of the toe of the embankment. Woody vegetation may not be planted or allowed to grow within 25 feet of the principal spillway structure or any inflow pipes.

Landscaping and Planting Plan. For Dry Detention Ponds and Dry Extended Detention Basins, a landscaping plan must be provided that indicates the methods used to establish and maintain vegetative coverage within the Detention Practice and its vegetated perimeter area. The planting plan should allow the pond to mature into a native forest in the right places, but yet keep mowable turf along the embankment and all access areas. Avoid plant species that require full shade, or are prone to wind damage.

Minimum elements of a plan include the following:

- Delineation of pondscaping zones within the pond and vegetated perimeter area
- Selection of corresponding plant species
- The planting plan
- Sources of native plant material

10.8 Detention Practices Construction Sequence

Underground Detention Facilities. Construction of proprietary Underground Detention Facilities must be in accordance with manufacturer's specifications. All runoff into the system should be blocked until the site is stabilized. The system must be inspected and cleaned of sediment after the site is stabilized.

Use of Dry Detention Pond or Dry Extended Detention Basin for Erosion and Sediment Control. A Dry Detention Pond may serve as a sediment basin during project construction. Installation of the permanent riser should be initiated during the construction phase, and design elevations should be set with final cleanout of the sediment basin and conversion to the post-construction Dry Detention Pond or Dry Extended Detention Basin in mind. The bottom elevation of the temporary sediment basin must be a minimum of six inches higher than the proposed bottom elevation of the Dry Detention Pond or Dry ED Basin to allow for accumulated sediment to be removed with the remaining material during conversion from sediment basin to permanent pond. When the sediment basin is being converted into a Dry Detention Pond or Dry ED Basin, the sediment basin must be dewatered in accordance with the approved plan and appropriate details from the Delaware Erosion and Sediment Control Handbook prior to removing accumulated sediment and regrading the pond bottom.

Dry Detention Pond and Dry Extended Detention Basin Construction Review. Multiple construction reviews are critical to ensure that stormwater ponds are properly constructed. A construction phase review checklist for Detention Practices should be used to verify that all required items have been completed. Construction reviews are required during the following stages of construction:

- Pre-construction meeting
- Initial site preparation (including installation of E&S controls)
- Construction of the embankment, including installation of the principal spillway and the outlet structure
- Excavation/Grading (interim and final elevations)
- Implementation of the pondscaping plan and vegetative stabilization
- Final inspection (develop a punch list for facility acceptance)

The following is a typical construction sequence to properly install a Dry Detention Pond or Dry Extended Detention Basin. The steps may be modified to reflect different designs, site conditions, and the size, complexity and configuration of the proposed facility.

Step 1: Stabilize the Drainage Area. Dry Detention Ponds or Dry Extended Detention Basins should only be constructed after the contributing drainage area is completely stabilized. If the proposed Dry Detention Pond or Dry ED Basin site will be used as a sediment trap or basin during the construction phase, the construction notes should clearly indicate that the facility will be dewatered, dredged and re-graded to design dimensions after the original site construction is complete.

Step 2: Assemble Construction Materials on-site, make sure they meet design specifications, and prepare any staging areas. Ensure that appropriate compaction and dewatering equipment is available. Locate the project benchmark and if necessary transfer a benchmark nearer to the Wet Pond location for use during construction.

Step 3: Install Erosion and Sediment Controls prior to construction, including temporary de-watering devices and stormwater diversion practices. All areas surrounding the pond or basin that are graded or denuded during construction must be planted with turf grass, native plantings, or other approved methods of soil stabilization.

Step 4: Clear and Strip the embankment area to the desired sub-grade.

Step 5: Excavate the Core Trench and Install the Principal Spillway Pipe in accordance with construction specification of NRCS Small Pond Code 378**.**

Step 6: Install the Riser or Outflow Structure and ensure the top invert of the overflow weir is constructed level at the design elevation.

Step 7: Construct the Embankment and any Internal Berms using acceptable material in 8 to 12-inch lifts and compact the lifts with appropriate equipment. Construction the embankment allowing for 10% settlement of the embankment.

Step 8: Excavate/Grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the Dry Detention Pond or Dry ED Basin. Construct forebays at the proposed inflow points.

Step 9: Construct the Emergency Spillway in cut or structurally stabilized soils.

***Step 10: Install Outlet Pipe*s**, including any flared end sections, headwalls, and downstream rip-rap apron protection underlain by stabilization geotextile.

Step 11: Stabilize Exposed Soils with the approved seed mixtures in accordance with the vegetative stabilization specifications on the approved Sediment and Stormwater Management Plan.

Step 12: Plant the Dry Detention Pond or Dry ED Basin and Vegetated Perimeter Area, following the pondscaping plan (see ***Section 10.7 Detention Practices Landscaping Criteria***).

Post Construction Verification. Following construction, the actual depth of each forebay and the pond or basin itself, must be measured, marked, geo-referenced on the post construction verification survey document. This simple data set will enable maintenance reviewers to determine sediment deposition rates in order to schedule sediment cleanouts.

10.9 Detention Practices Maintenance Criteria

Typical maintenance activities for Detention Practices are outlined in **Table 10.5.** Maintenance requirements for Underground Storage Facilities will generally require quarterly visual inspections from the manhole access points to verify that there is no standing water or excessive sediment buildup. Entry into the system for a full inspection of the system components (pipe or vault joints, general structural soundness, etc.) should be conducted annually. Confined space entry credentials are required for this inspection.

Table 10.5 Typical maintenance items for Detention Practices

Frequency	Maintenance Items
During establishment, as needed (first year)	• Water Dry Detention Pond and Dry ED Basin side slopes and bottom area to promote vegetation growth and survival
Quarterly or after major storms (>1 inch of rainfall)	• Remove sediment and oil/grease from inlets, pre-treatment devices, flow diversion structures, storage practices and overflow structures. • Ensure that the contributing drainage area, inlets, and facility surface are clear of debris. • Ensure that the contributing drainage area is stabilized. Perform spot-reseeding where needed. • Repair undercut and eroded areas at inflow and outflow structures.
Annually	• Measure sediment accumulation levels in forebay. Remove sediment when 50% of the forebay capacity has been lost. • Inspect the condition of stormwater inlets for material damage, erosion or undercutting. Repair as necessary. • Inspect the banks of upstream and downstream channels for evidence of sloughing, animal burrows, boggy areas, woody growth, or gully erosion that may undermine pond embankment integrity. • Inspect outfall channels for erosion, undercutting, rip-rap displacement, woody growth, etc. • Inspect condition of principal spillway and riser for evidence of spalling, joint failure, leakage, corrosion, etc. • Inspect condition of all trash racks, flashboard risers, and other appurtenances for evidence of clogging, leakage, debris accumulation, etc. • Inspect maintenance access to ensure it is free of debris or woody vegetation, and check to see whether valves, manholes and locks can be opened and operated. • Inspect internal and external side slopes of Dry Detention Ponds for evidence of sparse vegetative cover, erosion, or slumping, and make needed repairs immediately. • Monitor the growth of trees and shrubs planted in Dry Detention Ponds. Remove invasive species and replant vegetation where necessary to ensure dense coverage.

An Operation and Maintenance Plan for the project will be approved by the Department or the Delegated Agency prior to project closeout. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed. Detention Practices that are, or will be, owned and maintained by a joint ownership such as a homeowner's association must be located in common areas, community open space, community-owned property, jointly owned property, or within a recorded easement dedicated to public use.

Operation and Maintenance Plans should clearly outline how vegetation in the Dry Detention Pond or Dry ED Basin and its vegetated perimeter will be managed or harvested in the future. Periodic mowing of the vegetated perimeter area is only required within the maintenance access and the embankment. The remaining perimeter can be managed as a meadow (mowing every other year) or forest. The Operation and Maintenance Plan should schedule a shoreline cleanup at least once a year to remove trash and debris.

Maintenance of Detention Practices is driven by annual maintenance reviews that evaluate the condition and performance of the Detention Practice. Based on maintenance review results, specific maintenance tasks may be required.

10.10 References

Cappiella, K., Schueler, T., and T. Wright. 2005. *Urban Watershed Forestry Manual. Part 1: Methods for Increasing Forest Cover in a Watershed*. NA-TP-04-05. USDA Forest Service, Northeastern Area State and Private Forestry. Newtown Square, PA.

Hirschman, D., L. Woodworth and S. Drescher. 2009. *Technical Report: Stormwater BMPs in Virginia's James River Basin: An Assessment of Field Conditions & Programs*. Center for Watershed Protection. Ellicott City, MD.

11.0 Stormwater Filtering Systems

Definition:

Practices that capture and temporarily store the design storm volume and pass it through a filter media or material. Filtered runoff may be collected and returned to the conveyance system, or allowed to partially infiltrate into the soil. Design variants include:

- 11-A Non-Structural Sand Filter
- 11-B Surface Sand Filter
- 11-C Three-Chamber Underground Sand Filter
- 11-D Perimeter Sand Filter (including "Delaware" Modular Sand Filter)

Bioretention also functions as a Stormwater Filtering System; however, since it also requires a vegetative component, Bioretention is included as in a separate specification (see **Specification 2.0, Bioretention**).

Stormwater Filtering Systems are a useful practice to treat stormwater runoff from small, highly impervious sites. Stormwater Filtering Systems capture, temporarily store, and treat stormwater runoff by passing it through an engineered filter media, collecting the filtered water in an underdrain, and then returning it back to the storm drainage system. The filter consists of two chambers: the first is devoted to settling, and the second serves as a filter bed consisting of a sand filter media.

Stormwater Filtering Systems are a versatile option because they consume very little surface land and have few site restrictions. They provide moderate pollutant removal performance at small sites where space is limited. However, filters have limited or no runoff volume reduction capability, so designers should consider using up-gradient runoff reduction practices, which have the effect of decreasing the design storm volume (and size) of the filtering practices. Filtering practices are also suitable to provide special treatment at designated stormwater hotspots. A list of potential stormwater hotspots applications can be found in ***Appendix 4, Stormwater Hotspots Guidelines.***

Stormwater Filtering Systems are typically not to be designed to provide stormwater detention (Cv and Fv), but they may in some circumstances. Stormwater Filtering Systems shall generally be combined with a separate facility to provide those controls. However, the Three-Chamber Underground Sand Filter can be modified by expanding the first or settling chamber, or adding an extra chamber between the filter chamber and the clear well chamber to handle the detention volume, which is subsequently discharged at a pre-determined rate through an orifice and weir combination.

Proprietary filters must be verified for adequate performance, sizing, and longevity. (see **Specification 15, Proprietary Practices**).

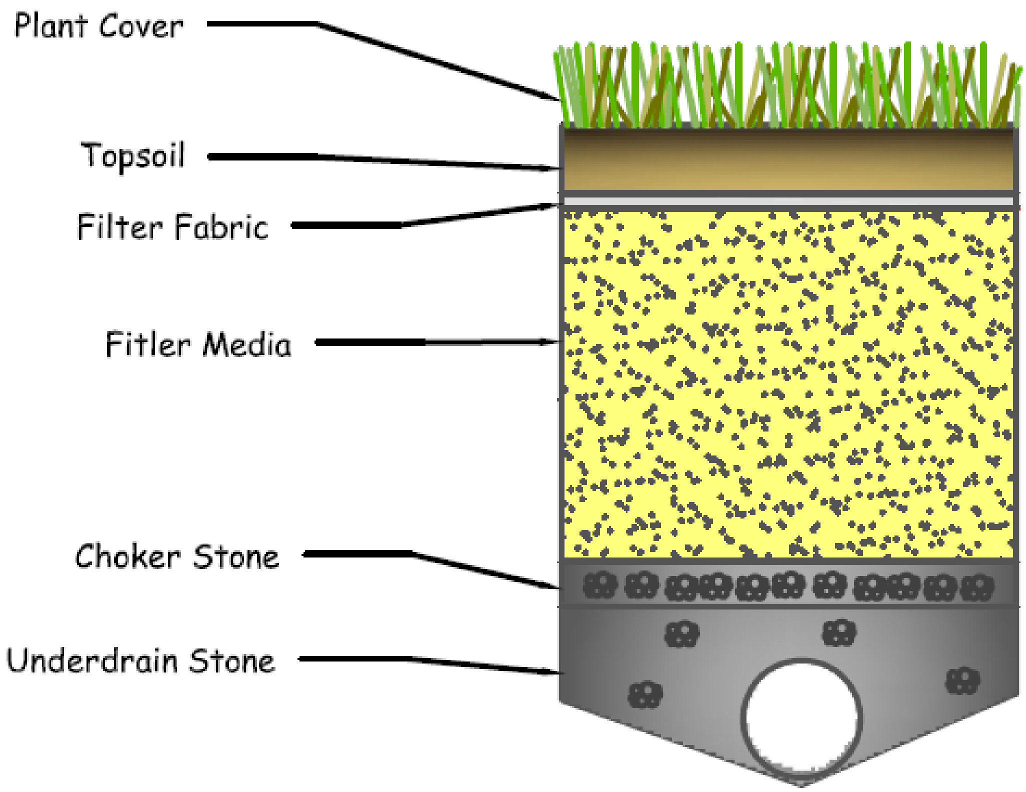


Figure 11.1. Non-Structural Sand Filter

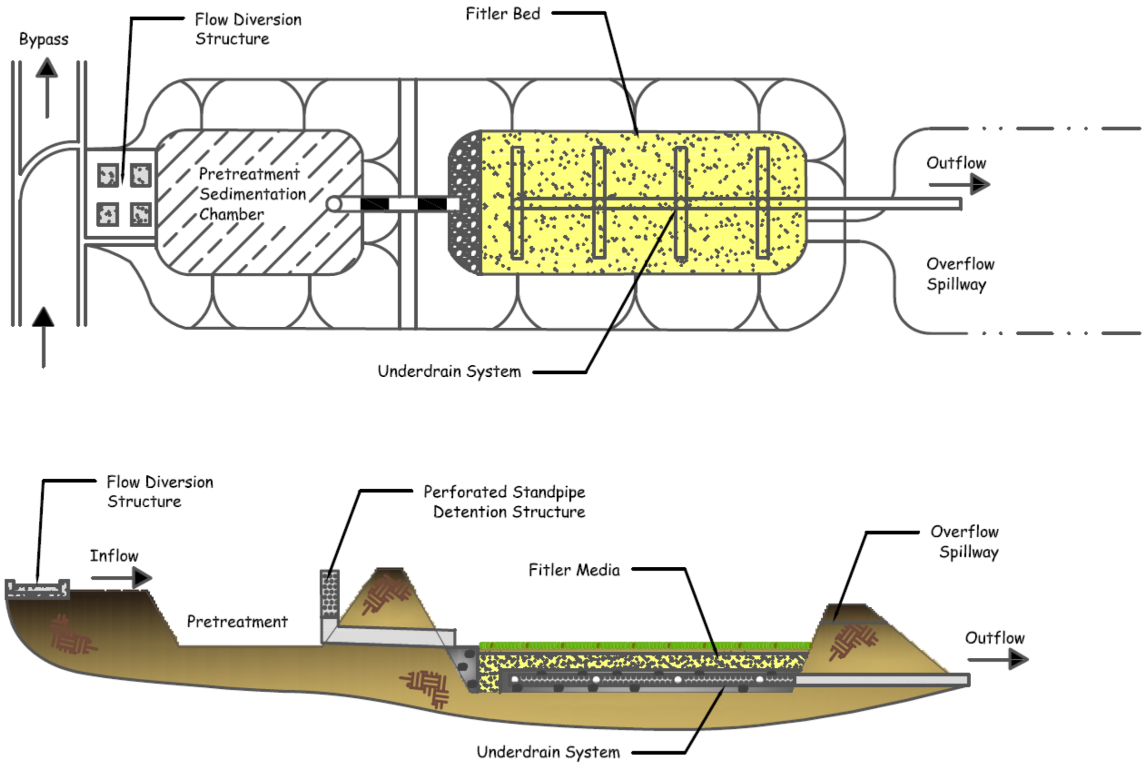


Figure 11.2. Surface Sand Filter

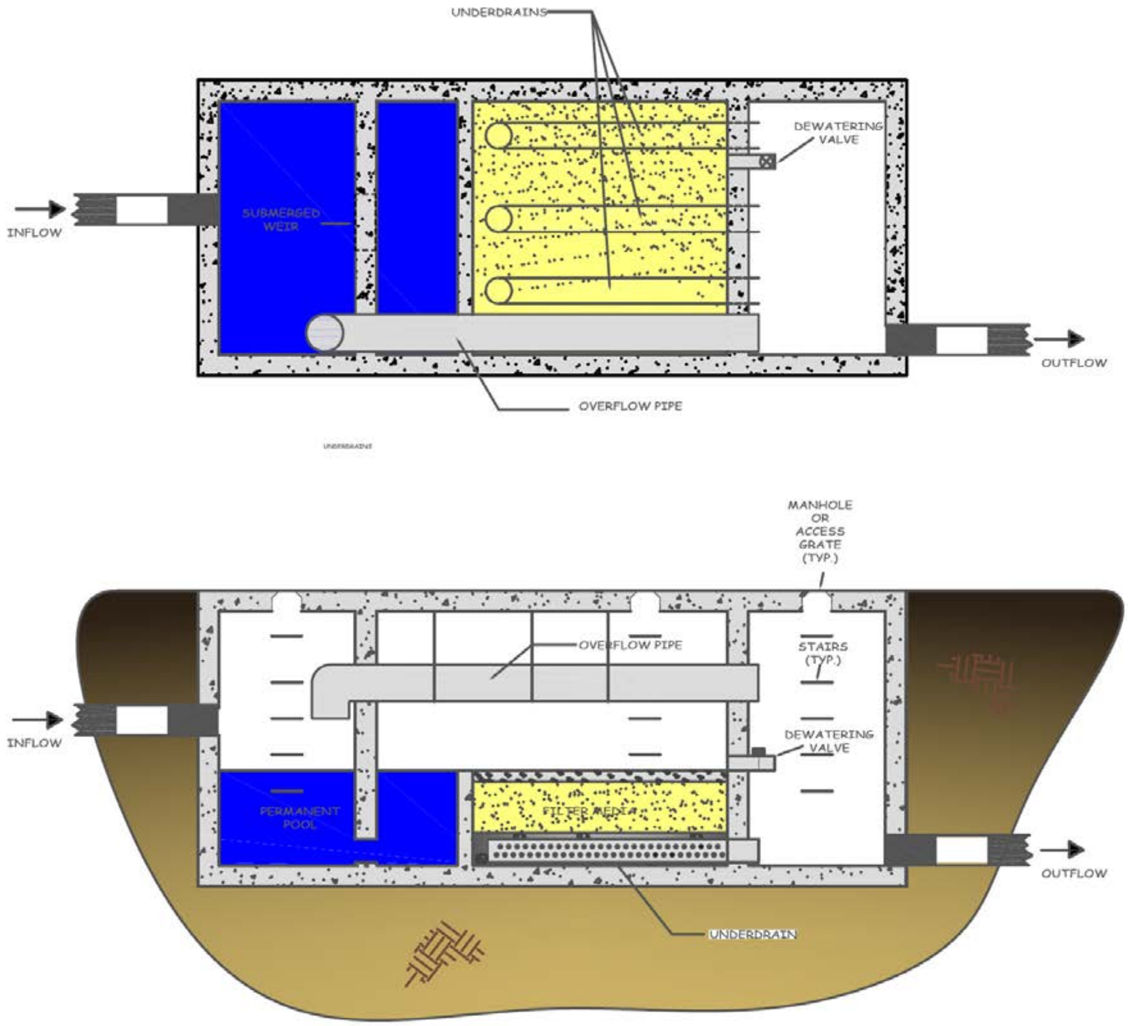


Figure 11.2. Three Chamber Underground Sand Filter

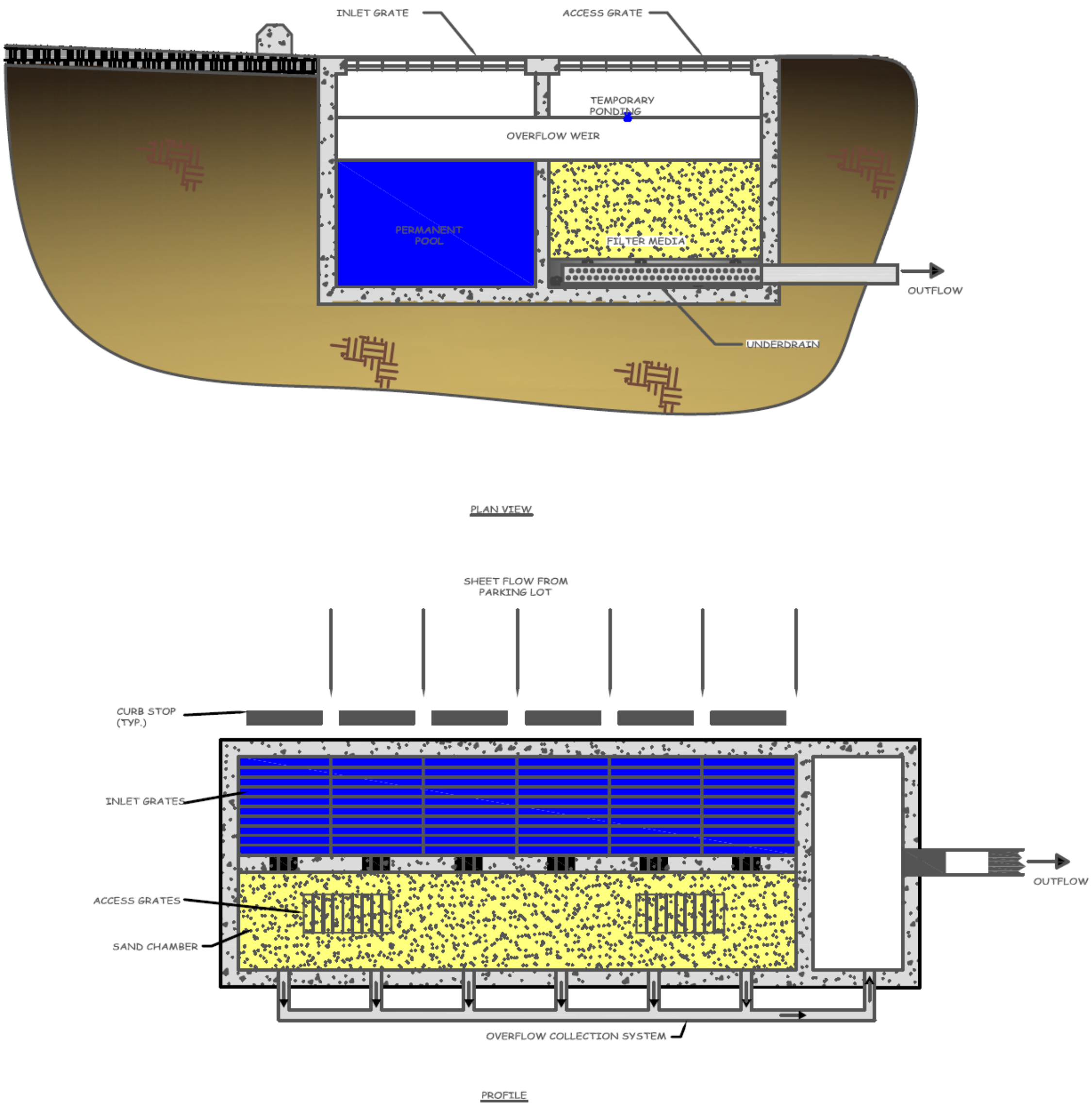


Figure 11.3. Perimeter Sand Filter

11.1. Filtering Practices Stormwater Credit Calculations

Filtering practices receive no runoff reduction credit, but are credited for pollutant filtering (see Table 11.1). In order to receive this credit, the practice must be sized according to the criteria outlined in Section 11.6.

11.1 Filtering Practices Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv -A/B Soil	0%
RPv - C/D Soil	0%
Cv	0%
Fv	0%
Pollutant Reduction	
TN Reduction	40%
TP Reduction	60%
TSS Reduction	80%

11.2 Stormwater Filtering Systems Design Summary

Table 11.2 summarizes design criteria for Stormwater Filtering Systems , and Table 11.3 summarizes the materials specifications for these practices. For more detail, consult Sections 11.3 through 11.7. Sections 11.8 and 11.9 describe practice construction and maintenance criteria.

Table 11.2 Stormwater Filtering Systems Design Summary*

	Surface and Non-Structural Filters (11-A and 11-B)	Underground and Perimeter Filters (11-C and 11-D)
Feasibility (Section 11.3)	• <5 Acre CDA, near 100% impervious • Consume 2%-3% of CDA	• <5 Acre CDA, near 100% impervious • Consume <1% of CDA
	• 10” to 10’ head requirement, with lowest requirement for Perimeter Filters (F-4) • Ideally suited to treat stormwater hotspots and parking lots. • <5 Acre CDA, near 100% impervious • Slopes <6% • 5’ clearance for utilities.	
Conveyance (Section 11.4)	• Typically designed off-line • In some cases, underground filters designed off-line; designer needs to ensure safe passage of the 10-year storm in these cases.	
Pretreatment (Section 11.5)	• Sediment chamber, *or* • A series of options including grassed	• Sediment Chamber designed to capture 25% of the design volume.

Table 11.2 Stormwater Filtering Systems Design Summary*

	Surface and Non-Structural Filters (11-A and 11-B)	Underground and Perimeter Filters (11-C and 11-D)
	channels, filter strip, check dam, and gravel diaphragm.	
Sizing: Filter Area (Section 11.6)	$SA_{filter} = (DesignVolume)(d_f) / \left[(k)(h_{avg} + d_f)(t_f)\right]$	
Variables	*Design Volume* = design storm volume, typically the water quality storm (cu. ft.) d_f = Filter media depth (thickness) = minimum 1 ft. (ft.) k = Coefficient of permeability – partially clogged sand (ft./day) = 3.5 ft./day h_f = Average height of water above the filter bed (ft.), with a maximum of 5ft./2 t_f = Allowable drawdown time = 1.67 day	
Sizing: Ponding (Section 11.6)	Minimum Ponding Volume of 75% of Design Volume	
Geometry/ Features (Section 11.6)	• Design designed to dewater within 48 hours • Sufficient head to allow gravity feeding • Preferred filter depth of 18", 12" minimum	
Safety/ Maintenance Features (Section 11.6)	• Observation wells and clean-outs • Safe maintenance access • Clearly visible (signs or markings for underground practices)	• Minimum 30" diameter manholes (for 11-C) with steps • Confined space considerations for 11-C may apply • Minimum 5' headroom for 11-C
Landscaping (Section 11.7)	• Dense, vigorous vegetation for pervious areas in the CDA • Grass cover can be used for designs 11-A and 11-B	
*Note: While proprietary filters are discussed in this document, they are highly variable in design, and consequently are not included in this table. Specification 15 outlines a process for acceptance of proprietary practices.		

Table 11.3. Stormwater Filtering Systems Material Specifications

Material	Specification
Surface Cover	*Non-structural and surface sand filters*: 3-inch layer of topsoil on top of a non-woven geotextile laid above the sand layer. The surface may also have DE #57 gravel inlets in the topsoil layer to promote filtration. *Underground sand filters:* DE #57 gravel layer on top of a coarse non-woven geotextile laid over the sand layer.
Sand	Clean AASHTO M-6/ASTM C-33 medium aggregate concrete sand with a particle size range of 0.02 to 0.04 inch in diameter.
Underdrain	The underdrain should consist of High Density Polyethylene (HDPE) smooth or corrugated flexible-wall pipe. Pipes must comply with ASHTO M252 and ASTM F405. Underdrains meeting ASTM F758 should be perforated with slots that have a maximum width of 3/8 inch and provide a minimum inlet area of 1.76 square inches per linear foot of pipe. Underdrains meeting ASTM F949 should be perforated with slots with a maximum width of 1/8 inch that provide a minimum inlet area of 1.5 square inches per linear foot of pipe. Underdrain pipe supplied with precision-machined slots provides greater intake capacity and superior clog-resistant drainage of fluids, as compared to standard round-hole perforated pipe.

	Slotted underdrain reduces entrance velocity into the pipe, thereby reducing the possibility that solids will be carried into the system. Slot rows can generally be positioned symmetrically or asymmetrically around the pipe circumference, depending upon the application.
Non-woven Geotextile	Use needled, non-woven, polypropylene geotextile meeting the following specifications: Flow Rate (ASTM D4491) ≥110 gpm/sq. ft. Apparent Opening Size (ASTM D4751) = US #70 or #80 sieve NOTE: Heat-set or heat-calendared fabrics are not recommended.
Underdrain Stone	Use DE #57 stone or the ASTM equivalent (1 inch maximum).
Impermeable Liner	Use a thirty mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd. non-woven geotextile.

11.3 Filtering Feasibility Criteria

Stormwater Filtering Systems can be applied to most types of urban land. They are not always cost-effective, given their high unit cost and small area served, but there are situations where they may clearly be the best option for stormwater treatment (e.g., hotspot runoff treatment, small parking lots, ultra-urban areas etc.). The following criteria apply to filtering practices:

Available Hydraulic Head. The principal design constraint for Stormwater Filtering Systems is available hydraulic head, which is defined as the vertical distance between the top elevation of the filter and the bottom elevation of the discharge pipe. The head required for Stormwater Filtering Systems ranges up to 10 feet, depending on the design variant. It is difficult to employ filters in extremely flat terrain, since they require gravity flow through the filter. The only exception is the Perimeter Sand Filter, which can be applied at sites with as little as 10 inches of head.

Depth to Water Table and Bedrock. The designer must assure that the seasonally high groundwater table and/or bedrock layer does not intersect the bottom invert of the filtering practice.

Contributing Drainage Area. Stormwater Filtering Systems are best applied on small sites where the contributing drainage (CDA) area is as close to 100% impervious as possible in order to reduce the risk that eroded sediments will clog the filter. A maximum CDA of 5 acres is recommended for surface sand filters, and a maximum CDA of 2 acres is recommended for perimeter or underground filters. Stormwater Filtering Systems have been used on larger drainage areas in the past, but greater clogging problems have typically resulted.

Space Required. The amount of space required for a Stormwater Filtering System depends on the design variant selected. Surface Sand Filters typically consume about 2% to 3% of the CDA, while Perimeter Sand Filters typically consume less than 1%. Underground Stormwater Filters generally consume no surface area except their manholes.

Land Use. As noted above, Stormwater Filtering Systems are particularly well suited to treat runoff from stormwater hotspots and smaller parking lots. Other applications include redevelopment of commercial sites or when existing parking lots are renovated or expanded. Stormwater Filtering Systems can work on most commercial, industrial, institutional or municipal sites and can be located underground if surface area is not available.

Site Topography. Stormwater Filtering Systems shall not be located on slopes greater than 6%.

Utilities. All utilities shall have a minimum 5' horizontal clearance from the filtering practice.

Facility Access. All Stormwater Filtering Systems shall be located in areas where they are accessible for inspection and for maintenance (by vacuum trucks).

Soils. Soil conditions do not constrain the use of Stormwater Filtering Systems. At least one soil boring must be taken at a low point within the footprint of the proposed filtering practice to establish the water table and bedrock elevations and evaluate soil suitability. A geotechnical investigation is required for all underground BMPs, including underground filtering systems. Geotechnical testing requirements are outlined in ***Appendix 1, Soil Investigation Procedures for Stormwater BMPs.***

11.4 Filtering Conveyance Criteria

Most Stormwater Filtering Systems are designed as off-line systems so that all flows enter the filter storage chamber until it reaches capacity, at which point larger flows are then diverted or bypassed around the filter to an outlet chamber and are not treated. Runoff from larger storm events should be bypassed using an overflow structure or a flow splitter. Claytor and Schueler (1996) and ARC (2001) provide design guidance for flow splitters for filtering practices.

Some underground filters will be designed and constructed as on-line BMPs. In these cases, designers must indicate how the device will safely pass larger storm events (e.g., the 10-year event) to a stabilized water course without resuspending or flushing previously trapped material.

All Stormwater Filtering Systems should be designed to drain or dewater within 48 hours after a storm event to reduce the potential for nuisance conditions.

11.5 Filtering Pretreatment Criteria

Adequate pre-treatment is needed to prevent premature filter clogging and ensure filter longevity. Dry or wet pretreatment shall be provided prior to filter media. Pre-treatment devices are subject to the following criteria:

- Sedimentation chambers are typically used for pre-treatment to capture coarse sediment particles before they reach the filter bed.

- Sedimentation chambers may be wet or dry but must be sized to accommodate at least 25% of the total design storm volume (inclusive).
- Sediment chambers should be designed as level spreaders such that inflows to the filter bed have near zero velocity and spread runoff evenly across the bed.
- Non-Structural and Surface Sand Filters may use alternative pre-treatment measures, such as a grass filter strip, forebay, gravel diaphragm, check dam, level spreader, or combination. The grass filter strip must be a minimum length of 15 feet and have a slope of 3% or less. The check dam may be wooden or concrete and must be installed so that it extends only 2 inches above the filter strip and has lateral slots to allow runoff to be evenly distributed across the filter surface. Alternative pre-treatment measures should contain a non-erosive flow path that distributes the flow evenly over the filter surface. If a forebay is used it should be designed to accommodate at least 25% of the total design storm volume (inclusive).

11.6 Filtering Design Criteria

Detention time: All Stormwater Filtering Systems should be designed to drain the design storm volume from the filter chamber within 48 hours after each rainfall event.

Structural Requirements: If a filter will be located underground or experience traffic loads, a licensed structural engineer should certify the structural integrity of the design.

Geometry. Stormwater Filtering Systems are gravity flow systems that normally require 2 to 5 feet of driving head to push the water through the filter media through the entire maintenance cycle; therefore, sufficient vertical clearance between the inverts of the inflow and outflow pipes is required.

Type of Filter Media. The normal filter media consists of clean, washed AASHTO M-6/ASTM C-33 medium aggregate concrete sand with individual grains between 0.02 and 0.04 inches in diameter.

Depth of Filter Media. The depth of the filter media plays a role in how quickly stormwater moves through the filter bed and how well it removes pollutants. The recommended filter bed depth is 18 inches. An absolute minimum filter bed depth of 12" above underdrains is required, although designers should note that specifying the minimum depth of 12" will incur a more intensive maintenance schedule and possibly result in more costly maintenance.

Non-woven Geotextile. A non-woven geotextile should be placed beneath the filter media and above the underdrain gravel layer. The geotextile should meet the criteria provided in **Table 11.3**.

Underdrain and Liner. Stormwater Filtering Systems are normally designed with an impermeable liner and underdrain system that meet the criteria provided in **Table 11.3**.

Underdrain Stone. The underdrain should be covered by a minimum 6-inch gravel layer consisting of clean, washed #57 stone.

Type of Filter. There are several design variations of the basic filter that enable designers to use Stormwater Filtering Systems at challenging sites or to improve pollutant removal rates. The choice of which filter design to apply depends on available space and hydraulic head and the level of pollutant removal desired. In ultra-urban situations where surface space is at a premium, Underground Sand Filters are often the only design that can be used. Surface and Perimeter Sand Filters are often a more economical choice when adequate surface area is available. The most common design variants include the following:

- **Non-Structural Sand Filter (11-A).** The Non-Structural Sand Filter is applied to sites less than 2 acres in size, and is very similar to a Bioretention practice (see ***Specification 2. Bioretention***), with the following exceptions:
  - The bottom is lined with an impermeable liner and always has an underdrain.
  - The surface cover is sand, turf or pea gravel.
  - The filter media is 100% sand.
  - The filter surface is not planted with trees, shrubs or herbaceous materials.
  - The filter has two cells, with a dry or wet sedimentation chamber preceding the sand filter bed.

  The Non-Structural Sand Filter is the least expensive filter option for treating hotspot runoff. The use of Bioretention areas is generally preferred at most other sites.

- **Surface Sand Filter (11-B).** The Surface Sand Filter is designed with both the filter bed and sediment chamber located at ground level. The most common filter media is sand; however, a peat/sand mixture may be used to increase the removal efficiency of the system. In most cases, the filter chambers are created using pre-cast or cast-in-place concrete. Surface Sand Filters are normally designed to be off-line facilities, so that only the desired water quality or runoff reduction volume is directed to the filter for treatment. However, in some cases they can be installed on the bottom of a Dry Extended Detention (ED) Pond (see ***Specification 10. Detention Practices***).

- **Three-Chamber Underground Sand Filter (11-C).** The Three-Chamber Underground Sand Filter is a gravity flow system. The facility may be precast or cast-in-place. The first chamber acts as a pretreatment facility removing any floating organic material such as oil, grease, and tree leaves. It should have a submerged orifice leading to a second chamber and it should be designed to minimize the energy of incoming stormwater before the flow enters the second chamber (filtering or processing chamber).

  The second chamber is the filter chamber. It should contain at the filter material consisting of gravel, geotextile fabric, and sand, and should be situated behind a weir. Along the bottom of the structure should be a subsurface drainage system consisting of a parallel PVC pipe system in a gravel bed. A dewatering valve should be installed at the top of the filter layer for safety release in cases of emergency. A by-pass pipe crossing the second chamber to carry overflow from the first chamber to the third chamber is required.

The third chamber is the discharge chamber. It should also receive the overflow from the first chamber through the bypass pipe when the storage volume is exceeded.

Water enters the first chamber of the system by gravity or by pumping. This chamber removes most of the heavy solid particles, floatable trash, leaves, and hydrocarbons. Then the water flows to the second chamber and enters the filter layer by overtopping a weir. The filtered stormwater is then picked up by the subsurface drainage system that empties it into the third chamber.

Whenever there is insufficient hydraulic head for a Three-Chamber Underground Sand Filter, a well pump may be used to discharge the effluent from the third chamber into the receiving storm or combined sewer. For Three-Chamber Underground Sand Filters in combined-sewer areas, a water trap shall be provided in the third chamber to prevent the back flow of odorous gas.

- **Perimeter Sand Filter (11-D).** The Perimeter Sand Filter also includes the basic design elements of a sediment chamber and a filter bed. The Perimeter Sand Filter typically consists of two parallel trenches connected by a series of overflow weir notches at the top of the partitioning wall, which allows water to enter the second trench as sheet flow. The first trench is a pretreatment chamber removing heavy sediment particles and debris. The second trench consists of the sand filter layer. A subsurface drainage pipe must be installed at the bottom of the second chamber to facilitate the filtering process and convey filter water into a receiving system.

  In this design, flow enters the system through grates, usually at the edge of a parking lot. The Perimeter Sand Filter is usually designed as an on-line practice (i.e., all flows enter the system), but larger events bypass treatment by entering an overflow chamber. One major advantage of the Perimeter Sand Filter design is that it requires little hydraulic head and is therefore a good option for sites with low topographic relief.

  The Delaware Modular Sand Filter was specifically developed to meet these conditions using a pre-cast structure. The Standard Detail & Specifications for the Delaware Modular Sand Filter are included as ***Appendix 11-1*** of this document.

Surface Cover. The surface cover for Non-Structural and Surface Sand Filters should consist of a 3-inch layer of topsoil on top of a non-woven filter fabric laid above the sand layer. The surface may also have pea gravel inlets in the topsoil layer to promote filtration. The pea gravel may be located where sheet flow enters the filter, around the margins of the filter bed, or at locations in the middle of the filter bed.

Underground Sand Filters should have a pea gravel layer on top of a coarse non-woven fabric laid over the sand layer. The pea-gravel helps to prevent bio-fouling or blinding of the sand surface. The fabric serves to facilitate removing the gravel during maintenance operations.

Maintenance Reduction Features. The following maintenance issues should be addressed during filter design to reduce future maintenance problems:

- ***Observation Wells and Cleanouts.*** Non-Structural and Surface Sand Filters should include an observation well consisting of a 6-inch diameter non-perforated PVC pipe fitted with a lockable cap. It should be installed flush with the ground surface to facilitate periodic inspection and maintenance. In most cases, a cleanout pipe will be tied into the end of all underdrain pipe runs. The portion of the cleanout pipe/observation well in the underdrain layer should be perforated. At least one cleanout pipe must be provided for every 2000 square feet of filter surface area.
- ***Access.*** Good maintenance access is needed to allow crews to perform regular inspections and maintenance activities. "Sufficient access" is operationally defined as the ability to get a vacuum truck or similar equipment close enough to the sedimentation chamber and filter to enable cleanouts. Direct maintenance access shall be provided to the pretreatment area and the filter bed. For underground structures, sufficient headroom for maintenance should be provided. A minimum head space of 5 feet above the filter is recommended for maintenance of the structure. However, if 5 feet headroom is not available, manhole access should be installed.
- ***Manhole Access (for Underground Sand Filters).*** Access to the headbox and clearwell of Underground Sand Filters must be provided by manholes at least 30 inches in diameter, along with steps to the areas where maintenance will occur.
- ***Visibility.*** Stormwater filters should be clearly visible at the site so inspectors and maintenance crews can easily find them. Adequate signs or markings should be provided at manhole access points for Underground Sand Filters.
- ***Confined Space Issues.*** Underground Sand Filters are often classified as a *confined space*. Consequently, special OSHA rules apply, and training may be needed to protect the workers that access them. These procedures often involve training about confined space entry, venting, and the use of gas probes.

Filter Material Specifications. The basic material specifications for filtering practices that utilize sand as a filter media are outlined in **Table 11.3**. Proprietary filters, including those being utilized for pre-treatment for rainwater harvesting systems, infiltration, and other applications that utilize alternative media must be evaluated as noted in Specification 15.

Filter Sizing . Stormwater Filtering Systems are sized to accommodate a specified design storm volume. The volume to be treated by the device is a function of the storage depth above the filter and the surface area of the filter. The storage volume is the volume of ponding above the filter. For a given design volume, **Equation 11.1** is used to determine the required filter surface area:

Equation 11.1. Minimum Filter Surface Area for Filtering Practices

$$SA_{filter} = (DesignVolume)(d_f)/\left[(k)(h_{avg} + d_f)(t_f)\right]$$

Where:

SA_{filter} = area of the filter surface (sq. ft.)
$DesignVolume$ = design storm volume, typically the water quality storm (cu. ft.)*
d_f = Filter media depth (thickness) = minimum 1 ft. (ft.)
k = Coefficient of permeability – partially clogged sand (ft./day) = 3.5 ft./day
h_f = Average height of water above the filter bed (ft.), with a maximum of 5 ft./2
t_f = Allowable drawdown time = 1.67 day

*The minimum design volume to receive credit for filtering is the runoff volume from the 2.7" NRCS Type II storm event.

The coefficient of permeability (ft./day) is intended to reflect the worst case situation (i.e., the condition of the sand media at the point in its operational life where it is in need of replacement or maintenance). Stormwater Filtering Systems are therefore sized to function within the desired constraints at the end of the media's operational life cycle.

The entire filter treatment system (including pretreatment) shall temporarily hold at least 75% of the design storm volume prior to filtration (**Equation 11.2**). This reduced volume takes into account the varying filtration rate of the water through the media, as a function of a gradually declining hydraulic head.

Equation 11.2. Required Volume of Storage for Filtering Practices

$$V_{ponding} = 0.75(DesignVolume)$$

Where:

$V_{ponding}$ = storage volume required prior to filtration (cu. ft.)

11.7 Filtering Landscaping Criteria

A dense and vigorous vegetative cover shall be established over the contributing pervious drainage areas before runoff can be accepted into the facility. Native plants should be used where possible. Stormwater Filtering Systems should be incorporated into site landscaping to increase their aesthetics and public appeal.

Surface and Non-Structural Sand Filters can have a grass cover to aid in the pollutant adsorption. The grass should be capable of withstanding frequent periods of inundation and drought.

11.8 Filter Construction Sequence

Erosion and Sediment Control. No runoff shall be allowed to enter the Stormwater Filtering System prior to completion of all construction activities, including revegetation and final site stabilization. Construction runoff shall be treated in separate sedimentation basins and routed to bypass the filter system. Should construction runoff enter the filter system prior to final site stabilization, all contaminated materials must be removed and replaced with new clean filter materials before a regulatory inspector approves its completion. The approved Sediment & Stormwater Plan shall include specific measures to provide for the protection of the filter system before the final stabilization of the site.

Filter Installation. The following is the typical construction sequence to properly install a Stormwater Filtering System. This sequence can be modified to reflect different filter designs, site conditions, and the size, complexity and configuration of the proposed filtering application.

Step 1: Stabilize Drainage Area. Filtering practices should only be constructed after the contributing drainage area to the facility is completely stabilized, so sediment from the CDA does not flow into and clog the filter. If the proposed filtering area is used as a sediment trap or basin during the construction phase, the construction notes should clearly specify that, after site construction is complete, the sediment control facility will be dewatered, dredged and regraded to design dimensions for the post-construction filter.

Step 2: Install E&S Controls for the Filtering Practice. Stormwater should be diverted around filtering practices as they are being constructed. This is usually not difficult to accomplish for off-line filtering practices. It is extremely important to keep runoff and eroded sediments away from the filter throughout the construction process. Silt fence or other sediment controls should be installed around the perimeter of the filter, and erosion control fabric may be needed during construction on exposed side-slopes with gradients exceeding 4H:1V. Exposed soils in the vicinity of the filtering practice should be rapidly stabilized by hydro-seed, sod, mulch, or other method.

Step 3: Assemble Construction Materials on-site, make sure they meet design specifications, and prepare any staging areas.

Step 4: Clear and Strip the project area to the desired subgrade.

Step 5: Excavate/Grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the filtering practice.

Step 6: Install the Filter Structure and check all design elevations (concrete vaults for surface, underground and perimeter sand filters). Upon completion of the filter structure shell, inlets and outlets should be temporarily plugged and the structure filled with water to the brim to demonstrate water tightness. Maximum allowable leakage is 5% of the water volume in a 24-hour period. If the structure fails the test, repairs must be performed to make the structure watertight before any sand is placed into it.

Step 7: Install the gravel, underdrains, and geotextile layer of the filter.

Step 8: Spread Sand Across the Filter Bed in 1 foot lifts up to the design elevation. Backhoes or other equipment can deliver the sand from outside the filter structure. Sand should be manually raked. Clean water is then added until the sedimentation chamber and filter bed are completely full. The facility is then allowed to drain, hydraulically compacting the sand layers. After 48 hours of drying, refill the structure to the final top elevation of the filter bed.

Step 9 (Surface Sand Filters Only): Install the Permeable Filter Fabric over the sand, add a 3-inch topsoil layer and pea gravel inlets, and immediately seed with the permanent grass species. The grass should be watered, and the facility should not be switched on-line until a vigorous grass cover has become established.

Step 10: Stabilize Exposed Soils on the perimeter of the structure with temporary seed mixtures appropriate for a buffer. All areas above the normal pool should be permanently stabilized by hydroseed, sod, or seeding and mulch.

Step 11*: *Conduct the final construction inspection.

Construction Inspection. Multiple construction inspections are critical to ensure that Stormwater Filtering Systems are properly constructed. Inspections are recommended during the following stages of construction:

- Pre-construction meeting.
- Initial site preparation (including installation of project E&S controls).
- Excavation/grading to design dimensions and elevations.
- Installation of the filter structure, including the water tightness test.
- Installation of the underdrain and filter bed.
- Check that stabilization in contributing area is vigorous enough to switch the facility on-line.
- Final Inspection (after a rainfall event to ensure that it drains properly and all pipe connections are watertight. Develop a punch list for facility acceptance. Log the filtering practice's GPS coordinates and submit them for entry into the local BMP maintenance tracking database.

Post Construction Verification Documentation. The following items shall be included in the

Post Construction Verification Documentation for Stormwater Filtering Systems:

- Surface dimensions of filter bed.
- Depth of filter media.
- Volume dimensions of any pre-treatment component.
- Elevations of any structural components, including inverts of pipes, weirs, etc.

11.9 Stormwater Filtering Systems Maintenance Criteria

An Operation and Maintenance Plan for the project will be approved by the Department or the Delegated Agency prior to project closeout. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed. Stormwater Filtering Systems that are, or will be, owned and maintained by a joint ownership such as a homeowner's association must be located in common areas, community open space, community-owned property, jointly owned property, or within a recorded easement dedicated to public use.

Operation and Maintenance Plans should clearly outline how vegetation in the Filtering Practice will be managed or harvested in the future. The Operation and Maintenance Plan should schedule a cleanup at least once a year to remove trash and debris.

Maintenance of Stormwater Filtering Systems is driven by annual maintenance reviews that evaluate the condition and performance of the practice. Based on maintenance review results, specific maintenance tasks may be required.

Table 11.4. Typical Stormwater Filtering System Maintenance Items and Frequency

Frequency	Maintenance Items
During establishment, as needed (first year)	• Inspect the site after storm event that exceeds 0.5 inches of rainfall. • Stabilize any bare or eroding areas in the contributing drainage area including the Wet Pond perimeter area • Water trees and shrubs planted in the Wet Pond vegetated perimeter area during the first growing season. In general, water every 3 days for first month, and then weekly during the remainder of the first growing season (April - October), depending on rainfall.
Quarterly or after major storms (>1 inch of rainfall)	• Remove debris and blockages • Repair undercut, eroded, and bare soil areas

Frequency	Maintenance Items
Twice a year	• Mowing of the Wet Pond vegetated perimeter area and embankment
Annually	• Shoreline cleanup to remove trash, debris and floatables • A full maintenance review • Open up the riser to access and test the valves • Repair broken mechanical components, if needed
One time –during the second year following construction	• Wet Pond vegetated perimeter and aquatic bench reinforcement plantings
Every 5 to 7 years	• Forebay sediment removal
From 5 to 25 years	• Repair pipes, the riser and spillway, as needed • Remove sediment from Wet Pond area outside of forebays

11.10 References

Atlanta Regional Commission (ARC). 2001. *Georgia Stormwater Management Manual, First Edition*. Available online at: http://www.georgiastormwater.com

Claytor, R. and T. Schueler. 1996. *Design of Stormwater Filtering Systems*. Chesapeake Research Consortium and the Center for Watershed Protection. Ellicott City, MD. http://www.cwp.org/PublicationStore/special.htm

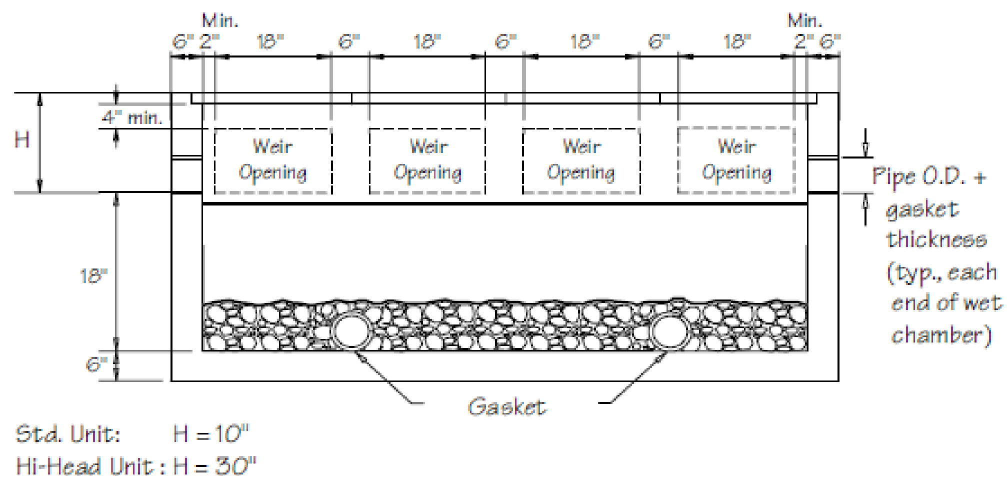
Shaver, E and R. Baldwin, *Sand Filter Design for Water Quality Treatment*, Delaware DNREC, 1991.

APPENDIX 11-1

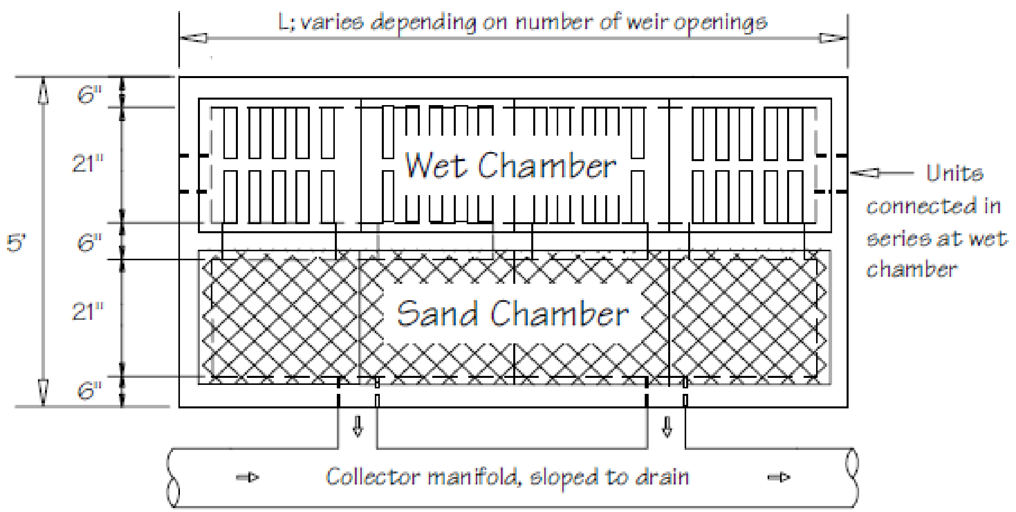
STANDARD DETAIL & SPECIFICATIONS FOR
DELAWARE MODULAR SAND FILTER

Standard Detail & Specifications

Delaware Modular Sand Filter



Elevation View

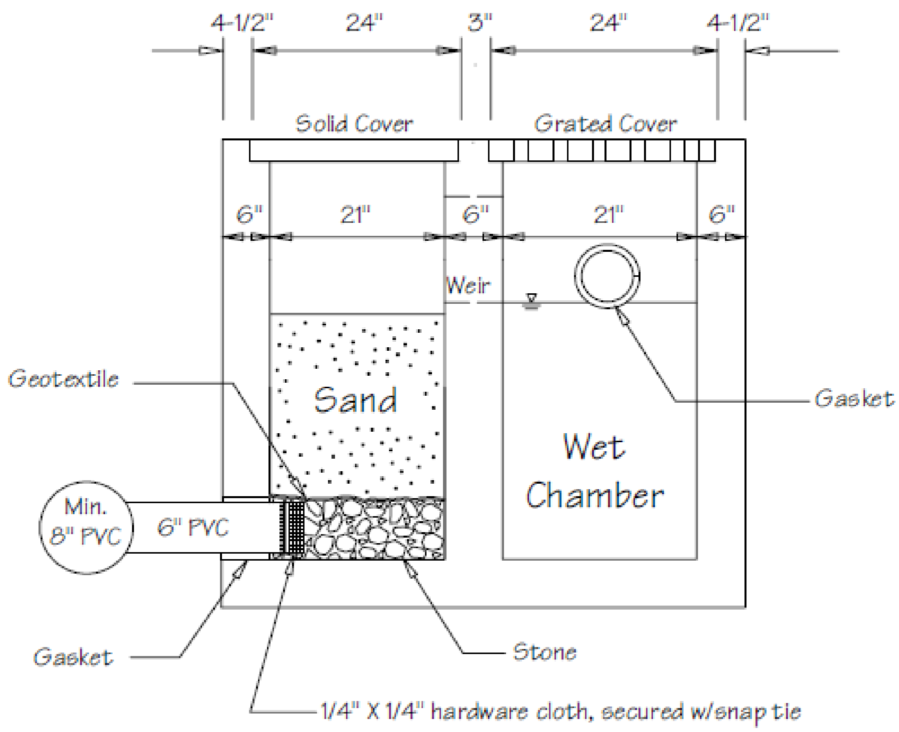


Plan View

Source:	Symbol:	Detail No.
Design: Shaver/Baldwin Modifications: Carey/Greer Drawing: Modified from Vandemark & Lynch	**Sand Filter**	**DE-SWM-1.0** Sheet 1 of 2 Date: 3/98

Standard Detail & Specifications

Delaware Modular Sand Filter



Section View

Materials

1. Sand - Concrete sand (AASHTO M6 or equiv.)
2. Stone - ¾" washed (DE No. 57 or equiv.)
3. Geotextile - Woven drainage fabric (Amoco 1198, Mirafi-700XG or equiv.)
4. Piping - PVC (Min. SDR 35)
5. Gaskets - Compatible w/ PVC schedule (A-LOK, Star Seal or equiv.)
6. Grates - Cast iron storm drain (East Jordan 6957 Type "M-2" or equiv.)
7. Solid covers - Cast iron storm drain (East Jordan 6957 Type "A" or equiv.)
8. Frames - ¼" steel angle
9. Concrete - 4500 psi at 28 days
10. Min. Reinforcing - 2 mats of 6" X 6" W4/W4 wire mesh

Source:	Symbol:	Detail No.
Design: Shaver/Baldwin Modifications: Carey/Greer Drawing: Modified from Vandemark & Lynch	**Sand Filter**	**DE-SWM-1.0** Sheet 2 of 2 Date: 3/98

12.0 Constructed Wetlands

Definition: Practices that mimic natural wetland areas to treat urban stormwater by incorporating permanent pools with shallow storage areas. Constructed Wetlands are explicitly designed to provide stormwater detention for larger storms (Cv and Fv) above the RPv storage. Design variants include:

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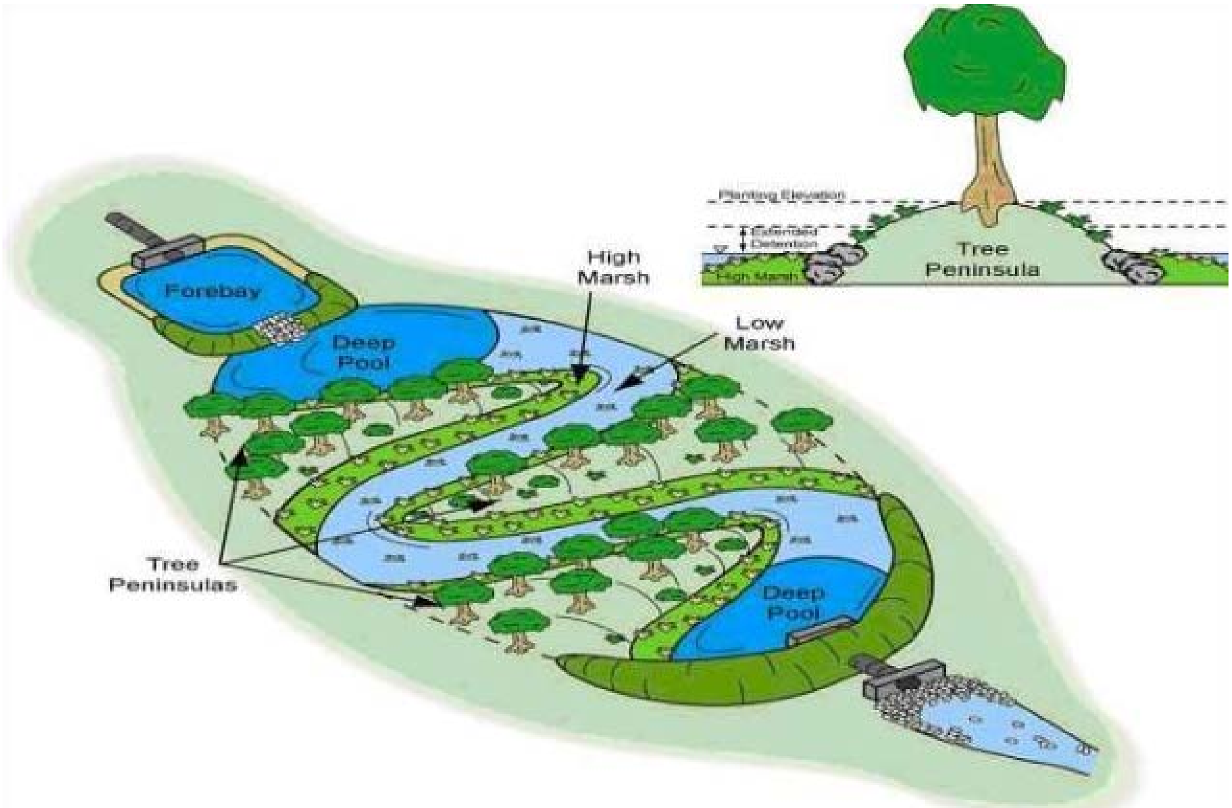
- 12-A Traditional Constructed Wetlands
- 12-B Wetland Swales
- 12-C Ephemeral Constructed Wetlands
- 12-D Submerged Gravel Wetland (to be added at a later date)

Constructed Wetlands are shallow depressions that receive stormwater inputs for water quality treatment. The majority of the wetland surface area is covered by shallow (<1' deep) wetland area, with greater depths in the forebay and pools within the wetland. Wetlands possess variable microtopography to promote dense and diverse wetland cover. Runoff from each new storm displaces runoff from previous storms, and the long residence time allows multiple pollutant removal processes to operate. The wetland environment provides an ideal environment for gravitational settling, biological uptake, and microbial activity.

The Constructed Wetlands design variants all share commonalities, but are also unique in their performance credits. None of the design variants receive any retention allowance, though they all have pollutant reduction capabilities. Traditional Constructed Wetlands (12-A), should be considered for use after all other upland runoff reduction opportunities have been exhausted and there is still a remaining treatment volume or runoff from larger storms (i.e. 10-year, 100-year or flood control events) to manage. Both Wetland Swales (12-B) and Ephemeral Constructed Wetlands (12-C) can provide some runoff reduction credits, particularly in well drained soils. Submerged Gravel Wetlands are to be added at a later date, and will only provide pollution reduction credits.

Constructed Wetlands have both community and siting criteria (see *Section 12.3 Wetland Feasibility Criteria*) that should be considered before incorporating the stormwater practice onsite.

Figure 12.1. Typical Traditional Constructed Wetland Plan View



12.1 Wetland Stormwater Credit Calculations

Stormwater wetlands receive 0% retention credit (R_v) and pollutant removals are outlined in **Table 12.1**. As a treatment practice, the wetland must be sized according to the standards outlined in Section 12.6 to receive full pollutant removal credit.

Table 12.1-A Traditional Constructed Wetlands Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv -A/B Soil	0%
RPv - C/D Soil	0%
Cv	0%
Fv	0%
Pollutant Reduction	
TN Reduction	30% Removal Efficiency
TP Reduction	40% Removal Efficiency
TSS Reduction	80% Removal Efficiency

Table 12.1-B Wetland Swale Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv -A/B Soil	15% Annual Runoff Reduction
RPv - C/D Soil	10% Annual Runoff Reduction
Cv	1% of RPv Allowance
Fv	0%
Pollutant Reduction	
TN Reduction	100% of Load Reduction + 20% Removal Efficiency
TP Reduction	100% of Load Reduction + 30% Removal Efficiency
TSS Reduction	100% of Load Reduction + 60% Removal Efficiency

Table 12.1-C Ephemeral Constructed Wetland Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv -A/B Soil	40% Annual Runoff Reduction
RPv - C/D Soil	10% Annual Runoff Reduction
Cv	1% of Rpv Allowance
Fv	0%
Pollutant Reduction	
TN Reduction	100% of Load Reduction + 20% Removal Efficiency
TP Reduction	100% of Load Reduction + 30% Removal Efficiency
TSS Reduction	100% of Load Reduction + 60% Removal Efficiency

12.2 Stormwater Wetlands Design Summary

Table 12.2 summarizes design criteria for stormwater wetlands. For more detail, consult Sections 12.3 through 12.7. Sections 12.8 and 12.9 describe practice construction and maintenance criteria.

Table 12.2 Stormwater Wetland Design Summary

Feasibility (Section 12.3)	• Requires a water balance calculation for drainage areas less than 5 acres. • Consumes about 10% of CDA. • Contributing slopes <8%. • Setbacks from property lines, buildings, septic fields, and wells. • Typically located in HSG C and D soils, or in areas of high groundwater. • Avoid construction within jurisdictional wetlands. Jurisdictional determinations and permits maybe required. Evaluate impacts to downstream waters, including existing wetlands.
Conveyance (Section 12.4)	• Max. 1% slope within wetland cells. • Max. 1 foot drop between wetlands cells. • Removable flashboard risers recommended to set pool elevation.
Pretreatment (Section 12.5)	• Sediment Forebay at Piped Inlets (Reference Wet Pond specification for additional information).
Sizing (Section 12.6)	• RPv event: Max. 12" above the normal pool elevation (no more than 6" after 48hrs, except 12-C) • Fv event: Max. 2.5 ft above the normal pool elevation. • Min. 1 ft of freeboard from the design high water surface elevation to the nearest structure, roadway, etc (can be outside the extents of the facility). • 15% to 35% of the total water storage must be provided within the permanent pools (12-A only).

Table 12.2 Stormwater Wetland Design Summary

<table>
<tr><td rowspan="2">Geometry</td><td>Traditional Constructed Wetland (12-A)
• 2:1 overall flow path to linear length ratio.
• 0.5:1 shortest flow path to overall length.
• Max. 20% of the contributing may enter with less than a 1:1 ratio of flow path to overall length.
• Side slopes 4:1 or flatter..
• Deep Pool depth minimum 18"; 22" if no groundwater source.
• Create microtopography within the wetland</td><td>Wetland Swale (12-B):
• Min. 1' bottom width, max 6'.
• Min. 4' wide bench set at 1-yr elevation.
• Side slopes 3:1 or flatter.
• Max. 1% avg. slope (increased if checkdams are used)
• Seasonal high groundwater may intersect the low flow channel to promote aquatic vegetation.
• Min. 100' length</td></tr>
<tr><td>Ephemeral Constructed Wetland (12-C)
• Side slopes 4:1 or flatter.
• Groundwater below bottom of wetland (seasonal high groundwater may intersect).</td><td>Submerged Gravel Wetland (12-D)
• To be added at a later date.</td></tr>
<tr><td>Landscaping (Section 12.7 and Landscaping Criteria Specification)</td><td colspan="2">• Min. 75% Native Species planted.
• Match Plants to Inundation Zones.
• Integrate trees into design (not for Wetland Swale, 12-B).
• Min. 4 aggressive colonizer species.
• Reference Landscape Criteria Specification for additional information.</td></tr>
</table>

12.3 Wetland Feasibility Criteria

Constructed wetland designs are subject to the following site constraints:

Adequate Water Balance. Traditional Constructed Wetlands (12-A) must have enough water supplied from groundwater, runoff or baseflow so that the permanent pools are designed to not go dry after a 30-day summer drought. A simple water balance calculation must be performed using the equation provided in *Section 12.6. Water Balance Testing* for drainage areas less than 5 acres.

Contributing Drainage Area (CDA). The contributing drainage area must be large enough to sustain a permanent water level within the stormwater wetland. If the only source of wetland hydrology is stormwater runoff, then typically more than 2 to 3 acres of drainage area is needed to maintain constant water elevations. Smaller drainage areas are acceptable if the bottom of the wetland intercepts the groundwater table or if the designer and the landowner are willing to accept periods of relative dryness (i.e., Ephemeral Constructed Wetlands, 12-C), and the plant species are chosen to accommodate this design variable.

Space Requirements. Constructed Wetlands normally require a footprint that takes up about 10% of the contributing drainage area, depending on the average depth of the wetland.

Site Topography. Wetlands are best applied when the grade of contributing slopes is less than 8%.

Reference ***Specification 6.0. Restoration Practices*** for additional information on a step pool approach to Constructed Wetlands that can be applied on steep sloped areas.

Available Hydraulic Head. The permanent pool elevation is typically fixed by the elevation of the existing downstream conveyance system to which the wetland will ultimately discharge. Because the storage needed for storm events in Constructed Wetlands is shallow, the amount of head needed is typically less than for Wet Ponds, usually a minimum of 2 to 4 feet.

Minimum Setbacks. Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines, structures, utilities, and wells. As a general rule, the edges of Constructed Wetlands should be located at least 20 feet away from property lines, 25 feet from building foundations, 100 feet from septic system fields, and 150 feet from public and private water supply wells.

Depth to Water Table. The depth to the groundwater table is not a major constraint for Constructed Wetlands, since a high water table can help maintain the permanent pool elevation. However, designers should keep in mind that high groundwater inputs may reduce pollutant removal rates, increase excavation costs and reduce the storage volume. For Ephemeral Constructed Wetlands, 12-C, the normal groundwater elevation shall be below the bottom of the wetland, though the seasonal high groundwater may fluctuate within the storage area.

Soils. Soil tests must be conducted to determine the infiltration rates and other subsurface properties of the soils underlying the proposed wetland. Highly permeable soils will make it difficult to maintain a healthy permanent pool. Underlying soils of Hydrologic Soil Group (HSG) C or D should be adequate to maintain a permanent pool. Most HSG A soils and HSG B soils are only suitable for variants 12-B or 12-C.

Use of, or Discharges to, Natural Wetlands. Constructed wetland should be constructed off-line from and designed to avoid impacts to federal or state jurisdictional waters, including perennial and intermittent streams and ditches, and tidal and non-tidal wetlands. Constructed wetlands may not be located within or otherwise impact federal or state jurisdictional waters without first obtaining a permit from the appropriate agency. Designers should request a jurisdictional determination from the federal regulatory agency (U.S. Army Corps of Engineers, Philadelphia District, 215-656-6728) and the state regulatory agency (Delaware Department of Natural Resources and Environmental Control, Wetland and Subaqueous Lands Section, 302-739-9943) to ensure that all federal and state jurisdictional areas are identified. An environmental consultant can be hired to assist with the determination.

Community and Environmental Concerns. In addition to the community and environmental concerns that can exist for Wet Ponds, Constructed Wetlands can generate the following, which must be addressed during design:

- **Aesthetics and Habitat.** Constructed Wetlands can create wildlife habitat and can also become an attractive community feature. Designers should think carefully about how the wetland plant community will evolve over time, since the future plant community may not resemble the one initially planted. A management plan must be put in place to help control noxious weeds and threatening invasive species from colonizing the wetlands.
- **Existing Forests.** Given the large footprint of a Constructed Wetland, there is a chance that the construction process may result in extensive tree clearing. The designer should preserve mature trees during the facility layout, and he/she should consider creating a wooded wetland (see Cappiella et al., 2006) to reduce clearing. Any felled trees, including the root wad, can be placed in the Constructed Wetland to provide wildlife habitat, bank stabilization, and shade.
- **Safety Risk.** Constructed Wetlands are generally safer than Wet Ponds due to their reduced depth, although forebays and deep micropools should be designed with aquatic benches to reduce safety risks.
- **Mosquito Risk.** Mosquito control can be a concern for Constructed Wetlands if they are under-sized or have a small contributing drainage area. Deepwater zones serve to keep mosquito populations in check by providing habitat for fish and other pond life that prey on mosquito larvae. Few mosquito problems are reported for well designed, properly-sized and frequently-maintained Constructed Wetlands; however, no design can eliminate them completely. Simple precautions can be taken to minimize mosquito breeding habitat within constructed wetlands (e.g., constant inflows, benches that create habitat for natural predators, and constant pool elevations –MSSC, 2005). Wetland Swales, due to the lack of deeper pools, may have higher mosquito populations, and should have limited residential applicability.

12.4 Wetland Conveyance Criteria

The longitudinal slope profile within individual wetland cells should generally be flat from inlet to outlet, at 1% maximum. The recommended maximum elevation drop between wetland cells should be 1 foot or less.

While many different options are available for setting the normal pool elevation, it is strongly recommended that removable flashboard risers be used, given their greater operational flexibility to adjust water levels following construction (see Hunt et al, 2007). A weir or spillway can also be designed to accommodate passage of the larger storm flows at relatively low ponding depths.

12.5 Wetland Pretreatment Criteria

Sediment regulation is critical to sustain Constructed Wetlands. Consequently, a forebay shall be located at the inlet, and a micropool pool shall be located at the outlet. Forebays are designed in the same manner as Wet Ponds. Reference the design criteria below for additional information.

12.6 Wetland Design Criteria

<u>Variant 12-A, Traditional Constructed Wetlands:</u>

Wetland Sizing. Traditional Constructed Wetlands provide water quality enhancement for stormwater volumes remaining after upstream practices have provided runoff reduction. Additionally, stormwater wetlands can be sized to control flows from the Cv and Fv storms. The available storage volume of storm events in Constructed Wetlands is equal to the volume provided above the permanent pool, or the normal water surface elevation. The permanent pool volume, or the volume below the normal water surface elevation, must account for a minimum of 15 to 35% of the total storage volume to maintain a healthy system.

The Constructed Wetland must be sized so that the 1-year RPv event has a maximum ponding depth of 12" above the normal water surface elevation, in order to reduce impact on the aquatic plantings. In addition, the RPv must be attenuated for a minimum of 24-hours, although no more than 6" of water can be ponded for more than 48 hours. The 100-year Fv event has a maximum ponding depth of 2.5 feet above the normal water surface elevation. Additionally, 1 foot of freeboard above the Fv or largest design storm water surface elevation must be provided to the surrounding roadways and structures requiring a Certificate of Occupancy. The extents of the Fv or highest design storm must be clearly denoted on the Sediment and Stormwater Management Plans.

Internal Design Geometry. Traditional Constructed Wetlands can be designed in several ways, all of which promote diverse emergent and aquatic vegetation, as well as anaerobic and aerobic conditions within the water to promote pollutant removal. In all cases, varied topography within each component of the wetland is encouraged to provide diverse ecology (e.g., hummocks, forested peninsulas, horizontal tree stumps, boulders, etc). Research and experience have shown that the internal design geometry and depth zones are critical in maintaining the pollutant removal capability and plant diversity of stormwater wetlands. Wetland performance is enhanced when the wetland has multiple cells, longer flowpaths, and a high ratio of surface area to volume.

Whenever possible, constructed wetlands should be irregularly shaped with long, sinuous flow paths. The total length of the flow path compared to the linear length through the wetland area, must be a minimum ratio of 2:1. In addition, the ratio of the shortest flow path through the system (due to an inlet located near the outlet) to the overall length must be at least 0.5:1. The drainage area served by any inlets located less than a 0.5:1 ratio shall constitute no more than 20% of the total contributing drainage area.

One continuous winding system can be designed that distributes the runoff through wetland areas and deeper permanent pools. The flow through the system shall be limited to maximum of 1% average slope excluding any drops or riffles. At least one shallow wetland area and one permanent pool area must be provided, but there is no maximum on how many times the systems can be alternated. See below for more detailed information on the various components.

If a more varied range in elevation is desired, a more step pool approach can be taken, where the different cells can be separated in elevation by bio or compost logs, sand berms anchored with rocks/boulders, or other stabilized protection. Forested peninsulas can also be extended across 95% of the width of the wetland, creating two separate zones. Riffles, or rock lined slopes of maximum 8%, can also be used to adjust the grades. The maximum elevation difference between the various cells shall be 1 foot.

Inundation Zones.

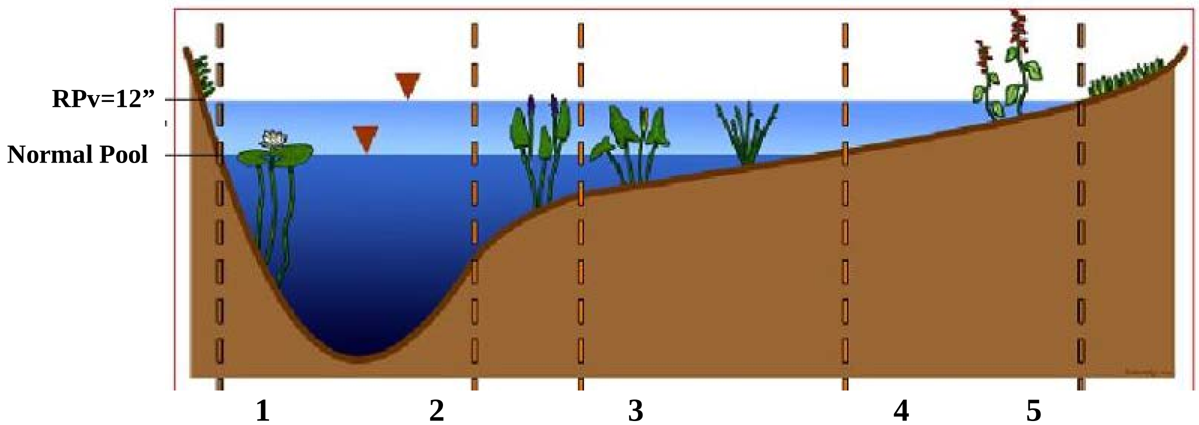


Figure 12.4. Traditional Constructed Wetland Inundation Zones: (1) Deep Pool (depth -36 to -18 inches), (2) Transition Zone (depth -18 to -6 inches), (3) Low Marsh Zone (depth -6 inches to normal pool), (4) High Marsh Zone (normal pool to +12 inches), and (5) Floodplain (+12 to +30 inches) (adapted from Hunt et al,. 2007).

Zone 1:

- ***Forebays.*** For all designs a forebay must be included at all pipe inlets to provide sedimentation prior to the runoff entering the main wetland system. The forebay must be 3 to 4 foot deep and follow the forebay specifications as described in ***Specification 13 – Wet Ponds***. The forebay will allow for easier access of accumulated sediments rather than being dispersed throughout the wetland system. In some instances, it might be desired to direct water from a Wet Pond to a wetland system, in which case a specified forebay is not necessary since one is provided in the Wet Pond.

- ***Deep Pools.*** The volume of water stored in the deep pools, also referred to as micropools, must be at least 15% of the total water storage volume. At least two deep pools in addition to the forebay must be provided, one of which must be located prior to the outlet location to provide for additional sediment deposition. Deep pools can help to provide fish habitat, cooler water temperatures, energy dissipation, and sedimentation. These interior deep pools range from -18 inches to -36 inches in depth below the normal pool elevation, and must be designed to remain permanently saturated. If groundwater will not support the permanent pool elevation in the summer months, then the minimum deep pool elevation should be lowered to -22 inches. The deep pools must be hydraulically connected within the water flow path. The deep pools shall be designed with a slope not steeper than 3:1.

Zone 2: Transition Zone. Zone 2 is only allowed as a short transition zone between the deeper pools and the low marsh zone, and ranges from -6 to -18 inches below the normal pool elevation. In general, this transition zone must have a maximum slope of 3:1, or flatter, from the deep pool to the low marsh zone. It is advisable to install biodegradable erosion control fabrics or similar materials during construction to prevent erosion or slumping of this transition zone.

Zone 3: Low Marsh Zone. Most of the wetland surface area will exist between the two marsh zones, zones 3 and 4. The low marsh zone ranges from 6 inches below the normal pool elevation to the normal pool elevation. It should therefore normally be saturated, and planted with species that thrive in this wet condition. The slope within the low marsh zone shall not be steeper than 4:1. Since this zone provides essential wetland function in between storm events, it should have a surface area between 75 and 125% of the high marsh zone surface area.

Zone 4: High Marsh Zone. The upper end of the marsh zone is the high marsh zone, which ranges from the normal pool elevation to +12 inches, allowing the RPv to inundate to the top of the high marsh zone. Where conditions allow, the RPv ponding depth should be reduced to be closer to 6", which will increase the plant survivability. The slope within the high marsh zone shall not be steeper than 4:1, and typically much flatter marsh zones are designed to increase storage.

Zone 5: Floodplain. Any storm events above the RPv event, should inundate into the floodplain area. A low floodplain should range between +12 and +18 inches above the normal water surface elevation, and be planted with plants suited for infrequent to temporary saturations, depending on weather patterns. An upper floodplain of elevations ranges +18 to +30 inches provides storage for the higher storm events, including the Fv. The two floodplains areas can be combined for smaller drainage areas less than 10 acres. Also, if the Constructed Wetland is connected to a Wet Pond then the Wet Pond can be utilized for the storage of the higher storm events, and the floodplain storage within the Constructed Wetland can be reduced. The slope within the floodplain shall not be steeper than 4:1, and typically much flatter floodplains are designed to increase storage.

Vegetated Perimeter. A minimum 50 foot wide vegetated perimeter around the wetland area must be planted with appropriate grasses, trees and shrubs (the emergency spillway shall either be grass or riprap). Existing vegetation can and should remain in the perimeter area, so long as noxious species are eradicated and invasive species are controlled.

Water Balance Testing. Traditional Constructed Wetlands can be scaled to accommodate small drainage areas, although it is necessary to calculate a water balance when the contributing drainage area is less than 5 acres (Refer to ***Specification 13. Wet Ponds***).

Similarly, if the hydrology for the permanent pools is not supplied by groundwater or dry weather flow inputs, a simple water balance calculation must be performed, using **Equation 12.2** (Hunt et al., 2007)**,** to assure the deep pools will not go completely dry during a 30 day summer drought.

Equation 12.2. The Hunt Water Balance Equation for Acceptable Water Depth in a Stormwater Wetland

$$DP = RF_m * EF * WS/WL - ET - INF - RES$$

Where:	DP	=	Depth of pool, inches
	RF_m	=	Monthly rainfall during drought, inches (assume 1 inch, or use historically data)
	EF	=	Fraction of rainfall that enters the stormwater wetland (Rational runoff coefficient)
	WS/WL	=	Ratio of contributing drainage area to the normal pool wetland surface area
	ET	=	Summer evapotranspiration rate, inches (assume 7 inches)
	INF	=	Monthly infiltration loss (assume 7.2 inches, or 0.01 inch/hour for 30 days, unless a higher infiltration rate is known)
	RES	=	Reservoir of water for a factor of safety, inches (assume 6 inches)

Variant 12-B, Wetland Swales:

Wetland Swale Sizing. Wetland swales are designed similar to traditional vegetated swales in that they should convey the Cv and Fv events with non-erosive velocities and should fully contain the Cv event (no freeboard required). If the Fv event is not contained within the swale top of bank, then the area of inundation or alternate route shall be noted. The RPv water surface elevation shall not pond more than 6 inches above the normal water surface elevation. There is no minimum or maximum drainage area, though typically swales are designed for less than 5 acres of contributing area.

Internal Geometry. Wetland swales should be designed as a two stage system. The low flow channel requires a minimum width of 1 foot, and should be designed with a permanent to semi-permanent water elevation of 4 to 6 inches. This can be accomplished through inception with the seasonal high groundwater or through the use of check dams or other control structures that back the water up to that level during wet conditions. The low flow channel should support plants that tolerate mostly wet conditions. The width of the low flow channel should be maximum 6 feet to prevent additional low flow channels from forming within (or braiding); very large drainage areas may require increased widths, but typically the low flow channel will fall in the 2 to 4 foot width range. To increase functionality, the low flow channel should be meandered within the total confines of the Wetland Swale (i.e., the top of bank does not need to meander, but the low flow channel should).

At the water surface elevation of the RPv event (within +/- 0.1'), a shallow floodplain bench shall be provided, which alleviates shear stress on the sides of the banks. The total bench width should be minimum 4 feet and is generally split on either side of the low flow channel, though the dimensions can alter as the low flow channel meanders through the swale section, with increased bench widths on the inside of a curve. Vegetation planted on the benches should also support wet periods, though will be inundated less frequently then the plants in the low flow channel.

Deep pools should not be incorporated into the Wetland Swales for safety purposes, as most people assume swales are traversable and would not suspect a deep portion. The average groundwater elevation must be below the bottom of the Wetland Swale; only the seasonal high groundwater may intersect the bottom.

Side Slopes. The Wetland Swales shall not have a steeper slope than 3:1.

Longitudinal Slope: The maximum longitudinal slope is an average of 1%. Grade breaks similar to variant 12-A can be used as necessary.

Vegetated Perimeter. A minimum 10 foot wide vegetated perimeter on both sides of the wetland swale must be planted with appropriate grasses, trees and shrubs. Existing vegetation can and should remain in the perimeter area, so long as invasive species are eradicated and invasive species are controlled.

Variant 12-C, Ephemeral Constructed Wetlands:

Wetland Sizing. Ephemeral Constructed Wetlands are designed without a permanent pool, since the intent is for them to be wet only in the spring and fall months. The Fv water surface shall be maximum 30 inches above the ground surface, and the RPv event must pond between 6-inches and 1-foot of water. An emergency spillway must be provided for the 100-year and larger events, but traditionally no other outlets are provided. If freezing in the winter is a concern, or for maintenance purposes, a drain pipe can be provided, but the Ephemeral Constructed Wetland should only be drained in late November after amphibian breeding seasons. The wetland can be modeled with the design infiltration rate, and is allowed to hold the RPv event for greater than 48 hours.

Internal Geometry. Ephemeral Constructed Wetlands should mimic those found naturally, which typically are ponded low areas. These shallow areas fill up with runoff during wet conditions, and will dry up during periods of little to no rain. These fluctuations typically provide more diversity in vegetation and animals. The shallow ponded area must be planted with a variety of vegetation that can tolerate both wet and dry conditions.

The seasonal high groundwater may fluctuate into the bottom of the Ephemeral Constructed Wetland, but the average groundwater elevation shall be below the wetland bottom. The wetland shall be modeled with the seasonal high groundwater if it does intersect the wetland bottom.

Depending on the existing grades, an embankment may be required to contain the wetland pool. If so, a core trench shall extend down to a limiting layer or minimum 4 feet below ground surface, which will help prevent lateral migration of water through the embankment, compromising the construction.

Side Slopes. The side slopes of the buffer area and within the wetland should be 4:1 or flatter.

Vegetated Perimeter. A minimum 50 foot wide vegetated perimeter around the wetland area must be planted with appropriate grasses, trees and shrubs (the emergency spillway shall either be grass or riprap). Existing vegetation can and should remain in the perimeter area, so long as noxious species are eradicated and invasive species are controlled.

Constructed Wetland Material Specifications:

Wetlands are generally constructed with materials obtained on-site, except for the plant materials, inflow and outflow devices (e.g., piping and riser materials), possibly stone for inlet and outlet stabilization, and stabilization fabric for lining banks or berms. In some instances clay may need to be imported to provide a permanent pool elevation in certain areas of the constructed wetland that may not otherwise support a permanent pool. Plant stock should be nursery grown, unless otherwise approved by the local regulatory authority, and should be healthy and vigorous native species free from defects, decay, disfiguring roots, sun-scald, injuries, abrasions, diseases, insects, pests, and all forms of infestations or objectionable disfigurements, as determined by the local regulatory authority.

12.7 Wetland Landscaping Criteria

A landscaping plan is required for all Constructed Wetlands and must be prepared by a licensed professional knowledgeable in wetland species. The plan shall outline a detailed schedule for the care, maintenance and possible reinstallation of vegetation in the wetland and its buffer, particularly for the first 10 years of establishment.

The plan should outline a realistic, long-term planting strategy to establish and maintain desired wetland vegetation. The plan should indicate how wetland plants will be established within each inundation zone (e.g., wetland plants, seed-mixes, volunteer colonization, and tree and shrub stock) and whether soil amendments are needed to get plants started. Reference the **Landscaping Criteria Appendix** for additional Constructed Wetland landscaping specifications.

12.8. Wetland Construction Sequence

The construction sequence for the wetland variants depends on site conditions, design complexity, and the size and configuration of the proposed facility. The following two-stage construction sequence is recommended for installing a wetland facility and establishing vigorous plant cover.

Stage 1 Construction Sequence: Wetland Facility Construction.

Step 1: Stabilize Drainage Area. Constructed wetlands should only be constructed after the contributing drainage area to the wetland is completely stabilized. If the proposed wetland site will be used as a sediment trap or basin during the construction phase, the construction notes should clearly indicate that the facility will be de-watered, dredged and re-graded to design dimensions after the original site construction is complete.

Step 2: Assemble Construction Materials on-site, make sure they meet design specifications, and prepare any staging areas.

Step 3: Install Erosion and Sediment (E&S) Controls prior to construction, including temporary dewatering devices, sediment basins, and stormwater diversion practices. All areas surrounding the wetland that are graded or denuded during construction of the wetland are to be planted with turf grass, native plant materials or other approved methods of soil stabilization. In some cases, a phased or staged E&S Control plan may be necessary to divert flow around the stormwater wetland area until installation and stabilization are complete.

Step 4: Excavate the Core Trench for the Embankment and Construct the Embankment (if required). Install the Outlet Pipe and Emergency Spillway.

Step 5: Install the Riser or Outflow Structure and ensure that the top invert of the overflow weir is constructed level and at the proper design elevation (flashboard risers are strongly recommended by Hunt et al, 2007).

Step 6: Clear and Strip the wetland project area to the desired sub-grade.

Step 7: Construct any Internal Berms in 8 to 12-inch lifts and compacted with appropriate equipment.

Step 8: Excavate/Grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the wetland. This is normally done by "roughing up" the interim elevations with a skid loader or other similar equipment to achieve the desired topography across the wetland. Spot surveys should be made to ensure that the interim elevations are 3 to 6 inches below the final elevations for the wetland.

Step 9: Install Micro-Topographic Features and Soil Amendments within wetland area. Since most stormwater wetlands are excavated to sub-soil, they often lack the nutrients and organic matter needed to support vigorous growth of wetland plants. It is therefore essential to add compost, topsoil or wetland mulch to all depth zones in the wetland. The importance of soil amendments in excavated wetlands cannot be over-emphasized; poor plant survival and sparse wetland plant coverage are likely if soil amendments are not added. The planting soil should be a high organic content loam or sandy loam, placed by mechanical methods, and spread by hand. Planting soil depth should be at least 4 inches for shallow wetlands. No machinery should be allowed to traverse over the planting soil during or after construction. Planting soil should be tamped, but it should not be overly compacted.

Step 10: Stabilize Exposed Soils above the normal pool elevation with permanent seed mixtures appropriate for a wetland environment by hydro-seeding or seeding under straw per the Landscape Plan. Temporary seed, such as annual rye or winter wheat, can be used to stabilize the soil but permanent species must then be planted or seeded at a later date. Stabilization matting shall be utilized in Wetland Swales, 12-B, and in all areas of concentrated flow and/or slopes at 3:1 or steeper.

Step 11: Post Construction Verification: After soil stabilization, but prior to planting individual species, perform a post construction verification of the constructed wetland. This will confirm the planting zones and normal pool elevation based on the outlet elevation. Three cross-sections (forebay, mid-wetland, and prior to the principal spillway) shall be measured, marked, and geo-referenced on the post construction verification survey document. This will enable maintenance reviewers to determine sediment deposition rates in order to schedule sediment cleanouts. Any embankments shall be verified per the requirements in ***Specification 13. Wet Ponds***.

Stage 2 Construction Sequence: Establishing the Wetland Vegetation.

Step 12: Open Up the Wetland Connection (if desired). Once the final grades are attained, the pond and/or contributing drainage area connection can be opened to allow the wetland cell to fill up to the normal pool elevation. Gradually inundate the wetland to minimize erosion of unplanted features. If the wetland area is connected than it will need to be dewatered to the lowest planting elevation (i.e., the low marsh zone) prior to planting.

Step 13: Finalize the Wetland Landscaping Plan (if needed). At this stage the engineer, landscape architect, and wetland expert work jointly to refine the initial wetland landscaping plan *after* the Constructed Wetland has been constructed and the normal pool elevation has been established if there have been any changes to the planting zones from the initial design. This can allow the designer to select appropriate species and additional soil amendments, based on field confirmation of soils properties and the actual depths and inundation frequencies occurring within the wetland, and also confirm plant availability

Step 14: Measure and Stake Planting Depths at the onset of the planting season. Depths in the wetland should be measured to the nearest inch to confirm the original planting depths of the planting zone. Surveyed planting zones should be marked on the post construction verification, and their locations should also be identified in the field, using stakes or flags. If necessary, dewater to the bottom of the low marsh zone prior to staking and planting.

Step 15: Propagate the Constructed Wetland. Three techniques are used in combination to propagate the emergent community over the wetland bed:

1. *Initial Planting of Container-Grown Wetland Plant Stock.* The transplanting window extends from early April to mid-June. Planting after these dates is quite chancy, since emergent wetland plants need a full growing season to build the root reserves needed to get through the winter. If at all possible, the plants should be ordered at least 6 months in advance to ensure the availability and on-time delivery of desired species.
2. *Broadcasting Wetland Seed Mixes*. The higher wetland elevations should be established by broadcasting wetland seed mixes to establish diverse emergent wetlands. Seeding of wetland seed mixes as a ground cover is recommended for all zones above 3 inches below the normal pool elevation. Hand broadcasting or hydroseeding can be used to spread seed, depending on the size of the wetland cell.
3. *Allowing "Volunteer Wetland Plants to Establish.*. The establishment of volunteer species should be encouraged with the exception of noxious weeds and invasives. Typically if properly managed, the constructed wetland will fill out with volunteer species and establishment of the planted and seeded species within 3 to 5 years.

Step 16: Install Goose Protection to Protect Newly Planted or Newly Growing Vegetation. This is particularly critical for newly established emergent and herbaceous plants, as predation by Canada geese can quickly decimate wetland vegetation. Goose protection can consist of netting, webbing, or string installed in a criss-cross pattern over the surface area of the wetland, above the level of the emergent plants.

Step 17: Plant the Wetland Floodplain and Buffer Area. This zone generally extends from 1 to 3 feet above the normal pool elevation. Consequently, plants in this zone are less frequently inundated but still must be able to tolerate periods of flooding and soil saturation. The buffer area can be planted with species that do not need wet conditions, and can be planted in the spring or fall.

Construction Reviews. Construction reviews are critical to ensure that the Constructed Wetlands are properly installed and established. Multiple site visits and reviews are recommended during the following stages of the wetland construction process:

- Pre-construction meeting
- Initial site preparation (including installation of project E&S controls)
- Excavation/Grading (e.g., interim/final elevations)
- Wetland installation (e.g., microtopography, soil amendments and staking of planting zones)
- Planting Phase (with an experienced landscape architect or wetland expert)
- Final Review (develop a punch list for facility acceptance)

12.9 Wetland Maintenance Criteria

An Operation and Maintenance Plan for the project will be approved by the Department or the Delegated Agency prior to project closeout. The Operation and Maintenance Plan will specify the property owner's primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed. Constructed Wetlands that are, or will be, owned and maintained by a joint ownership such as a homeowner's association must be located in common areas, community open space, community-owned property, jointly owned property, or within a recorded easement dedicated to public use.

Operation and Maintenance Plans should clearly outline how vegetation in the Constructed Wetland and its buffer will be managed or harvested in the future. Periodic mowing of the Constructed Wetland buffer is only required along the maintenance access and the embankment. The remaining buffer can be managed as a meadow (mowing every other year) or forest. The maintenance plan should schedule a shoreline cleanup at least once a year to remove trash and floatables.

Maintenance of a Constructed Wetland is driven by annual maintenance reviews that evaluate the condition and performance of the Constructed Wetland. Based on maintenance review results, specific maintenance tasks may be required. Additional reviews are required during the first two years of establishment.

First Two Years: The Constructed Wetland must be reviewed twice a year, once in the spring and once in the fall after a storm event that exceeds 1/2 inch of rainfall. This should be done for the first two years. Additional trips to the project site will be needed for watering, maintenance, etc which is described below.

- **Spot Reseeding.** Maintenance personnel should look for bare or eroding areas in the contributing drainage area, around the wetland buffer, and in the wetland cells, and make sure they are immediately stabilized with grass cover.
- **Watering.** Trees and shrubs planted in the buffer and on wetland islands and peninsulas need watering during the first growing season. In general, consider watering every three days for first month, and then weekly during the first growing season (April - October), depending on rainfall. In the summer months, and times of prolonged drought, all of the plantings may need watering to ensure survival.
- **Reinforcement Plantings.** Regardless of the care taken during the initial planting of the wetland and buffer, it is probable that some areas will remain non-vegetated and some species will not survive. Poor survival can result from many unforeseen factors, such as predation, poor quality plant stock, water level changes, and drought. Thus, it is advisable to budget for an additional round of reinforcement planting after one or two growing seasons. Construction contracts should include a care and replacement warranty extending at least two growing seasons after initial planting, to selectively replant portions of the wetland that fail to fill in or survive. Close-out on the project will not occur until a minimum of 70% of the wetland area is permanently vegetated,

which may take several growing seasons and additional plantings.

- **Invasive Species.** Designers should expect significant changes in wetland species composition to occur over time. Reviews should carefully track changes in wetland plant species distribution over time. Noxious plants and undesired invasive plants should be dealt with as soon as they begin to colonize the wetland. As a general rule, control of noxious weeds and undesirable invasive species (e.g., cattails and Phragmites) should commence as soon as they are spotted and before their coverage exceeds more than 5% of a wetland cell area. Herbicides must be applied by a Certified aquatic pesticide applicator through the Department of Agriculture and be aquatic safe (i.e., Glyphosate-based products). Extended periods of dewatering may also work, since early manual removal provides only short-term relief from invasive species. While it is difficult to exclude invasive species completely from stormwater wetlands, their ability to take over the entire wetland can be reduced if the designer creates a wide range of depth zones and a complex internal structure within the wetland.

Annual, On-going Maintenance: Managing vegetation is an important ongoing maintenance task at every Constructed Wetland and for each inundation zone.

- **Vegetation Management.** Thinning or harvesting of excess forest growth will be needed periodically to guide the forested wetland into a more mature state and prevent it from becoming overgrown. Thinning or harvesting operations should be scheduled to occur approximately 5 and 10 years after the initial wetland construction. Removal of woody species on or near the embankment, structural components such as inflow and outflow pipes, and maintenance access areas should be conducted every 2 years.
- **Mowing.** Regular mowing operations only need to occur along maintenance accessways, and should occur at minimum twice a year. Reference the Landscape Plan for additional requirements; some upland meadow areas may also require occasional mowing.
- **Sediment Removal.** Sediment removal in the pretreatment forebay must occur when 50% of total forebay capacity has been lost. The owner can plan for this maintenance activity to occur every 5 to 7 years.
- **Sediment Deposits.** Sediment removed from the forebay should be deposited in the designated maintenance set aside area for dewatering, prior to leveling and stabilization or removal from the site. Sediments excavated from Constructed Wetlands are not usually considered toxic or hazardous. They can be safely disposed of by either land application or land filling. Sediment testing may be needed prior to sediment disposal if the contributing area serves a hotspot land use.

12.10 References

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13.0 Wet Ponds

Definition: Wet Ponds are stormwater storage practices that consist of a combination of a permanent pool, micropool, or shallow marsh that promote a good environment for gravitational settling, biological uptake and microbial activity. Wet Ponds are widely applicable for most land uses and are best suited for larger drainage areas. Runoff from each new storm enters the wet pond and partially displaces pool water from previous storms. The pool also acts as a barrier to re-suspension of sediments and other pollutants deposited during prior storms. When sized properly, Wet Ponds have a residence time that ranges from many days to several weeks, which allows numerous pollutant removal mechanisms to operate. Wet Ponds can also provide storage above the permanent pool to help meet stormwater management requirements for larger storms. Design variants include:

- 13-A Wet Pond
- 13-B Wet Extended Detention (ED) Pond

A Wet ED Pond differs from a typical Wet Pond in that a Wet ED Pond provides 24-hour detention of all or a portion of the Resource Protection Volume (RPv). Optional internal baffles in the Wet ED Pond extend the flow path through the pond from the inflow point to the outlet. In addition, an undersized outlet structure restricts stormwater flow so it backs up and is stored within the Wet ED Pond. The temporary ponding enhances the ability of particulate pollutants to settle out and reduces the maximum peak discharge to the downstream channel, thereby reducing the effective shear stress on banks of the receiving stream.

Wet Ponds should be considered for use after all other upland runoff reduction opportunities have been exhausted and there is still a remaining treatment volume or runoff from larger storms (i.e. Cv an Fv) to manage.

Wet Ponds do not receive any stormwater retention credit and should be considered only for pollutant removal efficiency and to manage flood events. Wet Ponds have both community and environmental concerns (see ***Section 13.3 Wet Pond Feasibility Criteria***) that need to be considered before applying them.

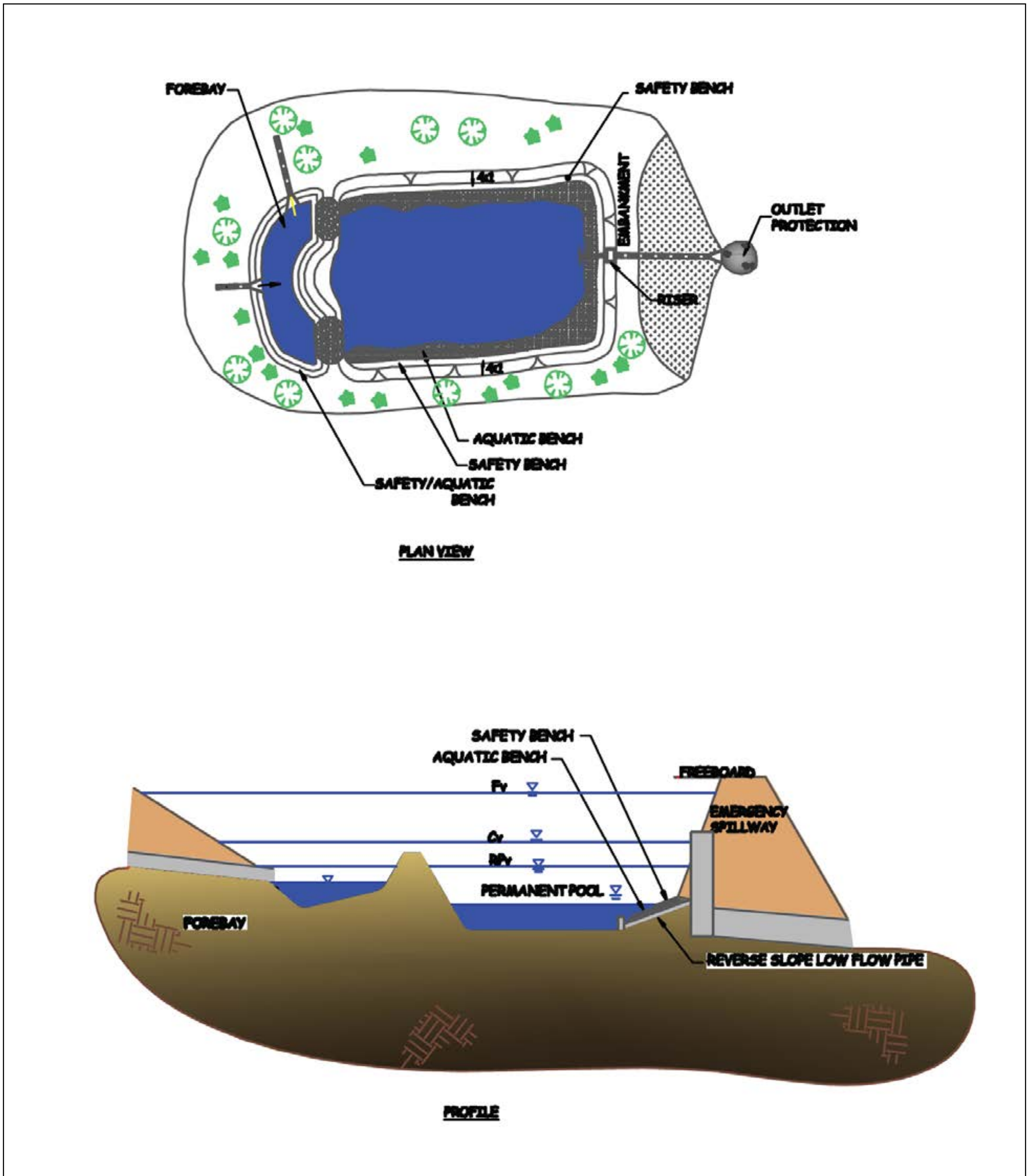

Figure 13.1. Wet Pond (13-A) Design Schematics.

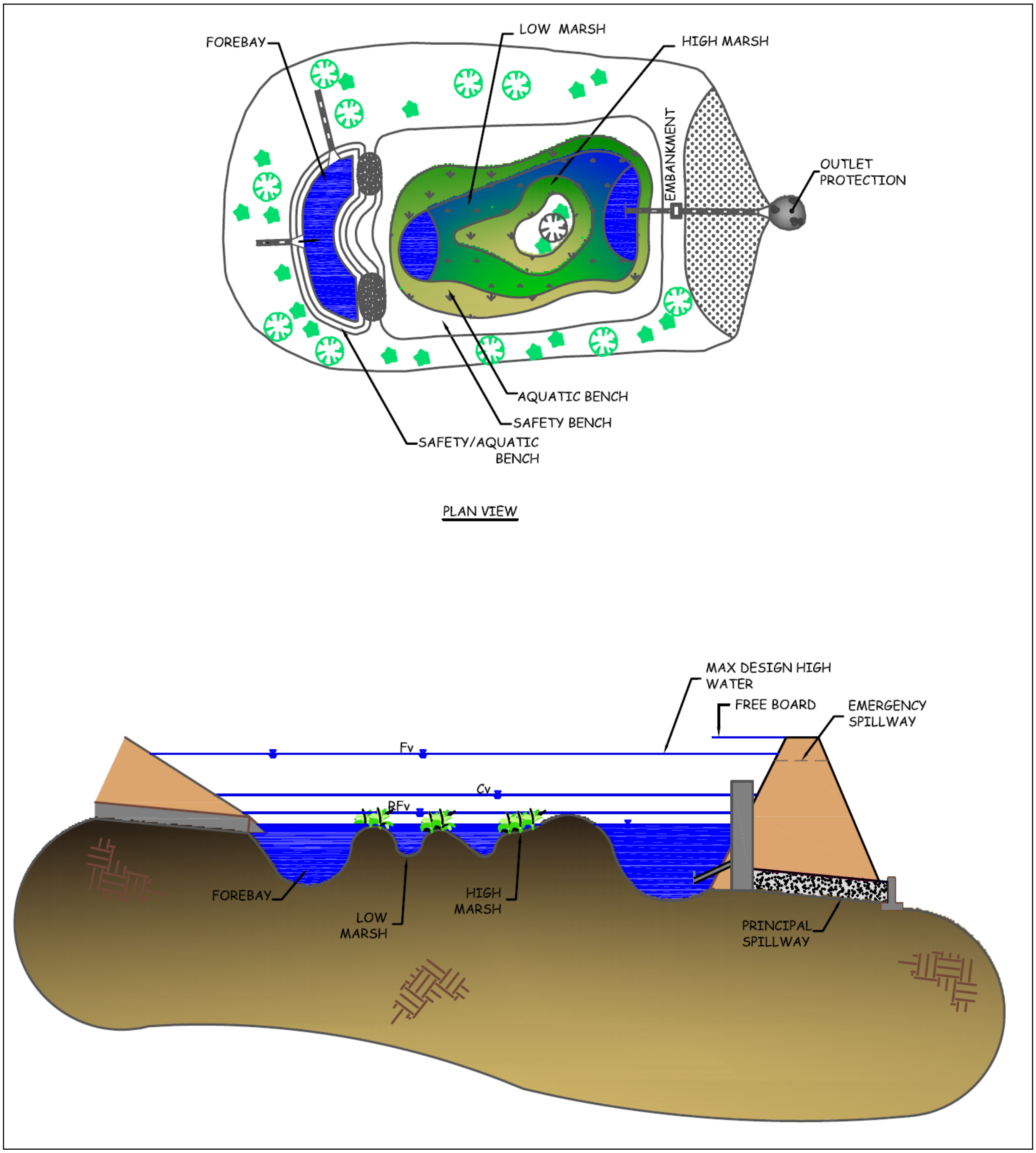

Figure 13.2. Typical Wet Extended Detention Pond (13-B) Details.

13.1 Wet Pond Credit Calculations

Wet Ponds receive 0% retention credit (R_v) and pollutant removals outlined in **Table 13.1**. As a treatment practice, the Wet Pond must be sized according to the standards outlined in Section 13.6 to receive full pollutant removal credit.

Table 13.1 Wet Pond and Wet ED Pond Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv -A/B Soil	0%
RPv - C/D Soil	0%
Cv	0%
Fv	0%
Pollutant Reduction	
TN Reduction	20%
TP Reduction	45%
TSS Reduction	60%

13.2 Wet Pond Design Summary

Wet Ponds constructed to meeting regulatory stormwater management requirements in the State of Delaware shall be designed and constructed in accordance with the USDA NRCS Small Pond Code 378 and this document. Table 13.2 summarizes design criteria for Wet Ponds. For more detail, consult Sections 13.3 through 13.7. Sections 13.8 and 13.9 describe practice construction and maintenance criteria.

Table 13.2 Wet Pond Design Summary

Feasibility Criteria (Section 13.3)	• Adequate groundwater, runoff or baseflow to support permanent pool • Recommended minimum Contributory drainage area (CDA) of 10 to 25 acres • Wet Pond surface area size allowance of 1% to 3% of CDA • Contributing slopes <15% • Wet Pond discharge point allows for gravity discharge • Setbacks in accordance with local codes • No utility may cross the embankment • Seasonal high water table < design permanent pool elevation • HSG C and D soils; HSG A and some HSG B soils may require a liner • Not located within jurisdictional waters, including wetlands or on perennial streams • Consider community and environmental concerns such as aesthetics, forests, safety, pollutants, mosquitoes and waterfowl
Conveyance Criteria (Section 13.4)	• Principal spillway must be accessible by dry land • Principal spillway must include trash racks and watertight joints • Small low flow orifices must be protected from clogging • Outfall channel designed to be stable for the Cv • Emergency spillway designed to safely convey the Fv • Emergency spillway must be in cut material or reinforced • Inflow points and forebays stable for the Cv • Secure necessary dam safety permits
Pretreatment Criteria (Section 13.5)	• Forebays at major inlets – those conveying >10% of runoff volume • Forebays sized for 10% of RPv • Non-erosive discharge from forebay to pond pool • Direct access provided to facilitate forebay maintenance
Design Criteria *Storage* (Section 13.6)	• Store RPv (2.7”) within the permanent pool and extended detention • Storage >5’ above permanent pool requires design enhancements • Water balance calculation necessary
Design Criteria *Geometry* (Section 13.6)	• Minimum length to width ratio = 1.5:1 • Maximum depth of permanent pool = 4.0 feet • Side slopes no steeper than 3H:1V • Ten foot wide safey bench constructed 1’ above permanent pool • Ten foot wide aquatic bench constructed 1’ below permanent pool
Design Criteria *Appurtenances* (Section 13.6)	• Soil borings / geotechnical tests will confirm need for a liner • Low Flow ED orifice protected from clogging • Riser structure must be accessible for maintenance • Trash racks provided on enclosed structure openings • Outlet pipe and pond drain equipped with adjustable gate valve • Materials meet Small Pond Code 378 specifications

Table 13.2 Wet Pond Design Summary

Design Criteria *Safety* (Section 13.6)	• Restrict entry to principal spillway • One foot of freeboard above the Fv elevation (2' if no emergency spillway) • Emergency spillway located to not impact downstream structures • Safety and aquatic benches landscaped to prevent access
Design Criteria *Maintenance* (Section 13.6)	• Provide access to forebays, safety bench, riser and outlet structure • Access roads built to withstand the expected frequency of use • Minimum width of access roads = 15', profile grade < 5:1 • Maintenance set aside area provided
Landscaping Criteria (Section 13.7)	• No woody vegetation within 15' of the embankment or 25' of principal spillway or inflow pipes • Detailed landscaping plan required

13.3 Wet Pond Feasibility Criteria

The following feasibility issues need to be considered when Wet Ponds are considered a final storm water management practice of the treatment train.

Adequate Water Balance. Wet Ponds must have enough water supplied from groundwater, runoff or baseflow so that the wet pools will not draw down by more than 2 feet after a 30-day summer drought. A simple water balance calculation must be performed using the **Equations 13.1** and **13.2** provided in **Water Balance Testing**.

Contributing Drainage Area. A contributing drainage area of 10 to 25 acres is typically recommended for Wet Ponds to maintain constant water elevations. Wet Ponds can still function with drainage areas less than 10 acres, but designers should be aware that these "pocket" ponds will be prone to clogging, experience fluctuating water levels, and generate more nuisance conditions. When the contributing drainage area of the Wet Pond is less than 10 acres, alternative outlet configurations should be used to eliminate the possibility of clogging of the outlet.

Space Requirements. The surface area of a Wet Pond will normally be at least 1% to 3% of its contributing drainage area, depending on the pond's depth.

Site Topography. Wet Ponds are best applied when the grade of contributing slopes is less than 15%.

Available Hydraulic Head. The ultimate discharge point from the Wet Pond should be used to determine the minimum elevation of the permanent pool. The permanent pool elevation must be higher than the outlet elevation in order to have a gravity discharge. In situations where there is little relief on the parcel and the head differential between the permanent pool elevation and the discharge elevation is small, an option for the Wet Pond outlet is a weir and outlet channel configuration.

Minimum Setbacks. Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines, structures, and wells. When not specified in local code, Wet Ponds should be set back at least 20 feet from property lines, 25 feet from building foundations, and 100 feet from septic system fields and 150 feet from public or private water supply wells.

Proximity to Utilities. For an open Wet Pond system, no utility lines shall be permitted to cross any part of the embankment of a wet pool.

Depth-to-Water Table. The depth to the seasonal high water table is an important consideration in planning of a Wet Pond. When the seasonal high water table elevation exceeds the proposed permanent pool elevation of the Wet Pond, the capacity planned for management of the Cv and Fv in the Wet Pond may be taken up by groundwater. Further, if the water table is close to the surface, it may make excavation difficult and expensive.

Soils. Highly permeable soils will make it difficult to maintain a healthy permanent pool. Underlying soils of Hydrologic Soil Group (HSG) C or D should be adequate to maintain a permanent pool. Most HSG A and B soils will not support a permanent pool without the use of a liner (See **Table 13.3** below). Geotechnical investigations must be conducted to determine the suitability of the soils to support a permanent pool. When soil borings confirm HSG A/B soils, an infiltration test should be conducted. If the infiltration test results in an infiltration rate greater than 1.0 inch/hour at the proposed Wet Pond invert, and the seasonal high groundwater table is two feet or more below the proposed Wet Pond invert, a stormwater management BMP other than a Wet Pond or Wet ED Pond should be designed.

Use of or Discharges to Natural Wetlands. Wet Ponds may not be located within jurisdictional waters, including wetlands, without obtaining a section 404 permit from the appropriate state or federal regulatory agency. In addition, the designer should investigate the wetland status of adjacent areas to determine if the discharge from the Wet Pond will change the hydroperiod of a downstream natural wetland (see Cappiella et al., 2006, for guidance on minimizing stormwater discharges to existing wetlands).

Perennial Streams. Locating Wet Ponds within perennial streams will require both a Section 401 and Section 404 permit from the appropriate state or federal regulatory agency.

Community and Environmental Concerns. Wet Ponds can generate the following community and environmental concerns that need to be addressed during design:

- **Aesthetic Issues.** Many residents feel that Wet Ponds are an attractive landscape feature, promote a greater sense of community and are an attractive habitat for fish and wildlife. Designers should note that these benefits are often diminished where Wet Ponds are under-sized or have small contributing drainage areas.
- **Existing Forests.** Construction of a Wet Pond may involve extensive clearing of existing forest cover. Designers can expect a great deal of neighborhood opposition if they do not make a concerted effort to save mature trees during Wet Pond design and construction.
- **Safety Risk.** Wet Pond safety is an important community concern, since both young children and adults have perished by drowning in Wet Ponds through a variety of accidents, including falling through thin ice cover. Gentle side slopes and safety benches should be provided to

avoid potentially dangerous drop-offs, especially where Wet Ponds are located near residential areas.

- **Pollutant Concerns.** Wet Ponds collect and store water and sediment to increase residence time that will increase the likelihood for contaminated water and sediments to be neutralized. However, poorly sized, maintained, and/or functioning Wet Ponds can export contaminated sediments and/or water to receiving waterbodies (Mallin, 2000; Mallin et al., 2001; Messersmith, 2007). Further, designers are cautioned that recent research on Wet Ponds has shown that some Wet Ponds can be hotspots or incubators for algae that generate harmful algal blooms (HABs).
- **Mosquito Risk.** Mosquitoes are not a major problem for larger Wet Ponds (Santana et al., 1994; Ladd and Frankenburg, 2003, Hunt et al, 2005). However, fluctuating water levels in smaller or under-sized Wet Ponds could pose some risk for mosquito breeding. Mosquito problems can be minimized through simple design features and maintenance operations described in MSSC (2005).
- **Geese and Waterfowl.** Wet Ponds with extensive turf and shallow shorelines can attract nuisance populations of resident geese and other waterfowl, whose droppings add to the nutrient and bacteria loads, thus reducing the removal efficiency for those pollutants. Several design and landscaping features can make Wet Ponds much less attractive to geese, such as allowing the perimeter of the Wet Pond to grow up in tall grass and planting shrubs and grasses around the pond (see Schueler, 1992).

13.4 Wet Pond Conveyance Criteria

Wet Ponds, including their conveyance systems, constructed to meet regulatory stormwater management requirements in the State of Delaware shall be designed and constructed in accordance with the USDA NRCS Small Pond Code 378 and this document.

Internal Slope. The longitudinal slope of the Wet Pond bottom should be at least 0.5% to facilitate maintenance.

Principal Spillway. The principal spillway may be composed of a structure-pipe configuration or a weir-channel configuration. The principal spillway must be accessible from dry land. A structure-pipe spillway shall be designed with anti-flotation, anti-vortex and trash rack devices on the structure. The outfall pipe and all connections to the outfall structure shall be made watertight. When reinforced concrete pipe is used for the principal spillway pipe to increase its longevity, “O-ring” gaskets (ASTM C361) shall be used to create watertight joints. Anti-seep collars will decrease movement of water along the outside of the outfall pipe. When the principal spillway is composed of a weir wall discharging to a channel, the channel below the weir must be reinforced (with riprap, for example) to prevent scour of the channel.

Non-Clogging Low Flow Orifice. A low flow orifice must be provided that is adequately protected from clogging by either an acceptable external trash rack or by internal orifice protection that may allow for smaller diameters. Orifices less than 3 inches in diameter may require extra attention during design, to minimize the potential for clogging.

Adequate Outfall Protection. The design must specify an outfall that will be stable for the conveyance storm (Cv). The channel immediately below the Wet Pond outfall must be modified to prevent erosion and conform to natural dimensions in the shortest possible distance. This is accomplished by placing appropriately sized riprap over stabilization geotextile in accordance with HEC-14 Hydraulic Design of Energy Dissipators for Culverts and Channels and Delaware Erosion and Sediment Control Handbook Specification 3.3.10 Riprap Outlet Protection or 3.3.11 Riprap Stilling Basin, which can reduce flow velocities from the principal spillway to non-erosive levels (3.5 to 5.0 fps) based upon the channel lining material. Flared pipe sections, which discharge at or near the stream invert or into a step pool arrangement, should be used at the spillway outlet.

When the discharge is to a manmade pipe or channel system, the system must be adequate to convey the required design storm peak discharge. Care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone in the shortest possible distance. Excessive use of rip-rap should be avoided. The final release rate of the facility shall be modified if any increase in flooding or stream channel erosion would result at a downstream structure, highway, or natural point of restricted streamflow.

Emergency Spillway. Wet Ponds must be constructed with overflow capacity to pass the maximum design storm event (Fv) if the Fv is being routed through the Wet Pond rather than bypassing. An emergency spillway designed to convey the Fv should be cut in natural ground or, if cut in fill, must be lined with stabilization geotextile and riprap. When the maximum design storm will be passing through the principal spillway, the principal spillway outlet pipe must have a minimum cross sectional area of 3 square feet.

Inflow Points Stabilization. Inflow points into the Wet Pond must be stabilized to ensure that non-erosive conditions exist during storm events up to the conveyance storm (i.e., the 10-year storm event). Inlet pipe inverts should generally be located at or slightly below the permanent pool elevation. A forebay (See **13.5 Wet Pond Pretreatment Criteria**) shall be provided at each inflow location, unless the inlet is submerged or inflow provides less than 10% of the total design storm inflow to the Wet Pond.

Dam Safety Permits. The designer should determine whether or not the embankment meets the criteria to be regulated as a dam by the Delaware Dam Safety Regulations. In the event that the embankment is a regulated dam, the designer should verify that the appropriate Dam Safety Permit has been approved by the Department's Dam Safety Program.

13.5 Wet Pond Pretreatment Criteria

Sediment forebays are considered to be an integral design feature to maintain the longevity of all Wet Ponds. A forebay must be located at each major inlet to trap sediment and preserve the capacity of the main treatment cell. The following criteria apply to forebay design:

- A major inlet is defined as an individual storm drain inlet pipe or open channel conveying at least 10% of the Wet Pond's contributing runoff volume
- The preferred forebay configuration consists of a separate cell, formed by an acceptable barrier such as a concrete weir, riprap berm, gabion baskets, etc. Riprap berms are the preferred barrier material.
- The forebay should be 3 to 4 feet deep. A safety bench is required at the pond shoreline for forebay depths greater than 3 feet. The safety bench need not continue around the entire forebay.
- The forebay must be sized to contain ten percent of the volume of runoff from the contributing drainage impervious area from the Resource Protection event. The relative size of individual forebays will be proportional to the percentage of the total inflow to the Wet Pond. The storage volume within the forebay may be included in the calculated required storage volume for the Wet Pond.
- The minimum length of the forebay is 10 feet. The forebay should have a length to width ratio of 2:1 or greater. Length is measured with the direction of flow into the Wet Pond.
- The forebay should be equipped with a metered rod in the center of the pool (as measured lengthwise along the low flow water travel path) for long-term monitoring of sediment accumulation. Metered wooden stakes will need to be replaced frequently in Wet Pond forebays; alternative materials should be considered for longevity.
- Vegetation should be included within forebays to increase sedimentation and reduce resuspension and erosion of previously trapped sediment.
- Exit velocities from the forebay shall be non-erosive or an armored overflow shall be provided. Direct maintenance access for appropriate equipment shall be provided to the each forebay.

13.6 Wet Pond Design Criteria

Wet Pond Sizing: In order to receive the credits outlined in Section 13.1, the permanent pool must be sized to store a volume equivalent to the Resource Protection storm (i.e., the runoff volume from the 1-year 2.7" Type II storm event). Further, Wet Ponds must provide 24 hours extended detention of any remaining treatment volume up to the full water quality volume.

Wet Ponds can be designed to capture and treat the remaining stormwater discharged from upstream practices to improve water quality. Additionally, Wet Ponds should be sized to control peak flow rates from the Conveyance Event and Flooding Event as required in accordance with the Delaware Sediment and Stormwater Regulations and accompanying Technical Document.

For treatment train designs where upland practices are utilized for treatment of the resource protection storm (RPv), designers can use a site-adjusted R_v or CN that reflects the volume reduction of upland practices to compute the Cv and Fv that must be treated by the Wet Pond.

Water Balance Testing: A water balance calculation is required to document that sufficient inflows to Wet Ponds and Wet ED Ponds exist to compensate for combined infiltration and evapo-transpiration losses during a 30-day summer drought without creating unacceptable drawdowns (see **Equation 13.1,** adapted from Hunt et al., 2007). The recommended minimum pool depth to avoid nuisance conditions may vary; however, it is generally recommended that the water balance maintain a minimum 24-inch reservoir.

Equation 13.1. Water Balance Equation for Acceptable Water Depth in a Wet Pond

$$DP > ET + INF + RES - MB$$

Where:

DP	=	Average design depth of the permanent pool (inches)
ET	=	Summer evapo-transpiration rate (inches) (assume 8 inches)
INF	=	Monthly infiltration loss (assume 7.2 @ 0.01 inch/hour)
RES	=	Reservoir of water for a factor of safety (assume 24 inches)
MB	=	Measured baseflow rate to the Wet Pond, if any (convert to inches)

Design factors that will alter this equation are the measurements of seasonal base flow and infiltration rate. The use of a liner could eliminate or greatly reduce the influence of infiltration. Similarly, land use changes in the upstream watershed could alter the base flow conditions over time (e.g., urbanization and increased impervious cover).

Translating the baseflow to inches refers to the depth within the Wet Pond. Therefore, **Equation 13.2** can be used to convert the baseflow, measured in cubic feet per second (ft^3/s), to pond-inches:

Equation 13.2. Baseflow Conversion Equation

$$\text{Pond inches} = (\text{MB in } ft^3/s) * (2.592E6) * (12''/ft) / \text{SA of Pond } (ft^2)$$

Where:

2.592E6	=	Conversion factor: ft^3/s to ft^3/month.
SA	=	surface area of Wet Pond in ft^2

Wet Pond Storage Design: The Wet Pond permanent pool, plus extended detention must store the Resource Protection volume (i.e., the runoff volume from the 1-year, 2.7" rainfall Type II storm event. Volume storage may be provided in multiple cells. Performance is enhanced when multiple treatment pathways are provided by using multiple cells, longer flow paths, high surface area to volume ratios, complex microtopography, and/or redundant treatment methods (combinations of pool, extended detention [ED], and marsh).

Maximum Extended Detention Levels: The maximum extended detention volume associated with the Resource Protection volume should occur within the storage for the Conveyance storm (Cv). The total storage, including any ponding for larger flooding events (100-year storm) should not extend more than 5 feet above the permanent pool unless specific design enhancements to ensure side slope stability, safety, and maintenance are identified and approved.

Wet Pond Geometry: Wet Pond designs should have an irregular shape and a long flow path from inlet to outlet, to increase water residence time and Wet Pond performance. Greater flow paths and irregular shapes are recommended. The total length of the flow path compared to the linear length through the Wet Pond from inlet to outlet, must be a minimum ratio of 2:1. Internal berms, baffles, or vegetated peninsulas can be used to extend flow paths and/or create multiple pond cells.

In addition, the ratio of the shortest flow path through the system (due to an inlet located near the outlet) to the overall length must be at least 0.5:1. The drainage area served by any inlets located less than a 0.5:1 ratio shall constitute no more than 20% of the total contributing drainage area.

Permanent Pool Depth: The maximum depth of the permanent pool should not exceed four feet.

Side Slopes: Side slopes for Wet Ponds must be no steeper than 3H:1V. Mild slopes promote better establishment and growth of vegetation and provide for easier maintenance and a more natural appearance.

Wet Pond Benches:

- ***Safety Bench.*** When Wet Pond side slopes above permanent pool are steeper than 4H:1V, a 10 foot wide safety bench shall be constructed one foot above the permanent pool. The safety bench allows for maintenance access and reduces safety risks. The maximum slope of the safety bench is 5%.
- ***Aquatic Bench.*** An aquatic bench is a shallow area below the permanent pool that promotes growth of aquatic and wetland plants. The bench also serves as a safety feature, reduces shoreline erosion, and conceals floatable trash. Incorporate a 10 foot wide aquatic bench one foot below permanent pool.

Liners: Highly permeable soils will make it difficult to maintain a healthy permanent pool. When a geotechnical investigation recommends a liner, acceptable options include the following: (1) a clay liner following the specifications outlined in **Table 13.3** below; (2) a 30 mil poly-liner; (3) bentonite; (4) use of chemical additives; or (5) other acceptable measures as recommended by a qualified geotechnical professional. A clay liner should have a minimum thickness of 12 inches with an additional 12 inch layer of compacted soil above it, and it must meet the specifications outlined in **Table 13.3**. Other synthetic liners can be used if the designer can supply supporting documentation that the material will achieve the required performance.

Table 13.3. Clay Liner Specifications

Property	Test Method	Unit	Specification
Permeability	ASTM D-2434	Cm/sec	1×10^{-6}
Plasticity Index of Clay	ASTM D-423/424	%	Not less than 15
Liquid Limit of Clay	ASTM D-2216	%	Not less than 30
Clay Particles Passing	ASTM D-422	%	Not less than 30
Clay Compaction	ASTM D-2216	%	95% of standard proctor density
Source: VA DCR (1999).			

Required Geotechnical Testing: Soil borings should be taken below the proposed embankment, if applicable, in the vicinity of the proposed outlet area, and in at least two locations within the proposed Wet Pond bottom. Soil boring data is needed to (1) determine the physical characteristics of the excavated material, (2) determine its adequacy for use as structural fill or spoil, (3) provide data for structural designs of the outlet works (e.g., bearing capacity and buoyancy), (4) determine compaction/composition needs for the embankment (5) determine the depth to groundwater and bedrock and (6) evaluate potential infiltration losses (and the potential need for a liner).

Non-clogging Low Flow (Extended Detention) Orifice: The low flow ED orifice shall be adequately protected from clogging by an acceptable external trash rack. The preferred method is a hood apparatus over the orifice that reduces gross pollutants such as floatables and trash, as well as oil and grease and sediment.

Orifices less than 3 inches in diameter may require extra attention during design, to minimize the potential for clogging. As an alternative, internal orifice protection may be used (i.e., an orifice internal to a perforated vertical stand pipe with 0.5-inch orifices or slots that are protected by wirecloth and a stone filtering jacket).

Riser: The riser must be located such that it is accessible from the pond side slope or safety bench for the purposes of inspection and maintenance. The riser may be located within the embankment for maintenance access, safety, and aesthetics. Access to the riser is to be provided by lockable manhole covers, and manhole steps within easy reach of valves and other controls.

Trash Racks: Trash racks shall be provided for low-flow pipes and for all riser structure openings. Open weirs without an upper enclosure will not require trash racks. Synthetic trash rack materials options are available and should be considered. All metal trash racks shall be coated with a rust inhibitor to increase longevity of the device.

Pond Drain: Wet Ponds should have a drain pipe that can completely or partially drain the permanent pool. In cases where a low level drain is not feasible (such as in an excavated Wet Pond), the Operation and Maintenance Plan should include requirements for dewatering the Wet Pond.

- The drain pipe should have an upturned elbow or protected intake within the Wet Pond to help keep it clear of sediment deposition, and a diameter capable of draining the Wet Pond within 24 hours.
- The Wet Pond drain must be equipped with an adjustable valve located within the riser, where it will not be normally inundated and can be operated in a safe manner.

Care should be exercised during Wet Pond drawdowns to prevent downstream discharge of sediments or anoxic water and rapid drawdown. The Department or the Delegated Agency shall be notified before a Wet Pond is drained.

Adjustable Gate Valve: If desired to adjust the pond permanent pool elevation, both the outlet pipe and the Wet Pond drain should be equipped with an adjustable gate valve (typically a hand wheel activated knife gate valve) or pump well and be sized one pipe size greater than the calculated design diameter. Valves should be located inside of the riser at a point where they (a) will not normally be inundated and (b) can be operated in a safe manner. To prevent vandalism, the hand wheel should be chained to a ringbolt, manhole step or other fixed object.

Material Specifications: All materials used in construction of a Wet Pond or Wet ED Pond shall meet the material specifications in USDA NRCS Small Pond Code 378.

Safety Features:

- The principal spillway opening must be designed and constructed to prevent entry by small children.
- Wet Ponds must incorporate an additional 1 foot of freeboard above the emergency spillway, or 2 feet of freeboard if design has no emergency spillway, for the maximum design storm (e.g., Fv) unless more stringent Dam Safety requirements apply.
- The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges. The emergency spillway exit channel must be designed to direct runoff to a point of discharge without impact to downstream structures.
- Fencing of the perimeter of Wet Ponds is discouraged. The preferred method to reduce risk is to manage the contours of the Wet Pond to eliminate drop-offs or other safety hazards.
- Wet Pond side slopes above permanent pool shall be no steeper than 3H:1V. When Wet Pond side slopes above permanent pool are steeper than 4H:1V a 10-foot wide safety bench must be provided.
- The steepness of Wet Pond side slopes below permanent pool will be determined by soil type and influence of groundwater. The 10-foot wide aquatic bench located one foot below permanent pool is a requirement for all Wet Ponds and may not be waived.
- Both the safety bench and the aquatic bench must be landscaped to prevent personnel access to the pool. Perimeter landscaping shall be designed so as to not hinder maintenance access by equipment.
- Warning signs may be posted.

Maintenance Reduction Features: The following Wet Pond maintenance issues can be addressed during the design, in order to make on-going maintenance easier:

- **Maintenance Access.** All Wet Ponds must be designed so as to be accessible to annual maintenance. Good access is needed so crews can remove sediments, make repairs and preserve Wet Pond treatment capacity.
    - Adequate maintenance access must extend to the forebay, safety bench, riser, and outlet structure and must have sufficient area to allow vehicles to turn around.
    - The riser may be located within the embankment for maintenance access, safety and aesthetics. Access to the riser should be provided by lockable manhole covers and manhole steps within easy reach of valves and other controls.

  - Access roads must (1) be constructed of load-bearing materials or be built to withstand the expected frequency of use, (2) have a minimum width of 15 feet, and (3) have a profile grade that does not exceed 5:1.
  - A maintenance right-of-way or easement must extend to the Wet Pond from a public or private road.
- Maintenance Set-Aside Area: Adequate land area adjacent to the Wet Pond should be provided for in the Operation and Maintenance Plan as a location for disposal of sediment removed from the Wet Pond when maintenance is performed. The maintenance set-aside area is necessary on all sites adjacent to the Wet Pond to adequately dewater sediment removed from the pond prior to spreading and seeding or transporting from the site.
  - The maintenance set-aside area shall accommodate the volume of 0.1 inches of runoff from the Wet Pond's contributory drainage area.
  - The maximum depth of the set aside volume shall be one foot.
  - The slope of the set aside area shall not exceed 5%; and
  - The area and slope of the set aside area may be modified if an alternative area or method of disposal is approved by the Department or Delegated Agency.

13.7 Wet Pond Landscaping Criteria

Vegetated Perimeter: A vegetated area should be provided around the perimeter of the Wet Pond that extends at least 25 feet outward from the maximum water surface elevation of the Wet Pond. This vegetated perimeter provides enhanced water quality management of runoff through filtering, provides adequate setback from structures to allow for Wet Pond maintenance, and when the Wet Pond perimeter is allowed to grow up into meadow, this area aids in deterring waterfowl from inhabiting the Wet Pond. Permanent structures (e.g., buildings) should not be constructed within the vegetated perimeter area. Where it is possible to do so, existing trees should be preserved in the vegetated perimeter area during construction. The full width of the vegetated perimeter should be located in common open space, not within recorded lots.

The soils in the Wet Pond vegetated perimeter area are often severely compacted during the construction process, to ensure stability. The density of these compacted soils can be so great that it effectively prevents root penetration and, therefore, may lead to premature mortality or loss of vigor. As a rule of thumb, planting holes should be three times deeper and wider than the diameter of the root ball for ball-and-burlap stock, and five times deeper and wider for container-grown stock. Organic matter such as locally generated compost may be used to amend compacted soil to improve soil structure, help establish vegetation, and reduce runoff.

For more guidance on planting trees and shrubs in Wet Pond vegetated perimeter areas, consult Cappiella et al (2006).

Woody Vegetation: Woody vegetation may not be planted or allowed to grow within 15 feet of the toe of the embankment. Woody vegetation may not be planted or allowed to grow within 25 feet of the principal spillway structure or any inflow pipes.

Landscaping and Planting Plan: A landscaping plan must be provided that indicates the methods used to establish and maintain vegetative coverage in the Wet Pond and its vegetated perimeter. The landscaping plan should provide elements that promote diverse wildlife and waterfowl use within the Wet Pond, wetland and vegetated perimeter areas. Avoid species that require full shade, or are prone to wind damage. Extra mulching around the base of trees and shrubs is strongly recommended as a means of conserving moisture and suppressing weeds.

Minimum elements of a landscaping plan include the following:

- Delineation of pondscaping zones within both the Wet Pond and vegetated perimeter area
- Selection of corresponding plant species
- The planting plan
- The sequence for preparing the aquatic bench (including soil amendments, if needed)
- Sources of native plant material

13.8. Wet Pond Construction

Use of Wet Ponds for Erosion and Sediment Control. A Wet Pond may serve as a sediment basin during project construction. If this is done, the volume of the sediment basin must be based on the more stringent sizing rule (erosion and sediment control requirement vs. storage volume requirement). Installation of the permanent principal spillway should be initiated during the construction phase, and design elevations should be set with final cleanout of the sediment basin and conversion to the post-construction Wet Pond in mind. The bottom elevation of the temporary sediment basin should be set elevation minimum of six inches higher than the design bottom elevation of the final Wet Pond to allow for maintenance cleanout of accumulated sediment during pond conversion. Appropriate procedures must be implemented to prevent discharge of turbid waters when the sediment basin is being converted into a Wet Pond.

Approval from the Department or the appropriate Delegated Agency must be obtained before any planned Wet Pond or Wet ED Pond can be used as a sediment basin. The Sediment and Stormwater Plan must include conversion steps from sediment basin to permanent Wet Pond in the construction sequence. The Department or Delegated Agency must be notified and provide approval prior to conversion from sediment basin to the final configuration of the Wet Pond or Wet ED Pond.

Construction Review. Multiple construction reviews are critical to ensure that Wet Ponds are properly constructed. Construction reviews are required during the following stages of construction, and noted on the plan in the sequence of construction:

- Pre-construction meeting
- Initial site preparation (including installation of E&S controls)
- Construction of the embankment, including installation of the principal spillway and the outlet structure
- Excavation/Grading (interim and final elevations)

- Implementation of the pondscaping plan and vegetative stabilization
- Final inspection (develop a punch list for facility acceptance)

Construction Sequence. The following is a typical construction sequence to properly install a Wet Pond. The steps may be modified to reflect different Wet Pond designs, site conditions, and the size, complexity and configuration of the proposed facility.

Step 1: Stabilize the Drainage Area. Wet Ponds should only be constructed after the contributing drainage area to the Wet Pond is completely stabilized. If the proposed Wet Pond site will be used as a sediment trap or basin during the construction phase, the construction notes should clearly indicate that the facility will be de-watered, dredged and re-graded to design dimensions after the original site construction is complete.

Step 2: Assemble Construction Materials on-site, make sure they meet design specifications, and prepare any staging areas. Ensure that appropriate compaction and dewatering equipment is available. Locate the project benchmark and if necessary transfer a benchmark nearer to the Wet Pond location for use during construction.

Step 3: Install Erosion and Sediment Controls prior to construction, including temporary de-watering devices and stormwater diversion practices. All areas surrounding the Wet Pond that are graded or denuded during construction must be planted with turf grass, native plantings, or other approved methods of soil stabilization.

Step 4: Clear and Strip the embankment area to the desired sub-grade.

Step 5: Excavate the Core Trench and Install the Principal Spillway Pipe in accordance with construction specification of NRCS Small Pond Code 378**.**

Step 6: Install the Riser or Outflow Structure, and ensure the top invert of the overflow weir is constructed level at the design elevation.

Step 7: Construct the Embankment and Any Internal Berms using acceptable material in 8- to 12-inch lifts, compact the lifts with appropriate equipment. Construct the embankment allowing for 10% settlement of the embankment.

Step 8: Excavate/Grade until the appropriate elevation and desired contours are achieved for the bottom and side slopes of the Wet Pond. Construct forebays at the proposed inflow points.

Step 9: Construct the Emergency Spillway in cut or structurally stabilized soils.

Step 10: Install Outlet Pipes, including any flared end sections, headwalls, and downstream rip-rap outlet protection underlain by stabilization geotextile.

Step 11: Stabilize Exposed Soils with the approved seed mixtures appropriate for the Wet Pond perimeter area. All areas above the normal pool elevation must be permanently stabilized in accordance with the vegetative stabilization specifications on the approved Sediment and Stormwater Management Plan.

Step 12: Plant the Wet Pond Benches and Vegetated Perimeter Area, following the pondscaping plan (see ***Section 13.7 Wet Pond Landscaping Criteria***).

Post Construction Verification. Following construction, the constructed Wet Pond depth at three areas within the permanent pool (forebay, mid-pond, and prior to the principal spillway) must be measured, marked, and geo-referenced on the post construction verification survey document. This simple data set will enable maintenance reviewers to determine sediment deposition rates in order to schedule sediment cleanouts.

13.9 Wet Pond Maintenance Criteria

Maintenance is needed so Wet Ponds continue to operate as designed on a long-term basis. Wet Ponds normally have fewer routine maintenance requirements than other stormwater control measures. Wet Pond maintenance activities vary regarding the level of effort and expertise required to perform them. Routine Wet Pond maintenance, such as mowing and removing debris and trash, is needed several times each year (See **Table 13.4**). More significant maintenance (e.g., removing accumulated sediment) is needed less frequently but requires more skilled labor and special equipment. Inspection and repair of critical structural features (e.g., embankments and risers) needs to be performed by a qualified professional who has experience in the construction, inspection, and repair of these features.

Sediment removal in the Wet Pond pretreatment forebay must occur when 50% of total forebay capacity has been lost. The owner can plan for this maintenance activity to occur every 5 to 7 years.

Sediment removed from the Wet Pond should be deposited in the designated maintenance set aside area for dewatering, prior to leveling and stabilization or removal from the site. Sediments excavated from Wet Ponds are not usually considered toxic or hazardous. They can be safely disposed of by either land application or land filling. Sediment testing may be needed prior to sediment disposal if the wet pond serves a hotspot land use.

Community awareness can contribute to a properly maintained Wet Pond. Signs describing the function and/or minimum maintenance requirements for the Wet Pond may be posted at the Wet Pond location to increase community awareness.

Table 13.4. Typical Wet Pond Maintenance Items and Frequency

Frequency	Maintenance Items
During establishment, as needed (first year)	• Inspect the site after storm event that exceeds 0.5 inches of rainfall. • Stabilize any bare or eroding areas in the contributing drainage area including the Wet Pond perimeter area • Water trees and shrubs planted in the Wet Pond vegetated perimeter area during the first growing season. In general, water every 3 days for first month, and then weekly during the remainder of the first growing season (April - October), depending on rainfall.
Quarterly or after major storms (>1 inch of rainfall)	• Remove debris and blockages • Repair undercut, eroded, and bare soil areas
Twice a year	• Mowing of the Wet Pond vegetated perimeter area and embankment
Annually	• Shoreline cleanup to remove trash, debris and floatables • A full maintenance review • Open up the riser to access and test the valves • Repair broken mechanical components, if needed
One time –during the second year following construction	• Wet Pond vegetated perimeter and aquatic bench reinforcement plantings
Every 5 to 7 years	• Forebay sediment removal
From 5 to 25 years	• Repair pipes, the riser and spillway, as needed • Remove sediment from Wet Pond area outside of forebays

An Operation and Maintenance Plan for the project will be approved by the Department or the Delegated Agency prior to project closeout. The Operation and Maintenance Plan will specify the property owner’s primary maintenance responsibilities and authorize the Department or Delegated Agency staff to access the property for maintenance review or corrective action in the event that proper maintenance is not performed. Wet Ponds that are, or will be, owned and maintained by a joint ownership such as a homeowner’s association must be located in common areas, community open space, community-owned property, jointly owned property, or within a recorded easement dedicated to public use.

Operation and Maintenance Plans should clearly outline how vegetation in the Wet Pond and its vegetated perimeter area will be managed or harvested in the future. Periodic mowing of the Wet Pond vegetate perimeter area is only required along the maintenance access and the embankment. The remaining Wet Pond perimeter can be managed as a meadow (mowing every other year) or forest. The maintenance plan should schedule a shoreline cleanup at least once a year to remove trash and floatables.

Maintenance of a Wet Pond is driven by annual maintenance reviews that evaluate the condition and performance of the Wet Pond. Based on maintenance review results, specific maintenance tasks may be required.

13.10 References

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14.0 Soil Amendments

Definition:

Soil Amendment (also called soil restoration) is a technique applied after construction to till compacted soils and restore their porosity by amending them with compost. These soil amendments can reduce the generation of runoff from compacted urban lawns and may also be used to enhance the performance of impervious cover disconnections and grass channels.

14.1 Soil Amendment Stormwater Credit Calculations

Soil Amendment does not receive a retention allowance. However, the use of soil amendments in accordance with this specification allows disturbed areas to receive a reduction credit for the annual runoff. The adjustment varies depending on the soil's Hydrologic Soil Group. Pollutant loads are assumed to be reduced by the equivalent reduction in runoff. **Table 14.1** summarizes the runoff and pollutant reduction credits for this practice. Soil amendments can also enhance the performance of other runoff reduction practices that rely on surface infiltration. Runoff and pollutant reduction credits for these types of applications are discussed in the respective specifications for those practices.

14.1 Soil Amendment Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv	HSG A – 38% Annual Runoff Reduction HSG B – 50% Annual Runoff Reduction HSG C - 29% Annual Runoff Reduction HSG D – 13% Annual Runoff Reduction
Cv	10% of RPv Allowance
Fv	1% of RPv Allowance
Pollutant Reduction	
TN Reduction	100% of Load Reduction
TP Reduction	100% of Load Reduction
TSS Reduction	100% of Load Reduction
NOTE: Runoff reduction allowances are for amendment area only.	

14.2 Soil Amendment Design Summary

Table 14.2 summarizes design criteria for soil amendments, For more detail, consult Sections 14.3 through 14.7. Sections 14.8 and 14.9 describe practice construction and maintenance criteria.

Table 14.2 Soil Amendment Design Summary

	Best Applications/ Purposes	Restrictions
Feasibility (Section 14.3)	• Reduce runoff from compacted lawns • Enhance performance of impervious cover disconnections on poor soils • Increase runoff reduction within a grass channel • Increase runoff reduction within a vegetated filter strip • Increase the runoff reduction function of a reforested area of the site	• The water table or bedrock ≤ 2.0 feet from soil surface • Slopes > 10% • Saturated or seasonally wet soils • Within existing tree drip line • Slopes running toward an existing or proposed building foundation • Contributing impervious surface area exceeds the surface area of the amended soils • Snow storage areas
Soil Testing (Section 14.6)	Test at two points, including: 1) Before amendment is incorporated, to estimate amount needed 2) One week after, to determine if additional amendments are needed	
Incorporation Depth (Section 14.6)	Short-Cut method to determine incorporation depth outlined in Table 14.4	
Compost Volume Need (Section 14.6)	$C = A * D * 0.0031$ Where: C = compost needed (cu. yds.) A = area of soil amended (sq. ft.) D = depth of compost added (in.)	

14.3 Soil Amendment Feasibility Criteria

Amended soils are suitable for any pervious area where soils have been or will be compacted by the grading and construction process. They are particularly well suited when existing soils have low infiltration rates (HSG C and D) and when the pervious area will be used to filter runoff (downspout disconnections and grass channels). The area or strip of amended soils should be hydraulically connected to the stormwater conveyance system. Soil Amendment is particularly recommended for sites that will experience mass grading of more than a foot of cut and fill across the site.

Soil Amendments are not recommended where:

- The water table or bedrock is located within 2.0 feet of the soil surface.
- Slopes exceed 10%.
- Existing soils are saturated or seasonally wet (including some soils in HSG D).
- They would harm roots of existing trees (keep amendments outside the tree drip line).
- The downhill slope runs toward an existing or proposed building foundation.
- The contributing impervious surface area exceeds the surface area of the amended soils.
- Areas that will be used for snow storage.

Soil Amendments can be applied to the entire disturbed pervious area of a development or be applied only to select areas of the site to enhance the performance of runoff reduction practices. Some common design applications include:

- Reduce runoff from compacted lawns.
- Enhance performance of impervious cover disconnections on poor soils.
- Increase runoff reduction within a grass channel.
- Increase runoff reduction within a vegetated filter strip.
- Increase the runoff reduction function of a reforested area of the site.

14.4 Soil Amendment Conveyance Criteria

There are no conveyance criteria for soil amendments.

14.5 Soil Amendment Pretreatment Criteria

There are no conveyance criteria for soil amendments.

14.6 Soil Amendment Design Criteria

Soil Testing. Soil tests are required during two stages of the Soil Amendment process. The first testing is done to ascertain pre-construction soil properties at proposed amendment areas. The initial testing is used to determine soil properties to a depth 1 foot below the proposed amendment area, with respect to bulk density, pH, salts, and soil nutrients. These tests should be conducted every 5000 square feet and at sufficient density to accurately characterize the heterogeneity of the site. These testing results are then used to characterize potential drainage problems and determine what, if any, further soil amendments are needed.

The second soil test is taken at least one week after the compost has been incorporated into the soils. This soil analysis should be conducted by a reputable laboratory to determine whether any further nutritional requirements, pH adjustment, and organic matter adjustments are necessary for plant growth. This soil analysis should be done in conjunction with the final construction inspection to ensure tilling or subsoiling has achieved design depths.

Determining Depth of Compost Incorporation. The depth of compost incorporation is based on the relationship of the surface area of the Soil Amendment to the contributing area of impervious cover that it receives. **Table 14.3** presents some general guidance derived from soil modeling by Holman-Dodds (2004) that evaluates the required depth to which compost must be incorporated. Some adjustments to the recommended incorporation depth were made to reflect alternative recommendations of Roa-Espinosa (2006), Balousek (2003), Chollak and Rosenfeld (1998) and others.

Table 14.3. Short-Cut Method to Determine Compost and Incorporation Depths

	Contributing Impervious Cover to Soil Amendment Area Ratio [1]			
	IC/SA = 0 [2]	**IC/SA = 0.5**	**IC/SA = 0.75**	**IC/SA = 1.0 [3]**
Compost (in) [4]	2 to 4 [5]	3 to 6 [5]	4 to 8 [5]	6 to 10 [5]
Incorporation Depth (in)	6 to 10 [5]	8 to 12 [5]	15 to 18 [5]	18 to 24 [5]
Incorporation Method	Tiller	Tiller	Excavation + Mixing	Excavation + Mixing

Notes:
[1] IC = contrib. impervious cover (sq. ft.) and SA = surface area of compost amendment (sq. ft.)
[2] For amendment of areas that do not receive off-site impervious cover runoff
[3] In general, IC/SA ratios greater than 1 should be avoided
[4] Average depth of compost added
[5] Lower end for A/B soils, higher end for C/D soils

Compost Incorporation. Incorporation depths up to 12” can generally be achieved by placing the recommended depth of compost material over the proposed amendment area and tilling down to the specified incorporation depth using appropriate equipment. Incorporation depths greater than 12” require actual removal of the existing soil mantle down to the incorporation depth and physically mixing with compost in accordance with the recommended procedures in **Section 14.8**.

Once the area and depth of the compost amendments are known, the designer can estimate the total amount of compost needed, using an estimator developed by TCC, (1997):

$$C = A * D * 0.0031$$

Where: C = compost needed (cu. yds.)
A = area of soil amended (sq. ft.)
D = depth of compost added (in.)

Compost Specifications
Compost used to fulfill regulatory requirements shall meet the criteria set forth in ***Appendix 3, Compost Material Properties***. In addition, it must be provided by a member of the U.S. Composting Seal of Testing Assurance (STA) program.

14.7 Soil Amendment Landscaping Criteria

There are no specific landscaping criteria for Soil Amendments other than what would be necessary to provide adequate stabilization.

14.8 Soil Amendment Construction Sequence

The construction sequence for Soil Amendments differs depending on whether the practice will be applied to a large area or a narrow area such as a filter strip or grass channel. Construction techniques also differ depending on the specified incorporation depth. The following typical sequences are provided as general guidance.

Incorporation Depth Up to 12”:

1. The proposed area should be deep tilled to a depth of 2 to 3 feet using a tractor and sub-soiler with two deep shanks (curved metal bars) to create rips perpendicular to the direction of flow. (This step is usually omitted when compost is used for narrower filter strips.)
2. It is important to have dry conditions at the site prior to incorporating compost.
3. Place a layer of an approved compost mix on surface of proposed amendment area to the depth specified in **Table 14.3**.
4. Compost mix is then incorporated into the soil using a roto-tiller or similar equipment.

Incorporation Depth Greater Than 12”:

1. Excavate proposed amendment area to recommended incorporation depth, as follows:
   1.1. Scrape off topsoil and stockpile for use in 2.2.

1.2. Excavate subsoil working in strips perpendicular to the slope/flowpath, using multiple lifts.

1.3. Separate and remove 25% - 30% of the subsoil, taking the most densely compacted soils for removal. Stockpile remaining subsoil next to excavated area, separately from topsoil, for use in 2.1.

1.4. Scarify bottom of excavated area.

2. Replace subsoil, followed by topsoil and compost amendment, loosening/aerating, and mixing subsoil layers, as follows, to achieve a final settled grade at three months post-installation that matches original grade:

   2.1. Replace subsoils by loosening/aerating, and mixing subsoil as multiple lifts are dropped into place. Replace stockpiled topsoil, breaking up and mixing in any grass/soil clumps.

   2.2. Incorporate recommended amount of compost from **Table 14.3**, such that compost is uniformly incorporated throughout.

   2.3. Repeat above steps for each lift. Number of lifts may vary depending on the capabilities of the equipment being used, but a minimum of 2 lifts is required.

3. Rake to level and remove surface woody debris and rocks larger than 1”

4. The finished grade of the combination of replaced subsoils and topsoil should be approx. 4” above the existing grade to account for settlement, but must be adjusted to account for field conditions and soil texture, such that a final settled grade at three months post-installation matches the original grade.

Once the compost has been incorporated, vegetative stabilization should be initiated immediately. Lime and irrigation may be necessary to ensure adequate germination and quick establishment of vegetation. The amended area should be protected from re-compaction, particularly following the first 3 months of completion as settlement occurs. Areas of Soil Amendment exceeding 5000 square feet should employ simple erosion control measures, such as silt fence, to reduce the potential for erosion and trap sediment.

Construction Inspection. Construction inspection involves digging a test pit to verify the depth of mulch, amended soil and scarification. A rod penetrometer should be used to establish the depth of uncompacted soil at one location per 10,000 square feet.

14.9 Soil Amendment Maintenance Criteria

Maintenance Agreements. When Soil Amendments are applied on private residential lots, homeowners will need to be educated on their routine maintenance needs, understand the long-term maintenance plan, and be subject to a deed restriction or other mechanism enforceable by the qualifying local program to ensure that infiltrating areas are not converted or disturbed. The mechanism should, ideally, grant authority for local agencies to access the property for inspection or corrective action. In addition, the GPS coordinates for all amended areas should be provided upon facility acceptance to ensure long term tracking.

A simple maintenance agreement should be provided if the Soil Amendment is associated with more than 10,000 square feet of reforestation. A conservation easement or deed restriction, which also identifies a responsible party, may be required to make sure the newly developing forest cannot be cleared or developed management is accomplished (i.e., thinning, invasive plant removal, etc.). Soil compost amendments within a filter strip or grass channel should be located in a public right-of-way, or within a dedicated stormwater or drainage easement.

First Year Maintenance Operations. In order to ensure the success of Soil Amendments, the following tasks must be undertaken in the first year following soil restoration:

- *Initial inspections.* For the first six months following the incorporation of soil amendments, the site should be inspected at least once after each storm event that exceeds 1/2-inch of rainfall.
- *Spot Reseeding.* Inspectors should look for bare or eroding areas in the contributing drainage area or around the soil restoration area and make sure they are immediately stabilized with grass cover.
- *Fertilization.* Depending on the amended soils test, a one-time, spot fertilization may be needed in the fall after the first growing season to increase plant vigor.
- *Watering.* Water once every three days for the first month, and then weekly during the first year (April-October), depending on rainfall.

Ongoing Maintenance. There are no major on-going maintenance needs associated with Soil Amendments, although the owners may want to de-thatch the turf every few years to increase permeability. The owner should also be aware that there are maintenance tasks needed for filter strips, grass channels, and reforestation areas.

Table 14.4. Typical Soil Amendment Maintenance Items and Frequency

Frequency	Maintenance Items
During establishment, as needed (first year)	• Inspect the site after storm event that exceeds 0.5 inches of rainfall. • Stabilize any bare or eroding areas in the contributing drainage area including the Wet Pond perimeter area • Water trees and shrubs planted in the Wet Pond vegetated perimeter area during the first growing season. In general, water every 3 days for first month, and then weekly during the remainder of the first growing season (April - October), depending on rainfall.
Quarterly or after major storms (>1 inch of rainfall)	• Remove debris and blockages • Repair undercut, eroded, and bare soil areas

Frequency	Maintenance Items
Twice a year	• Mowing of the Wet Pond vegetated perimeter area and embankment
Annually	• Shoreline cleanup to remove trash, debris and floatables • A full maintenance review • Open up the riser to access and test the valves • Repair broken mechanical components, if needed
One time –during the second year following construction	• Wet Pond vegetated perimeter and aquatic bench reinforcement plantings
Every 5 to 7 years	• Forebay sediment removal
From 5 to 25 years	• Repair pipes, the riser and spillway, as needed • Remove sediment from Wet Pond area outside of forebays

14.10 References

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Low Impact Development Center. 2003. *Guideline for Soil Amendments*. Available online at: http://www.lowimpactdevelopment.org/epa03/soilamend.htm

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15.0 Proprietary Practices

Definition: Proprietary Practices are manufactured stormwater treatment practices that utilize settling, filtration, absorptive/adsorptive materials, vortex separation, vegetative components, and/or other appropriate technology to manage the impacts caused by stormwater runoff.

Certain Proprietary Practices may be eligible for some amount of treatment credit, provided they have been approved by the Department and meet the performance criteria outlined in this specification. Proprietary practices will generally not be eligible for retention volume credit unless the practice can demonstrate the occurrence of runoff reduction processes.

15.1 Proprietary Practice Stormwater Credit Calculations

Proprietary Practices will receive no retention credit (R_v) unless explicitly approved by the Department. However, they may be credited as treatment practices, provided they meet the performance criteria outlined in ***Section 15.5, Proprietary Practice Design Criteria*.**

15.1 Proprietary Practices Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv -A/B Soil	0%
RPv - C/D Soil	0%
Cv	0%
Fv	0%
Pollutant Reduction	
TN Reduction	See DURMM documentation
TP Reduction	See DURMM documentation
TSS Reduction	See DURMM documentation

15.2 Proprietary Practice Design Summary

Individual proprietary practices will have different site constraints and limitations. Manufacturer's specifications should be consulted to ensure that proprietary practices are feasible for application on a site-by-site basis.

15.3 Proprietary Practice Conveyance Criteria

All proprietary practices must be designed to safely overflow or bypass flows from larger storm events to downstream drainage systems. The overflow associated with the 10-yr storms should be controlled so that velocities are non-erosive at the outlet point (i.e., to prevent downstream erosion).

Manufactured treatment devices may be constructed on-line or off-line. On-line systems receive upstream runoff from all storms, providing runoff treatment for the water quality design storm and conveying the runoff from larger storms through an overflow. In off-line devices, most or all of the runoff from storms larger than the stormwater quality design storm bypass the device through an upstream diversion.

15.4 Proprietary Practice Pretreatment Criteria

Individual Proprietary Practices may require pretreatment, or may be appropriate for use as pretreatment devices. Manufacturer's specifications should be consulted to determine the device-specific pretreatment requirements.

15.5 Proprietary Practice Design Criteria

The basic design parameters for a Proprietary Practice will depend on the techniques it employs to control stormwater runoff and remove particulate and dissolved pollutants from runoff. In general, the design of devices that treat runoff with no significant storage and flow rate attenuation must be based upon the peak design flow rate. However, devices that do provide storage and flow rate attenuation must be based, at a minimum, on the design storm runoff volume and, in some instances, on a routing of the design runoff hydrograph.

The Department shall verify performance criteria for all proprietary practices proposed for use in Delaware. The removal efficiencies used for Proprietary Practices are included in the DURMM model documentation. Performance criteria for Proprietary Practices shall be based on the pollutant removal efficiencies assigned by EPA's Chesapeake Bay Program (CBP) for inclusion in the Chesapeake Bay Model. Manufacturers who feel that the performance of their particular product exceeds the CBP performance criteria as currently assigned may request a formal review of their product following the procedures developed by the Scientific and Technical Advisory Committee (STAC) for evaluating stormwater BMPs. In order to be considered for improved performance criteria, the manufacturer shall notify the Department in writing of its intention to proceed with such formal review and shall forward subsequent findings and results from the STAC.

15.6 Proprietary Practice Landscaping Criteria

Proprietary Practices may or may not require landscaping considerations. Manufacturer's specifications should be consulted to determine any landscaping requirements for the device.

15.7 Proprietary Practice Construction Sequence

The construction and installation of individual Proprietary Practices will vary based on the specific proprietary practice. Manufacturer's specifications should be consulted to determine the device specific construction sequencing requirements.

Post Construction Verification Documentation. Documentation shall be provided to the Department or its appropriate Delegated Agency verifying that the Proprietary Practice has been installed in accordance with manufacturer's recommendations.

15.8 Proprietary Practice Maintenance Criteria

In order to ensure effective and long-term performance of a Proprietary Practice, regular maintenance tasks and inspections are required.

All Proprietary Practices should be inspected and maintained in accordance with the manufacturer's instructions and/or recommendations and any maintenance requirements associated with the device's certification by the Department.

15.9 References

No references.

16.0 Source Controls

Definition: Source Control consists of measures to prevent pollutants from coming into contact with stormwater runoff. Preventing pollutant exposure to rainfall and runoff is an important management technique that can reduce the amount of pollutants in runoff and the need for stormwater treatment.

Source Control practices and pollution prevention can include a wide variety of management techniques that address nonpoint sources of pollution. These practices are typically non-structural, require minimal or no land area, and involve moderate effort and cost to implement, when compared to structural treatment practices. Therefore, project planning and design should consider measures to minimize or prevent the release of pollutants so they are not available for mobilization by runoff.

Design variants include:

- 16-A Nutrient Management
- 16-B Street Sweeping

Urban Nutrient Management involves the reduction of fertilizer to grass lawns and other urban areas down to the minimum required to sustain adequate vegetative cover. The implementation of urban Nutrient Management is based on public education and awareness, targeting suburban residences and businesses, with emphasis on reducing excessive fertilizer use. Although the availability of “Lo-P” or “No-P” fertilizer formulations have improved the situation, managing excess nutrient applications in urban settings will continue to be an important element in the overall goal to minimize impacts from urban stormwater runoff.

Street Sweeping and storm drain cleanout practices rank among the oldest practices used by communities for a variety of purposes to provide a clean and healthy environment, and more recently to comply with their National Pollutant Discharge Elimination System (NPDES) stormwater permits. The ability for these practices to achieve pollutant reductions is uncertain given current research findings. Only a few Street Sweeping studies provide sufficient data to statistically determine the impact of street sweeping and storm drain cleanouts on water quality and to quantify their improvements. Fewer studies are available to evaluate the pollutant reduction capabilities due to storm drain inlet or catch basin cleanouts. Nevertheless, the use of modern equipment under a well-managed program has been shown to yield measurable benefits and thus this practice should be considered for inclusion in any source control program.

16.1 Source Controls Stormwater Credit Calculations

Source controls do not typically receive runoff reduction credits. The ability of these practices to reduce nutrients and particulates varies. Table 16.1(a) summarizes the stormwater performance credits for Nutrient Management. Table 16.1(b) summarizes the stormwater performance credits for street sweeping.

16.1(a) Nutrient Management Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv -A/B Soil	0%
RPv - C/D Soil	0%
Cv	0%
Fv	0%
Pollutant Reduction	
TN Reduction	17%
TP Reduction	22%
TSS Reduction	0%

16.1(b) Street Sweeping Performance Credits

Runoff Reduction	
Retention Allowance	0%
RPv -A/B Soil	0%
RPv - C/D Soil	0%
Cv	0%
Fv	0%
Pollutant Reduction	
TN Reduction	3%
TP Reduction	3%
TSS Reduction	9%

16.2 Source Controls Design Summary

Source Controls do not have traditional design criteria. Instead, these practices are usually implemented based on guidance documents, or in some cases, formal regulations. The "Urban Nutrient Management Handbook" published by the Virginia Cooperative Extension Service, included as Appendix 16-1 of this document, is an example of the former. The Delaware Nutrient Management Law (**3 Del. C. Ch. 22**) is an example of the latter.

The Delaware Nutrient Management Law requires any person who owns, leases, or otherwise controls 10 acres to which nutrients are applied to develop a nutrient management plan for those lands. Nutrient management plans must be updated every three years or when significant alterations to the nutrient application occurs. In addition the Law requires anyone who applies nutrients to lands or water in excess of 10 acres to have certification endorsed by the Delaware Nutrient Management Commission.

The ability of Street Sweeping to measurably reduce pollutant loadings is highly dependent on its frequency. The pollutant reductions shown in Table 16.1(b) are based on the values used in the Phase 5.3 Chesapeake Bay Model. These values are based on the following assumptions (from personal correspondence, Ms. Olivia Devereux):

The assumption is that there is a nitrogen, phosphorus, and sediment reduction when the same section of a street is swept approximately every two weeks, or 25 times a year. When a street is swept periodically and less than every two weeks, the accumulated matter can be mobilized and moved into the stream system with any rainfall. Therefore, less regularly swept streets are given credit solely for the sediment removed.

There are three ways to track street sweeping:

1. Streets swept 25 times a year: track the acres that were swept this number of times, not the acres swept once times 25.
2. Streets swept 25 times a year: track as percent of land area. This is the percent of the land area that received this treatment 25 times a year.
3. Street sweeping lbs. Enter the lbs of sediment removed. The number entered is simply subtracted from the total sediment load. This requires weighing the sweeper before it goes out and when it returns to determine the lbs of material removed.

For option 1 and 2, there is a N, P, and SED reduction. The N and P reductions are 3% and the Sed reduction is 9%.

16.3 References

Goatley, Michael, Jr. and Kevin Hensler, "Urban Nutrient Management Handbook", Virginia Cooperative Extension Service. May 2011.

APPENDIX 16-1

VIRGINIA COOPERATIVE EXTENSION SERVICE
URBAN NUTRIENT MANAGEMENT
HANDBOOK

Urban Nutrient Management Handbook

Virginia Cooperative Extension

VirginiaTech
Invent the Future

VSU
VIRGINIA STATE

DCR
Virginia Department of Conservation & Recreation

Urban Nutrient Management Handbook

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Published by:

Virginia Cooperative Extension

Project funded by:

Virginia Department of Conservation and Recreation

Produced by:

Communications and Marketing,
College of Agriculture and Life Sciences,
Virginia Polytechnic Institute and State University

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This material is based upon work supported by the Virginia Department of Conservation and Recreation, under Agreement 50301-2009-01-SF. Any opinions, findings, conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the Virginia Department of Conservation and Recreation.

May 2011

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Chapter 13. Turf and Landscape Nutrient Management Planning

Chapter 1. The Objectives of Turf and Landscape Nutrient Management

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Introduction

The locations of many towns and cities in the mid-Atlantic region are closely linked to a clean, readily available, and abundant water resource. The water source must be sufficient in size and quality to meet the daily life needs of the general population at home (e.g., drinking, cooking, cleaning, leisure, etc.) and its industrial base (e.g., transportation/shipping, cooling/heating, manufacturing applications as a solvent/diluent, etc.).

By nature, urban areas are frequently undergoing either expansion and/or renovation in both commercial and/or residential development. Expansive development in rolling topography requires significant soil disturbance. Soils that took millions of years to form are quickly altered and/or removed during construction, eliminating sod cover and forested areas that are naturally occurring water filtration and soil stabilization systems. Expansions in roof area and paved surfaces increase the need for comprehensive stormwater management planning. By law, soil disturbance, therefore, must be accompanied by appropriate stormwater management strategies (e.g., silt fences, compost berms, natural and synthetic erosion-control mats, etc.) that are designed to protect water quality and minimize soil erosion and sediment loss.

In the final stages of both commercial and residential development, an urban ecosystem intermingles grasses, groundcovers, shrubs, ornamental plants, and trees with the structural and hardscape (e.g., sidewalks, parking lots, driveways, streets, etc.) components. This myriad of urban landscape components results in many recommendations regarding appropriate plant material selection and management protocol. Due to the complexity of plant materials, the abundance of hardscapes, and the proximity of water sources, urban ecosystems have great potential to negatively impact water quality if managed inappropriately. All plant materials have nutrient requirements, but the levels and timing of applications of nutrients are highly variable and plant-specific. The following factors are a few of the most important to consider in the development and implementation of a nutrient management program (NMP):

1. The overall climate (rainfall patterns) of a particular location and the variability in topography, such as aspect, slope, elevation, etc.
2. An understanding of the plant material's periods of active growth and its inherent growth rate.
3. The physical and chemical characteristics of the soil as determined by soil testing (an absolute requirement for an NMP) and/or review of soil maps (where appropriate).
4. The intended use of the plant material.
5. The selection and application of the nutrient source.
6. Consideration of the surrounding environment and how it can either impact or be impacted by fertilization.

An NMP considers each of these factors and presents a recommendation for the selection and timing of nutrient applications that meets the needs of the plant and minimizes the loss of nutrients to the environment.

What Is Nutrient Management?

Nutrient management plans serve two primary purposes: (1) ensuring that plants have optimum soil nutrient availability for good productivity and quality, and (2) ensuring minimum movement of nitrogen and phosphorus from the specified area of application to surface and groundwaters where they can potentially have a detrimental effect on water quality. Although NMPs cover more than nitrogen and phosphorus, only these two nutrients are considered a risk for impairing water quality. Other nutrients are essential for plant growth but do not cause water quality problems in the mid-Atlantic region.

Most soils in the mid-Atlantic are highly weathered and low in plant-available nutrients, particularly nitrogen, phosphorus, and potassium. Some form of fertilization is required for even the lowest quality turfgrass, if only to maintain a functioning turfgrass population that will protect the soil from erosion. Turf stands subjected to high traffic and intensive use require regular fertilization to maintain functionally adequate levels of leaf density, vigor, recuperative potential, stress tolerance, and color. Similarly, ornamental landscape plants require appropriate fertilization and cultural management strategies in order to optimize their aesthetic and functional uses. The challenge of nutrient management is to consider the characteristics of the turfgrass and landscape plants being grown on each specific site and then make appropriate decisions regarding the timing, material, and application method of required nutrients.

Nutrient management plans also have economic considerations, because there are both savings and costs involved in the process. One cost may be hiring a certified nutrient management planner to write a plan. Some lawn care companies and other consultants may offer free nutrient management planning as part of their service. Making extra trips to apply nitrogen, purchasing different fertilizer materials to meet specific recommendations, setting aside buffer areas along water bodies, etc., could all potentially increase a client's budget. By implementing an NMP, savings accrue from avoiding the purchase and application of unnecessary fertilizer and lime. There may also be savings from greater plant survival because nutrient deficiency will be avoided. Nutrient management planning is also expected to have a societal economic benefit by maintaining high-quality water for drinking, ecological, and recreational purposes.

A brief overview of the basic components of nutrient management planning and implementation follows.

Selection of Nutrient Sources

There are substantial differences in nutrient requirements between plants and also in the time nutrients are required. For example, legumes can produce their own nitrogen and therefore do not require nitrogen fertilization, making them a popular component of highway rights-of-way vegetation where there is no desire to supply additional nitrogen after establishment. However, cool- and warm-season grasses (discussed in chapter 6) require nitrogen, but their periods of maximum growth differ, resulting in different timing of optimal nitrogen applications.

The age of plants is also important because mature plants with well-developed root systems require fewer nutrients than young plants. This is often realized for phosphorus recommendations when they are typically greater for plant establishment than they are for maintenance.

Knowledge of the physical and chemical characteristics of nutrient sources can prove invaluable in calculating application rates, reducing fertilizer costs, and managing applications to minimize potential for losses through volatilization, runoff, and leaching. Most soil test reports will provide specific recommendations regarding appropriate fertilizer and/or liming materials to address soil limitations. However, a greater understanding of fertilizer sources, their characteristics, and their appropriate use (information presented in chapters 8 and 9) is invaluable in optimizing nutrient management strategies. For instance, knowing that prilled urea can volatilize under existing conditions may lead you to choose another nitrogen source, a different application method, or a best management practice (e.g., irrigating immediately after application) to reduce volatile nitrogen losses. In other situations, a slow-release nitrogen source might be most appropriate because of an anticipated rainy season or the inability to deliver suitable levels of readily available nitrogen sources on a frequent basis.

There is a great deal of interest in expanding the use of organic compounds (both fertilizers and soil amendments), and information in this handbook will detail how to properly utilize these materials in responsible plant management programs. Organic sources are perceived by most to be "environmentally friendly," and generally speaking, this is true. Organic fertilizers and amendments are often an effective way of recycling waste products and they also can improve the physical, chemical, and biological aspects of soils. However, consider that organic sources almost always contain phosphorus, and if a soil test shows that no phosphorus is needed, then an organic fertilizer does not fit the requirements of an NMP. Instead, an inorganic fertilizer containing no phosphorus would be a better fertilizer selection. Knowledge of nutrient sources will greatly improve your management options and capabilities.

Nutrient Application Rates

Nutrient needs for turfgrasses and landscape materials are based on Virginia Cooperative Extension and land-grant university research. Nutrient application rates for plan development are determined differently for nitrogen compared to phosphorus and potash. Nitrogen rates are determined on an annual basis and are specific to the plant species, the use of the plant material, and the management area. For turf, nitrogen rates are often specific to the plant species; for instance, whether it is a heavy or light nitrogen feeder. In cool-season grasses, Kentucky bluegrass has a higher seasonal nitrogen requirement than does fine-leaf fescue. In warm-season grasses, bermudagrass responds to aggressive nitrogen programs whereas zoysiagrass requires much smaller amounts annually. The use of the turf is also an important factor in seasonal application rates, with lawns often utilizing a simple nitrogen program involving relatively low annual nitrogen rates and a limited number of applications per growing season.

On the other hand, athletic fields and golf courses will have higher annual nitrogen application rates with more frequent applications. Higher rates are often required due to the foot and vehicular traffic associated with areas of concentrated play at these facilities. Intensive management of these areas enables the turf to recover from constant, and, in some cases, damaging use and often includes the practice of "spoon feeding" (very low, but frequent applications) nitrogen over the course of the growing season as a key component in maintaining acceptable turf. Experienced turf professionals are constantly evaluating their nitrogen programs as the turf they manage reacts and responds to daily use and seasonal changes. The relationship between nutrient application and overall turf and landscape plant quality (and often density for grasses) is used to make the appropriate adjustments in their fertility programs.

Is it possible for turf to negatively impact the environment if it is inadequately fertilized? Certainly. Inadequately fertilized turfgrass can be too weak to recover from environmental stress or pest attack. Turf that is thin, weak, and spindly due to lack of adequate nitrogen levels is considered to be "hungry" and can experience soil loss due to inadequate soil cover. Experienced turf managers identify a "hungry turf" not just by its color, but also by its growth rate and its ability to recover from pest or environmental stress.

However, the part of turfgrass management that gets the most attention when it comes to environmental impact is excessive fertilization. Excessive nitrogen applications increase plant succulence, making the turf more susceptible to environmental stress (e.g., heat, cold, and moisture extremes) and pest attack, and overall, less wear-tolerant. Overfertilization of nitrogen leads to excessive shoot and stem growth at the expense of root growth. And of course, excessive applications of nitrogen increase the potential that it enters a water source and becomes a pollution hazard.

Sound fertility programs are obviously not based on nitrogen alone, because any excess or deficiency of other nutrients can negatively affect plant health and survival. The annual requirements of most other macronutrients (those required in large quantities) such as phosphorus, potassium, calcium (Ca), and magnesium (Mg) are applied based on current soil test results. In conjunction with an appropriate pH, soil levels of these nutrients are maintained within a range that assures an adequate supply of these nutrients to provide good turf growth and quality. Similar to nitrogen, excessive applications can be damaging to the plant, resulting in nutrient imbalances and, particularly for phosphorus, the potential to negatively impact water quality.

Nutrient Application Timing

Ideally, nutrient applications should be timed to maximize use efficiency by the targeted plants (VDCR 2005). To minimize losses, it is important to closely match growth cycles and nutrient demands. Proper timing is especially important to prevent losses on soils with high leaching or runoff potential. From the viewpoint of the plant, appropriate timing of the first and last applications in the growing season is crucial to plant health, survivability, disease, stress tolerance, and so forth.

Nutrient Placement and Application Methods

For turfgrass, a variety of application methods may be used, depending on the situation. For turf establishment, broadcast application followed by incorporation is commonly used for lime and fertilizer amendments. Surface applications of granular fertilizers on new plantings and established turf may be made using truck-mounted, push-type rotary, or drop spreaders, depending on the size of the area to be covered. In addition, liquid fertilizers and foliar nutrients may be sprayed. New equipment can even vary the rate of application in conjunction with global positioning systems (GPS) and preprogrammed application maps. Each method has advantages, such as increased labor efficiency, improved application precision, and reduced potential for nutrient losses.

A nutrient management plan should also include the detailing of site characteristics that require changes in management from place to place. Considerations should include environmentally sensitive areas such as buffers and water bodies and significant differences in soils, vegetative cover, management intensity, and potential nutrient loss pathways. Finally, best management practices to prevent or reduce losses of soil, nutrients, and plant protection chemicals should be identified for each of these areas and the site as a whole.

Improving Water Quality Through Turf and Landscape Nutrient Management

A primary goal of turf and landscape nutrient management is water quality protection. Appropriate product selection, delivery rate and timing, and method of application are by far the most important variables in water quality protection in urban landscape management. The development and implementation of a nutrient management plan also provides potentially significant economic savings as applications are made based on soil test recommendations. Similarly, since soil test data are used in developing the plan, plant health and performance will also be enhanced on the basis of scientific data. Nutrient management plans allow for informed decisions to be made regarding fertilization such that plant health and function are optimized in an environmentally responsible manner.

This handbook provides a series of chapters devoted to the challenges associated with water quality protection in an urban environment. It presents extensive information on the basic principles in soil and plant sciences, fertility and fertilizers, plant management, soil amendments, equipment calibration for fertilizer delivery, irrigation sources and quality, and stormwater management. A standard NMP format is provided in the chapter 13. A certified nutrient management planner will combine the information from a soil test with extensive agronomic knowledge of plants, soils, fertilizers, nutrition, and the climate in developing the NMP. Incorporating this information into the design, installation, and management of urban soils and plant materials will greatly improve water quality.

Literature Cited

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Chapter 2. General Soil Science Principles

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Soil Formation and Soil Horizons

Introduction and Soil Composition

Soil covers the vast majority of the exposed portion of the earth in a thin layer. It supplies air, water, nutrients, and mechanical support for the roots of growing plants. The productivity of a given soil is largely dependent on its ability to supply a balance of these factors to the plant community.

A desirable surface soil in good condition for plant growth contains approximately 50 percent solid material and 50 percent pore space (figure 2.1). The solid material is composed of mineral material and organic matter. Mineral material comprises 45 to 48 percent of the total volume of a typical mid-Atlantic soil. About 2 to 5 percent of the volume is made up of organic matter, which may contain both plant and animal residues in varying stages of decay or decomposition. Under ideal moisture conditions for growing plants, the remaining 50 percent soil pore space would contain approximately equal amounts of air (25 percent) and water (25 percent) on a volume basis.

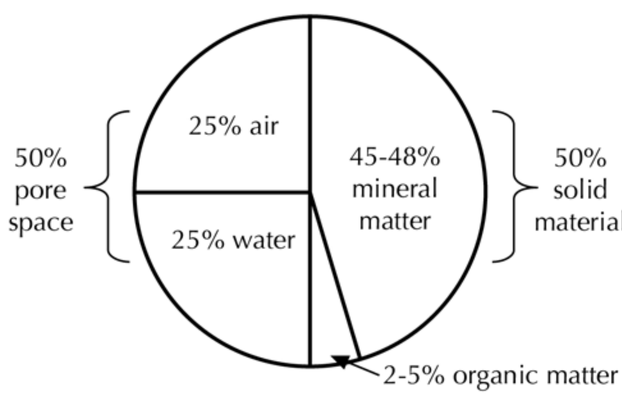

Figure 2.1. Volume composition of a desirable surface soil.

Soil Formation

The mineral material of a soil is the product of the weathering of underlying rock in place or the weathering of transported sediments or rock fragments. The material from which a soil has formed is called its "parent material." The weathering of residual parent materials to form soils is a slow process that has been occurring for millions of years in most of the mid-Atlantic region. However, certain soil features (such as "A horizons," discussed below) can form in several months to years. More detail on parent material and soil relationships in our area can be found at *www.mawaterquality.org/publications/pubs/manhcomplete.pdf*.

The rate and extent of parent material and soil weathering depends on:

1. The chemical composition of the minerals that make up the rock or sediment.
2. The type, strength, and durability of the material that holds the mineral grains together.
3. The extent of rock flaws or fractures.
4. The rate of leaching through the material.
5. The extent and type of vegetation at the surface.

Physical weathering is a mechanical process that occurs during the early stages of soil formation as freeze-thaw processes and differential heating and cooling break up rock parent material. After rocks or coarse gravels and sediments are reduced to a size that can retain adequate water and support plant life, the rate of soil formation increases rapidly. As organic materials decompose in the surface soil, the evolved carbon dioxide dissolves in water to form carbonic acid — a weak acid solution that constantly bathes weatherable minerals below. The carbonic acid reacts with and alters many of the primary minerals in the soil matrix to chemically alter and etch the sand and silt fractions and to produce secondary clay minerals. The decomposing organic matter also releases other organic acids (e.g., oxalic, citric, and tartaric) that further accelerate weathering (Brady and Weil 2008).

As soil-forming processes continue, some of the fine clay soil particles (smaller than 0.002 mm) are carried, or leached, by percolating water from the upper portions of the soil (topsoil) down into the lower or subsoil layers. As a result of this leaching action, the surface soil texture becomes coarser and the subsoil texture becomes finer as the soil weathers.

Soil Horizons

Soils are layered because of the combined effects of organic matter additions to the surface soil and long-term leaching. These layers are called "horizons." The vertical sequence of soil horizons found at a given location is collectively called the "soil profile" (figure 2.2).

The principal master soil horizons found in managed soil systems are:

- **A horizon** or mineral surface soil. (If the soil has been plowed, this is called the "Ap horizon.")
- **B horizon** or subsoil.
- **C horizon** or partially weathered parent material, which is also part of the subsoil.
- **Rock (R layer)** or unconsolidated parent materials similar to that from which the soil developed.

Unmanaged and relatively undisturbed forest soils also commonly contain an organic O horizon (litter layer) on the surface and a light-colored, acid-leached zone (E horizon) just below the A horizon.

In addition to the master soil horizons that are noted by capital letters (e.g., A and B), soil scientists also assign lowercase letters called "subscripts" (e.g., Ap) to describe the nature of the master horizon (U.S. Department of Agriculture (USDA) 1993). There are several dozen commonly used subscripts, but the most common ones in urbanized areas of the mid-Atlantic are Ap (plowed topsoil), "Bt" (clayey subsoil), and "Cd" (very dense, compacted subsoil). Another important combination to recognize is "Btg," which indicates a clayey subsoil with color features (gleying or gray coloration) indicative of poor internal drainage, as discussed later in this chapter.The surface soil horizon(s) or "topsoil" (the Ap or A plus E horizons) is often coarser than the subsoil layer and contains more organic matter than the other soil layers. The organic matter imparts a tan, dark-brownish, or black color to the topsoil. Soils that are high in organic matter (more than 3 percent) usually have very dark surface colors. The A or Ap horizon tends to be more fertile and have a greater concentration of plant roots than any other soil horizon. In unplowed soils, the "eluviated" (E) horizon below the A horizon is often light-colored or gray, coarser-textured, and more acidic than either the A horizon or the horizons below it because of acid leaching over time.

The subsoil (B horizon) is typically finer in texture, denser, and firmer than the surface soil. Organic matter content of the subsoil tends to be much lower than that of the surface layer, and subsoil colors are often stronger and brighter, with shades of red, brown, and yellow predominating due to the accumulation of iron-coated clays. Subsoil layers with high clay accumulation relative to their overlying A horizon are described as Bt horizons. If the B is still observed based on color or structural development but not enriched in clay, it is labeled "Bw" by default.

The C horizon is partially decomposed and weathered parent material that retains some characteristics of the parent material. It is more like the parent material from which it has weathered than the subsoil above it. By definition, C horizons are "diggable" with a spade or soil auger, while R layers cannot be excavated with hand tools. Images with horizon designations for soils typical of our region (Ultisols), along with distribution maps and information links can be found at *http://soils.cals.uidaho.edu/soilorders/ultisols.htm.*

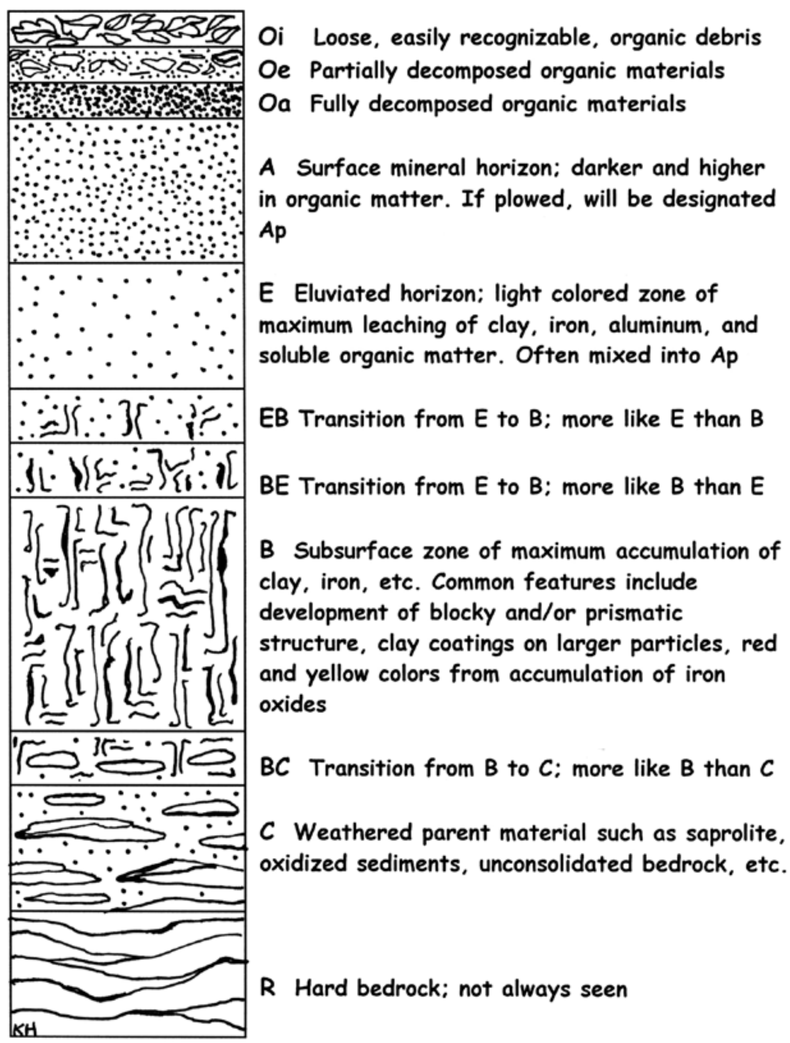

Figure 2.2. Soil profile horizons. *Graphic by Kathryn Haering.*

As discussed in greater detail in chapter 3, soils in the urban landscape are frequently highly disturbed and often contain distinct layering due to cut/fill and grading practices that are quite dissimilar from the natural soil horizons discussed above. It is also quite common for the native topsoil (A horizon) layers to be absent and for deeper subsoil materials (Bt) to appear at the surface. Graded and layered urban soils also commonly contain highly compacted subsoil layers (Cd horizons).

Soil Physical Properties

The physical properties of a soil are the result of soil parent materials being acted on by climatic factors (such as rainfall and temperature), and being affected by relief (slope and direction or aspect) and by vegetation over time. A change in any one of these soil-forming factors usually results in a difference in the physical properties of the resulting soil. The important physical properties of a soil are texture, aggregation/structure, porosity, and bulk density.

Texture

The relative amounts of the different soil-sized particles (smaller than 2 mm), or the fineness or coarseness of the mineral particles in the soil, is referred to as soil "texture." Mineral grains that are larger than 2 mm in diameter are called rock fragments and are measured separately. Soil texture is determined by the relative amounts of sand, silt, and clay in the fine-earth fraction (smaller than 2 mm).

Sand particles vary in size from very fine (0.05 mm) to very coarse (2.0 mm) in average diameter. Most sand particles can be seen without a magnifying glass. Sands feel coarse and gritty when rubbed between the thumb and fingers, except for mica flakes, which tend to smear when rubbed.

Silt particles range in size from 0.05 mm to 0.002 mm. When moistened, silt feels smooth but is not slick or sticky. When dry, it is smooth and floury and if pressed between the thumb and finger, it will retain the imprint. Silt particles are so fine they cannot usually be seen by the unaided eye and are best seen with the aid of a strong hand lens or microscope.

Clay is the finest soil particle size class. Individual particles are finer than 0.002 mm. Clay particles can be seen only with the aid of an electron microscope. They feel extremely smooth or powdery when dry and become plastic and sticky when wet. Clay will hold the form into which it is molded when moist and will form a long ribbon when extruded between the fingers.

There are 12 primary classes of soil texture defined by the USDA (1993). The textural classes are defined by their relative proportions of sand, silt, and clay as shown in the USDA's "textural triangle" (figure 2.3). Each textural class name indicates the size of the mineral particles that are dominant in the soil. Regardless of textural class, all soils in the mid-Atlantic region contain sand-, silt-, and clay-sized particles, although the amount of a particular particle size may be small.

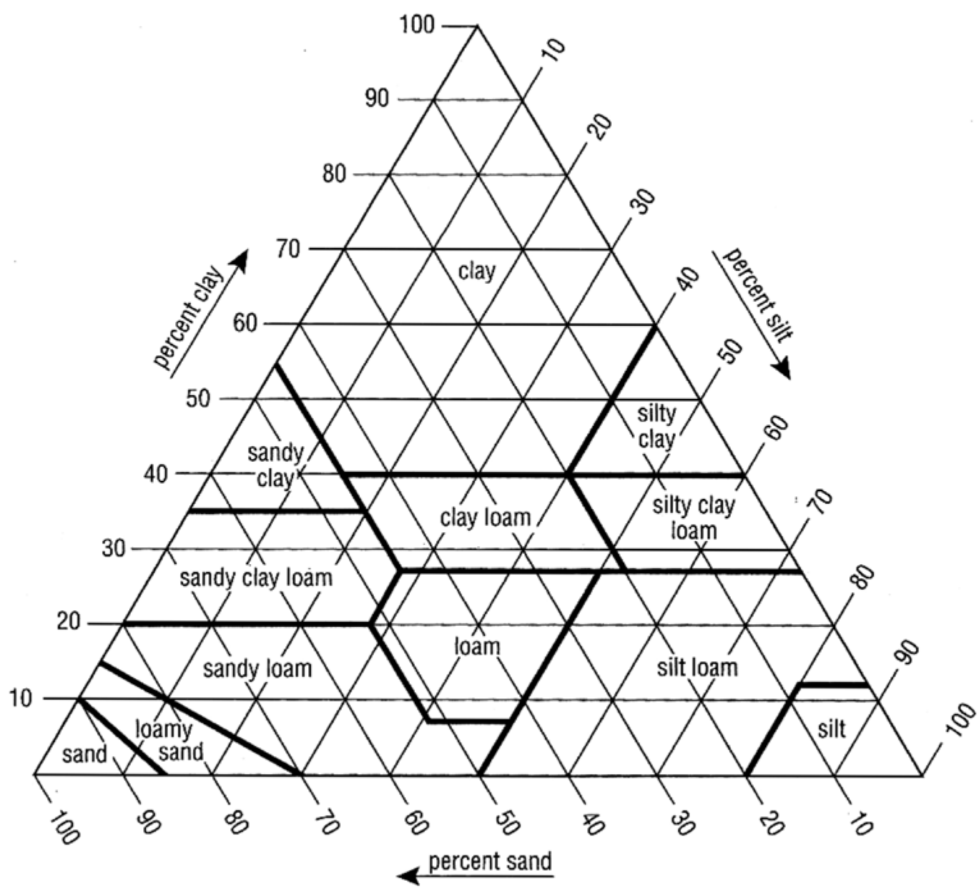

Figure 2.3. The USDA textural triangle (USDA 1993).

Texture can be estimated in the field after a moderate amount of training by manipulating and feeling the soil between the thumb and fingers. However, for precise measurement and/or prescriptive use, texture should be quantified by laboratory particle-size analysis.

To use the textural triangle:

1. First, you will need to know the percentages of sand, silt, and clay in your soil, as determined by laboratory particle-size analysis.
2. Locate the percentage of clay on the left side of the triangle and move inward horizontally, parallel to the base of the triangle.
3. Follow the same procedure for sand, moving along the base of the triangle to locate your percentage of sand.
4. Then, move up and to the left until you intersect the line corresponding to your clay percentage value.
5. At this point, read the "textural class" written within the bold boundary on the triangle. For example, a soil with 40 percent sand, 30 percent silt, and 30 percent clay will be a clay loam. With a moderate amount of practice, soil textural class can also be reliably determined in the field.

When soil textures fall very close to the boundary between two adjacent classes, it is appropriate to name both (e.g., sandy clay loam to sandy clay). Also, within a given textural class, soils with high clay contents are often referred to as "heavy" versus those low in clay content that are called "light." Thus, a "heavy clay loam" indicates a soil texture in the upper portion of that textural class, close to being clay. This latter convention is **not** defined or formally accepted by the USDA but is commonly used by field practitioners.

If a soil contains 15 percent or more rock fragments (larger than 2 mm), a rock fragment content modifier is added to the soil's texture class. For example, the texture class designated as "gravelly silt loam" would contain 15 to 35 percent gravels within a silt loam (smaller than 2 mm), fine-soil matrix. A sample with more than 35 percent gravel would be described as "very gravelly silt loam," etc. More detailed information on USDA particle-size classes and other basic soil morphological descriptors can be found at *http://soils.usda.gov/technical/handbook/download.html* or in the USDA Soil Survey Manual (USDA 1993).

Effects of Texture on Soil Properties

The clay fraction in soils is charged and relatively minor amounts (10 to 15 percent) of clay can significantly increase net charge that directly influences both water-holding and nutrient retention in soils. Water infiltrates more quickly and moves more freely in coarse-textured or sandy soils, which increases the potential for leaching of mobile nutrients. Sandy soils also hold less total water and fewer nutrients for plants than finer-textured soils like clays or clay loams. In addition, the relatively low water-holding capacity and the larger amount of air present in sandy soils allow them to warm faster than fine-textured soils. Sandy and loamy soils are also more easily tilled than clayey soils, which tend to be denser.

In general, fine-textured soils hold more water and plant nutrients and therefore require less frequent applications of water, lime, and fertilizer. Soils with high clay content (more than 40 percent clay), however, actually hold less plant-available water than loamy soils. Fine-textured soils have a narrower range of moisture conditions under which they can be worked satisfactorily than sandy soils. Soils high in silt and clay may puddle or form surface crusts after rains, impeding seedling emergence. High-clay soils often break up into large clods when worked while either too dry or too wet.

Aggregation and Soil Structure

Soil "aggregation" is the cementing of several soil particles into a secondary unit or aggregate. Soil particles are arranged or grouped together during the aggregation process to form structural units (known to soil scientists as "peds"). These units vary in size, shape, and distinctness (also known as strength or grade). In topsoils, soil organic matter is the primary material that cements particles together into water-stable aggregates. In subsoil, aluminum and iron oxides play a major role in cementing aggregates, as do finer clay particles which — due to their charge (discussed later in this chapter) — can also bind and stabilize much larger sand and silt particles together. The types of soil structure found in most mid-Atlantic soils are described in table 2.1 and illustrated in figure 2.4.

Effects of Soil Structure on Soil Properties

The structure of the soil affects pore space size and distribution, and therefore, rates of air and water movement and overall root proliferation. Well-developed structure allows favorable movement of air and water,

Table 2.1. Types of soil structure.

Structure type	Description
Granular	Soil particles are arranged in small, rounded units. Granular structure is very common in surface soils (A horizons) and is usually most distinct in soils with relatively high organic matter content.
Blocky	Soil particles are arranged to form block-like units, which are about as wide as they are high or long. Some blocky peds are rounded on the edges and corners; others are angular. Blocky structure is commonly found in the subsoil, although some eroded fine-textured soils have blocky structure in the surface horizons.
Platy	Soil particles are arranged in plate-like sheets. These plate-like pieces are approximately horizontal in the soil and may occur in either the surface or subsoil, although they are most common in the subsoil. Platy structure strongly limits downward movement of water, air, and roots. It may occur just beneath the plow layer, resulting from compaction by heavy equipment, or on the soil surface when it is too wet to work satisfactorily.
Prismatic	Soil particles are arranged into large peds with a long vertical axis. Tops of prisms may be somewhat indistinct and normally angular. Prismatic structure occurs mainly in subsoils, and the prisms are typically much larger than other typical subsoil structure types such as blocks.
Structureless	Massive, with no definite structure or shape, as in some C horizons or compacted material. - or - Single grain, which is typically individual sand grains in A or C horizons not held together by organic matter or clay.

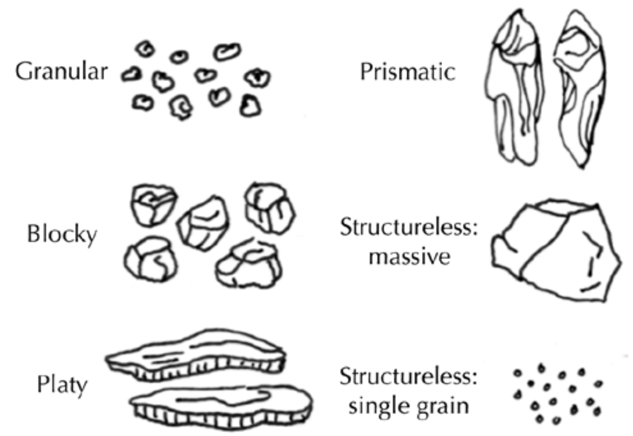

Figure 2.4. Types of soil structures. *Graphic by Kathryn Haering.*

while poor structure retards movement of air and water. Because plant roots move through the same channels in the soil as air and water, well-developed structure also encourages extensive root development. With respect to rooting, the size of the pores and their degree of interconnection are also critically important. In general, the penetration of air, water, and roots through soils is favored by "macropores" (larger than or equal to 0.05 mm, or sand-sized) that are physically interconnected, particularly vertically. In general, soil productivity is favored when water, air, and roots can move readily through the soil. It is also important that soil metabolic gasses (e.g., carbon dioxide) be able to diffuse back into the atmosphere.

Water can enter a surface soil that has well-developed (strong) granular structure (particularly fine-textured soils) more rapidly than one that has relatively weak structure. Surface soil structure is usually granular, but such granules may be indistinct or completely absent if the soil is continuously tilled, the soil is very coarse, or if organic matter content is low.

The size, shape, and strength of subsoil structural peds are particularly important to soil productivity. Sandy soils generally have poorly developed structure relative to finer-textured soils because of their lower clay content. When the subsoil has well-developed blocky structure, there will usually be good air and water movement in the soil. If platy structure has formed in the subsoil, downward water, air movement, and root development in the soil will be slowed. Distinct prismatic structure is often associated with subsoils, but those larger prisms will usually break down into primary blocky peds. Very large and distinct subsoil prisms are also commonly associated with "fragipans" (Bx horizons), which are massive and dense subsoil layers.

Porosity and Bulk Density

Soil "porosity," or pore space, is the volume percentage of the total soil that is not occupied by solid particles. Pore space is commonly expressed as a percentage:

$$\% \text{ pore space} = 100 - \left(\frac{\text{bulk density}}{\text{particle density}}\right) \text{ x } 100$$

"Bulk density" is the dry mass of soil solids per unit volume of soils, and "particle density" is the density of soil solids, which is assumed to be constant at 2.65 grams per cubic centimeter (g/cm^3). Bulk densities of mineral soils are usually in the range of 1.1 to 1.7 g/cm^3. A soil with a bulk density of about 1.32 g/cm^3 will generally possess the ideal soil condition of 50 percent solids and 50 percent pore space. Bulk density varies depending on factors such as texture, aggregation, organic matter, compaction/consolidation, soil management practices, and soil horizon. In general, root penetration through soils will be limited in sandy soils when the bulk density approaches 1.75 g/cm^3 and in clayey soils at 1.40 g/cm^3 (Brady and Weil 2008). However, water, air, and roots can penetrate high bulk-density soils that have well-developed structure with interconnected macropores, as discussed above.

Macropores (larger than 0.05 mm) allow the ready movement of air, roots, and percolating water. In contrast, micropores (smaller than 0.05 mm) in moist soils are typically higher in water content and poorly interconnected, and this does not permit much air movement into or out of the soil. Internal water movement is also very slow in micropores. Thus, the movement of air and water through a coarse-textured sandy soil can be surprisingly rapid despite its low total porosity because of the dominance of macropores.

Under field conditions, the total soil pore space is filled with a variable mix of water and air. If soil particles are packed closely together, as in well-graded surface soils or compact subsoils, total porosity is low and bulk density is high. If soil particles are arranged in porous aggregates, as is often the case in medium-textured soils high in organic matter, the pore space per unit volume will be high and the bulk density will be correspondingly low.

Fine-textured clay soils, especially those without a stable blocky (Bt) or granular (Ap) structure, may have reduced movement of air and water even though they have a large volume of total pore space. In these fine-textured soils, micropores are dominant. Because these small pores often stay full of water, aeration — especially in the subsoil — can be inadequate for root development and microbial activity. The loosening and granulation of fine-textured soils promote aeration (gas exchange) by increasing the number of macropores.

Soil Organic Matter

Soil organic materials consist of plant and animal residues in various stages of decay. Primary sources of organic material inputs are dead roots, root exudates, litter and leaf drop, and the bodies of soil animals such as insects and worms. Earthworms, insects, bacteria, fungi, and other soil organisms use organic materials as their primary energy and nutrient source. Nutrients released from the residues through decomposition are then available for use by growing plants.

Soil "humus" is fully decomposed and stable organic matter that is primarily derived from the bodies of soil microbes and fungi. Humus is the most reactive and important component of soil organic matter and is the form of soil organic material that is typically reported as "organic matter" on soil testing reports. Soil organic matter in Virginia soils typically ranges between 0.5 and 2.5 percent in A horizons and can approach 5 percent in heavily enriched garden soils or soils with poor drainage. Higher levels are typically found only in wetlands. Soil organic matter is so reactive (charged) that when it exceeds 12 to 20 percent by weight, it dominates soil properties and we refer to it as "organic soil material."

Factors That Affect Soil Organic Matter Content

The organic matter content of a particular soil will depend on:

Type of vegetation: Soils that have been in grass for long periods usually have a relatively higher percentage of organic matter in their surface. Soils that develop under trees usually have a low organic matter percentage in the surface mineral soil but do contain a surface litter layer (O horizon). Organic matter levels are typically higher in a topsoil that supports perennial hay, pasture, or forest than in a topsoil used for cultivated crops.

Tillage: Soils that are tilled frequently are usually lower in organic matter. Plowing and otherwise tilling the soil increases the amount of oxygen in the soil, which increases the rate of organic matter decomposition. This detrimental effect of tillage on organic matter is particularly pronounced in very sandy, well-aerated soils because of the tendency of frequent tillage to promote organic matter oxidation to carbon dioxide.

Drainage: Soil organic matter is usually higher in poorly drained soils because of limited oxidation, which slows down the overall biological decomposition process.

Soil texture: Soil organic matter is usually higher in fine-textured soils because soil humus forms stable complexes with clay particles and fine-textured soils limit the penetration of atmospheric oxygen in and carbon dioxide out of surface soils.

Effect of Organic Matter on Soil Properties

Adequate soil organic matter levels benefit soils in several ways. The addition of organic matter improves soil physical conditions, particularly aggregation and macropore space. This improvement leads to increased water infiltration, improved soil tilth, and decreased soil erosion. Organic matter additions also improve soil fertility because plant nutrients are released to plant-available mineral forms as organic residues are decomposed (or "mineralized"), and soil humus is highly charged and retains nutrients against leaching, as discussed later.

A mixture of organic materials in various states of decomposition helps maintain a good balance of air and water components in the soil. In coarse-textured soils, organic material bridges some of the space between sand grains, which increases water-holding capacity. In fine-textured soil, organic material helps maintain porosity by keeping very fine clay particles from packing too closely to one another, thereby enhancing macroporosity.

Soil-Water Relationships

Water-Holding Capacity

Soil water-holding capacity is determined largely by the interaction of soil texture, bulk density/pore space, and aggregation. Sands hold little water because they have little net charge and their large intergranular pore spaces allow water to drain freely from the soils. Clays adsorb a relatively large amount of water, and their small pore spaces retain it against gravitational forces. However, clayey soils hold water much more tightly than sandy soils so that much of the water retained (more than 40 percent) is unavailable to growing plants. As a result, moisture stress can become a problem in fine-textured soils despite their high total water-holding capacity.

Field Capacity and Permanent Wilting Percentage

The term "field capacity" defines the amount of water remaining in a soil after downward gravitational drainage has stopped. This value represents the maximum amount of water that a soil can hold against gravity following saturation by rain or irrigation. Field capacity is usually expressed as percentage by weight (for example, a soil holding 25 percent water at field capacity contains 25 percent of its dry weight as retained water). On a volumetric basis, values for field capacity range from 8 percent in a sand to 35 percent in a clay (Brady and Weil 2008).

The amount of water a soil contains after plants are wilted beyond recovery is called the "permanent wilting percentage." Considerable water may still be present at this point, particularly in clays, but it is held so tightly that plants are unable to extract it. The amount of water held by the soil **between** field capacity and the permanent wilting point is the "plant-available water" and is maximized in loamy-textured soils. The volumetric plant-available water for sand is typically less than 5 percent but may approach 25 percent volumetric water for a well-aggregated, loamy soil (see figure 2.1).

Tillage and Moisture Content

Soils with a high clay content are sticky when wet and form hard clods when dry. Therefore, tilling clayey soils at the proper moisture content is extremely important. Although sandy soils are inherently droughty, they are easier to till at varying moisture contents because they do not form dense clods or other high-strength aggregates. Sandy soils are also far less likely than clays to be compacted if cultivated when moist or wet. However, soils containing high proportions of very fine sand or coarse silts may be compacted by tillage when moist.

Soil Drainage

The overall hydrologic balance of soils — including infiltration and internal permeability — is discussed in greater detail in chapter 11. However, soil scientists commonly use the term "soil drainage" to describe the rate and extent of vertical or horizontal water movement and internal soil saturation during the growing season.

Important factors affecting soil drainage class are:

- Slope (or lack of slope).
- Depth to the seasonal water table.
- Texture of surface and subsoil layers and of underlying materials.
- Type and strength of soil structure.
- Problems caused by improper tillage or grading, such as compacted subsoils or lack of surface soil structure.

Another definition of drainage refers to the removal of excess water from the soil to facilitate agriculture, forestry, or other higher land uses. This is usually accomplished through a series of surface ditches or the installation of subsoil drains.

Soil Drainage and Soil Color

The nature of internal soil drainage in relatively undisturbed soils is usually indicated by soil color patterns and color variations with depth. Clear, bright red, and/or yellow subsoil colors indicate well-drained conditions where iron and other compounds are present in their oxidized forms. A soil is said to be well-drained when the "solum" (A plus E plus B horizons) exhibits strong red/yellow colors without any gray coloration (mottles or redox depletions). The term "mottle" is used generically to describe any differences in coloration within a given soil horizon. When those differences in coloration are due to wetness, however, the correct term is "redoximorphic features."

When soils become saturated for significant periods of time during the growing season, these oxidized (red/yellow) forms of iron are biochemically reduced to soluble forms and can be moved with drainage waters. This creates a matrix of drab, dominantly gray colors that are described as "redox depletions." The iron that is mobilized is typically reprecipitated locally into contrasting red/yellow features that are called "redox concentrations." Subsoil zones with mixtures of bright red/yellow and gray colors are indicative of seasonally fluctuating water tables, where the subsoil is wet during the winter/early spring and unsaturated in the summer/early fall. Poorly drained soils also tend to accumulate large amounts of organic matter in their surface horizons because of limited oxidation and may have very thick and dark A horizons.

Soils that are wet in their upper 12 inches for considerable amounts of time during the growing season, support hydrophytic vegetation typical of wetlands, and exhibit redoximorphic features are designated as "hydric soils." Further information on mid-Atlantic hydric soils and redox features can be found online at *www.epa.gov/reg3esd1/wetlands/hydric.htm.*

Interpretation of soil redox features can be highly complicated in an urban environment due to the effects of soil layer mixing via the cut/fill and grading processes and changes in internal soil drainage due to ditching and pavement interception of normal infiltration.

Drainage Classes

The "drainage class" of a soil defines the frequency of soil wetness as it limits agricultural practices and is usually determined by the depth in soil to significant gray redox depletions. The soil drainage classes in table 2.2 are defined by the USDA Natural Resources Conservation Service (USDA 1993). They refer to the natural drainage condition of the soil without artificial drainage.

Table 2.2. Soil drainage classes.

Drainage class	Soil characteristics	Effect on cropping
Excessively drained	Water is removed rapidly from soil.	Will probably require supplemental irrigation.
Somewhat excessively drained		
Well-drained	Water is removed readily, but not rapidly.	No drainage required.
Moderately well-drained	Water is removed somewhat slowly at some periods of the year.	May require supplemental drainage if crops that require good drainage are grown.
Somewhat poorly drained	Water is removed so slowly that soil is wet at shallow depths periodically during the growing season.	Will probably require supplemental drainage for satisfactory use in production of most crops.
Poorly drained		
Very poorly drained	Free water is present at or near the surface during the growing season.	

Soil Chemical Properties

The plant root obtains essential nutrients almost entirely by uptake from the soil solution. The chemistry and nutrient content of the soil solution is, in turn, controlled by the solid material portion of the soil. Soil chemical properties, therefore, reflect the influence of soil minerals and organic materials on the soil solution.

Soil pH

Soil pH defines the relative acidity or alkalinity of the soil solution. It is important to note that pH can only be measured in soil solution that has equilibrated with soil solids; you cannot measure the pH of a solid. The pH scale in natural systems ranges from 0 to 14. A pH value of 7.0 is neutral. Values below 7.0 are acidic and those above 7.0 are alkaline, or basic. Many agricultural soils in the mid-Atlantic region have a soil pH between 5.5 and 6.5. Any soil pH value less than 4.0 is indicative of acid-sulfate influenced soils (see chapter 3).

Soil pH is a measurement of hydrogen ion (H^+) activity in soil solution or effective concentration in a soil and water solution. Soil pH is expressed in logarithmic terms, which means that each unit change in soil pH amounts to a tenfold change in acidity or alkalinity. For example, a soil with a pH of 6.0 has 10 times as much active H^+ (or is 10 times more acidic) as one with a pH of 7.0.

Soils become acidic when basic cations (positively charged ions such as calcium, or Ca^{2+}) held by soil colloids are leached from the soil and replaced by aluminum ions (Al^{3+}), which then hydrolyze to form aluminum hydroxide ($Al(OH)_3$) solids, which then liberate H^+ ions to solution as water hydrolyzes (splits into H^+ and OH^- ions). This long-term acidification process is accelerated by the decomposition of organic matter that also releases acids to soil solution. Most soils in the mid-Atlantic region were formed under high rainfall with abundant vegetation and are considerably more acidic than soils of the midwestern and western United States. In fact, very few soils in Virginia were above pH 6.0 when settlers first arrived in the 17th century.

Cation Exchange Capacity: Our Measure of Soil Charge and Reactivity

The net ability of a soil to hold, retain, and exchange cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), sodium (Na^+), ammonium (NH_4^+), aluminum (Al^{3+}), and hydrogen (H^+) is called "cation exchange capacity," or CEC. All soils contain clay minerals and organic matter that typically possess negative electrical surface charges. These negative charges are present in excess of any positive charges that may exist, which gives soil a net negative charge.

Negative surface charges attract positively charged cations and prevent their leaching. These ions are held against leaching by electrostatic positive charges but are not permanently bound to the surface of soil particles. Positively charged ions are held in a "diffuse cloud" within the water films that are also strongly attracted to the charged soil surfaces. Cations that are retained by soils can thus be replaced, or "exchanged," by other cations in the soil solution. For example, Ca^{2+} can be exchanged for Al^{3+} and/or K^+ and vice versa. The higher a soil's CEC, the more cations it can retain.

There is a direct and positive relationship between the relative abundance of a given cation in solution and the amount of this cation that is retained by the soil CEC. For example, if the predominant cation in the soil solution is Al^{3+}, Al^{3+} will also be the predominant exchangeable cation. Similarly, when large amounts of Ca^{2+} are added to soil solution by lime dissolving over time, Ca^{2+} will displace Al^{3+} from the exchange complex and allow it to be neutralized in solution by the alkalinity added with the lime.

The CEC of a soil is expressed in terms of moles of charge per mass of soil. The units used are "cmol$^+$/kg" (centimoles of positive charge per kilogram) or "meq/100 g" (milliequivalents per 100 grams; 1.0 cmol$^+$/kg = 1.0 meq/100 g). Soil scientists have used the former unit in publications since the early 1980s, while meq/100 g is commonly used in other disciplines. Numerically, they are the same. Soil CEC is calculated by adding the charge equivalents of K^+, NH_4^+, Ca^{2+}, Mg^{2+}, Al^{3+}, Na^+, and H^+ that are extracted from a soil's exchangeable fraction.

Sources of Negative Charge in Soils

The mineralogy of the clay fraction and the soil's humus content greatly influence the quantity of negative charges present. One source of negative charge is "isomorphous substitution," which is the replacement of a Si^{4+} or Al^{3+} cation in the clay mineral structures with a cation that has a lower surface charge. For example, Si^{4+} might be replaced with Al^{3+}, or Al^{3+} might be replaced with either Mg^{2+} or Fe^{2+}. Clay minerals with a repeating layer structure of two silica sheets sandwiched around an aluminum sheet (two-to-one clays, such as vermiculite or smectite), typically have a higher total negative charge than clay minerals with one silica sheet and one aluminum sheet (one-to-one clays, such as kaolinite). Soil humus is also highly charged due to a large number of chemically reactive sites called “functional groups.”

Soil pH also has a direct relationship to the quantity of negative charges contributed by organic matter and, to a lesser extent, from mineral surfaces such as iron oxides. As soil pH increases, the quantity of negative charges increases due to the reactions of exposed organic matter functional groups and similar reactions that occur on the surfaces of iron and aluminum oxides and the edges of clays. This pH-dependent charge is particularly important in highly weathered topsoils where organic matter dominates overall soil charge.

It is important to point out that while we use CEC as our measure of net charge or reactivity in soils, all soils contain a certain amount of positive charges as well. These positive charges are important in retaining anions (negatively charged ions) like NO_3^-, Cl^-, or SO_4^{2-} against leaching in certain soils as well. In particular, highly weathered soils that are high in aluminum and iron (very red) and low in pH (less than 5.5) may actually have more positive charges on their surfaces than negative charges. These soils also have a very strong affinity to bind (or fix) phosphorus in very tight complexes that will be discussed in chapter 4.

Cation Retention and Leaching in Soils

The negatively charged surfaces of clay particles and organic matter strongly attract cations. However, the retention and release of these cations, which affects their mobility in soil, is dependent on several factors. Two of these factors are the relative retention strength of each cation and the relative amount or mass of each cation present.

For a given cation, the relative retention strength by soil is determined by the charge of the ion and its size (or diameter). In general, the greater the positive charge and the smaller the ionic diameter of a cation, the more tightly the ion is held (i.e., higher retention strength) and the more difficult it is to remove that cation and leach it down through the soil profile. For example, Al^{3+} has a positive charge of three and a very small ionic diameter and thus moves through the soil profile very slowly. Potassium (K^+), on the other hand, has a charge of one and a much larger ionic radius, so it leaches much more readily. This difference in cation retention has important soil fertility implications that will be discussed in chapter 4.

If cations are present in equal amounts, the general strength of adsorption that holds cations in the soil is in the following order:

$$Al^{3+} >> Ca^{2+} > Mg^{2+} > K^+ = NH_4^+ > Na^+$$

Effect of CEC on Soil Properties

A soil with a **low CEC value** (1-10 meq/100 g) may have some, or all, of the following characteristics:

- High sand and low clay content.
- Low organic matter content.
- Low water-holding capacity.
- Low soil pH.
- Not easily resistant to changes in pH or other chemical changes.
- Enhanced leaching potential of plant nutrients such as Ca^{2+}, NH_4^+, K^+.
- Low productivity.

A soil with a **higher CEC value** (11-40 meq/100 g) may have some or all of the following characteristics:

- Lower sand and higher silt plus clay content.
- Moderate-to-high organic matter content.
- High water-holding capacity.
- Ability to resist changes in pH or other chemical properties.
- Less nutrient losses to leaching than low CEC soils.

Base Saturation

Of the common soil-bound cations, Ca^{2+}, Mg^{2+}, K^+, and Na^+ are considered to be basic cations. The base saturation of the soil is defined as the percentage of the soil’s CEC (on a charge-equivalent basis) that is occupied by these cations. A high base saturation (more than 50 percent) enhances calcium, magnesium, and potassium availability and prevents soil pH decline. Low base saturation (less than 25 percent) is indicative of a strongly acidic soil that may maintain Al^{3+} activity high enough to cause phytotoxicity.

Buffering Capacity

The resistance of soils to changes in the pH of the soil solution is called “buffering.” In practical terms, buffering capacity for pH increases with the amount of clay and organic matter. Thus, soils with high clay and organic matter content (high buffer capacity) will require more lime to increase pH than sandy soils with low amounts of organic matter (low or weak buffer capacity).

One laboratory measure of the acid buffering capacity (or lime demand) of a given soil is called "buffer pH" and will be discussed in more detail in chapters 4 and 5. It is very important to realize, however, that buffer pH is quite different from conventional soil-to-water pH, as discussed above.

Essential Elements for Plant Growth

Higher plants and the microbial biomass in soils need a wide array of essential elements to sustain them and build biomass. The soil biota take carbon, hydrogen, and oxygen from soil, air, and water, so these are not considered soil-supplied nutrients. Six essential elements (nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium) are taken up by plants from the soil in relatively large amounts; these are referred to as "macronutrients." All of the essential elements are taken up primarily as dissolved ions from solution; table 2.3 lists their common forms and sources. The ionic form (i.e., cation versus anion) of each nutrient and its specific charge characteristics directly control its relative sorption and availability from the soil. Higher plants also require a wide range of other elements (boron, chlorine, cobalt, copper, iron, molybdenum, manganese, nickel, and zinc) in much smaller amounts and these are referred to as "micronutrients." More detail on the specific forms and supply of plant nutrients can be found in chapters 4, 5, 7, 8, and 9.

Limiting Factors to Plant Growth

Higher plants rely on the soil for a wide range of services in support of their growth. Physically, the soil must be deep and strong enough to support the plant, hold and supply sufficient plant-available water, be able to moderate extreme air temperatures, and allow for adequate exchange of gasses between the root zone and the atmosphere. Chemically, the soil must maintain an adequate pH and soluble-salt environment for locally adapted plants and supply all of the soil nutrients detailed above in adequate amounts to meet the plant's demand. The overall productivity of the plant community will be controlled by the soil factor that is present in the lowest relative amount, regardless of the adequacy/availability of the rest of the important soil physical and chemical factors. This concept is known as the "the law of the minimum." For example, overall plant growth in urban soils is commonly directly limited by compaction and associated lack of rooting volume, regardless of the adequacy of soil pH and nutrient levels. Once you loosen these soils to provide adequate rooting depth, plant growth will increase until it becomes limited by the next limiting factor (e.g., low soil pH or phosphorus). Therefore, the overall guiding principle underpinning appropriate soil management is that we must manage all important plant growth factors together to maintain adequate plant growth over time.

Soil Survey

The soils of all counties have been mapped by the USDA-NRCS soil survey (1993), and these maps are available in soil survey reports, although some county reports are quite old and in need of modern recorrelation. A soil survey report reveals the kinds of soils that exist in the county (or other area) covered by the report at a level of detail that is usually sufficient for agricultural interpretations. The soils are described in terms of their location on the landscape, their profile characteristics, their relationships to one another, their suitability for various uses, and their needs for particular types of management. Each soil survey report contains information about soil morphology, soil genesis, soil

Table 2.3. Soil-supplied macronutrients, sources, and ionic forms for plant uptake.

Nutrient	Primary sources	Dominant form in soil solution
Nitrogen (N)	Organic matter, manures, fertilizers (N-P-K), legumes	NH_4^+: low pH or wet NO_3^-: moderate pH and oxidized
Phosphorus (P)	Organic matter, fertilizers	$H_2PO_4^-$: between pH 5 and 7
Potassium (K)	Plant litter, fertilizers, soil minerals (micas and feldspars)	K^+
Calcium (Ca)	Limes, plant litter, soil minerals (feldspars and carbonates)	Ca^{2+}
Magnesium (Mg)	Dolomitic limes, soil minerals	Mg^{2+}
Sulfur (S)	Atmospheric and gypsum additions, soil sulfides	SO_4^{2-}

conservation, and soil productivity. Soil survey reports are available from county and state USDA-NRCS cooperative Extension offices and online at *http://soils.usda.gov/survey/online_surveys/.*

Parts of a Soil Survey

There are two major sections in a soil survey report. One section contains the soil maps. In most reports, the soil map is printed over an aerial photographic base image. In the past, soil mapping was done at scales ranging from 1-to-10,000 to 1-to-50,000, with 1-to-15,840 being the most common scale used before the 1980s. Current USDA-NRCS mapping is published at 1-to-24,000 to match U.S. Geologic Survey topographic quadrangle maps.

Each soil area is delineated by an enclosing line on the map. Soil delineation boundaries are drawn wherever there is a significant change in the type of soil. The boundaries often follow natural contours, but they may also cross and incorporate multiple portions of the landscape if the soils are similar across local topographic variations.

The other section of a soil survey report is the narrative portion. Without it, the soil maps would have little meaning. Symbols on each map are keyed to a list of soil mapping units. The nature, properties, and classification and use potentials of all mapping units are described in detail.

Terminology Used in Soil Surveys

Soil series is a basic unit of soil classification, consisting of soils that are essentially alike in all main profile characteristics. Most soil mapping units in modern cooperative soil surveys are named for their dominant component soil series.

Soil phase is a subdivision of a soil series or other unit of classification having characteristics that affect the use and management of the soil but do not vary enough to merit a separate series. These include variations in slope, erosion, gravel content, and other properties.

Soil complexes and **soil associations** are naturally occurring groupings of two or more soil series with different use and management requirements that occur in a regular pattern across the landscape but cannot be separated at the scale of mapping that is used. Soil complexes are used to map two or more series that are commonly intermixed on similar landforms in detailed county soil maps. Soil associations are utilized in more general and less detailed regional soil maps.

Map units are the actual units that are delineated on the soil map and are usually named for the dominant soil series and slope phase. Map units generally contain more than one soil series. Units are given the name of the dominant soil series if 85 percent or more of the area is correlated as a single soil series (or similar soils in terms of use and management). Soil complexes are used to name the map unit if the dissimilar inclusions exceed 15 percent. Each map unit is given a symbol (numbers or letters) on the soil map that designates the name of the soil series or complex being mapped and the slope of the soil. More details on how soil mapping units are developed and named can be found in the Soil Survey Manual at *http://soils.usda.gov/technical/manual/.*

Using a Soil Survey

A user interested in an overall picture of a county's soils should probably turn first to the soil association section of the soil survey report. The general soil pattern of the county is discussed in this section. A user interested in the soils of a particular farm must first locate that farm on the soil map and determine what soils are present. Index sheets located with the soil maps help the user find the correct section of the map. The map legend gives the soil map the unit names for each symbol and assists with the location of descriptive and interpretive material in the report.

Detailed soil descriptions that provide information to those who are primarily interested in the nature and properties of the soils mapped are located in the narrative portion of the soil survey report. The section concerned with the use and management of the soils (soil interpretations) is helpful to farmers and others who use the soil or give advice and assistance in its use (e.g., soil conservationists, cooperative Extension agents). Management needs and estimated yields are included in this section. Newer reports have engineering properties of soils listed in tables that are useful to highway engineers, sanitary engineers, and others who design water storage or drainage projects.

It is important for the urban user of soil surveys to understand that very few soil surveys recognize and appropriately interpret the drastically disturbed nature of their landscape. Where the soil survey shows mapping units named for soil series, they represent the dominant undisturbed soils in that landscape that existed predevelopment. Some older soil surveys simply mapped previously developed areas as "made land" or "urban lands." Virginia soil surveys produced after

1980 often map disturbed soils as "Udorthents," which simply indicates that they are dominantly young soils due to their native profiles being largely destroyed.

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Chapter 3. Managing Urban Soils

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What Is an Urban Soil?

More often than not, the soils we manage for plant growth in urban and suburban areas have been significantly altered from their natural state by excavation (cut and fill), grading, topsoil return, or other operations that fundamentally alter their morphological, physical, and chemical properties (Brown et al. 2000; Scheyer and Hipple 2005). In rural areas, similar disturbances associated with road construction, mining, and utility corridors generate similar soil conditions that frequently limit plant growth (Booze-Daniels et al. 2000). Simply put, urban soils do not contain the natural sequence of intact soil horizons that was described in chapter 2. Therefore, many of our underlying assumptions about soil testing results, plant growth response and overall soil-plant relations may not apply to these materials, and they must be modified to overcome their inherent limitations for plant growth.

Urban Soil Properties

When we compare these urban soils materials with nearby natural soil profiles (see chapter 2), a number of differences are usually readily apparent (adapted from Craul 1992):

- Highly variable in all directions.
- Abrupt differences in soil texture and density (layering) with depth.
- Presence of high-clay materials at the surface/lack of topsoil.
- Soil structure that has been degraded, leading to loss of large pores (macropores) and their vertical continuity.
- High bulk density due to mechanical compaction and lack of structure/macropores.
- Common occurrence of surface crusts on finer-textured materials.
- Soil pH may be higher or lower than normal.
- Restricted aeration and water drainage.
- Interrupted nutrient cycles and associated microbial populations.
- Very low organic matter and nutrient levels compared to natural topsoils.
- Presence of anthropic materials (e.g., wood, rags, cement) and other contaminants (e.g., oil, metals).
- Higher temperature variability due to lack of natural litter layer or vegetation.

Figure 3.1 depicts a number of these plant-growth limiting soil factors that we commonly encounter around building sites, particularly (1) high variability, (2) layering, (3) presence of acidic and infertile clayey materials at the surface, and (4) issues related to excessive compaction (high bulk density). Recognizing and dealing with these limitations will therefore be the primary focus of this chapter, but other issues and their remedies will be addressed as well.

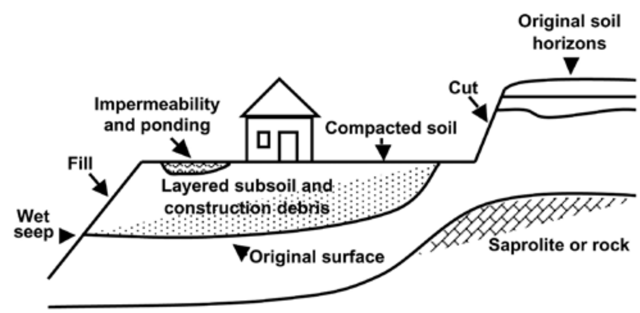

Figure 3.1. Diagram of urban soils and important plant growth limiting features. Note that the soil limitations in one portion of a home lot may be quite different from those encountered in another location of the same lot. *Diagram by Kathryn Haering.*

Types of Urban Soil Materials and Their Variability

The entire process of site development for housing, construction, or landscape development results in large amounts of soil disturbance, movement, and mixing. The degree of impact ranges from limited surface soil compaction to complete removal of the native soil profile and its replacement with mixed and dissimilar fill materials (figures 3.1 and 3.2). Thus, while predevelopment native soil properties will be fairly uniform and predictable on a given site due to the long-term effect of the soil-forming factors (see chapter 2) the postdevelopment site will be much more variable and extreme short-range differences in important plant-growth related properties such as compaction, texture, and pH will be common. While there is an almost endless variety of mechanisms and expressions of soil disturbance, the most common types are (1) exposed subsoil materials, (2) exposed cut materials, and (3) filled materials that are compacted and layered.

1. Exposed Subsoil Materials

The simplest urban soil scenario to recognize and deal with is where the topsoil (A plus E horizons) has been removed. Subsoil materials (B and C horizons) are frequently encountered at the surface of the ground as a result of erosion of the native topsoil or severe soil disturbance associated with earthmoving and construction activities. In most instances, these materials will be red or yellow in color, but they may range from white to gray in certain instances. Unlike topsoil, this material is often quite clayey and dense, devoid of organic matter, and generally resists plant growth. Subsoils in the mid-Atlantic region are usually highly leached, acidic, and infertile and may also be gravelly or rocky.

Figure 3.2. Typical soil disturbance in subdivision during construction. Each lot is graded out (cut and filled) to approximately level the area immediately surrounding the house. Note large amounts of sand and other construction debris that will more than likely be graded out and incorporated into fills.

2. Cut Slopes and Banks

Cut materials are commonly encountered on sites where the natural topography is rolling or sloping and must be reshaped to accommodate yards, driveways, landscaping, and/or drainage features. Cuts are usually a relatively minor component of subdivision developments but are a dominant feature on highway rights-of-way, as discussed in more detail later. In general, cut materials expose subsoil and/or deeper geologic strata and may therefore be very clayey and/or quite coarse and rock-like. One limitation of these materials is that during grading, cut clays will smear and seal and thereby limit water and root penetration. The lower sections of cut materials may also be subject to the limitations described above for exposed subsoils such as clayey textures and acidic pH. However, due to the fact that they are much less variable, less compacted, and tend to retain their native soil structure, cut slopes are usually superior to fill materials as described next.

3. Fills

Overall site development and final land shaping and grading generate extensive areas of filled materials at most sites (figure 3.1). These fills may range from relatively shallow lifts of returned topsoil over intact subsoils to very thick, multi-layered fills of strongly contrasting materials. Fills can often be recognized due to their long linear and uniform slopes or "unnatural" slope shapes and configurations. However, competent grading and landscaping can make fills virtually indistinguishable from natural landforms. Fills are typically much more difficult to manage than either exposed subsoils or cuts for a variety of reasons that are discussed in more detail below. Fill materials tend to be highly variable and layered and compacted, all of which limit plant growth and water movement.

Common Soil Limitations in the Urban Environment

Compaction

Simple soil compaction (high bulk density) is the most common plant growth and water movement limitation in urban soils (see figure 3.3). Dense layers in soils are commonly called "pans" and may result from a variety of natural long-term soil processes (e.g., dense Bt horizons), but are most commonly formed by site development and grading machinery. These compacted zones may occur at the surface or deep in the subsoil but are often denser than natural pans or subsoil layers. Artificially induced pans are particularly common where several layers of soil have been disturbed, such as when topsoil is returned to a regraded lawn after house construction, or where cut-and-fill operations have reshaped an area for landscaping. Natural soil structure is usually destroyed by these activities; not only are soils made abnormally dense, but there are no longer any natural channels or planes of weakness for roots, water, and air to penetrate. It is also important to point out that normal foot traffic, game playing, or infrequent tire traffic can also cause compaction of the immediate surface soil, particularly when the soil is moist and readily compressible.

The ability of a growing root tip to penetrate soil is directly dependent on soil strength. Soil strength — which essentially is its resistance to deformation or shearing — is controlled primarily by a soil's bulk density and moisture content. Workable, loose soils have bulk densities of 1.0 to 1.4 grams per cubic centimeter (g/cm^3). In a clayey soil, root penetration is greatly retarded during dry conditions when bulk density exceeds 1.5 g/cm^3. The same soil when moist, however, may not impede rooting because soil strength is then decreased. Sandy soils resist compaction due to their larger packing voids between particles and can support adequate rooting at bulk densities approaching 1.8 g/cm^3, but will still be limiting at higher levels of compaction.

Soils that are compacted also resist water movement and gas exchange, which can seriously hinder plant growth. Compacted soils also lack macropore space, which lessens water-holding capacity and rooting depth. Due to their lack of large pore spaces, water passes very slowly; therefore, dense soils often alternate between being very wet in the winter and very dry in the summer. Compacted soils also perch wet spots in unexpected locations and enhance runoff over infiltration. Finally, a compacted soil can severely limit plant growth, even if other physical and chemical characteristics such as texture and pH are optimal (see figure 3.4). Thus, soil compaction cannot be recognized by conventional soil testing and is often a "hidden limitation."

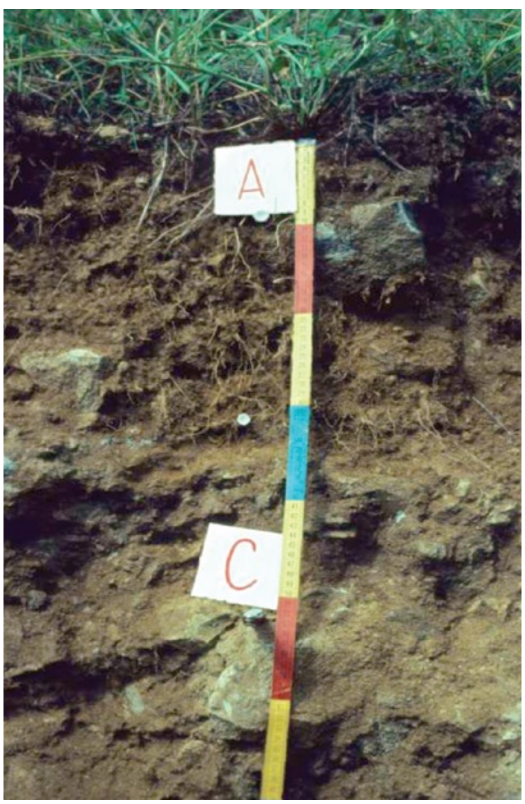

Figure 3.3. High bulk density (2.0 g/cm^3) traffic pan on a mining site under loose spoil materials. Similar traffic pans are routinely found in home construction and highway environments. Roots cannot penetrate or loosen zones that are packed to a bulk density greater than approximately 1.5 g/cm^3 for a clay or 1.9 g/cm^3 for a sandy-textured soil.

Figure 3.4. Turf growth limited by compaction. The bare soil on the left was pH 6.5 and fertile but heavily compacted and therefore, not capable of supporting viable turf after seed germination. The turf in the rest of this photo is also growing in moderately compacted soil as evidenced by its "clumpy" appearance.

Soil Layering and Associated Problems

When downward percolating water encounters a compacted zone or a zone of strongly contrasting soil texture (such as sand over clay or vice versa), water will back up or "perch" just above the contact and saturate the zone above it. The nature and quantity of porosity, particularly the amount of large, continuous pores and channels in the soil, is the primary factor controlling the rate of water movement. Temporarily perched water tables may persist close to the soil surface from several days to months, depending on local soil and climatic conditions. A similar perching occurs when water passes through a coarse-textured soil layer with many large pores and then encounters a finer-textured soil layer (even if noncompacted) with much smaller pores. Perching also occurs — but for an altogether different reason — when water passing through a fine-textured layer encounters a coarser sand or gravel stratum. In this case, the finer-textured clay soil actually holds on to its water so tightly (due to capillary forces or suction) that it significantly slows its movement into the coarser material below. Saturated conditions within the rooting zone cause a number of problems for plant growth, including lack of oxygen, loss of available nitrogen, and potential heavy-metal toxicities.

Adverse Soil Texture or Rock Content

As discussed in detail in chapter 2, loamy textures are optimum for plant growth, and most native A horizons (topsoil) are within this texture class. However, subsoil layers (B horizons) are commonly quite clayey, and deeper C horizons may be very sandy or rocky. Because of the very fine texture and small pore size of clayey soils, water is so tightly held that uptake by plant roots is limited. Clayey soils also limit plant growth due to higher soil strength, their tendency to dry and crack, their tendency to form crusts after rain events, and other adverse chemical properties as discussed below. On the other hand, very coarse-textured (sandy) or rocky soils are also prone to drought and do not retain added fertilizer and lime elements.

Adverse pH and Nutrient Status

Most subsoils (B and C horizons) in our region are low in pH (4.0 to 6.0) due to long-term acid-leaching processes and are very low in available nutrients because they formed well below the zone of active nutrient cycling and/or fertilization and liming. This acidic condition greatly increases the solubility of naturally occurring phytotoxic metals like aluminum and manganese. In certain instances (e.g., Piedmont saprolites), however, deep subsoil materials may actually be quite moderate in pH and nutrient cations (calcium, magnesium, potassium), but they will still be very low in plant-available nitrogen and phosphorus. The red and yellow colors commonly seen in subsoil materials are due to coatings of iron-oxides, which tend to be ubiquitous in regional subsoils. These amorphous iron coatings along with associated aluminum oxides (which are not readily visible) have the ability to adsorb large amounts of applied phosphorus fertilizers via a process called phosphorus-fixation (see chapter 4), particularly when the soil pH is less than 6.0 (Brady and Weil 2008).

In certain instances — particularly where high pH mortar mix or quick lime (see discussion later) have been added to the soil in excessive amounts — the soil pH may be abnormally high (more than 8.2). This can lead to a variety of plant nutrient deficiencies and toxicities and soil physical problems (Brady and Weil 2008). If the soil is alkaline (pH more than 8.2) but weakly buffered, the pH can be readily reduced via addition of aluminum sulfate ($Al_2(SO_4)_3$) or by adding acid-forming organic matter like pine needles and leaves and allowing natural decomposition to reacidify the soil. However, if the soil alkalinity is highly buffered (i.e., more than 5 to 10 tons of calcium carbonate equivalence; CCE) it will be necessary to add elemental sulfur (flowers of sulfur) to quickly form sulfuric acid in soil solution to neutralize the excess alkalinity. This must be done very carefully because, as discussed later, reduced sulfur is highly reactive in the soil and even a minor over-application can drive the soil pH below 4.0.

Low Organic Matter and Microbial Activity

Unless topsoil layers are properly salvaged, stored, and returned, newly constructed urban soils are much lower in their organic matter content and microbial biomass than nearby natural soil profiles. This particularly affects surface soil aggregation, infiltration, and water-holding capacity. The lack of microbial activity may also limit the soils' nitrogen, phosphorus, and sulfur cycles, which are highly dependent on the active microbial biomass for important mineralization transformations. Revegetated urban soils will accumulate stable organic matter levels and microbial communities over time, but their development may also be strongly limited by the combined adverse soil properties discussed above.

Inclusion of Mixed and Foreign Materials

One of the unique diagnostic features of most urban soils is their inclusion of a wide array of dissimilar natural and man-made (anthropogenic) materials. This is particularly true of soils on residential lots where contractors are unlikely to remove excess sand, gravel or other materials due to the cost of loading and hauling. By definition, these materials usually are found in the fill portions of urban soils, but they may also occur in scattered pockets or thin veneers over exposed subsoils or cut areas. Following is a summary of a few of the more problematic materials:

Gravel and sand are commonly found in layers or pockets related to mortar mix areas, temporary roads, or storage areas. These are usually capped with finer-textured fill or topsoil layers, generating a very strong textural discontinuity that limits water drainage.

Cement and mortar mix are usually found in localized areas but may be mixed throughout a given fill layer when materials are bulldozed or moved during final site grading. Mortar mix will impart very high soil pH (9.0 or more) to localized areas for long periods of time until it fully reacts with natural soil acidity. Poorly cured waste concrete can also cause locally high soil pH.

Waste wood, drywall, nails, rags, etc. tend to be discarded or to fall into the open excavation next to home foundations and block walls and are commonly mixed into the soils that constitute the backfill. As waste wood or rags decompose, they generate locally anaerobic zones that are adverse to the roots of many native and ornamental plants. Drywall, on the other hand, is primarily gypsum and paper and is actually used as an approved soil amendment (after grinding) in several southeastern states. Nails, wire, metal flashing, and glass are also commonly encountered in this zone and pose more of a safety hazard to the home gardener than a plant growth limitation.

Managing Urban Soils and Their Limitations

Soil Sampling, Testing, and Fertilizer Plus Lime Prescriptions

Appropriate soil sampling and testing is critical to managing urban soils. First of all, you need to take some time to try to understand the nature of your local urban soil landscape. Start by looking for areas of obvious cut slopes and fills. Using a shovel or a tiling spade, try to discern if you have topsoil return over cut subsoils or exposed cut and fill materials. With a little investigation and thought about how your landscape's soil materials were moved around, you should be able to discern a pattern. As you do this, pay attention to whether or not the soil is readily "diggable" or dense and resists penetration. Remember that soils are much stronger and resistant to digging and penetration when they are dry, so try to do this evaluation when the soil is moist (but not too wet).

Next, follow the soil sampling instructions outlined in chapter 5, but try to separate areas of cut, fill, and exposed subsoil where possible into different soil sampling zones. Once a competent lab analyzes the samples, follow the fertilizer and lime prescriptions. If areas of strongly contrasting vegetation patterns occur (see figure 3.4), sample them separately. When possible, resample and retest problematic areas in future years to confirm that soil conditions are improving.

It is important to note that the soil testing procedures and fertilizer/lime recommendation systems used by the majority of university and private-sector laboratories were developed and correlated for use on natural weathered surface soils and therefore may not accurately predict amendment needs for newly disturbed urban soils. This is not to say that soil testing is not appropriate for urban soils, but the results of a given test need to be specifically interpreted for their application to these types of materials. This is particularly true when unweathered sediments or soft rocks are being revegetated or the road cut exposes unusually reactive materials (e.g., sulfidic soils) as discussed later. Once these urban soils have been managed and equilibrated to support vegetation for several years, however, interpretation of soil testing results is more straightforward.

Managing Dense Soils

Field determination of bulk density is difficult for an untrained person, but a general identification of compacted or dense soils can be estimated via the "calibrated shovel" technique discussed above. Tillage (e.g., rototilling) or deep ripping (via a ripper or chisel plow) is the only practical way to improve soil porosity but may be too expensive or impractical for many home lawns or confined urban situations. Hollow-tine aerification can also be effective for surface compaction in home lawns. However, care must be taken to avoid excessive tillage, which can lead to destruction of large aggregates. Too much tillage also decreases organic matter content by speeding its oxidation and decomposition. Addition of compost and/or other organic amendments into surface soil layers will promote aggregation and macroporosity and thereby decrease bulk density over time.

Gypsum and other soil amendments and conditioners are commonly advertised as being able to "cure compaction." While these products may improve soil aggregation they will have virtually no effect on soil bulk density unless they are actively tilled and mixed into the loosened soil zone. Similarly, certain plants (e.g., switchgrass and alfalfa) are widely touted as being able to root deeply into compacted soils and "loosen" them. This is not a viable solution for highly compacted soils that lack structure and vertical continuous macropores, because the growing root tip of these plants is actually quite pliable and must find an open soil pore to exploit before it can subsequently enlarge and open it further as it penetrates downward and subsequently expands in diameter.

Managing Clayey Subsoils

First, problems of acidity and infertility must be solved through appropriate soil liming and fertilization strategies as discussed above. Usually, another factor to correct immediately is the low organic matter content. Appropriate amounts of compost or other organic materials (see chapter 9) should be repeatedly mixed in **deeply** (6 inches or more, if possible). Over time, the organic matter decomposes and stabilizes the new surface soil, aiding in essential soil particle aggregation and building nutrient supplies. Remember that the establishment and maintenance of organic matter in the soil does much to aid long-term fertility as well as physical properties like aggregation, infiltration, and water-holding capacity.

Most subsoils are dense and/or clayey, so particular attention must be paid to the problems of poor drainage and water saturation as discussed next. Even the addition of trucked-in topsoil usually will not solve poor drainage problems caused by clayey or compacted subsoils. Before new topsoil is added or created by the addition of organic matter, poorly drained exposed subsoils should be deeply ripped or tilled. In many situations the use of raised beds greatly eases the required modification of surface soil properties.

Preserving and Maintaining Native Shrubs and Trees

Most of our native woody trees and shrubs in the mid-Atlantic region are adapted to acidic soil conditions but also rely on the maintenance of a litter layer (O horizon) and its provision of essential nutrients as it decomposes over time. Thus, a large majority of the tree's fine feeder roots exist in the upper 6 inches or so of soil and are generally adapted to a loose and well-aerated surface. Unfortunately, the urban soil development process frequently removes the litter layer and compacts the soil. Furthermore, typical home lawn liming targets (i.e., pH 6.5 to 7.0) can drive the soil pH to levels where the trees become deficient in critical micronutrients, particularly iron and manganese. To protect these valuable trees during the construction process, it is important to keep all heavy traffic and fill placement off the soil immediately around and under the tree's canopy. This will usually require placing a temporary fence around the tree (to the extent of the canopy drip line) and continued vigilance by the homeowner or an informed construction supervisor.

After construction is completed, it is best to leave natural litterfall on these areas where possible and to avoid the addition of excess lime or fertilizers to the soil. Unfortunately, many homeowners and landscapers desire to establish turfgrass on these areas, which are often undulating due to shallow roots and other manifestations of the formerly forest soil profile. One particularly damaging practice is the placement of thick (more than 4 inches) lifts of topsoil over the roots in an effort to smooth the surface soil out and establish viable turf. This frequently leads to soil compaction, inadequate gas exchange, and a soil chemical environment that is not suitable for the long-term survival of the native trees or shrubs (see figure 3.5).

Figure 3.5. Inappropriate addition of topsoil over native trees: The topsoil material was added too thickly (12 inches) and then compacted (as seen at left) to a point that gas exchange by the living tree roots was limited. Most of these white oaks died within two years of this application.

A Common Combination of Problems and a Prescription

Dense, clayey, acidic soils are commonly found throughout the urban and roadside environment and these materials are usually quite low in plant-available phosphorus when they are freshly graded or exposed in cuts. Because of this, it is always important to sample and soil test these materials. Based on soil tests, it is not uncommon to see recommendations calling for applications of lime at 2 to 4 tons per acre, coupled with enhanced phosphorus fertilization (150 pounds or more per acre as phosphorus oxide (P_2O_5)) to address fertility issues. The addition of high-quality compost (1 inch) and tillage of all amendments to 6 inches will rapidly remediate these problems for turf establishment and growth. This treatment will not correct deeper compaction problems, however, so other soil modification procedures may be necessary for deeper-rooted landscape plantings or to solve problems with water percolation, as discussed below. It is also important to point out that older established home lawns may actually be quite high in plant-available phosphorus due to long-term fertilization, so phosphorus fertilizer rates should always be based on an appropriate soil test.

Managing Wet Soils

Compacted and/or clayey soils cause numerous watering problems. The most obvious is surface ponding caused by slow water penetration into the ground. When dense or high-clay layers limit downward water movement, the soil becomes saturated and oxygen — which moves very slowly through water — cannot reach plant roots. If the saturated condition persists, roots will die from oxygen starvation. Highly compacted soils, even when dry, cause the same problem. Extended periods of water saturation also lead to increased availability of heavy metals such as iron and manganese, which in some soils may actually be phytotoxic. Saturated conditions can also accelerate soil nitrogen losses due to denitrification (see chapter 4).

There are a number of ways to manage saturation problems in soil. One is to increase internal water movement by improving aggregation and pore space. There are several ways to do this: increasing and maintaining organic material levels, changing or keeping pH in the range between 5.5 and 6.5, adding a soil conditioner such as very coarse sand, cultivation only when moisture levels are ideal, and remediating compaction. However, the addition of organic material and associated mixing and tillage is probably the single most-effective action you can take, assuming the underlying soil zone is well-drained and can accept percolating water.

Another way to increase internal water movement in wet soils is to shatter subsoil pans. If just a few deep cracks for water percolation are made down through the subsoil, large amounts of saturated water will flow through them (assuming the underlying layers will accept the water). Alternatively, subsurface drainage can be installed beneath the soil to carry away excess water. This is usually expensive, but may be the only alternative in many situations. Still another approach is to limit the amount of water entering the soil by diverting surface water away from the poorly drained area or by digging interceptor trenches just uphill from it. Plastic mulch can also be used to decrease total water penetration.

Acid Sulfate Soil Conditions and Management

Over the past decade, many highway, commercial, and home residential construction activities in the mid-Atlantic region have exposed what are known as “sulfidic materials” that quickly react to produce “acid sulfate soil conditions” (Wagner et al. 1982). Without question, these materials and their associated effects on plant growth, water quality, and construction materials pose the greatest risk of any materials managed in the urban soil environment (Fanning et al. 2007). Even though they are not routinely encountered, their affects are so catastrophic that they deserve detailed coverage here. Sulfidic soil and geologic materials occur throughout the mid-Atlantic region, but are particularly common in the Middle and Upper Coastal Plain region between Richmond and Stafford County, Va. (Orndorff and Daniels 2004).

Acid sulfate soils are earthen materials that have been degraded by oxidation of sulfides (like pyrite, FeS_2) to produce unusually low soil pH conditions (less than 3.9) when they are excavated from nonoxygenated zones below the surface and exposed to atmospheric conditions. As they oxidize, a wide array of acidity and soluble-salt-related plant growth and material damage problems are common. Essentially, these materials contain sulfidic minerals that react with water and oxygen to form sulfuric acid. This active set of processes is called “sulfuricization.” The vast majority of acid sulfate soils is the result of land-disturbing activities that bring previously unoxidized (reduced) materials up to the surface and allow them to react.

The normal maximum range of pH for soils in the mid-Atlantic region is between 4.0 and 7.5. In the absence of liming, the great majority of these soils are naturally acidic with a pH between 4.5 and 5.5. In almost all instances, any soil with a pH less than 3.9 in Virginia is indicative of active or historic acid sulfate soil conditions and is quite toxic to plant growth and local receiving streams. In worst-case instances, soil pH values as low as 1.8 have been measured at locations such as the Stafford Airport in Virginia (Fanning et al. 2004).

Where Do Sulfidic Materials Come From and What Do They Look Like?

Sulfides precipitate naturally in tidal marshes, accumulate in sediments, and are enriched in certain metamorphic and igneous rocks. Thus, they occur naturally in many of the sediments underlying our Coastal Plain and in other rock types throughout the mid-Atlantic region. For example, most of the soils in the Fredericksburg/Stafford County, Va., area formed out of parent materials that originally contained sulfides, but they oxidized and weathered out of the surface soil horizons (layers) tens of thousands of years ago. These subsoil horizons are usually bright yellow to red in color and are usually quite acidic (pH 4.0 to 5.5). However, many deeper cuts (more than 10 to 20 feet) can reveal unoxidized sulfidic materials that are typically gray, steel blue, or sometimes black in color but still have a high pH (more than 6.5) *in situ.* Once exposed at the surface, however, the pH of these materials can drop below 4.0 within several months.

How Do I Recognize Acid Sulfate Materials?

Because fresh, unreacted, sulfidic materials have a near-neutral pH, the only way to identify them before disturbance is appropriate testing and lab analyses as described later. Once they react to become "active acid sulfate" soils, distinctive indicators include (1) dead vegetation, (2) red iron staining on concrete and block walls, (3) concrete etching and dissolution, (4) rapid corrosion of iron and galvanized metal, and (5) strong sulfurous odor from rubbed hand samples.

What Is the Potential Risk and Damage From Acid Sulfate Soil Processes?

Acid sulfate soil conditions and associated sulfuricization reactions generate a number of extreme soil and water quality challenges. First of all, plants are killed by the direct effects of low pH, high heavy-metal solubility, and soluble sulfate salt stress. The extremely acidic (pH 1.8 to 3.8) soil solutions and percolates directly degrade concrete, iron, and galvanized metal via a number of mechanisms. Finally, acid runoff and seepage from these materials can seriously degrade local receiving streams. Thus, it is critically important that these materials be isolated or treated to remediate their acid-producing potential and limit damage.

How Do I Confirm Whether or Not I Have Acid Sulfate Materials in My Soil?

In addition to the visual symptoms described above, active acid sulfate materials will usually exhibit a combination of low pH (less than 3.9) and high levels of potential acidity (total lime demand) relative to native soils. Fresh, unoxidized, sulfidic materials may have a normal pH but will have high levels of potential acidity (see below).

What Is Potential Acidity and How Is It Expressed?

Potential acidity is estimated by several lab techniques that have been used and refined by the mining industry since the 1970s to prevent the formation of "acid mine drainage" from coal and metal mines. The most widely used technique is called "acid-base accounting" (ABA), which assumes that all sulfides in the material will fully react to form sulfuric acid and then balances that against the material's inherent lime or neutralizing capacity. The results are expressed in tons of lime demand per 1,000 tons of material, which handily also happens to be the average weight of 1 acre of soil, 6 inches deep. Reduced sulfur is very reactive and every 1.0 percent of sulfidic sulfur, if fully reacted, generates enough acidity to require approximately 32 tons of agricultural limestone (finely ground calcium carbonate ($CaCO_3$)) per 1,000 tons of soil to fully neutralize! Thus, even 0.3 percent sulfidic sulfur in these materials can generate a lime demand of 10 tons per acre (6 inches deep), which is much higher than we ever apply to "normal" soils. Occasionally, Coastal Plain sediments do contain sufficient lime (as fine shell fragments, etc.) to completely or partially offset their acid-forming potential, but this is a rare occurrence.

At Virginia Tech, we use a similar technique to ABA for potential acidity called the peroxide potential acidity (PPA) technique. In this method, we use strong hydrogen peroxide (H_2O_2) to force the complete reaction of the sulfides and their internal neutralization by carbonates. In our experience, it correlates very well with ABA for a wide range of Virginia materials. For example, our long-term research results indicate that acid sulfate materials in the Fredericksburg/Stafford County region average between 10 and 20 tons of lime demand per acre (or per 1,000 tons of soil) in their fresh/unoxidized state. On occasion, we have tested small pockets of materials that exceeded 50 tons of lime per 1,000 tons of soil or per acre net acid demand! Once these materials have fully reacted and oxidized, however, they typically require only 4 to 6 tons of lime per acre to bring their low pH (less than 4.0) up to 7.0.

What Can I Do to Remediate Acid Sulfate Soil Conditions?

First of all, the **only way** to prevent these reactions from occurring in disturbed cut/fill materials is to keep them out of contact with the oxidizing atmosphere and water. However, once they are placed and graded on a home site, the only practical way to remediate them is to bulk blend sufficient agricultural limestone (or other approved liming materials) with them to offset the full amount of acidity that will be produced over extended periods of time (i.e., their potential acidity). We also recommend applying 25 percent more lime to ensure long-term alkaline buffering in the system. For example, let's assume the soil in your backyard has a net potential acidity of 10 tons per acre of lime demand. With the 25 percent buffer factor added to it, you need to add the equivalent of 12.5 tons of lime per acre, 6 inches deep. Usually, your yard will be much less than an acre in size, so we need to convert this to a more practical liming rate per 1,000 square feet. As a matter of convenience, one 50-pound bag of agricultural lime per 1,000 square feet is approximately equivalent to 1 ton per acre. So, the basic liming requirement for your back yard would be 12.5 x 50 pounds = 625 pounds of agricultural lime per 1,000 square feet. These materials would need to be well-mixed (with a rototiller or air knife) to a depth of 6 inches to ensure full reaction and remediation of the surface rooting zone. Once this material is allowed to react following several rainfall or irrigation events, you should be able to use normal plant/lawn establishment procedures, but we recommend adding compost to the surface soil mix whenever possible. It is important to note that the deeper soil layers will not be affected by this treatment, so planting holes for deep-rooted vegetation (e.g., trees) require deeper treatment.

We also recommend a similar remedial treatment for all soils in direct contact with uncoated concrete or foundations, block walls, or metal conduits and pipes. The exception would be where those materials (concrete, metal, etc.) are under the water table or buried deeply enough in the soil that they are beyond the depth of oxygen diffusion.

What Kind of Lime Should I Use?

The "lime" that we refer to above is "agricultural lime" ($CaCO_3$ or $Ca/MgCaCO_3$) and not hydrated lime ($Ca(OH)_2$) or burnt lime (CaO). These two latter materials are commercially available and occasionally used by the geotechnical engineering community for soil cementation or waste treatment. They do have advantages of being more concentrated and quicker to react. However, they are more expensive, can burn your eyes, and can rapidly drive soil pH to very high values that are also toxic to plants. Therefore, we only recommend the use of certified agricultural lime for this purpose. The use of pelletized lime products is acceptable and may make application of the very high rates easier with minimal dusting issues.

Ideally, How Can We Avoid These Problems in the First Place?

Based on our work with the Virginia Department of Transportation and others (see website below for details), we have developed a statewide map layer that indentifies all geologic strata that have documented sulfide risk. Predisturbance geologic drill cores by developer's consultants in these units should be evaluated for color, and any gray, blue-gray, or black strata should be tested for total sulfur. If total sulfur is more than 0.25 percent, those same strata should be tested for acid-base-accounting or peroxide potential acidity. Any materials with a net lime demand of more than 5 tons of lime per 1,000 tons of material (or soil) should be isolated from the surface and either heavily compacted in place to limit permeability or bulk limed before placement to offset acidity production over time.

Where Can I Get More Information?

We maintain current information and reports on this subject posted to our research website at Virginia Tech (*www.cses.vt.edu/revegetation/remediation.html*). Additionally, the most sophisticated program in the world for recognition and remediation of acid sulfate materials is carried out in Queensland, Australia, due to its preponderance of acid-forming parent materials. Their website (*www.nrw.qld.gov.au/land/ass/index.html*) is quite comprehensive and informative, with numerous links to their reports, methods, and regulations.

Soil Conditions in Highway Rights-of-Way

In a typical highway construction corridor, materials lying above the grade of the proposed road are removed (cut) by a variety of earthmoving techniques and hauled to adjacent lower areas for disposal. Whenever possible, the cut materials are utilized as subgrade materials for the roadbed or as fill to span depressions and valleys beneath the corridor. Excess fill materials are usually disposed of in compacted fills as near to the road corridor as possible to minimize hauling costs. The combination of cut and fill activity generates fundamentally different surfaces for revegetation as the road-building project progresses across the landscape. Cut slopes will frequently expose a surficial weathered soil profile and then extend well down into the underlying rock or sediments. These materials will therefore vary considerably in fundamental chemical and physical properties with depth, particularly in regions like the mid-Atlantic United States, where the geochemical weathering profiles are deep and soil horizonation is strong. These gradations with depth are predictable, however, and will tend to recur in a prescribed sequence as the cuts proceed through the landscape.

Fill materials, on the other hand, tend to be quite different from road cuts due to the mixing effects of the earthmoving operations and the fact that they are typically heavily compacted in place to meet stability and strength specifications. Fill materials may be more or less variable than adjacent cut areas, depending on how they are handled and placed, but they are typically quite compact and lack the well-developed aggregation or structure that undisturbed soils usually possess. Therefore, soils in highway fill materials as a rule will be less permeable to air, water, and roots than their natural precursors. Fills and fill slopes also are plagued by inclusions of aggregate, rock, concrete, and other construction debris that seriously limit their water-retention characteristics. In contrast, soils on cut slopes generally retain the physical and chemical properties of the original soil/geologic profile, but their surfaces are often compacted to some extent by the earthmoving equipment, and the soil is often "smeared" and sealed, particularly in fine-textured soils.

Regardless of whether you are dealing with cut or fill materials, it is critically important to understand that the vast majority of materials that will be revegetated are composed primarily of subsoil or deeper geologic materials that will be very low in organic matter and associated macronutrients, particularly nitrogen and phosphorus. When highly weathered subsoils are exposed, we are often left with a very clayey and highly acidic substrate that will require significant inputs of lime and phosphorus fertilizers before its basic chemical properties begin to resemble native topsoils. Deeper cuts that extend below the weathered soil zone will frequently contain large amounts of fresh, unweathered rocks and sediments that can be significant sources of calcium, magnesium, potassium, and other nutrient elements as they rapidly weather in their newly exposed geochemical environment. Acid-forming sulfidic materials (as discussed earlier) are also commonly encountered in deeper road cuts in a variety of geologic settings and can generate extremely harsh soil chemical conditions and associated runoff water quality complications as they oxidize.

The cut/fill and site development operations for new highways or other construction activities may cause uncontrolled water flows and sediment loss from bare soil areas. Many small, localized, disturbed areas with seemingly insignificant losses of water and soil will often coalesce into massive and rapid flows of water with high sediment loads, causing severe damage in highway corridors as well as flooding and contamination of receiving streams. Even the initial slow flows of clear water from numerous small areas of disturbance within a highway development corridor can cause progressively larger erosive flows of water. Thus, it is imperative to minimize water flow and sediment losses from the initial stages of grading operations. Uncontrolled erosion also can severely degrade the site quality of the eroded area, particularly if applied topsoil, lime, and fertilizers are lost or a less-hospitable substrate is exposed.

Manufactured Soils

In certain high-value situations like landscape planting beds and constructed athletic fields, the use of manufactured topsoil materials is a viable alternative to having to manage the pre-existing urban soils (Puhalla et al. 2010). This is particularly true when we consider what is typically available and marketed as topsoil in rapidly developing areas of the mid-Atlantic. The majority of materials that are marketed and sold as topsoil are generated by the land development and construction process and may or may not be true topsoil as defined earlier (A plus E horizons). Additionally, these natural topsoils are highly variable over time as they are hauled from differing sites with different soil properties, soil-removal depths, and handling/storage procedures. Very few of these materials are offered with any guarantee of pH, texture, or nutrient-supplying ability relative to established soil testing standards.

The "ideal" soil for most turf establishment and landscaping applications is loamy in texture to ensure adequate water-holding capacity and aeration without being sticky and plastic when handled and graded. Beyond that, the soil should be moderate in pH (between 6.5 and 7.5) to ensure maximum beneficial biological activity and moderate to high in plant-available nutrients such as calcium (Ca), magnesium (Mg), potassium (K), and phosphorus (P). Good topsoils also contain small but adequate amounts of plant-essential micronutrients like iron (Fe) and copper (Cu), but should also be low in soluble salts and sodium (Na), which can disperse soil structure and harm plants. Finally, the ideal soil would contain approximately 3 to 5 percent organic matter that serves as a long-term source of plant nutrients (especially nitrogen), maintains biological activity, and greatly enhances physical properties such as water-holding capacity. Perhaps most importantly, the ideal soil for turf and landscaping applications would be consistent over time in all of the above properties so that the user will not have to "fine-tune" establishment and management protocols for each batch of soil received.

There are currently a number of manufactured topsoils available in the region. One example of a manufactured soil developed cooperatively by Luck Stone and

Virginia Tech (Greene premium topsoil) is described below. This description is not intended as an endorsement of this particular product, but simply as an example of one of many commercially viable products.

The Greene topsoil product is manufactured from native soil saprolite, compost, and mineralized igneous rock dust to produce loamy topsoil that is well-balanced in organic matter, available plant nutrients, and pH. This product was developed cooperatively with the Department of Crop and Soil Environmental Sciences at Virginia Tech, and as seen in table 3.1, is equal to or exceeds natural topsoils in productivity potential for most horticultural, landscaping, and gardening applications. The Greene topsoil is high in organic matter (5 to 7 percent), moderate in pH (6.0 to 7.5) and soluble salts (up to 2.0 millimhos per centimeter (mmhos/cm)), and low in sodium. Plant-available phosphorus is more than 70 parts per million (ppm), potassium and magnesium are both more than 100 ppm, and calcium is more than 1,000 ppm. This topsoil also provides balanced levels of plant-available micronutrients (e.g., boron, copper, iron, manganese, and zinc).

The Greene topsoil is higher than natural topsoils in organic matter content and available nutrients because it is carefully blended with fresh, unweathered primary mineral fines and compost to generate the characteristics displayed in table 3.1. Perhaps most importantly, the Greene topsoil product has been tested and proven to be quite consistent over time and has been proven effective in a wide range of plant growth uses in research at Virginia Tech and on-site applications by the producer's client base of landscapers and developers.

Due to the inherent fertility of the Greene topsoil, use of initial or starter fertilizers (especially phosphorus and potassium) is probably not necessary or warranted, particularly in light of current concerns over minimizing losses of nutrients to surface waters. However, initially high levels of available nutrients will be depleted over time by plant uptake, and like any soil, subsequent fertilization will be required. The Greene topsoil product is not recommended for root zone use with acid-loving plants such as blueberries, azaleas, and native pines unless it is blended with naturally acidic (pH less than 6.0) soil materials.

Modified Soils and Mulches

Another approach to mitigate the adverse properties of urban soils is *via* "soil modification" or "conditioning," a process that generally involves the incorporation of inorganic or organic amendments into bulk soil to fundamentally alter important soil physical properties (Wallace and Terry 1998). Certain inorganic amendments (e.g., sand or bottom ash) can be added to clayey soils to reduce their stickiness and plasticity, but the volumes required to generate a loamy texture (10 to 40 percent), coupled with the costs and logistics involved limit this approach to high-value locales. Similarly, waste clays from sand mining operations (e.g., slimes) can be added into extremely coarse-textured soils to convert them to loamy textures but similar issues of cost and logistics apply. Other inorganic amendments (e.g., gypsum and lime) can be added to clayey or dispersed soils to promote aggregation, but this usually involves much lower loading rates than textural modification

Table 3.1. Important soil properties for the Greene topsoil compared to highly productive prime farmland topsoil from Dinwiddie County, Va., and the range of typical topsoil properties found in Virginia.

Soil property	Greene topsoil	Prime farmland	Average Virginia topsoil
Texture	Sandy loam	Sandy loam	Sandy loam to clay loam
pH (acidity)	6.6-7.2	6.0-6.5	4.5-7.5
Organic matter	5-7%	1-2%	0.5-3%
Available* calcium (Ca)	>1,200 ppm	300-600 ppm	<50-600 ppm
Available potassium (K)	>250 ppm	30-60 ppm	<20-80 ppm
Available phosphorus (P)	75-150 ppm	20-30 ppm	<5-30 ppm
Available copper (Cu)	1.5 ppm	0.6 ppm	0.2-0.7 ppm

Data compiled from research reports by W. Lee Daniels, Virginia Tech.

*Available soil nutrients are those contained in an acid-extractable form that would be expected to contribute to plant uptake needs over the growing season and are typically expressed in parts per million (ppm) of total soil weight. For a common-sense conversion, 100 ppm of available Ca in a soil would equate to approximately 200 pounds of calcium in the upper 6 inches of topsoil over 1 acre.

and really differs little from conventional liming practice. Certain inorganic soil conditioners (e.g., fly ash or waste gypsum) may also contain significant levels of soluble salts or potentially phytotoxic elements like boron, so their use must be carefully considered and controlled.A wide array of organics (e.g., composts, biosolids, animal manures, and paper sludges) are also routinely utilized to enhance aggregation, porosity, and water-holding capacity in urban soils. Usually, these materials are most effective when incorporated or bulk blended with surface soil layers, which may require up to 25 percent volumetric addition rates. One potential drawback of many organic amendments (e.g., biosolids and manures) is that addition at these rates may pose significant nutrient runoff or leaching risks (see chapters 2, 9, 10, and 12). Another long-term management factor to consider is that organic amendments will naturally decompose with time, and their "bulking effect" on porosity will thereby decline as well. However, the humus fraction they leave behind will make a very valuable and long-lived contribution to urban soil quality.

Finally, surface mulches can also be utilized to buffer soil temperature, enhance water infiltration and retention, limit traffic-related soil compaction, and reduce weed competition (Brady and Weil 2008). More detail on use of organic mulches is found in chapter 9.

A more thorough discussion of the full array of soil amendments, conditioners, and mulches and their relative advantages and management is beyond the scope of this book. However, greater detail on these topics can be found in the various resources cited below.

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Chapter 4. Basic Soil Fertility

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Plant Nutrition

Essential Elements

An essential mineral element is one that is required for normal plant growth and reproduction. With the exception of carbon (C) and oxygen (O), which are supplied from the atmosphere, the essential elements are obtained from the soil. The amount of each element required by the plant varies; however, all essential elements are equally important in terms of plant physiological processes and plant growth.

The exact number of elements that should be considered "essential" to plant growth is a matter of some debate. For example, cobalt (Co), which is required for nitrogen (N) fixation in legumes, is not considered to be an essential element by some researchers. Table 4.1 lists 18 elements that are considered essential by many scientists. Other elements that are sometimes listed as essential are sodium (Na), silicon (Si), and vanadium (V).

Table 4.1. Eighteen essential elements for plant growth and the chemical forms most commonly taken up by plants.

Element	Symbol	Form absorbed by plants
Carbon	C	CO_2
Hydrogen	H	H^+, OH^-, H_2O
Oxygen	O	O_2
Nitrogen	N	NH_4^+, NO_3^-
Phosphorus	P	HPO_4^{2-}, $H_2PO_4^-$
Potassium	K	K^+
Calcium	Ca	Ca^{2+}
Magnesium	Mg	Mg^{2+}
Sulfur	S	SO_4^{2-}
Iron	Fe	Fe^{2+}, Fe^{3+}
Manganese	Mn	Mn^{2+}, Mn^{4+}
Boron	B	H_3BO_3, BO_3^-, $B_4O_7^{2-}$
Zinc	Zn	Zn^{2+}
Copper	Cu	Cu^{2+}
Molybdenum	Mo	MoO_4^{2-}
Chlorine	Cl	Cl^-
Cobalt	Co	Co^{2+}
Nickel	Ni	Ni^{2+}

Categories of Essential Elements

Essential elements can be grouped into four categories, based on their origin or the relative amount a plant needs in order to develop properly (table 4.2).

1. Nonmineral essential elements are derived from the air and water.
2. Primary essential elements are most often applied in commercial fertilizers or in manures.
3. Secondary elements are normally applied as soil amendments or are components of fertilizers that carry primary nutrients.

   Nonmineral, primary, and secondary elements are also referred to as "macronutrients," because they are required in relatively large amounts by plants.
4. "Micronutrients" are required in very small, or "trace," amounts by plants. Although micronutrients are required by plants in very small quantities, they are equally essential to plant growth.

Table 4.2. Essential elements, their relative uptake, and sources where plants obtain them.

Macronutrients			
Nonmineral	**Primary**	**Secondary**	**Micronutrients**
(Mostly from air and water)	(Mostly from soil)	(Mostly from soil)	(Mostly from soil)
Carbon Hydrogen Oxygen	Nitrogen Phosphorus Potassium	Calcium Magnesium Sulfur	Iron Manganese Boron Zinc Copper Molybdenum Chlorine Cobalt Nickel

Functions of Essential Elements in Plants

Carbon (C), Hydrogen (H), and Oxygen (O)

- Directly involved in photosynthesis, which accounts for most plant growth.

Nitrogen (N)

- Found in chlorophyll, nucleic acids, and amino acids.
- Component of protein and enzymes, which control almost all biological processes.

Phosphorus (P)

- Essential component of adenosine triphosphate (ATP) — which is directly responsible for energy transfer reactions in the plant — and of DNA and RNA.
- Essential component of phospholipids, which play critical roles in cell membranes.
- Important for plant development — including development of a healthy root system, normal seed development, and photosynthesis — respiration, cell division, and other processes.

Potassium (K)

- Responsible for regulation of plants' water usage, disease resistance, and stem strength.
- Involved in photosynthesis, drought tolerance, winter hardiness, and protein synthesis.

Calcium (Ca)

- Essential for cell elongation and division.
- Specifically required for root and leaf development, function of cell membranes, and formation of cell wall compounds.
- Involved in the activation of several plant enzymes.

Magnesium (Mg)

- Primary component of chlorophyll, and therefore, actively involved in photosynthesis.
- Structural component of ribosomes, which are required for protein synthesis.
- Involved in phosphate metabolism, respiration, and the activation of several enzyme systems.

Sulfur (S)

- Required for the synthesis of the sulfur-containing amino acids cystine, cysteine, and methionine, which are essential for protein formation.
- Involved with development of enzymes and vitamins, chlorophyll formation, and formation of several organic compounds that give characteristic odors to garlic, mustard, and onion.

Iron (Fe)

- Serves as a catalyst in chlorophyll synthesis.
- Involved in many oxidation-reduction reactions during respiration and photosynthesis.

Manganese (Mn)

- Functions primarily as a part of the enzyme systems in plants.
- Activates several important metabolic reactions.
- Plays a direct role in photosynthesis.
- Along with iron, serves as a catalyst in chlorophyll synthesis.

Boron (B)

- Essential for germination of pollen grains and growth of pollen tubes, seed, and cell wall formation.
- Essential for development and growth of new cells in meristematic tissue.
- Sugar/borate complexes associated with translocation of sugars, starches, nitrogen, and phosphorus.
- Important in protein synthesis.

Zinc (Zn)

- Essential for promoting certain metabolic/enzymatic reactions.
- Necessary for the production of chlorophyll, carbohydrates, and growth hormones.
- Aids in the synthesis of plant growth compounds and enzyme systems.

Copper (Cu)

- Necessary for chlorophyll formation.
- Serves as a catalyst for several enzymes.

Molybdenum (Mo)

- Required for the synthesis and activity of the enzyme system that reduces nitrate to ammonium in the plant.
- Essential in the process of symbiotic nitrogen fixation by *Rhizobia* bacteria in legume root nodules.

Chlorine (Cl)

- Involved in energy reactions in the plant, breakdown of water, regulation of stomata guard cells, maintenance of turgor, and rate of water loss.
- Involved in plant response to moisture stress and resistance to some diseases.
- Activates several enzyme systems.
- Serves as a counter ion in the transport of several cations in the plant.

Cobalt (Co)

- Essential in the process of symbiotic nitrogen fixation by *Rhizobia* bacteria in legume root nodules.
- Not proven to be essential for the growth of all higher plants.

Nickel (Ni)

- Component of the urease enzyme.
- Essential for plants in which ureides are important in nitrogen metabolism.

Nutrient Deficiency Symptoms

Visual diagnosis of plant deficiencies can be very risky. There may be more than one deficiency symptom expressed, which can make diagnosis difficult. Both soil and tissue samples should be collected, analyzed, and interpreted before any recommendations are made concerning application of fertilizer.

Terminology used to describe deficiency symptoms (table 4.3) includes:

Chlorosis	Yellowing or lighter shade of green.
Necrosis	Browning or dying of plant tissue.
Interveinal	Between the leaf veins.
Meristem	Growing point of a plant.
Internode	Distance of the stem between the leaves.

Elements can be either "mobile" or "not mobile" within plants. This determines where symptoms of an element deficiency will first appear in a plant. A mobile element is one that is able to "translocate" (move) from one part of the plant to another depending on its need. Mobile elements generally move from older (lower) plant parts to the meristem, or growing point.

Soil pH, Nutrient Availability, and Liming

Effect of pH on Nutrient Availability

Many soil elements change form as a result of chemical reactions in the soil. Plants may or may not be able to use elements in some of these forms. Because pH influences the soil concentration and, thus, the availability of plant nutrients, it is responsible for the solubility of many nutrient elements. Figure 4.1 illustrates the relationship between soil pH and the relative plant availability of nutrients.

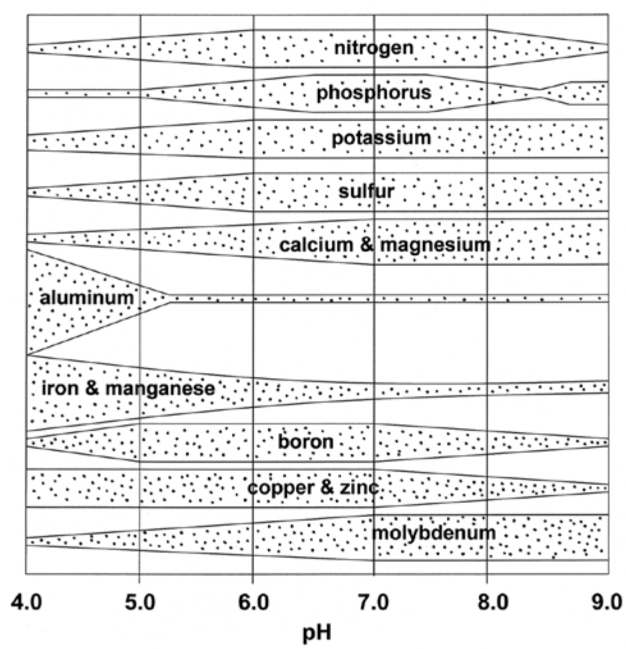

Figure 4.1. Relationship between soil pH and nutrient availability.
Graphic by Kathryn Haering.

Phosphorus solubility and plant availability are controlled by complex soil chemical reactions, which are often pH-dependent. Plant availability of P is generally greatest in the pH range of 5.5 to 6.8. When soil pH falls below 5.8, P reacts with Fe and Al to produce insoluble iron and aluminum phosphates that are not readily available for plant uptake. At high pH values, phosphorus reacts with Ca to form calcium phosphates that are relatively insoluble and have low availability to plants.

Table 4.3. Element mobility and specific deficiency symptoms.

Element	Mobility	Deficiency Symptoms and Occurrence
Nitrogen	Mobile within plants; lower leaves show chlorosis first.	Stunted, slow-growing, chlorotic plants; reduced yield; plants more susceptible to weather stress and disease. Some plants may mature earlier.
Phosphorus	Mobile within plants; lower leaves show deficiency first.	Overall stunted plant and a poorly developed root system. Can cause purple or reddish color associated with the accumulation of sugars. Difficult to detect from visual symptoms.
Potassium	Mobile within plants; lower leaves show deficiency first.	Scorching or firing along leaf margins, slow growth, poorly developed root systems, weak stalks, small and shriveled seeds and fruit, and low disease-resistance. Deficiencies most common on acidic sandy soils or soils that have received large applications of Ca and/or Mg.
Calcium	Not mobile within plants; upper leaves and the growing point show deficiency symptoms first.	Poor root growth and failure of terminal buds of shoots and apical tips of roots to develop, causing plant growth to cease. Most often occurs on very acidic soils where Ca levels are low but other deficiency effects such as high acidity usually limit growth before Ca deficiency becomes apparent.
Magnesium	Mobile within plants; lower leaves show deficiency first.	Yellowish, bronze, or reddish color in leaves while leaf veins remain green.
Sulfur	Somewhat mobile within plants, but upper leaves tend to show deficiency first.	Chlorosis of the longer leaves and possible chlorosis and stunting of entire plant with severe deficiencies. Symptoms resemble those of N deficiency; can lead to incorrect diagnoses.
Boron	Not mobile within plants; upper leaves and the growing point show deficiency symptoms first.	Reduced leaf size and deformation of new leaves, interveinal chlorosis, distorted branches and stems, possible flower and/or fruit abortion, stunted growth. May occur on very acidic, sandy-textured soils or alkaline soils.
Copper	Not mobile within plants; upper leaves and the growing point show deficiency symptoms first.	Reduced leaf size, uniformly pale yellow leaves, leaves may lack turgor and can develop a bluish-green cast, become chlorotic, and/or curl. Flower production fails to take place.
Iron	Not mobile within plants; upper leaves show deficiency symptoms first.	Interveinal chlorosis that progresses over the entire leaf. With severe deficiencies, leaves turn entirely white. Factors contributing to Fe deficiency include imbalance with other metals, excessive soil P levels, high soil pH, wet and cold soils.
Manganese	Not mobile within plants; upper leaves show deficiency symptoms first.	Interveinal chlorosis, brownish-black specks. Occurs most often on high-organic-matter soils and soils with neutral-to-alkaline pH and low native Mn content.
Zinc	Not mobile within plants; upper leaves and the growing point show deficiency symptoms first.	Shortened internodes between new leaves, death of meristematic tissue, deformed new leaves, interveinal chlorosis. Occurs most often on alkaline (high pH) soils or soils with high available P levels.
Molybdenum	Not mobile within plants; upper leaves show deficiency symptoms first.	Interveinal chlorosis, wilting, marginal necrosis of upper leaves. Occurs principally on very acidic soils because Mo becomes less available with low pH.
Chlorine	Mobile within plant, but deficiency symptoms usually appear on the upper leaves first.	Chlorosis in upper leaves; overall wilting of plants. Deficiencies may occur in well-drained soils under high rainfall conditions.
Cobalt	Used by symbiotic N-fixing bacteria in root nodules of legumes and other plants.	Causes N deficiency, chlorotic leaves, and stunted plants. Occurs in areas with soils deficient in native Co.

Potassium, calcium, and magnesium are most present in soils with pH levels greater than 6.0. They are generally not as available for plant uptake in acidic soils because they may have been partially leached out of the soil profile.

At pH values less than 5.0, Al, Fe, and Mn may be soluble in sufficient quantities to be toxic to the growth of some plants. Aluminum toxicity limits plant growth in most strongly acidic soils. Aluminum begins to solubilize from silicate clays and Al hydroxides below a pH of approximately 5.3, which increases the activity of exchangeable Al^{3+}. High concentrations of exchangeable Al are toxic and detrimental to plant root development.

In general, most micronutrients are more available in acidic than in alkaline soils. As pH increases, micronutrient availability decreases, and the potential for deficiencies increases. An exception to this trend is Mo, which becomes less available as soil pH decreases. In addition, B becomes less available when the pH is less than 5.0 and again when the pH exceeds 7.0.

Soil organisms also grow best in near-neutral soil. In general, acidic soil inhibits the growth of most organisms, including many bacteria and earthworms. Thus, acidic soil slows many important activities carried on by soil microbes, including nitrogen fixation, nitrification, and organic matter decay. *Rhizobia* bacteria, for instance, thrive at near-neutral pH and are sensitive to solubulized Al.

Soil Acidification and Liming

Acidification is a natural process that occurs continuously in soils throughout the mid-Atlantic region and is caused by the following factors:

- The breakdown of organic matter can cause acidification of the soil as amino acids are converted into acetic acid, hydrogen gas, dinitrogen gas, and carbon dioxide by the reaction:

  $$2C_3H_7NO_3 + O_2 \rightarrow 2HC_2H_3O_2 + 3H_2 + N_2 + 2CO_2.$$

- The movement of acidic water from rainfall through soils slowly leaches basic essential elements such as Ca, Ma, and K, below the plant root zone and increases the concentration of exchangeable soil Al. Soluble Al^{3+} reacts with water to form hydrogen ions, which make the soil acidic.
- Soil erosion removes exchangeable cations adsorbed to clay particles.
- Hydrogen is released into the soil by plants' root systems as a result of respiration and ion uptake processes during plant growth.
- Nitrogen fertilization speeds up the rate at which acidity develops, primarily through the acidity generated by nitrification:

  $$2NH_4^+ + 4O_2 \rightarrow 2H_2O + 4H^+ + 2NO_3^-.$$

Liming is a critical management practice for maintaining soil pH at optimal levels for plant growth. Liming supplies the essential elements Ca and/or Mg, reduces the solubility and potential toxicity of Al and Mn, and increases the availability of several essential nutrients. Liming also stimulates microbial activity (e.g., nitrification) in the soil, and improves symbiotic nitrogen fixation by legumes. However, over-liming can induce micronutrient deficiencies by increasing pH above the optimum range.

Most plants grow well in the pH range 5.8 to 6.5. Leguminous plants generally grow better in soils limed to pH values of 6.2 to 6.8. Some plants, such as blueberries, mountain laurel, rhododendron, and others, grow best in strongly acidic (pH less than 5.2) soils.

Determining Lime Requirements

Soil pH is an excellent indicator of soil acidity; however, it does not indicate how much total acidity is present, and it cannot be used to determine a soil's lime requirement when used alone.

The "lime requirement" for a soil is the amount of agricultural limestone needed to achieve a desired pH range for the plants that are grown. Soil pH determines only active acidity — the amount of H^+ in the soil solution at that particular time — while the lime requirement determines the amount of exchangeable or reserve acidity held by soil clay and organic matter (figure 4.2).

Most laboratories use soil pH in combination with "buffered" solutions to extract and measure the amount of reserve acidity, or "buffering capacity" in a soil. The measured amount of exchangeable/reserve acidity is then used to determine the proper amount of lime needed to bring about the desired increase in soil pH.

The rate of limestone applied to any area should be based on soil test recommendations. A soil test every two to three years will reveal whether or not lime is needed. Sandy soils generally require less lime at any one application than silt loam or clay soils to decrease soil acidity by a given amount. Sandy soils, however, usually need to be limed more frequently because their buffering capacity is low.

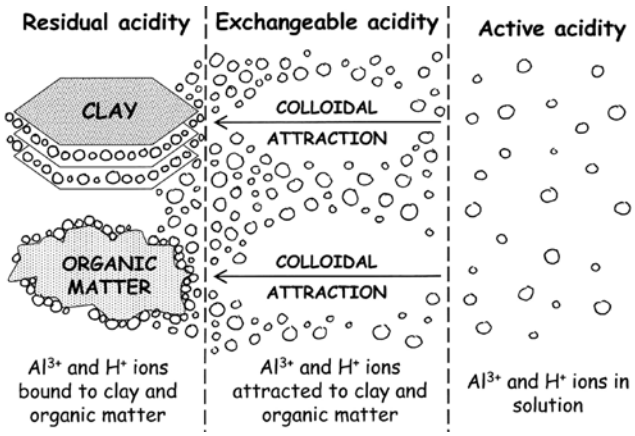

Figure 4.2. Relationship between residual, exchangeable, and active acidity in soils. *Graphic by Kathryn Haering.*

Nitrogen

The Nitrogen Cycle

Nitrogen is subject to more transformations than any other essential element. These cumulative gains, losses, and changes are collectively termed the "nitrogen cycle" (figure 4.3). The ultimate source of N is N_2 gas, which comprises approximately 78 percent of the earth's atmosphere. Inert N_2 gas, however, is unavailable to plants and must be transformed by biological or industrial processes into forms that are plant-available. As a result, the turf and landscape industry is heavily dependent on commercial N fertilizer. Some of the more important components of the N cycle are discussed below.

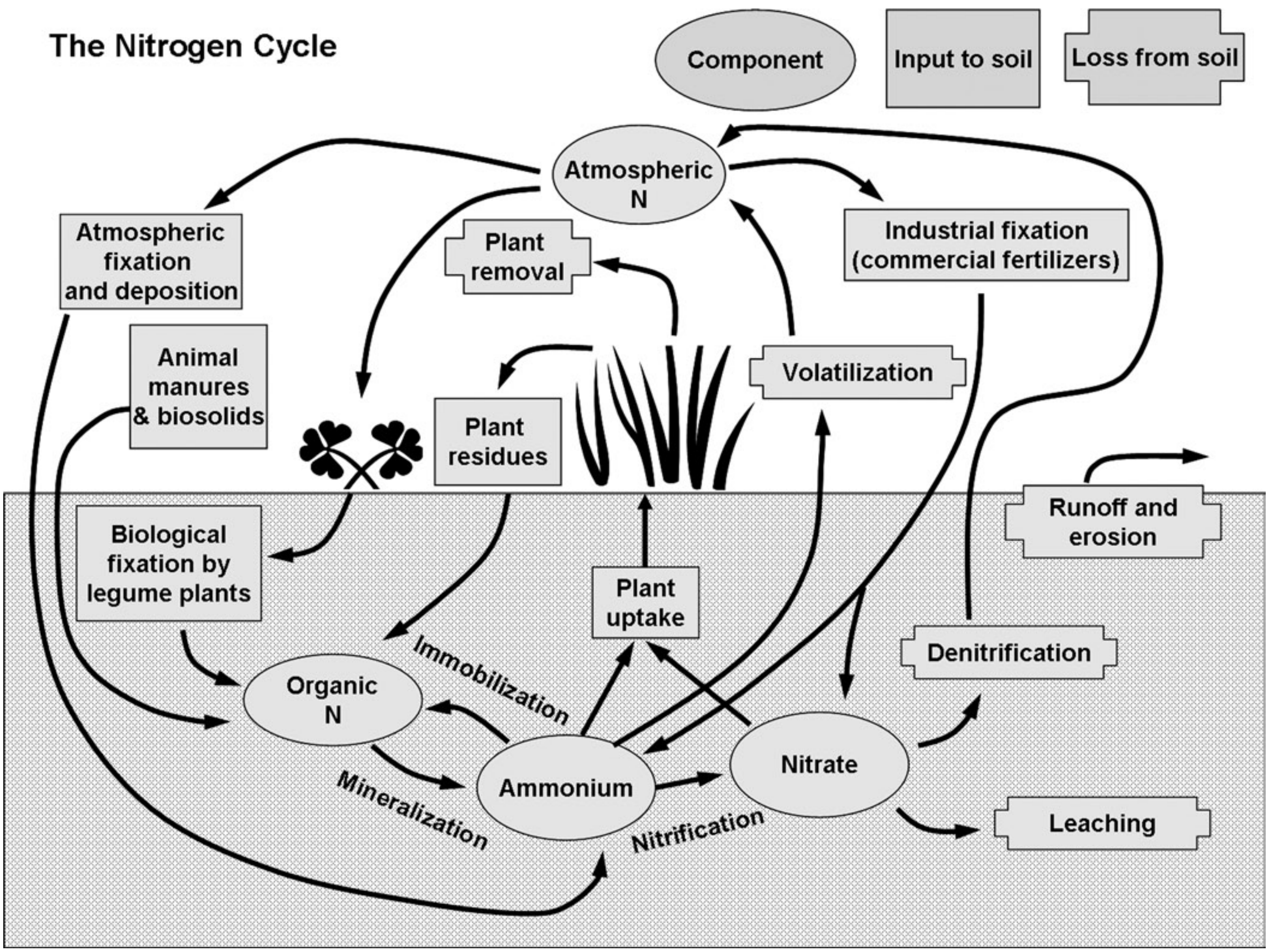

Figure 4.3. The nitrogen cycle (modified from the Potash & Phosphate Institute website at *www.ppi-ppic.org*).

Nitrogen Fixation

"Nitrogen fixation" is the process whereby inert N_2 gas in the atmosphere is transformed into forms that are plant-available, including ammonium (NH_4^+) and nitrate (NO_3^-). Fixation can take place by biological or by nonbiological processes.

Biological nitrogen-fixation processes include:

Symbiotic Nitrogen Fixation

This process is mediated by bacteria with the ability to convert atmospheric N_2 to plant-available N while growing in association with a host plant. Symbiotic *Rhizobium* bacteria fix N_2 in nodules present on the roots of legumes. Through this relationship, the bacteria make N_2 from the atmosphere available to the legume as it is excreted from the nodules into the soil.

Nonsymbiotic Nitrogen Fixation

This is a N_2-fixation process that is performed by free-living bacteria and blue-green algae in the soil. The amount of N_2 fixed by these organisms is much lower than that fixed by symbiotic N_2 fixation.

Nonbiological N-fixation processes include:

Atmospheric additions

Small amounts of N in the order of 5 to15 pounds per acre per year can be added to the soil in the form of rain or snowfall. This includes N that has been fixed by the electrical discharge of lightning in the atmosphere and industrial pollution.

Industrial Nitrogen Fixation

The industrial fixation of nitrogen is the most important source of N as a plant nutrient. The production of N by industrial processes is based on the Haber-Bosch process where H_2 and N_2 gases react to form ammonia (NH_3). Hydrogen gas for this process is obtained from natural gas and N_2 comes directly from the atmosphere. The NH_3 produced can be used directly as a fertilizer or as the raw material for other N fertilizer products, including ammonium phosphates, urea, and ammonium nitrate.

Forms of Soil Nitrogen

Soil N occurs in both inorganic and organic forms. Most of the total N in surface soils is present as organic nitrogen. Organic soil N occurs in the form of amino acids, amino sugars, and other complex nitrogen compounds. Inorganic forms of soil nitrogen include ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), nitrous oxide (N_2O_{gas}), nitric oxide (NO_{gas}), and elemental nitrogen ($N_{2\ gas}$). Ammonium, nitrite, and nitrate are the most important plant nutrient forms of N and usually make up 2 to 5 percent of total soil N.

Nitrogen "mineralization" (figure 4.4) is the conversion of organic nitrogen to NH_4^+. This is an important process in the N cycle because it results in the liberation of plant-available, inorganic nitrogen forms.

Nitrogen "immobilization" is the conversion of inorganic, plant-available nitrogen (NH_4^+ or NO_3^-) by soil microorganisms to organic N forms (amino acids and proteins). This conversion is the reverse of mineralization, and these immobilized forms of N are not readily available for plant uptake.

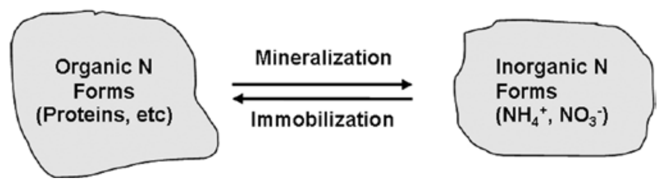

Figure 4.4. Mineralization and immobilization of soil nitrogen.
Graphic by Greg Mullins.

Carbon-to-Nitrogen Ratios

Mineralization and immobilization are ongoing processes in the soil and are generally in balance with one another. This balance can be disrupted by the incorporation of organic materials that have high carbon to nitrogen ratios (C:N). The ratio of %C to %N, or the C:N ratio, defines the relative quantities of these elements in residues and living tissues. Whether N is mineralized or immobilized depends on the C:N ratio of the organic material being decomposed by soil microorganisms.

- Wide C:N ratios of more than 30-to-1: Immobilization of soil N will be favored. Materials with wide C:N ratios include bark mulch, straw, pine needles, dry leaves, and sawdust.
- C:N ratios of 20-to-1 to 30-to-1: Immobilization and mineralization will be nearly equal.
- Narrow C:N ratios of less than 20-to-1: Favor rapid mineralization of N. Materials with narrow C:N ratios include manure and biosolids.

The decomposition of an organic material with a high C:N ratio is illustrated in figure 4.5. Shortly after incorporation, high C:N ratio materials are attacked and used as an energy source by soil microorganisms. As these

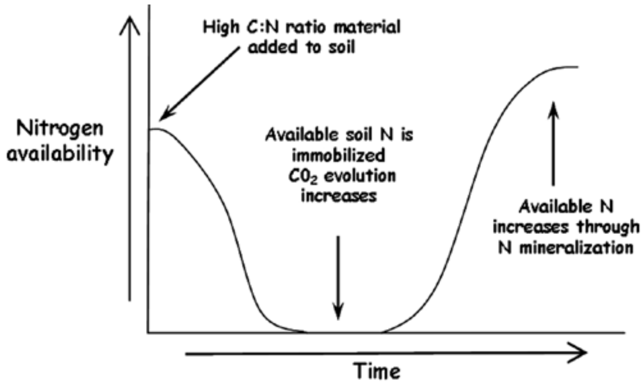

Figure 4.5. Nitrogen immobilization and mineralization after material with a high C:N ratio is added to soil. *Graphic by Kathryn Haering.*

organisms decompose the material, there is competition for the limited supply of available N because the material does not provide adequate N to form proteins in the organisms.

During this process, available soil N is decreased and the carbon in the decomposing material is liberated as CO_2 gas. As decomposition proceeds, the material's C:N ratio narrows and the energy supply is nearly exhausted. At this point, some of the microbial populations will die and the mineralization of N in these decaying organisms will result in the liberation of plant-available N. The timing of this process will depend on such factors as soil temperature, soil moisture, soil chemical properties, fertility status, and the amount of organic material added.

Nitrification

"Nitrification" is the biological oxidation of ammonium (NH_4^+) to nitrate (NO_3^-) in the soil. Sources of NH_4^+ for this process include both commercial fertilizers and the mineralization of organic residues. Nitrification is a two-step process where NH_4^+ is converted first to NO_2^-, and then to NO_3^- by two autotrophic bacteria in the soil (*Nitrosomonas* and *Nitrobacter*). These bacteria get their energy from the oxidation of nitrogen and their carbon from CO_2.

Nitrification is important to N fertility because nitrate-nitrogen (NO_3-N) is readily available for uptake and use by plants and microbes. However, NO_3^- is an "anion," or negatively charged ion. Anions usually leach more readily than cations because they are not attracted to the predominantly negative charge of soil colloids. Because of its negative charge and relatively large ionic radius, nitrate is not readily retained in the soil and is easily leached to groundwater and surface waters. Nitrate losses can be minimized through proper N management, including the proper rate and timing of N fertilizer applications.

Nitrate-N can be also be lost through denitrification, the process where NO_3^- is reduced to gaseous nitrous oxide (N_2O) or elemental nitrogen (N_2) and lost to the atmosphere. During nitrification, 2 H^+ ions are produced for every NH_4^+ ion that is oxidized. These H^+ cations will accumulate and significantly reduce soil pH; thus, any ammonium-containing fertilizer will ultimately decrease soil pH due to nitrification.

Phosphorus

The Phosphorus Cycle

Soil P originates primarily from the weathering of soil minerals, such as apatite, and from P additions in the form of fertilizers, plant residues, manure, or biosolids (figure 4.6). Orthophosphate ions (HPO_4^{-2} and $H_2PO_4^-$) are produced when apatite breaks down, organic residues are decomposed, or fertilizer P sources dissolve. These forms of P are taken up by plant roots and are present in very low concentrations in the soil solution.

Many soils contain large amounts of P, but most of that P is unavailable to plants. The types of P-bearing minerals that form in soil are highly dependent on soil pH. Soluble P, regardless of the source, reacts very strongly with Fe and Al to form insoluble Fe and Al phosphates in acid soils and with Ca to form insoluble Ca phosphates in alkaline soils. Phosphorus in these insoluble forms is not readily available for plant growth and is said to be "fixed."

Phosphorus Availability and Mobility

As discussed earlier, plant roots take up P in the forms of orthophosphates: HPO_4^{-2} and $H_2PO_4^-$. The predominant ionic form of P present in the soil solution is pH-dependent. In soils with pH values greater than 7.2, the HPO_4^{-2} form is predominant, while in soils with a pH between 5.0 and 7.2, the $H_2PO_4^-$ form predominates.

Phosphorus has limited mobility in most soils because it reacts strongly with many elements and compounds and the surfaces of clay minerals. Unlike nitrate, P anions (HPO_4^{2-}, $H_2PO_4^-$) do not easily leach through the soil profile because of their specific complexing reactions with soil components. The release of soil P to plant roots and its potential movement to surface water is controlled by several chemical and biological processes (figure 4.6). Phosphorus is released to the soil solution as P-bearing minerals dissolve, as P bound to the surface of soil minerals is uncoupled or "desorbed," and as soil organic matter decomposes or mineralizes (figure 4.7).

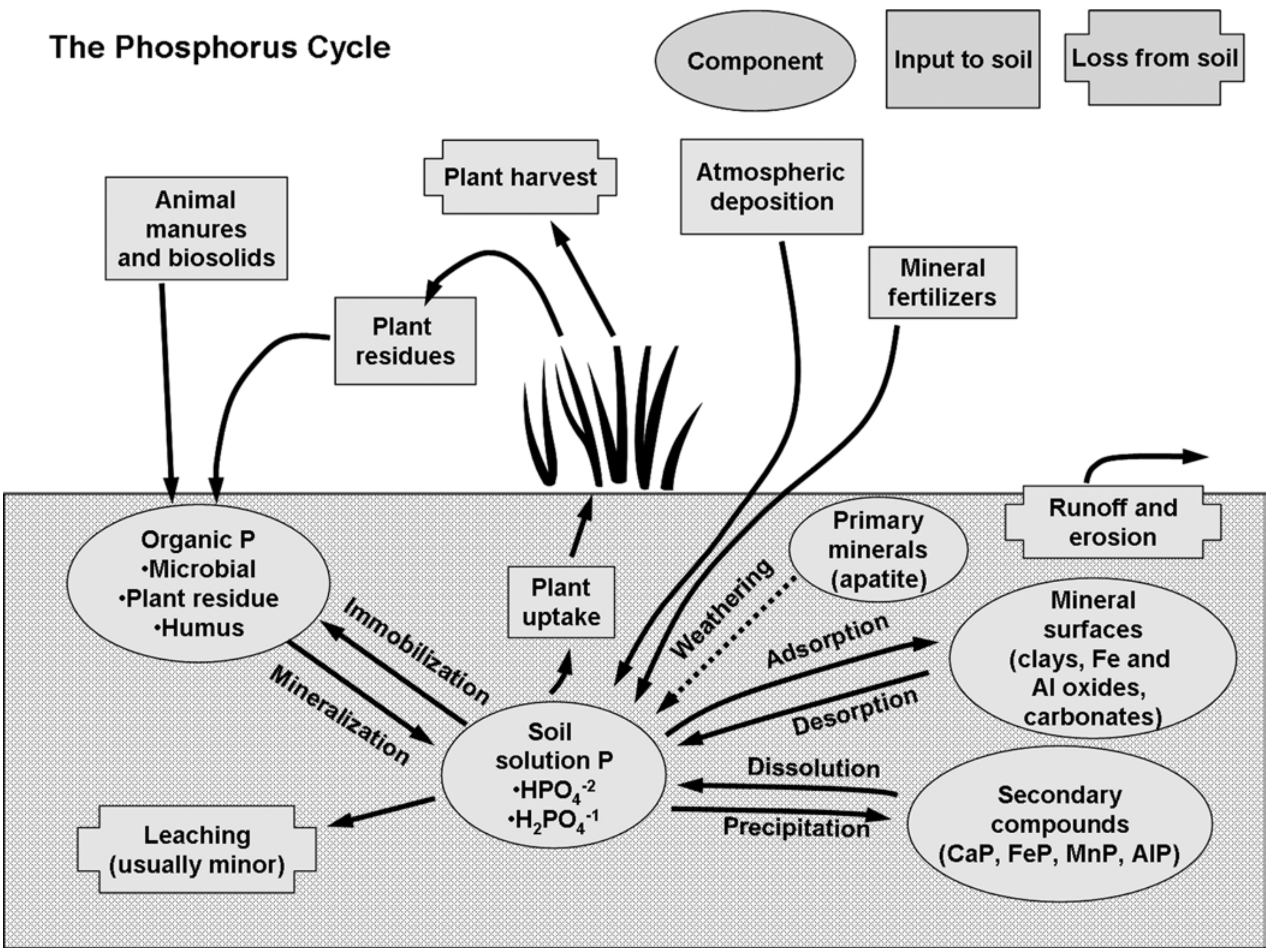

Figure 4.6. The phosphorus cycle (modified from the Potash & Phosphate Institute website at *www.ppi-ppic.org*).

Most of the P added as fertilizer and organic sources is rapidly bound by soil minerals in chemical forms that are not subject to rapid release; thus, soil solution P concentrations are typically very low (less than 0.01 to 1.00 ppm). The supply of adequate P to a plant will depend on the soil's ability to replenish soil solution P throughout the growing season (figure 4.7).

Phosphorus availability and mobility is influenced by several factors:

Soil pH

In acidic soils, P precipitates as relatively insoluble iron and Al phosphate minerals. In neutral and calcareous soils, P precipitates as relatively insoluble Ca phosphate minerals. As illustrated in figures 4.1 and 4.8, soil P is most available in the pH range of 5.5 to 6.8, where the availability of soluble Al and Fe is low.

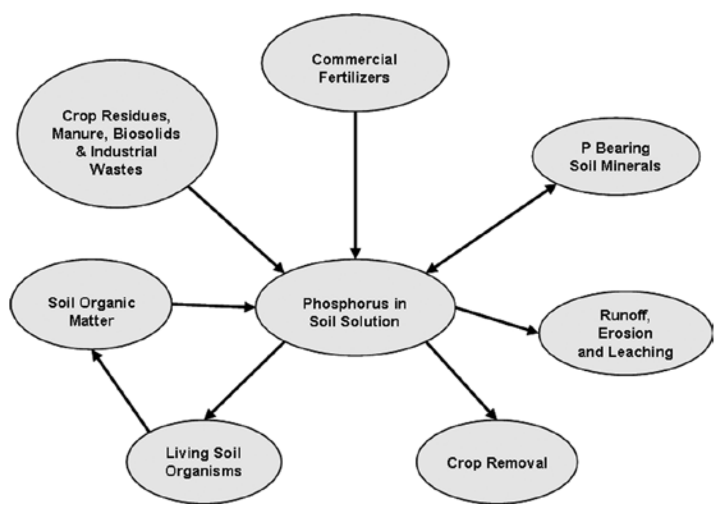

Figure 4.7. Phosphorus content of the soil solution.
Graphic by Greg Mullins.

Movement of Soil Phosphorus to Plant Roots

Phosphorus moves from soil solids to plant roots through the process of "diffusion." Diffusion is a slow and short-range process with distances as small as 0.25 inch. This limited movement has important implications because soil P located more than 0.25 inch from a plant root will never reach the root surface. Dry soils reduce the diffusion of P to roots; therefore, plants take up P best in moist soils.

Residual Fertilizer Phosphorus Recovery

A plant uses only 10 to 30 percent of the P fertilizer applied during the first year following application. The rest goes into reserve and can be used by plants in later years.

Timing and Placement of Phosphorus Fertilizer

New plants need a highly available P source in order to establish a vigorous root system early in the season. Once the root system begins to explore the entire soil volume, there should be adequate amounts of residual P to maintain plant growth.

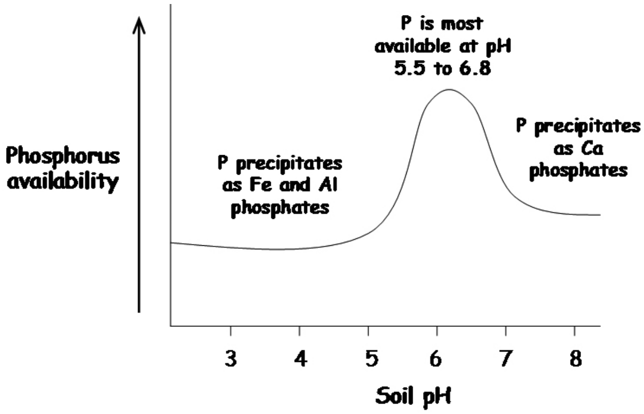

Figure 4.8. Effect of pH on phosphorus availability to plants.
Graphic by Kathryn Haering.

Phosphorus Transport to Surface Waters

Transport of soil P occurs primarily via surface flow (runoff and erosion), although leaching and subsurface lateral flow may also be possible in soils with high degrees of P saturation and artificial drainage systems. Water flowing across the soil surface may dissolve and transport soluble P, and erode and transport particulate P. Virtually all soluble P transported by surface runoff is biologically available, but particulate phosphorus that enters streams and other surface waters must undergo solubilization before becoming available for aquatic plants. Thus, both soluble and sediment-bound P are potential pollutants of surface waters and both can contribute to excessive growth of aquatic organisms, which can have detrimental environmental impacts.

Soils have a finite capacity to bind P. When a soil becomes saturated with P, desorption of soluble phosphorus can be accelerated, with a consequent increase in dissolved inorganic P in runoff. Thus, if the level of residual soil phosphorus is allowed to build up by repeated applications of phosphorus in excess of plant needs, a soil can become saturated with P and the potential for soluble phosphorus losses in surface runoff will increase significantly.

Research conducted in the mid-Atlantic shows that the potential loss of soluble P will increase with increasing levels of soil test P. Very high levels of soil-test P can result from over-application of manure, biosolids, or commercial phosphate fertilizer. Soils with these high soil-test P levels will require several years without P additions to effectively reduce these high P levels.

Potassium

The Potassium Cycle

Potassium is the third primary plant nutrient and is absorbed by plants in larger amounts than any other nutrient except nitrogen. Plants take up K as the monovalent cation K^+. Potassium is present in relatively large quantities in most soils, but only a small percentage of the total soil K is readily available for plant uptake.

The K cycle is illustrated in figure 4.9. In the soil, weathering releases K from a number of common minerals, including feldspars and micas. The released K^+ can be taken up easily by plant roots, adsorbed by the cation exchange complex of clay and organic matter, or "fixed" in the internal structure of certain two-to-one clay minerals. Potassium that is fixed by these clay minerals is very slowly available to the plant.

Potassium Availability and Mobility

Although mineral K accounts for 90 to 98 percent of the total soil K, readily and slowly available K represent only 1 to 10 percent of the total soil K. Plant-available K (K that can be readily absorbed by plant roots) includes the portion of the soil K that is soluble in the soil solution and the exchangeable K held on the soil's exchange complex. Exchangeable K is that portion of soil K that is in equilibrium with K in the soil solution. Potassium is continuously made available for plant uptake through

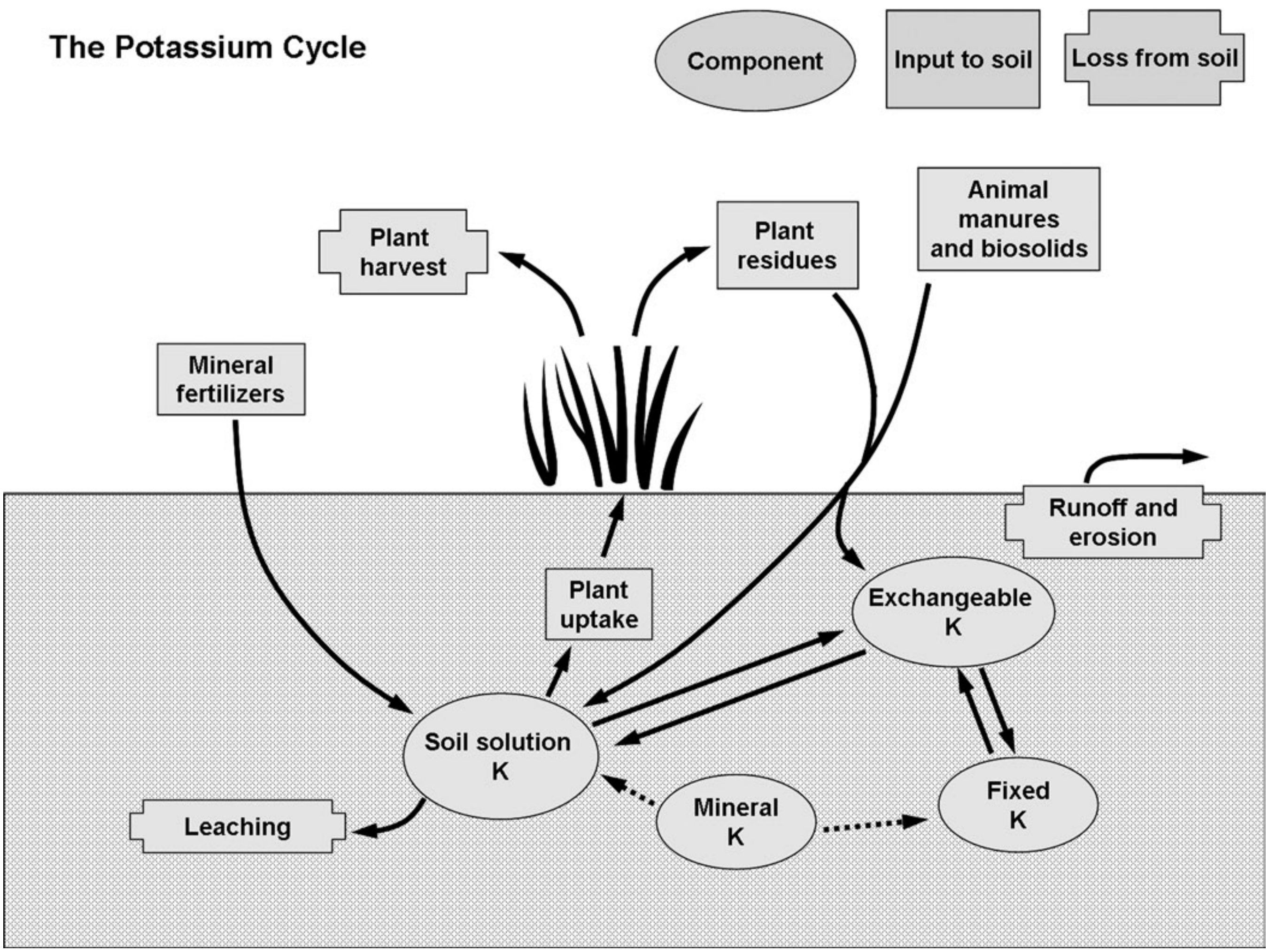

Figure 4.9. The potassium cycle (modified from the Potash & Phosphate Institute website at *www.ppi-ppic.org*).

the cation exchange process. There can be a continuous, but slow, transfer of K from soil minerals to exchangeable and slowly available forms as K is removed from the soil solution by plant uptake and leaching.

Potassium applied as fertilizer can have various fates in the soil.

- Potassium cations can be attracted to the cation-exchange complex where it is held in an exchangeable form and readily available for plant uptake.
- Some of the K+ ions will remain in the soil solution.
- Exchangeable and soluble K may be absorbed by plants.
- In some soils, some K may be fixed by the clay fraction.
- Applied K may leach from sandy soils during periods of heavy rainfall.

Potassium moves more readily in soil than phosphorus does, but less readily than nitrogen. Because potassium is held by cation exchange, it is less mobile in fine-textured soils and most readily leached from sandy soils. Most plant uptake of soil K occurs by diffusion.

Potassium fertilizers are completely water-soluble and have a high salt index, so they can decrease seed germination and plant survival when placed too close to seed or transplants. The risk of fertilizer injury is most severe on sandy soils, under dry conditions, and with high rates of fertilization. A convenient and usually effective method of applying K fertilizers is by broadcasting and mixing with the soil before planting. Fertilizer injury is minimized by this method, but on sandy soils, leaching may cause the loss of some K.

Secondary Plant Nutrients

Introduction

Secondary macronutrients Ca, Mg, and S are required in relatively large amounts for good crop growth. These nutrients are usually applied as soil amendments or applied along with materials that contain primary nutrients. Secondary nutrients are as important to plant nutrition as major nutrients, because deficiencies of secondary nutrients can depress plant growth as much as major plant nutrient deficiencies.

Calcium and Magnesium

Calcium and magnesium have similar chemical properties and behave very similarly in the soil. Both of these elements are cations (Ca^{2+}, Mg^{2+}), and both cations have the same amount of positive charge and a similar ionic radius. The mobility of both Ca and Mg is relatively low, especially compared to anions or to other cations such as Na and K; thus, losses of these cations via leaching are relatively low.

Total Ca content of soils can range from 0.1 percent in highly weathered tropical soils to 30 percent in calcareous soils. Calcium is part of the structure of several minerals and most soil calcium comes from the weathering of common minerals, which include dolomite, calcite, apatite, and calcium-feldspars. Calcium is present in the soil solution and because it is a divalent cation, its behavior is governed by cation exchange, as are the other cations. Exchangeable Ca is held on the negatively charged surfaces of clay and organic matter. Calcium is the dominant cation on the cation exchange complex in soils with moderate pH levels. Normally, it occupies 70 to 90 percent of cation exchange sites above pH 6.0.

Total soil Mg content can range from 0.1 percent in coarse, humid-region soils to 4 percent in soils formed from high-magnesium minerals. Magnesium occurs naturally in soils from the weathering of rocks with Mg-containing minerals such as biotite, hornblende, dolomite, and chlorite. Magnesium is found in the soil solution and because it is a divalent cation (Mg^{2+}), its behavior is governed by cation exchange. Magnesium is held less tightly than calcium by cation exchange sites, so it is more easily leached and soils usually contain less Mg than calcium. In the mid-Atlantic region, Mg deficiencies occur most often on acidic and coarse-textured soils.

Sulfur

Soil sulfur is present in both inorganic and organic forms. Most of the sulfur in soils comes from the weathering of sulfate minerals such as gypsum; however, approximately 90 percent of the total sulfur in the surface layers of noncalcareous soils is immobilized in organic matter. Inorganic sulfur is usually present in the sulfate (SO_4^{2-}) form, which is the form of S absorbed by plant roots.

Both soluble SO_4^{2-} in the soil solution and adsorbed SO_4^{2-} represent readily plant-available S. Elemental sulfur is a good source of S, but it must first undergo biological oxidation to SO_4^{2-}, driven by *Thiobacillus thiooxidans* bacteria, before plants can assimilate it. This oxidation can contribute to soil acidity by producing sulfuric acid.

Several fertilizer materials contain the SO_4^{2-} form of sulfur, including gypsum ($CaSO_4$), potassium sulfate (K_2SO_4), magnesium sulfate ($MgSO_4$), and potassium magnesium sulfate (K-Mag or Sul-Po-Mag). These fertilizer sources are neutral salts and will have little or no effect on soil pH.

In contrast, there are other SO_4^{2-}-containing compounds, including ammonium sulfate ($(NH_4)_2SO_4$), aluminum sulfate ($(Al_2SO_4)_3$), and iron sulfate ($FeSO_4$), that contribute greatly to soil acidity. The SO_4^{2-} in these materials is not the source of acidity. Ammonium sulfate has a strong acidic reaction primarily because of the nitrification of NH_4^+, and aluminum and iron sulfates are very acidic due to the hydrolysis of Al^{3+} and Fe^{3+}.

Sulfate, a divalent anion (SO_4^{2-}) is not strongly adsorbed and can be readily leached from most soils. In highly weathered, naturally acidic soils, SO_4^{2-} often accumulates in subsurface soil horizons, where positively charged colloids attract the negatively charged SO_4^{2-} ion. Residual soil SO_4^{2-} resulting from long-term applications of S-containing fertilizers can meet the S requirements of plants for years after applications have ceased.

Micronutrients

Introduction

Eight of the essential elements for plant growth are called micronutrients or trace elements: B, Cl, Cu, Fe, Mn, Mo, Ni, Zn. Cobalt has not been proven to be essential for higher plant growth, but nodulating bacteria need cobalt for fixing atmospheric nitrogen in legumes. Although micronutrients are not needed in large quantities, they are as important to plant nutrition and development as the primary and secondary nutrients. A deficiency of any one of the micronutrients in the soil can limit plant growth, even when all other essential nutrients are present in adequate amounts.

Micronutrients can exist in several different forms in soil: within structures of primary and secondary minerals, adsorbed to mineral and organic matter surfaces, incorporated in organic matter and microorganisms, and in the soil solution. Many micronutrients combine with organic molecules in the soil to form complex molecules called chelates, which are metal atoms surrounded by a large organic molecule. Plant roots absorb soluble forms of micronutrients from the soil solution.

A micronutrient deficiency, if suspected, can be identified through soil tests or plant analysis. Total soil content of a micronutrient does not indicate the amount available for plant growth during a single growing season, although it does indicate relative abundance and potential supplying power. Micronutrient availability decreases as soil pH increases for all micronutrients except Mo and Cl.

Specific soil-plant relationships for B, Cu, Fe, Mn, Mo, and Zn are discussed in the next sections.

Boron

Boron exists in minerals, adsorbed on the surfaces of clay and oxides, combined in soil organic matter, and in the soil solution. Organic matter is the most important potentially plant-available soil source of B.

Factors that affect the availability of B to plants include:

Soil Moisture and Weather

Boron deficiency is often associated with dry or cold weather, which slows organic matter decomposition. Symptoms may disappear as soon as the surface soil receives rainfall or soil temperatures increase and root growth continues, but yield potential is often reduced.

Soil pH

Plant availability of B is maximized between pH 5.0 and 7.0. Boron availability decreases with increasing soil pH, which means that B uptake is reduced at high pH.

Soil Texture

Coarse-textured (sandy) soils, which are composed largely of quartz, are typically low in minerals that contain boron. Plants growing on such soils commonly show boron deficiencies. Boron is mobile in the soil and is subject to leaching. Leaching is of greater concern on sandy soils and in areas of high rainfall.

Recommended rates of B fertilization depend on such factors as soil-test levels, plant-tissue concentrations, plant species, weather conditions, soil organic matter, and the method of application.

Copper

In mineral soils, Cu concentrations in the soil solution are controlled primarily by soil pH and the amount of Cu adsorbed on clay and soil organic matter. A majority of the soluble Cu_2^+ in surface soils is complexed with organic matter, and Cu is more strongly bound to soil organic matter than any of the other micronutrients. Sandy soils with low organic matter content may become deficient in Cu because of leaching losses. Heavy, clay-type soils are least likely to be Cu-deficient. The concentrations of Fe, Mn, and Al in soil affect the availability of Cu for plant growth, regardless of soil type.

Like most other micronutrients, large quantities of Cu can be toxic to plants. Excessive amounts of Cu depress Fe activity and may cause Fe deficiency symptoms to appear in plants. Such toxicities are not common.

Iron

Iron is the fourth-most abundant element, but the solubility of Fe is very low and highly pH-dependent. Iron solubility decreases with increasing soil pH. It can react with organic compounds to form chelates or iron-organic complexes.

Iron deficiency may be caused by an imbalance with other metals, such as Mo, Cu, or Mn. Other factors that may trigger iron deficiency include excessive phosphorus in the soil; a combination of high-pH, high-lime, wet, cold soils and high bicarbonate levels; and low soil organic matter levels.

Reducing soil pH in a narrow band in the root zone can correct iron deficiencies. Several S products will lower soil pH and convert insoluble soil iron to a form the plant can use.

Manganese

Availability of Mn to plants is determined by the equilibrium among solution, exchangeable, organic, and mineral forms of soil Mn. Chemical reactions affecting Mn solubility include oxidation reduction and complexation with soil organic matter. “Redox” or oxidation-reduction reactions depend on soil moisture, aeration, and microbial activity.

Manganese solubility decreases with increasing soil pH, so Mn deficiencies occur most often on high organic-matter soils and on those soils with neutral-to-alkaline pH that are naturally low in Mn. Manganese deficiencies may also result from an antagonism with other nutrients, such as Ca, magnesium, and Fe. Soil moisture also affects Mn availability. Excess moisture in organic soils favors Mn availability because reducing conditions convert Mn4+ to Mn2+, which is plant-available.

Manganese deficiency is often observed on sandy Coastal Plain soils under dry conditions that have previously been wet.

Molybdenum

Molybdenum is found in soil minerals as exchangeable Mo on the surfaces of iron/aluminum oxides and bound soil organic matter. Adsorbed and soluble Mo is an anion (MoO_4^-).

Molybdenum becomes more available as soil pH increases, so deficiencies are more likely to occur on acidic soils. Since Mo becomes more available with increasing pH, liming will correct a deficiency if the soil contains enough of the nutrient. Sandy soils are deficient in Mo more often than finer-textured soils are, and soils high in Fe/Al oxides tend to be low in available Mo because Mo is strongly adsorbed to the surfaces of Fe/Al oxides. Heavy P applications increase Mo uptake by plants, while heavy S applications decrease Mo uptake.

Zinc

The various forms of soil Zn include soil minerals, organic matter, adsorbed Zn on the surfaces of organic matter and clay, and dissolved Zn in the soil solution. Zinc released from soil minerals during weathering can be adsorbed onto the Cation Exchange Complex, incorporated into soil organic matter, or react with organic compounds to form soluble complexes. Organically complexed, or chelated, Zn is important for the movement of Zn to plant roots. Soils can contain from a few to several hundred pounds of Zn per acre. Fine-textured soils usually contain more Zn than sandy soils do.

Total Zn content of a soil does not indicate how much Zn is available. The following factors determine its availability:

- Zinc becomes less available as soil pH increases. Coarse-textured soils limed above a pH of 6.0 are particularly prone to develop Zn deficiency. Soluble Zn concentrations in the soil can decrease three-fold for every pH unit increase between 5.0 and 7.0.
- Zinc deficiency may occur in some plant species on soils with very high P availability and marginal Zn concentrations due to Zn/P antagonisms. Soil pH further complicates Zn/P interactions.
- Zinc forms stable complexes with soil organic matter. A significant portion of soil Zn may be fixed in the organic fraction of high organic-matter soils. It may also be temporarily immobilized in the bodies of soil microorganisms, especially when animal manures are added to the soil.
- At the opposite extreme, much of a mineral soil's available Zn is associated with organic matter. Low organic-matter levels in mineral soils are frequently indicative of low Zn availability.

Zinc availability is affected by the presence of certain soil fungi, called mycorrhizae, which form symbiotic relationships with plant roots. Removal of surface soil in land leveling may remove the beneficial fungi and limit plants' ability to absorb Zn.

Acknowledgement

This chapter is dedicated to the memory of Greg Mullins (1955-2009).

Chapter 5. Soil Sampling and Nutrient Testing

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Introduction

Soil testing is a fundamental management practice for turfgrass and the ornamental landscape. A soil analysis provides essential information on relative levels of organic matter, pH, lime requirement, cation exchange capacity (CEC), and levels of plant-available nutrients (nitrogen, phosphorus, potassium, and specific micronutrients) contained in the soil.

The goals of soil testing are to determine existing nutrient levels, predict additional lime and nutrient needs, and evaluate potential excesses or imbalances within a given soil. A soil test report usually includes suggested lime and fertilizer treatments for turf and landscape areas being maintained. Note that soil tests do not measure nitrogen (N), because it is a highly mobile nutrient. Suggested nitrogen rates are general recommendations based on years of research on the nitrogen needs of the turf species or ornamental plant present.

While soil testing has been around for nearly 50 years, soil test results and recommendations may vary from lab to lab. To understand this, you need to understand how labs use chemical extraction procedures to predict nutrient needs and the amounts required to avoid deficiencies. The chemical extraction must be calibrated, that is, tested and proven under actual growing conditions using replicated nutrient response field trials with the plant species of interest. These trials should be conducted under a wide range of soils, water regimes, and climatic conditions. The calibration process is an essential component relating laboratory results to field performance; thus, the quality of the calibration data determines the accuracy of the resulting recommendations.

Soil testing laboratories may also vary in the chemical methods they use to assess soil nutrient levels and the manner in which they report data. Many mid-Atlantic states use the Mehlich-1 extractant, while other laboratories use the newer Mehlich-3. Some states have not adopted the Mehlich-3 extractant because new calibration data are required to relate soil test levels to field performance. Some labs report their results in parts per million, some in pounds per acre, and others as a predictive index. Regardless, most laboratories report a rating indicating the relative status for each nutrient (figure 5.1).

Very low: A plant response is most likely if the indicated nutrient is applied. A large portion of the nutrient requirement must come from fertilization.

Low: A plant response is likely if the indicated nutrient is applied. A portion of the nutrient requirement must come from fertilization.

Medium: A plant response may or may not occur if the indicated nutrient is applied. A small portion of the nutrient requirement must come from fertilization.

High: Plant response is not expected. No additional fertilizer is needed.

Very high: Plant response is not expected. The soil can supply much more than the turf requires. Additional fertilizer should not be added to avoid nutritional problems and adverse environmental consequences.

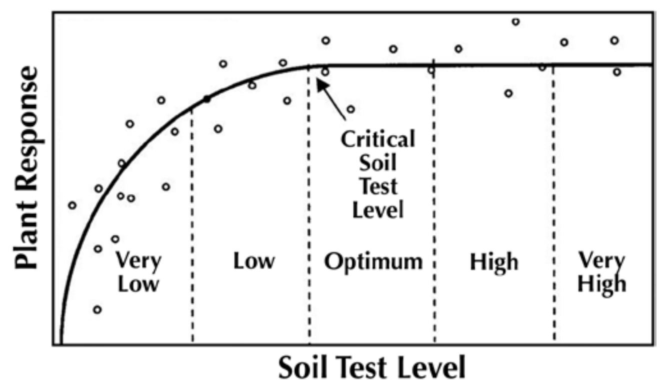

Figure 5.1. A typical plant response curve as influenced by varying levels of soil nutrients.

Soil Test Interpretation and Recommendations

Soil test results must be related to the expected level of plant response and the appropriate rate of fertilizers required to eliminate nutrient deficiency. Soil testing labs may disagree with the manner in which results are interpreted and recommendations are made.

Sufficiency Level Approach

Most land-grant universities base their recommendations on the "sufficiency level" concept. Basically, this extensively tested approach says "fertilize the crop, not the soil" by ceasing to recommend nutrient additions when test levels exceed proven responsive levels. It is also the most conservative approach, and as such, it has been attacked at times as being too conservative. This philosophy is difficult for the home landscape because no yield is taken. However, this philosophy has the greatest potential for producing the most favorable results and is in harmony with the concepts of nutrient management planning. In areas of the mid-Atlantic with highly weathered, low CEC soils, this philosophy minimizes losses of potassium (K), magnesium (Mg), and the more mobile nutrients via leaching.

Buildup and Maintenance Approach

The "buildup and maintenance" approach recommends that soil test levels be built to the "high" or nonresponsive level. Soil levels are then maintained by annual replacement of nutrients to be removed as clippings or sod, regardless of soil test level. This method assumes that all soils can hold high levels of nutrients, which is not the case for soils having relatively low CEC (less than 10).

Cation Saturation Ratio Approach

The final approach, the "cation saturation ratio" method, focuses on the ratio of nutrients on the soil exchange sites. Most often, these labs suggest that 5 percent of the CEC be occupied by potassium, 10 to 20 percent by magnesium, and 70 to 85 percent by calcium (Ca). Again, this approach assumes that the soil has sufficient exchange capacity to support these ratios and stay above sufficiency level. For low CEC soils, this approach can result in nutrient additions for the sake of adjusting the soil ratio that are unnecessary for high-quality turf production and could result in inadequate levels of potassium for some soils.

Keep in mind that regardless of the approach to fertilization, in a few cases, soil-testing may not accurately predict a response or lack of response in any given situation. Because recommendations are based on many years of data, they may not predict needs in a specific situation because of unique climatic or soil conditions, management practices, or pest pressure.

Regardless of the lab used, familiarize yourself with the reporting system and be especially sure the lab has calibrated their recommendations for the plant material being grown. Unverified recommendations or recommendations based on forages or row crops may prove inadequate for intensively managed turfgrass and other landscape plants.

The following sections will describe proper soil sampling and interpretation of soil test reports.

Soil Sampling

General Sampling Considerations

Soil sampling should be done every one to five years, depending on the soil type and management. Completely modified, sand-based soils used on golf greens, tees, and athletic fields should likely be tested on an annual basis. For naturally occurring, coarse-textured (i.e., sandy) soils, a typical sampling frequency is every two to three years. On fine-textured (i.e., loamy or clayey) soil, sampling likely does not need to be done more than every four to five years. If clippings are removed, sample more frequently according to the soil type.

When submitting soils for analysis, it is common to request recommendations for specific plants, i.e., turf or ornamentals. As nutrient requirements vary by plant type, separate soil samples should be submitted for each recommendation that is required — even if the soil looks the same and is in a similar location.

For fine-turf maintenance, divide the property into logical areas. For example, it is logical to divide a single hole on a golf course into green, tee(s), fairway, and rough categories and to conduct a test on each of these areas as a unique entity.

The turf of a football or baseball field should be divided into two to four areas for separate sampling. It is important to remember that the quality of the test report is only as good as the sample submitted; simply testing a single sample that was gathered from a large area does not provide sufficiently detailed information regarding that soil.

Soil samples can be taken at any time of the year but, in general, it is recommended to take samples in advance of planting or the time of regular fertilization. Fall sampling is most common, as this allows time to get results and apply lime and nutrients in advance of spring growth. Limestone takes months to fully react with soil, so liming should be done well in advance of spring growth, while nutrients are more reactive and should be applied closer to the time of plant growth. Soil sampling should not be done for at least two months after fertilization or liming.

Undisturbed areas need to be sampled separately from disturbed areas. Because soils vary with their location in the landscape, they should at the very least be separated into upland, side slopes, and lowland or bottomland positions. Disturbed soil areas should be separated into smaller units based on amount of disturbance, soil removal, or soil addition. These soil variations are often visible as different soil colors or as differences in soil texture (sand versus clay).

The upper diagram in figure 5.2 shows how landscape position affects soil properties; the lower diagram shows how soil color can vary. Each soil type, colored differently in these figures, should ideally be sampled separately. Soil samples should accurately represent the area being sampled.

The best way to collect a soil sample is with a soil probe, which is fast and easy and collects an even amount of soil down to the depth sampled. Soil probes can be purchased from many locations, such as garden centers or online, but it is acceptable to sample using a shovel or trowel if you are not going to soil-test frequently. Soil sample containers and information sheets are available from laboratories that analyze the samples.

Once you select uniform areas to sample, the next step is to collect a representative sample from the correct depth. The depth of sampling depends on the land use: It should be 2 to 4 inches for established turf, 6 to 8 inches for vegetable and flower beds, and 6 inches for trees and shrubs, excluding any mulch (Hunnings and Donohue 2009). For any land that is going to be tilled, such as vegetable gardens or during turf establishment, take the sample to the depth you intend to till.

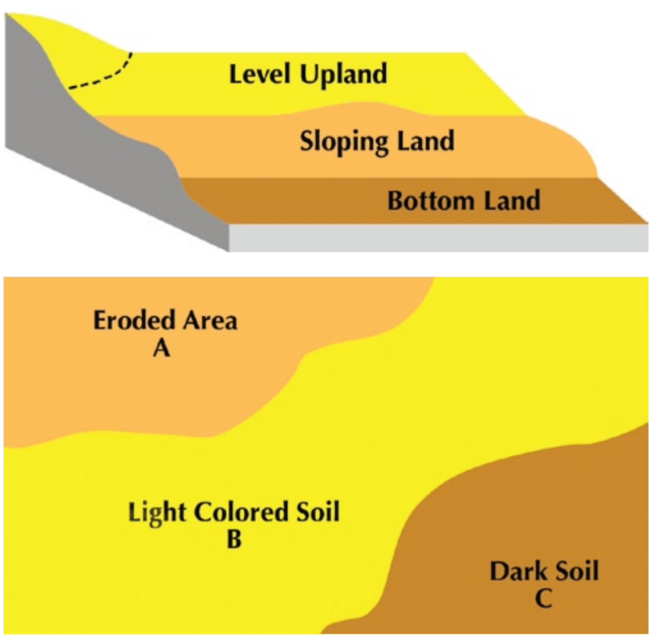

Figure 5.2. *Upper*: Changes in soils by landscape position. *Lower*: How soil type and soil color can change spatially.

Figure 5.3. Example of a soil probe, mixing bucket, and soil box filled with soil.

A representative soil sample consists of a well-mixed composite of many subsamples. A soil sample from a single spot, instead of the representative sample described here, could result in inaccurate nutrient and lime recommendations. Collect at least 10 subsamples from the uniform area you have identified and mix them together in a clean plastic bucket. It is important the bucket is clean because small amounts of nutrients or lime in the bucket could contaminate your sample.

Push the soil probe into the soil to the desired depth and remove any surface plant material such as turf thatch before placing it in the bucket. Collect the subsamples from random spots within the sample area by following a zigzag pattern as you walk across the landscape (figure 5.4). When you have collected the necessary number of subsamples in your bucket, break up any aggregates or clumps and mix thoroughly. It is this thoroughly mixed composite of your subsamples that you will submit for testing.

There are several private and public soil testing laboratories and each has its own system for submitting samples. Virginia Cooperative Extension also has offices

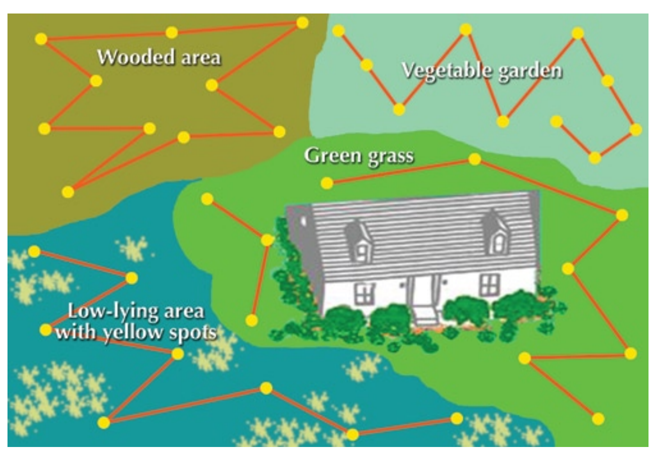

Figure 5.4. Example of soil sampling locations for a homeowner. Yellow dots indicate individual sampling points, and lines collecting dots indicate samples that are pooled and mixed.

located throughout the state where you can pick up soil testing boxes appropriate for submitting soil samples to the Virginia Tech Soil Testing Laboratory (*www.soiltest.vt.edu*). These soil boxes hold about a cup or 0.5 pound or more of soil, and you should try to fill them to ensure you submit sufficient soil. An acre contains about 2 million pounds of topsoil, so the importance of collecting a representative subsample cannot be overemphasized.

The sample identification should be placed on the laboratory container and placed on a corresponding map or identification sheet for the areas to be sampled. More information on the appropriate steps in sampling soils, submitting the sample, and interpreting the soil test results can be found in *Soil Testing for the Lawn and Landscape*, Virginia Cooperative Extension publication 430-540 (Goatley, Mullins, and Ervin 2005; *http://pubs.ext.vt.edu/430/430-540/430-540.html*).

Dealing With Thatch

Thatch is an accumulation of dead and living plant tissue (primarily undecomposed stems) located immediately above the soil surface. Thatch is resistant to chemical change and microbial degradation. As thickness increases, thatch may become a major area of root proliferation and significantly influence the supply of plant nutrients. Grasses that creep by rhizomes (belowground stems) and stolons (aboveground stems) are most likely to produce thatch. High nitrogen rates, in particular, favor thatch development. Because thatch is almost all organic and very lightweight, it becomes a misleading component of a normal soil sample.

In turfgrass areas where thatch thickness exceeds 0.5 inch, the thatch should be removed before taking any soil sample used to measure soil pH or other nutrients, such as phosphorus and potassium. This suggests that turfgrass areas with thick thatch covers should have two samples taken for analysis to more correctly reflect maintenance nutrient needs. Areas with a thatch thickness of 0.5 inch or less can be analyzed for nutrient needs with the thatch either mixed in as part of the sample or removed before taking the sample cores.

Remember that thatch is an indication of “imbalance” in turfgrass management; low-input turfgrasses, even those with lateral stems, do not produce appreciable thatch because the soil microbial population is able to adequately degrade the stems. Detailed information on thatch management is presented in chapter 6.

Sampling Problem Areas

When sampling problem areas, take a representative sample from the problem area and a representative sample from an area adjacent to the problem area. Both samples should be sent to a laboratory for analysis to allow for comparison and more accurate determination of the severity of the problem. Although some conclusions can be drawn from a single sample, having another sample result from soil or growing media near

Table 5.1. Sampling considerations for problem identification and verification.

Suspected problem	Probable cause	Sampling considerations
Low pH	Nitrogen fertilization.	Sample as needed to a depth of 3-4 inches.
High pH or soluble salts	Large amounts of salts or carbonates are added through long-term use of irrigation water applied to high management areas.	Periods of high rainfall will reduce the problem, so sample during dryer periods of the season to assess the maximum severity. CEC should be determined as part of any test for “salt” problems, especially on low CEC soils. Sample cores should be taken to a depth of 3-4 inches.
Nutrient deficiency	Inadequate fertilization, especially where clippings are removed; excessive irrigation; low CEC leading to leaching.	Sample more frequently on modified or very sandy soils (at least annually). Analysis may indicate a need for more-frequent application of nutrients or modification of other management factors to reduce nutrient losses. Unfortunately, few soil test correlations are available for turf grown in these modified soils. Sample cores should be taken to a depth of 3-4 inches.
Nutrient toxicity	Low pH; excessive fertilization; sludge, manures, or other biosolids application.	Soil pH is the most important factor in determining the availability of these nutrients to the turfgrasses. Most grasses are quite tolerant to trace metals, but careful monitoring is important to prevent buildup of toxic levels. Subsample cores should be taken to a depth of 3-4 inches.

the problem allows evaluation of results on like materials. See table 5.1 for probable causes of a suspected problem area.

General Crop Nutrient Deficiency Symptoms

Nitrogen (N): Restricted growth of tops and roots; growth is upright and spindly; leaves pale and yellow-green in early stages, more yellow and even orange or red in later stages; deficiency shows up first on lower leaves.

Phosphorus (P): Restricted growth of tops and roots; growth is upright and spindly; leaves bluish-green in early stages with green color sometimes darker than plants supplied with adequate phosphorus; more purple in later stages with occasional browning of leaf margins; defoliation is premature, starting at the older leaves.

Potassium (K): Browning of leaf tips; marginal scorching of leaf edges; development of brown or light-colored spots in some species that are usually more numerous near the margins; deficiency shows up first on lower foliage.

Calcium (Ca): Deficiency occurs mainly in younger leaves near the growing point; younger leaves distorted with tips hooked back and margins curled backward or forward; leaf margins may be irregular and display brown scorching or spotting.

Magnesium (Mg): Interveinal chlorosis with chlorotic areas separated by green tissue in earlier stages, giving a beaded, streaking effect; deficiency occurs first on lower foliage.

Sulfur (S): Younger foliage is pale yellowish-green, similar to nitrogen deficiency; shoot growth somewhat restricted.

Zinc (Zn): Interveinal chlorosis followed by dieback of chlorotic areas.

Manganese (Mn): Light-green to yellow leaves with distinctly green veins; in severe cases, brown spots appear on the leaves and the leaves are shed; usually begins with younger leaves.

Boron (B): Growing points severely affected; stems and leaves may show considerable distortion; upper leaves are often yellowish-red and may be scorched or curled.

Copper (Cu): Younger leaves become pale-green with some marginal chlorosis.

Iron (Fe): Interveinal chlorosis of younger leaves.

Molybdenum (Mo): Leaves become chlorotic, developing rolled or cupped margins; plants deficient in this element often become nitrogen-deficient.

Chlorine (Cl): Deficiency not observed under field conditions.

Source: Brann, Holshouser, and Mullins (2000).

Understanding Soil Test Reports

Fertilizer Recommendation

Fertilizer recommendations may be used for the same lawn or landscape situation for two to three years. When the soil tests “very high” for phosphorus or potassium, no fertilizer for these nutrients is recommended.

Lime Recommendation

If needed, a lime recommendation is given to neutralize soil acidity and should last two to three years. The measured soil test levels of calcium and magnesium are used to determine the appropriate type of limestone to apply. If neither dolomitic nor calcitic lime is mentioned, or just “ag” type or “agricultural” limestone is stated on the report, then it does not matter what type is used. When no information on the soil sample information sheet is provided regarding the last lime application, the lab assumes you have not applied lime in the past 18 months. Do not overlime! Too much lime can be as harmful as too little. For best results, apply lime, when possible, several months ahead of the crop/plant to be planted to allow time for a more complete soil reaction.

Methods and Meanings

For more detail on the lab procedures used, go to *www.soiltest.vt.edu* and click on “Laboratory Procedures.”

Soil pH (or soil reaction) measures the “active” acidity in the soil’s water (or hydrogen ion activity in the soil solution), which affects the availability of nutrients to plants. It is determined on a mixed suspension of a 1-1, volume-to-volume ratio of soil material to distilled water.

Virginia soils naturally become acidic, and limestone periodically needs to be applied to neutralize some of this acidity. A slightly acid soil is where the majority of nutrients become most-available to plants and where soil organisms that decompose organic matter and contribute to the general "overall health" of soils are the most active. When a soil is strongly acidic (< 5.0 to 5.5 pH), many herbicides lose effectiveness and plant growth is limited by aluminum toxicity. When soils are overlimed and become alkaline (> 7.0 pH), micronutrients such as manganese and zinc become much less-available to plants.

For most agronomic crops and landscaping plants, lime recommendations are provided to raise the soil pH to a slightly acid level of between 5.8 and 6.8. Blueberries and acid-loving ornamentals generally prefer a 4.5 to 5.5 pH, and an application of liming material is suggested when the soil pH drops below 5.0.

For the majority of other plants, lime may be suggested before the pH gets below 6.0; this is to keep the soil pH from dropping below the ideal range because lime is slow to react and it affects only a fraction of an inch of soil per year, when the lime is not incorporated into the soil. If the soil pH is above the plant's target pH, then no lime is recommended. If the pH is well above the ideal range, then sometimes an application of sulfur is recommended to help lower the pH faster; however, most of the time one can just let the soil pH drop on its own.

The **Buffer Index**, which provides an indication of the soil's total (active and reserve) acidity and ability to resist a change in pH, is determined by a Mehlich buffer solution. This buffer measurement is the major factor in determining the amount of lime to apply. The Buffer Index starts at 6.6 and goes lower as the soil's total acidity increases and more lime is needed to raise the soil pH. A sandy soil and a clayey soil can have the same soil pH; however, the clayey soil will have greater reserve acidity (and a lower Buffer Index) as compared to the sandy soil, and the clayey soil will require a greater quantity of lime be applied in order to raise the soil pH the same amount as the sandy soil. A reported Buffer Index of "N/A" means that it was not measured because the soil (water) pH was either neutral or alkaline and not acidic (soil pH ≥ 7.0) and therefore requires no lime.

Nutrients available for plant uptake are extracted from the soil with a Mehlich-1 solution using a 1-5, volume-to-volume, soil-to-extractant ratio and are then analyzed by Inductively Coupled Plasma-Atomic Emission Spectrometry (commonly referred to as an ICP-AES instrument). An extractable Mehlich-1 level of phosphorus from 12 to 35 pounds per acre is rated as medium or optimum. A medium level of potassium is from 76 to 175 pounds per acre. Medium levels of calcium and magnesium are 721 to 1,440 and 73 to 144 pounds per acre, respectively. Calcium and magnesium are normally added to the soil through the application of limestone. It is rare for very high fertility levels of phosphorus, potassium, calcium, and magnesium to cause a reduction in crop yield or plant growth. Levels of micronutrients, (zinc, manganese, molybdenum, copper, iron, and boron) are typically present in the soil at adequate levels for plants <u>if</u> the soil pH is in its proper range. See Soil Test Note 4 for documented micronutrient deficiencies that occur in Virginia (*www.soiltest.vt.edu/stnotes*).

Soluble salts or fertilizer salts are estimated by measuring the electrical conductivity of a 1-2, volume-to-volume ratio of soil material to distilled water. Injury to plants may start at a soluble-salts level above 844 parts per million when grown in natural soil, especially under dry conditions and to germinating seeds and seedlings. Established plants will begin to look wilted and show signs related to drought. This test is used primarily for greenhouse, nursery, and home garden soils where very high application rates of fertilizer may lead to an excessive buildup of soluble salts.

Soil organic matter (SOM) is the percentage by weight of the soil that consists of decomposed plant and animal residues and is estimated by using either the weight Loss-on-Ignition (LOI) method from 150 to 360 degrees Celsius (C) or a modified Walkley-Black method. Generally, the greater the organic matter level, the better the overall soil tilth or soil quality, because nutrient and water-holding capacities are greater, and improved aeration and soil structure enhance root growth.

The percentage of soil organic matter in a soil can affect the application rate and performance of some pesticides, but this is not usually a problem in lawn and landscape situations. Soil organic matter levels from 0.5 percent to 2.5 percent are ordinary for natural, well-drained soils. For completely modified, sand-based soils, it is typically recommended that SOM levels become no greater than 3 percent because large SOM levels can greatly reduce water infiltration and percolation rates in these soils. Due to relatively large amounts of organic materials being commonly added to gardens, the SOM in garden soils can be raised into the range of 5 percent to 10 percent.

The remaining values that are reported under the "Lab Test Results" section are calculated from the previously measured values and are of little use to most turf and landscape managers.

Estimated cation exchange capacity (Est-CEC) gives an indication of a soil's ability to hold some nutrients against leaching. Natural soils in the mid-Atlantic usually range in CEC from 1 to 12 millequivalent (meq) per 100 grams (g). A very sandy soil will normally have a CEC of 1 to 3 meq per 100 g. The CEC value will increase as the amount of clay and organic matter in the soil increases. This reported CEC is an estimate because it is calculated by adding the Mehlich-1 extractable cations (calcium plus magnesium plus potassium) and the acidity estimated from the Buffer Index and converting to units commonly used for CEC. This value can be erroneously high when the soil pH or soluble-salts level is high.

The percentage of **acidity** is a ratio of the amount of acid-generating cations (as measured by the Buffer Index) that occupy soil cation-exchange sites to the total CEC sites. The higher this percentage, the higher the amount of reserve acidity in the soil, the higher the amount of acidity there will be in the soil solution, and the lower the soil pH will be. A reported acidity percentage of "N/A" means that a Buffer Index was not determined, the acidity is probably less than 1 meq per 100 g and/or 5 percent, and the soil pH is alkaline (> 7.0).

The **base saturation percentage** is the ratio of the quantity of nonacid-generating cations (i.e., the exchangeable bases calcium, magnesium, and potassium) that occupy the cation exchange sites.

The **percentage of calcium, magnesium, or potassium saturation** refers to the relative number of CEC sites that are occupied by that particular nutrient and is a way of evaluating for any gross nutrient imbalance.

Plant Tissue Analysis

Tissue analysis has two main applications:

- To confirm a suspected nutrient element deficiency when visual symptoms are present.
- To monitor plant nutrient element status in order to determine whether each tested nutrient is in sufficient concentration for optimum performance.

Plant Analysis as a Diagnostic Tool

Whenever turfgrasses fail to meet color and quality expectations in response to nutrient applications, plant analysis is the tool used by many managers to diagnose the problem. Visual symptoms can offer helpful clues but can also be easily confused and misinterpreted, especially where micronutrients or sulfur are involved. Turf and landscape managers should confirm a suspected deficiency by plant analysis before applying a corrective treatment. Numerous cases can be given where incorrect diagnosis in the field has led to turf problems as well as costly and ineffective corrective treatments.

Nutrient Monitoring

It is important to remember that tissue-sufficiency ranges used by most labs are based on values common in turfgrasses and landscape plants with acceptable quality under a wide range of growing conditions and management levels. It is not, at this point, refined to the point that it can ensure quality for your specific growing conditions, management practices, and quality demands. Some golf course superintendents currently submit samples bimonthly or monthly — especially for creeping bentgrass grown on completely modified, sand-based putting greens. Upward or downward trends can be observed and adjustments in lime and fertilizer treatments made before deficiencies or excesses develop that would reduce quality.

Establishing your own routine monitoring program using these recommendations as a base will allow you to follow the effectiveness of your nutrient management practices while making corrective treatments before significant loss in quality occurs. In addition, by comparing plant analysis results with turf quality, nutrient applications, and soil test levels samples over time, you can refine the nutrient sufficiency ranges and nutrient management practices required to maintain turf quality for your specific site, climatic conditions, and management constraints.

Monitoring does not need to be done for every possible situation. Carefully decide the areas you may need to sample. Choose areas representative of the turf quality, use, composition, and soils to be managed. Take plant samples at regular intervals from each representative area prior to and during growth cycles. Record turf quality (clipping yields, if available), weather situation, and any known problems at the time of sampling. Track nutrient additions on each monitored site and collect routine soil samples at least once a year (prior to phosphorus and potassium fertilization) to supplement your records.

Sampling Considerations

Sample the aboveground portion of the plant, clipped just above ground level no more than two days after mowing. As a general rule, monitoring samples can be taken from turfgrass clippings. When whole plants are sampled, cut off and discard the roots and wash the shoots to remove soil particles. Under normal conditions, rainfall is frequent enough to keep leaf surfaces fairly free from dust and soil particles. If recently sprayed or if iron is of primary interest, a quick wash in a dilute (0.3 percent) detergent solution followed by a quick rinse in a strainer or colander will help remove residues and soil particles that could bias the sample.

To prevent decay during transport to the lab, reduce excess moisture by partially air-drying plant tissue samples before shipment to the laboratory. Never put fresh samples in a tightly sealed or plastic bag unless they will be kept cold during transport. Decayed samples will not be analyzed.

It is a good idea to have recent soil test results available when interpreting the results of a plant tissue analysis. If none are available, submit a soil sample along with the tissue sample.

For diagnostic samples, obtain samples as soon as symptoms appear. Plants showing severe deficiency symptoms are often the most difficult to interpret correctly because a difficult-to-detect deficiency of one element may result in deficiencies or excess accumulation of other elements if uncorrected. Plants under prolonged stress of any kind can also display unusual nutrient contents. This would include damage from heat, cold, drought, flooding, disease, insects, or mechanical treatments.

Comparative sampling can improve diagnosis accuracy. Collect both plant and soil samples from “good” and “bad” areas in close proximity to each another. Both areas should have similar soil types, species composition, and management (mowing height, irrigation, etc.). Because the recommended ranges of plant nutrient content are somewhat general, a “good” sample offers a measure of what should be expected for your site and management conditions. Differences in nutrient concentrations can then be compared with soil samples to determine if the problem is related to fertility management or is an uptake problem, such as disease, water, compaction, or root damage. For example, differences in magnesium and manganese between plants could be related to differences in soil pH.

Interpreting a Plant Analysis Result

Plant analysis indicates only what the root and internal transport system is able to deliver to the sampled tissue. Tissue analysis is excellent for determining nutrient deficiencies, but as previously discussed, the analysis does not tell you why the limitation is occurring; that is the importance of usually submitting a soil sample at the same time as a tissue sample. Levels below the sufficiency range can result from low or excessive soil test levels, inadequate or excessive fertilization, and improper pH. Even where soil fertility levels are correctly managed, biotic factors (e.g., nematodes, disease, herbicide injury, etc.) and physical conditions (e.g., compaction, flooding, drought, root injury, incorrect mowing) can limit nutrient uptake and distribution in the plant. In other cases, visual symptoms might not even be nutrient-related (for example, pesticide injury).

The effects of the time of sampling, turf species, traffic and use, and environmental factors such as soil moisture, temperature, light quality, and intensity may significantly affect the relationship between nutrient concentration and turf quality. It is important that the time of sampling, stage of growth, and character of growth prior to sampling be known and considered when interpreting a plant analysis result.

Table 5.2 offers general guidelines on interpretations of plant analysis results for turfgrasses. Other landscape plant materials would also likely fall within these ranges, but there are exceptions for particular categories of plants. Ornamental landscape plant management is covered in chapter 7. A complete discussion of fertilizer sources and programs is provided in chapter 8.

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Table 5.2. Typical nutrient sufficiency ranges, interpretations, and recommendations for the analysis of turfgrass tissues.

Element	**Sufficiency range** (% or ppm)	Interpretation and recommendation
Nitrogen (N)	2.2-4.0%	Nitrogen is the nutrient most commonly found to be low in turfgrasses, which is generally due to inadequate fertilization, heavy leaching rains, overirrigation, or possible root damage. N deficiency may be manifested with a light-green color, slow growth rate, or excessive seedhead production. If a deficiency is detected, apply N according to soil test recommendations, being sure to split applications where leaching may be a problem.
Phosphorus (P)	0.3-0.7%	Deficiency is usually due to low soil P; cool, wet growing conditions; or excessively low soil pH. If deficiency is detected, apply P and limestone based on soil test recommendations. High levels of P generally pose more problems with intensively managed turf than deficiencies do. Excessive P levels in the leaves can cause deficiencies of other nutrients, particularly iron. High P-K ratios in leaf tissue increase winterkill in bermudagrass and St. Augustinegrass. When high P is detected, omit P from the fertilization program until P is within acceptable limits. In most instances, three or more years may be required.
Potassium (K)	1.5-3.0%	Low K is generally due to low soil test K levels, inadequate K fertilization, or when grass is grown on coarse-textured, sandy soil that is subject to leaching. Low K may also be associated with low N fertilization. When soil K is adequate, N fertilization increases the uptake of K by the grass. When low K is detected in the tissue, apply potash and nitrogen based on soil test recommendations. When K drops below 1.0 percent in the tissue, deficiency symptoms appear and are characterized by spindly growth (narrow leaves, thin turf), leaf tip burn, reduced wear, cold and disease tolerance, and reduced growth rate. Excessive K levels may induce Mg deficiency. If high K levels are detected in the tissue, reduce the K fertilization rate or omit K from the program until K is within the sufficiency range.
Calcium (Ca)	0.20-1.25%	Grasses are able to take up Ca under a wide range of soil conditions and it is rarely deficient. May be drought induced. Heavy N and K fertilization will decrease Ca levels but not cause deficiencies in well-limed soils. If low levels are detected, check for low soil pH and apply limestone based on recommendations. A high Ca level may indicate some other nutrient deficiency or disorder.
Magnesium (Mg)	0.15-0.60%	Low levels may occur on sandy soils, soils with low pH and low Mg, where high rates of NH4-N and K fertilizers have been applied, and where clippings are continuously removed. If low levels are detected, include Mg in the fertilization program at the rate of 0.5 pounds Mg per 1,000 sq ft. If soil pH is low and limestone is required, apply dolomitic limestone according to soil test recommendations. Excessively high Mg in tissue is not a common occurrence.
Sulfur (S)	0.2-0.4%	Low S may occur on sandy soils low in organic matter where S-free fertilizers have been used following extensive periods of heavy rainfall, where grass has been overirrigated, and where high application rates of N have been applied. The ratio of N to S is as important as the S content itself and should not exceed 20-to-1. Ideally, the N-S ratio should be approximately 14-to-1 for optimum growth and turf quality. If S is low and/or the N-S ratio exceeds 20-to-1, include 0.25-0.50 pound S per 1,000 sq ft in the fertilization program. Sulfur may be supplied as gypsum, elemental sulfur or sulfur-containing fertilizers.

Table 5.2. Typical nutrient sufficiency ranges, interpretations, and recommendations for the analysis of turfgrass tissues. (cont.)

Element	Sufficiency range (% or ppm)	Interpretation and recommendation
Manganese (Mn)	20-300 ppm	Deficiencies are rare but may occur occasionally on sandy soils that are low in Mn, high in organic matter, and when the soil pH is > 6.8. Mn deficiencies can be corrected by applying a foliar application of manganese sulfate or manganese chelate by dissolving 2 ounces of manganese sulfate or 1 ounce of manganese chelate in 1 gallon of water and spraying at the rate of 0.5 gal per 1,000 sq ft. Color should improve within 24 hours. Repeated applications will be required to prevent reoccurrence of the deficiency. Excessive Mn levels can occur in some turfgrasses when the soil pH is < 5.5 or where soils are consistently overwatered. High Mn levels can be corrected by proper liming, proper irrigation practices, and by improving drainage on waterlogged soils.
Iron (Fe)	50-200 ppm	Iron determinations are invalid unless samples are properly washed to remove soil contaminates. Generally if Fe and Al levels are both high, it is due to contamination rather than inherent levels in the grass. Iron deficiency can occur on high pH soils (≥ 7.0), during periods of cool temperatures, where grasses are overwatered, and where soil P levels are excessively high. Iron deficiency is best controlled by applying a foliar application of iron as iron sulfate or iron chelate at a rate of 0.5 ounce of Fe per 1,000 sq ft. Repeated applications may be needed indefinitely to prevent reoccurrence of the deficiency. Do not apply foliar applications of iron to grasses in the heat of the day. Soil applications of Fe materials are not recommended for correcting Fe deficiencies.
Boron (B)	5-60 ppm	Grasses have very low B requirements. Deficiency is unlikely; however, toxicity is possible with some sources of irrigation water, particularly along the coastal areas. Boron content of irrigation water should be less than 0.5 ppm to guard against the possible development of toxic soil levels.
Copper (Cu)	5-20 ppm	Deficiency is not likely to occur unless high levels of organic matter are added or pH is excessively high.
Zinc (Zn)	15-50 ppm	Deficiencies are not common on turfgrasses unless grown under alkaline soil conditions. In some cases, low Zn levels will be detected in grass grown on soils that are excessively high in P or when grown on compacted or waterlogged soils. Deficiency symptoms do not show up unless the Zn content is less than 10 ppm. Zinc deficiencies can be corrected with foliar applications of zinc sulfate or zinc chelate at the rate of 0.5 ounce per gal of water per 1,000 sq ft.
Aluminum (Al)		Aluminum is not an essential plant nutrient but can be a factor affecting plant growth. High Al levels (soil-free samples) result from very low soil pH (<5.0) or anaerobic soil conditions such as flooded or heavily compacted soils. Plants do not readily absorb Al; its presence indicates an extreme soil condition.

Chapter 6. Mid-Atlantic Turfgrasses and Their Management

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Introduction

Much of the mid-Atlantic climate falls into what is commonly termed the "transition zone" of the United States. This region is noted for its hot summers, cold winters, and varying levels of moisture. In terms of selecting appropriate turfgrasses, it means that almost any warm- or cool-season turfgrass can be grown in much of the region, but not necessarily grown well, given the possible environmental extremes of winter and summer. Most species grown in the mid-Atlantic offer a wide variety of cultivars from which to select. The U.S. Department of Agriculture's National Turfgrass Evaluation Program (NTEP) presents regularly updated field research data on numerous turfgrass variety trials from around the country (*www.NTEP.org*). Within the mid-Atlantic, the research efforts of turfgrass scientists at Virginia Tech and the University of Maryland result in an annual Turfgrass Variety Recommendations list that features the top-performing cultivars in the region. This report can be found at *http://pubs.ext.vt.edu*.

Primary Cool-Season Grasses of Importance

The primary cool-season grasses used in this region are Kentucky bluegrass (*Poa pratensis* L.); hybrid bluegrass (*Poa pratensis* x *P. arachnifera*); tall fescue (*Festuca arundinacea* Schreb.); perennial ryegrass (*Lolium perenne* L.); the fine-leaf fescues of creeping red (*Festuca rubra* L.), chewings [*F. rubra* L. ssp. *fallax* (Thuill.) Nyman], and hard fescue (*F. brevipila* Tracey)]; creeping bentgrass (*Agrostis stolonifera* var. *palustris* L.); and annual ryegrass (*Lolium multiflorum* L.).

Kentucky Bluegrass (figure 6.1)

Description: A fine-to-medium-textured grass noted for its dark green color and aggressive lateral growth habit from rhizomes (below-ground stems).

Primary uses: Lawns, athletic fields, golf course fairways, tees, and roughs; commonly mixed with perennial ryegrass for athletic fields, and with ryegrass and fine fescue for sun/shade lawns.

Primary establishment method(s): Seed readily available for many improved cultivars; sod also available.

Figure 6.1. Kentucky bluegrass is a highly desirable lawn grass in the cooler regions of the mid-Atlantic, but it requires intensive maintenance to perform as desired.

Strengths: Excellent cold tolerance; excellent density; rapid recuperation potential due to aggressive lateral growth habit; summer dormancy during drought.

Weaknesses: Poor shade tolerance; 14 to 21 days for seed germination; aggressive lateral growth habit from rhizomes can make it a weed in plant beds; heavy thatch (an organic layer primarily composed of nondecomposed stems) under aggressive maintenance programs; disease and insect pressures can be high under intensive maintenance programs.

Typical seasonal nitrogen requirements: 1 to 2 pounds per 1,000 square feet for low-maintenance lawns; 3 to 4.5 pounds per 1,000 square feet for golf- and sports-turf uses.

Hybrid Bluegrasses

Similar descriptive and maintenance characteristics as for Kentucky bluegrass, but these grasses potentially have genetic improvements in heat and drought tolerance. See more comments below in the section on tall fescue.

Tall Fescue (figure 6.2)

Description: "Turf-type" varieties are fine- to medium-textured, older varieties are medium- to coarse-textured; managed primarily as a bunch/clump-forming grass with little spreading potential, but newer varieties with more aggressive rhizome formation are in development; deepest root system of the cool-season grasses.

Figure 6.2. A general purpose, turf-type tall fescue turf at a business park in Richmond, Va.

Primary uses: Most important lawn and "all purpose" turf for the mid-Atlantic; low-maintenance athletic fields, golf course roughs; turf-type varieties are commonly mixed with either Kentucky bluegrass or hybrid bluegrass in sod production systems. Preliminary research in the warmer, coastal regions of the mid-Atlantic suggest that 90 percent/10 percent (by weight) seed mixtures of tall fescue and hybrid bluegrass provide a more disease-tolerant lawn turf than single species plantings.

Primary establishment method(s): Seed readily available for many improved cultivars; sod available also.

Strengths: Excellent drought avoidance characteristics; rapid germination rates (four to seven days); early spring greening; moderate shade tolerance; adapted to a wide range of soils.

Weaknesses: High mowing requirement during active growing periods; limited to no recuperative potential; Rhizoctonia blight is a common disease problem under aggressive spring fertility programs.

Typical seasonal nitrogen requirements: 0.5 to 1 pound per 1,000 square feet for low-maintenance lawns; up to 3.5 pounds per 1,000 square feet for higher-maintenance lawns and golf/sports turfs.

Perennial Ryegrass

Description: A shallow-rooted, fine-textured, bunch-type grass noted for its dark green color and exceptional visual appeal due to "striping" when clipped.

Primary uses: Not recommended as a monostand except at elevations above 2,000 feet, where it can be used for lawns and golf and sports turf; also commonly mixed with Kentucky bluegrass for lawns and athletic fields; primary cool-season grassing option for overseeding bermudagrass for winter color/playability.

Primary establishment method(s): Seed readily available for many improved cultivars.

Strengths: Rapid germination (four to seven days) and establishment from seed; exceptional visual appeal due to glossy leaf surface that results in striping by mowing; excellent wear tolerance as a mature turf; tolerates cutting heights as low as 0.5 inch.

Weaknesses: No recuperative potential; poor cold tolerance; poor drought tolerance; high disease pressure.

Typical seasonal nitrogen requirements: 1 to 2 pounds per 1,000 square feet for low-maintenance lawns; 3 to 4.5 pounds per 1,000 square feet for golf- and sports-turf uses.

Fine-Leaf Fescues (figure 6.3)

Three species of fine-leaf fescues predominate in the mid-Atlantic: creeping red, chewings, and hard fescue.

Description: All species have exceptionally fine leaf blades commonly referred to as "needle-like." Chewings and hard fescues are bunch-type grasses, while creeping red possesses short rhizomes; all are managed as bunchgrasses.

Primary uses: Excellent low-maintenance turf with the best shade tolerance of cool-season grasses; often mixed with Kentucky bluegrass as the "shade component" of sun/shade seed mixtures.

Primary establishment method: Seed available for limited number of varieties.

Strengths: Good shade tolerance; excellent cold tolerance; good drought tolerance; minimal fertility and liming requirement; reduced mowing requirement compared to other grasses.

Figure 6.3. Fine-leaf fescues are ideal for minimal-maintenance turfs where limited fertility and mowing are desired.

Weaknesses: Intolerant of persistently wet soils; poor traffic tolerance and recuperative potential; 10 to 14 day germination from seed.

Typical seasonal nitrogen requirements: 0.5 to 2 pounds nitrogen per 1,000 square feet.

Creeping Bentgrass (figure 6.4)

Description: a very shallow-rooted, fine-textured grass with an aggressive stoloniferous (aboveground stem) growth habit; many cultivars have a characteristic pale blue-green color.

Primary uses: Almost exclusively for golf turf as bentgrass is the primary choice on putting greens; also receives extensive use on tees and is used for fairways at high-maintenance/well-budgeted golf facilities.

Primary establishment method: Seed available for many improved cultivars; sod available from regional producers.

Figure 6.4. Owing to its ability to be maintained at cutting heights of 0.1 to 0.5 inch, creeping bentgrass is a popular grass for golf putting greens, tees, and fairways.

Strengths: Surface smoothness, density, and its tolerance to cutting heights as low as 0.1 inch are predominate reasons for bentgrass use; excellent cold tolerance.

Weaknesses: Very poor heat and drought tolerance; poor traffic tolerance; high disease and insect pressure.

Typical seasonal nitrogen requirements: 2.5 to 4.5 pounds nitrogen per 1,000 square feet.

Annual Ryegrass

Description: A bunch-type, medium-to-coarse-bladed grass typically having a very light green color.

Primary uses: Cost-effective temporary soil stabilization, either seeded alone or as a nurse grass for perennial species; winter overseeding of lawns or sports fields.

Primary establishment method: Exclusively by seed with most cultivars available having been developed as a temporary forage grass; the first releases of annual ryegrass varieties developed for turfgrass use are now available; there are also intermediate ryegrass hybrids (*Lolium perenne* x *L. multiflorum*) for which early releases were of similar quality to annual ryegrass, but later releases display quality characteristics more comparable to perennial ryegrass.

Strengths: The most rapid germination from seed results in quick establishment and soil stabilization.

Weaknesses: A very fast growth rate results in a very high mowing requirement; poor cold tolerance; dies quickly the following summer (but note that some might consider this a strength when used for winter overseeding and a rapid, natural transition is desired).

Typical seasonal nitrogen requirements: 1 to 2.5 pounds nitrogen per 1,000 square feet.

Figure 6.5 details the seasonal anticipated shoot and root growth and carbohydrate (i.e., stored food) levels across the seasons. Optimal temperatures for cool-season grass growth are 65 to 75° F, resulting in the primary period for nitrogen fertilization being late summer through midfall, followed by early to midspring. Under the cooling temperatures and shorter days of fall, fertilization optimizes root development and carbohydrate storage rather than excessive shoot growth, and the benefits of fall fertilization continue into the spring by delivering a steady and sustained spring greening and growth response.

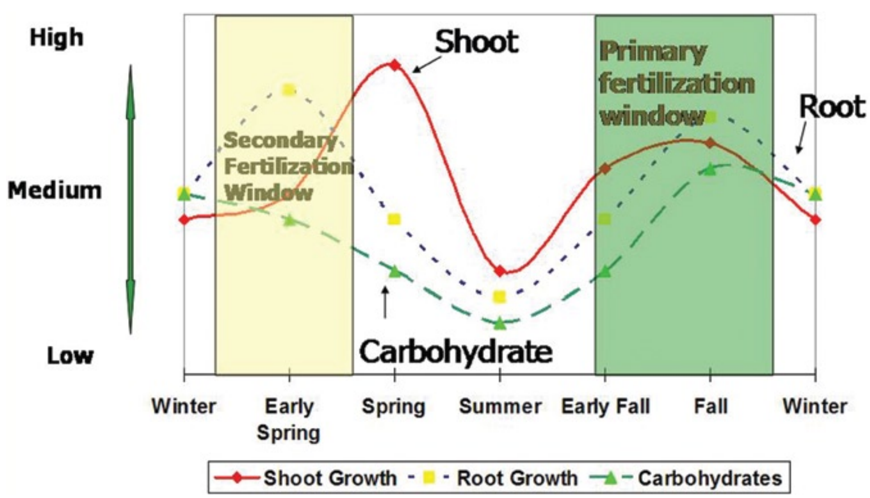

Figure 6.5. The anticipated seasonal root and shoot growth patterns and carbohydrate levels of cool-season turfgrasses.

During the secondary window for fertilizing cool-season grasses during the spring, limited amounts of nitrogen (0.5 to 1 pound nitrogen per 1,000 square feet total) can support the period when the largest increase in root development occurs. However, as indicated in the figure, spring shoot development very quickly responds to the increasing temperatures and can exceed root development if promoted by heavy nitrogen fertilization. Excessive shoot growth, while resulting in a great-looking turf for the spring months, promotes a shallow-rooted turf that will struggle in the summer months when environmental extremes are likely. Carbohydrate levels begin to decline in the spring (and continue to decline throughout the summer) as the plant utilizes stored food to support early season root and shoot growth; the decline can be exaggerated by excessive spring nitrogen applications. For most purposes, summer nitrogen fertilization is discouraged because temperatures exceed optimal growing conditions for the turfgrasses.

Primary Warm-Season Grasses of Importance

The primary warm-season grasses used in the mid-Atlantic are bermudagrass (*Cynodon* spp.), zoysiagrass (*Zoysia* spp.), centipedegrass [*Eremochloa ophiuroides* (Munro) Hack], and St. Augustinegrass [*Stenotaphrum secundatum* (Walter) Kuntze]. Bermudagrass and zoysiagrass can be found throughout the region, while centipedegrass and St. Augustinegrass are primarily found in the southern Piedmont and coastal plains.

Bermudagrass (figure 6.6)

Description: A highly diverse species with ecotypes varying in leaf textures from very fine to coarse; aggressive lateral growth habit from both rhizomes and stolons.

Primary uses: An important lawn grass in central to southern Piedmont and coastal regions, with uses ranging from roadside turf to manicured lawns; major advancements in the cold tolerance and quality of seeded (*Cynodon dactylon* L.) and vegetative bermudagrasses (*C. dactylon* x *transvaalensis*) have greatly expanded bermudagrass use throughout the mid-Atlantic, especially on golf and sports turfs.

Primary establishment method: Improved common varieties now available from seed; vegetative-only cultivars are sterile and can only be established by sod, sprigs (i.e., stems), or plugs.

Figure 6.6. Improvements in density and cold tolerance of bermudagrasses, coupled with its rapid recuperative potential and tolerance to close clipping, have made bermudagrass a popular sports turf throughout the mid-Atlantic.

Strengths: Exceptional heat and drought tolerance; rapid establishment and recuperation rates; exceptional density; cutting heights as low as 0.1 inch for golf green ecotypes, 0.5 to 0.75 inch for golf and fairway uses, to 2.5 inches for lawn use; minimal pest pressure.

Weaknesses: Rapid lateral and foliar growth rates result in high mowing requirement and weed potential in ornamental beds, gardens, etc.; cold tolerance a concern in extreme winter conditions; poor shade tolerance; loss of color due to winter dormancy.

Typical seasonal nitrogen requirements: 1 to 2 pounds per 1,000 square feet for low-maintenance lawns and 4 to 6 pounds of nitrogen per 1,000 square feet for intensively maintained golf and sports turfs, higher rates being used for ryegrass-overseeded turf.

Zoysiagrass (figure 6.7)

Description: An extremely dense, fine-to-medium-textured species that spreads by both rhizomes and stolons.

Primary uses: Lawns, golf fairways and tees.

Primary establishment method(s): Improved cultivars are mostly established by sod, sprigs, or plugs (sod is available throughout the region); a limited number of seeded cultivars now available.

Strengths: Exceptional heat tolerance and moderate drought tolerance; exceptional density; slow vertical and lateral growth rates result in reduced mowing requirement and limited invasiveness; moderate shade tolerance; minimal pest pressure.

Weaknesses: Slow to establish from seed, sprigs, or plugs; sod very expensive; loss of color due to winter dormancy.

Figure 6.7. Zoysiagrass provides one of the highest-quality, lowest-maintenance lawn turfs in the mid-Atlantic, while also being used for golf fairways and tees.

Typical seasonal nitrogen requirements: 1 to 2 pounds per 1,000 square feet.

Centipedegrass (figure 6.8)

Description: Medium-to-coarse-textured species with a stoloniferous growth habit.

Primary uses: Lawns and other low-maintenance turfs, primarily in the coastal regions.

Primary establishment method(s): Both seed and sod are available; very limited variety selection.

Strengths: Good-quality, low-maintenance turf that is well-adapted to acidic soils; moderate shade tolerance; slow vertical and lateral growth rates that reduce mowing requirement and its ability to become a weed.

Weaknesses: Poor traffic tolerance; slow to establish; marginal cold tolerance.

Typical seasonal nitrogen requirements: 1 to 2 pounds per 1,000 square feet.

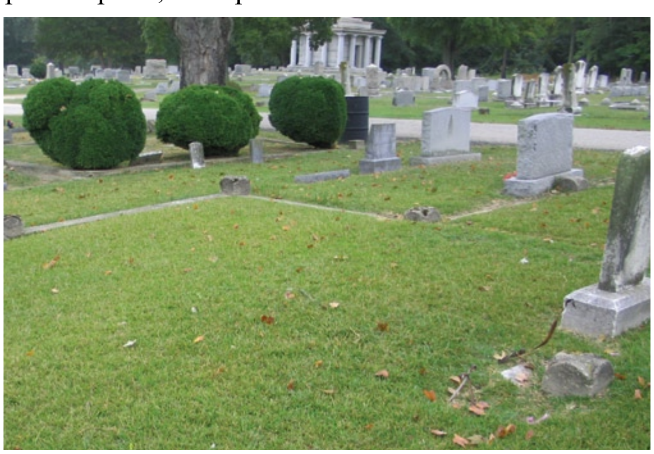

Figure 6.8. Centipedegrass is an excellent choice for low-input turfgrass sites such as cemeteries in the southern coastal plain of the mid-Atlantic.

St. Augustinegrass

Description: Coarse-textured species with a stoloniferous growth habit.

Primary uses: Lawns and general-purpose turf in the Tidewater region.

Primary establishment method: Sod or plugs; limited varieties available in the region.

Strengths: Best shade tolerance of warm-season grasses; good quality, very dense turf with an aggressive growth rate; good heat and drought tolerance.

Weaknesses: Poor cold tolerance; requires frequent mowing; the most insect and disease pressures of the warm-season grasses.

Typical seasonal nitrogen requirements: 3 to 4 pounds per 1,000 square feet.

The growth rates for warm-season grasses are optimized at 85 to 95° F. Their seasonal root and shoot growth patterns and stored carbohydrate levels are detailed in figure 6.9. The grasses enter dormancy after frost events in the fall and do not resume active growth until early to midspring the following season. Nitrogen fertilization is preferably initiated in the spring after complete greening, but — at the least — after 50 percent spring greening for situations where fertilizers are applied in combination with pre-emergent herbicides in traditional “weed and feed” products. Fertilization can continue through the summer and into early fall during periods of active growth. As the persistently cool temperatures of fall arrive, nitrogen fertilization ceases as the plants prepare for winter dormancy.

Warm-season grasses have inherent advantages in water-use efficiency over cool-season grasses, and for this reason alone, their use is increasing. However, the winter dormancy period that results in the complete loss of green color (figure 6.10) continues to be a primary reason why many homeowners are reluctant to establish and maintain warm-season lawns.

Native Turfgrasses and Specialty Use Applications

A native plant evolved in a particular climate and where it can be grown, there are logical advantages to utilizing plant materials that evolved in a site’s specific climate and soils. Since the climax vegetation of the mid-Atlantic is primarily hardwood forest, there are no native turfgrasses of significance for turfgrass use.

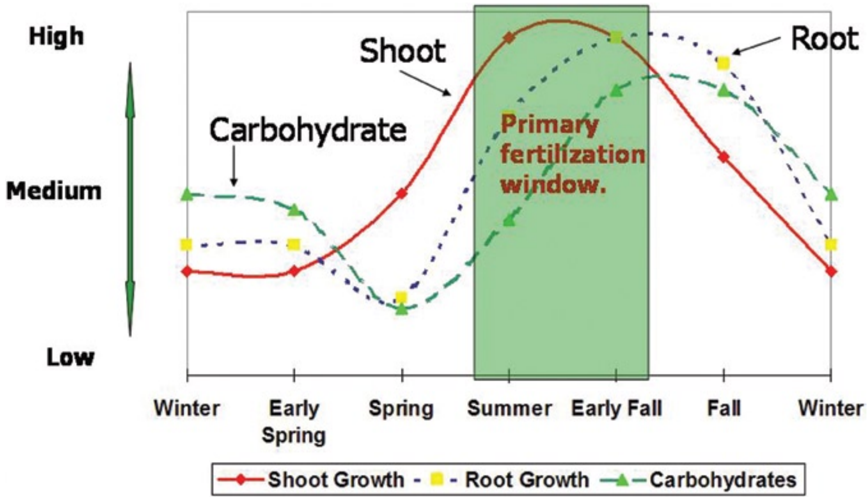

Figure 6.9. The anticipated seasonal root and shoot growth patterns and carbohydrate levels of warm-season turfgrasses.

Figure 6.10. Warm-season grasses have a winter dormancy period ranging from four to five months in the mid-Atlantic.

However, there are native grasses that evolved in the arid (less than 15 inches of annual rainfall) plains states of the Midwestern United States that have desirable characteristics as potential turfgrasses for low-input management situations.

Buffalograss [*Bouteloua dactyloides* (Nutt.) J.T. Columbus] is a plains grass that has had a great deal of breeding work to improve its quality as a managed turf. Buffalograss has many highly desirable characteristics, such as outstanding heat, cold, and drought tolerance and slow lateral growth by stolons. Improved varieties tolerate regular clipping as low as 1.5 inches. However, even with all of these desirable features of a low-input turf, buffalograss has struggled to persist as an acceptably dense turf under the much higher rainfall conditions of the mid-Atlantic (30 to 45 inches per year on average). Recently released seeded and vegetatively established cultivars and experimental lines show promise in this region, but they have not yet withstood the test of time.

Blue grama [*Bouteloua gracilis* (Willd. ex Kunth) Lag. ex Griffiths] is a minimal-maintenance native that has consistently performed well in Virginia Tech's low-input turf trials. This fast-establishing, bunch-type, seeded warm-season native of the Midwestern plains is likely not suitable as a fine turf where aesthetics and/or traffic tolerance are important. However, it has persisted for multiple seasons in low-input turf variety trials at Virginia Tech with minimal invasion by weedy species. Blue grama will require mowing only a few times per year as a low-input turf.

In research that simulated a cemetery setting at Virginia Tech, a cool-season native turfgrass called Prairie junegrass [*Koeleria macrantha* (Ledeb.) J. A. Schultes, variety "Barleria"] that was mixed at 95 percent junegrass to 5 percent "Baron" Kentucky bluegrass (by weight) at establishment was one of the highest-quality, lowest-input turfgrasses in the trial. After three years in the field, this was one of the highest-rated cool-season grass plots that particularly withstood the extreme drought of 2007 in this region. By the end of the trial, no Kentucky bluegrass was visibly evident in the plots. There are very few choices in cultivars of prairie junegrass, but it is anticipated there will be future development in this area.

Other native grasses that are used for minimal-maintenance, no-mow situations are little bluestem [*Schizachyrium scoparium* (Michx.) Nash], big bluestem (*Andropogon gerardii* Vitman, figure 6.11), Indiangrass [*Sorghastrum nutans* (L.) Nash], and switchgrass (*Panicum virgatum* L.). These tall-grass prairie species are intended for low-maintenance sites that will typically receive only an annual "cleanup" mowing event to control woody species that develop in

Figure 6.11. Big bluestem serves as a wildlife-friendly, visually appealing, low-input perennial groundcover in out-of-play areas on this golf course.

these minimal-maintenance conditions. They are noted for the color of their foliage and seedheads and serve as a refuge for animal life. They can be found in turfed areas as divergent as highway rights of ways and secondary roughs on golf courses. Their establishment to desirable quality stands takes patience, because two to three years are often required to achieve the "look" associated with a tall-grass prairie. During this establishment period, herbicide applications are often required to reduce weed invasion in these relatively low-density grasses.

In summary, the best way to achieve long-term success with low-input grasses is to select adapted species that have demonstrated perennial success in this region, rather than those classified as natives because they originate in the United States. The native grasses detailed here are outstanding performers in the arid prairie states of this country. In the aforementioned simulated cemetery trial at Virginia Tech, the highest-quality, lowest-input turfgrasses were hard fescue, prairie junegrass, and either seeded or sodded zoysiagrass. Of this group, only prairie junegrass is native to the United States and it is still considered somewhat of an "experimental" turfgrass with very limited availability. The other grasses — while not native by definition — are well adapted to the mid-Atlantic and have better performance characteristics than most natives.

Turfgrass Establishment

Soil Preparation

Whether it is a new establishment or a spot renovation, it is important to ensure that soil‚Äôs physical or chemical properties are suitable for turfgrass establishment and long-term success. If a turf stand has failed, is it possibly due to the soil? For native soils, conducting a soil test is an inexpensive and logical preventative maintenance step that should accompany almost any establishment scenario, especially if a soil test has not been conducted for the past three years. Applying recommended levels of lime and fertilizer will ensure the turf has maximum opportunity to establish.

For new establishments in many urban settings, the physical properties of the existing soil (often a "B" horizon subsoil remaining after construction) are an immediate limitation to turf establishment (see chapter 4 for a complete discussion on the challenges of urban soils). Whenever possible, stockpile the top 4 to 6 inches of the topsoil before construction begins for later redistribution across the site after construction is complete (figure 6.12).

Figure 6.12. Stockpile topsoil prior to construction for later distribution before turf and landscape planting.

Unfortunately, stockpiled topsoil is often not available in urban settings and what remains is a nutrient-deficient, compacted, poorly drained subsoil material that is to be used for turf and landscape plant establishment. Far too often, the unsuitable soil is masked by a sod installation that provides immediate cover but ultimately fails as environmental extremes (heat, cold, drought, or saturated conditions) arrive.

No amount of water, fertilizers, and pesticides can overcome an unsuitable soil, and the potential for turfgrass management to impact water quality is exaggerated as homeowners attempt to overcome the soil limitations with excessive water and chemical inputs. Instead of utilizing the benefits of turfgrass as a filter and soil stabilizer to protect water quality, the end result is a declining stand of turfgrass that negatively impacts water quality by the likely movement of sediment and unused nutrients during heavy rainfall events.

Remove and dispose of all rocks and construction debris (brick, piles of gravel, lumber, spilled concrete, electrical wire, etc.) from the site — do not bury it in the soil. Any utility, irrigation, drainage, or sewer lines for the site should be installed well before the installation of turf or ornamentals. Be sure to confirm that these lines have been installed to appropriate depths so they won't be hit by tillage equipment during final soil preparation. Ensure that the grade on the property is suitable so that surface drainage moves water away from buildings, sidewalks, etc. This is also the time to consider the feasibility (and/or design and installation) of rain gardens or other stormwater retention systems.

Conduct soil tests for the lawn and ornamental beds in order to address any chemical limitations (pH and nutrient levels) of the growing medium (Goatley, Mullins, and Ervin 2009). Prior to planting, recommended lime and fertilizer materials should then be incorporated into the top 4 to 6 inches of soil. This will also be the time to incorporate any organic or inorganic amendments recommended to improve the soil (discussed in chapter 9). Thoroughly till the soil but do not attempt to turn the lawn seedbed into a fine powder typically equated to garden soil — some clods are fine for turf establishment! The soil can then be smoothed and firmed with a lightweight roller prior to planting, but avoid extensive surface compaction. If additional construction traffic occurs prior to planting, conduct another light tillage to remove surface compaction.

Little (or no) soil preparation of thinning or degraded turf areas most often leads to failed turfgrass establishment, even though it might seem logical that sowing seed or installing sod into/on a sparse turf canopy could work. Seed applied into thin turfs usually germinate, but many of the newly emerging roots do not adequately penetrate the soil such that the new plants persist. For spot seed renovations, it is recommended to core aerate the soil in multiple directions, seed, and then drag the cores back into the area after seeding to improve soil-to-seed contact. For sod installations, success is usually achieved through complete soil preparation.

Timing

Across the mid-Atlantic, the optimum period to seed cool-season grasses is late summer to early fall. This timing optimizes root development and carbohydrate storage in the young plants because of more favorable environmental conditions that maximize plant development before summer arrives. Early to midspring is the secondary window for seed establishments. Seed readily germinates as the soil warms, but the root system is rarely developed sufficiently to ensure survival during a hot, dry summer season. Seed is readily available for all cool-season grasses.

For seeded warm-season grasses, the ideal establishment period is midspring to early summer. These grasses perform optimally during hot weather conditions as long as they receive adequate moisture to maintain growth. The first winter survival of plants established from seed later than mid-July can be greatly reduced in extreme winters; the more mature a warm-season turf is, the better its chance of surviving the first winter. There are seeded varieties for bermudagrass, zoysiagrass, and centipedegrass but not all varieties of these grasses are available from seed (i.e., they must be established vegetatively by sprigs, plugs, or sod). St. Augustinegrass is almost exclusively established from sod or plugs (seed is viable but of limited availability since it cannot easily be extracted from the seedhead). Sprigging (inserting vegetative stems into a prepared seedbed) establishments should follow these same timing guidelines.

Sod establishments are much more flexible in terms of timing success, but the ideal establishment period follows the previous guidelines for both warm- and cool-season grasses. However, both warm- and cool-season sods can be successfully established as long as they are not applied to frozen soils. The key to success is to remember that these sods, while having reduced moisture needs, still require some water to prevent desiccation of the newly emerging roots. Dormant sods of warm-season grasses should have minimal moisture requirements but should be checked regularly during abnormally dry winters. Establishing cool-season sods in the summer is possible, but it requires regular monitoring and applications of soil moisture because evapotranspiration losses are so high. No nitrogen fertilizer should be applied to sods when established outside the optimal establishment window.

Nutrient Management and Fertility Recommendations

Successful turfgrass establishments are closely linked to responsible nutrient management programs, regardless of the turfgrass and its use. These nutrient management recommendations were developed in a cooperative effort between the turfgrass faculty at Virginia Tech and representatives of the Virginia Department of Conservation and Recreation that ultimately resulted in the Virginia Nutrient Management Standards and Criteria (2005). Fertility recommendations for establishment consider that the following criteria are met: (1) selection of appropriate grass for the climate and its intended use, and (2) establishment occurs under optimal planting conditions.

Nutrient management strategies for new plantings will vary widely depending on the grass and its intended use. For instance, consider the inherent differences in growth rates between grasses, even within the groupings of cool-season and warm-season species. Bermudagrass and St. Augustinegrass (warm-season grasses) or tall fescue and perennial ryegrass (cool-season grasses) are noted for quick establishment, whereas zoysiagrass and centipedegrass (warm-season) or Kentucky bluegrass and fine fescue (cool-season) are very slow. Similarly, consider differences in establishment challenges between roadside vegetation being seeded on cut-and-fill soils high in B- or C-horizon material versus seeding on completely modified, sand-based systems for golf and sports turfs. Regardless of the site characteristics, the newly established sites planted from seed, sprigs (i.e., rhizomes or stolons), plugs, or sod have immature root systems that are limited in both size and depth. These limitations in initial root development place an even greater importance on the need for soil testing in order to correct chemical deficiencies — especially pH and plant-available phosphorus and nitrogen. Consult with a certified nutrient management planner or with local cooperative Extension office personnel when developing a suitable nutrient management program for turf establishment in your area.

Phosphate and Potash Recommendations for Establishment

Soil testing is appropriate for adjusting soil phosphorus and potassium levels prior to planting. Table 6.1 details general phosphate and potash recommendations for turfgrass establishments.

Table 6.1. Phosphorus and potassium levels applied at turfgrass establishments on the basis of soil testing.

	Nutrient needs (lb/1,000 sq ft)	
Soil test level*	**Phosphorus** (P_2O_5)	**Potassium** (K_2O)
Low	3-4	2-3
Medium	2-3	1-2
High	1-2	.5-1
Very high	0	0

*For low soil test levels within a category (e.g., L-), use the higher side of the range of nutrient needs. For high soil test levels (e.g., H+) use the lower side of the range of nutrient needs.

Research in Maryland (Turner 2005) has demonstrated that there are limited advantages in turfgrass establishment at seeding from utilizing traditional high phosphorus-analysis “starter fertilizers” (e.g., 5-15-5, etc.), with the advantages being realized primarily when soil temperatures are suboptimal for establishment. Similarly, the same advantages in the use of starter fertilizers can apply to overseeding, spot renovations, and sodding as well, but their importance is minimal on soils with adequate phosphorus and optimal temperature and moisture conditions for establishment.

Nitrogen

Establishing turfgrasses in an environmentally responsible manner is a challenge in any situation. When possible (or affordable), establishing by sod provides immediate soil stabilization; sediment loss is essentially negated. However, seed, sprig, or plug establishments present the challenge of applying relatively large amounts of water and fertilizer to promote quick establishment (i.e., reduce sediment loss), but not at the expense of leaching or movement of the fertilizer into nearby water sources.

Nitrogen amounts during grow-in will vary depending on the turfgrass, water solubility of the nitrogen source, soil characteristics, and timing of the establishment. At establishment, there are at least three factors that require fertility programs to be adjusted for the specifics of a planting situation:

1. All new establishments, even sod, lack a fully developed root system to efficiently utilize nutrients and water soon after planting.
2. The requirement for frequent irrigation during turf establishment to sustain the emerging root and shoot systems increases the potential for nutrient loss.
3. With seed, plug, or sprig establishments, the lack of a dense turf canopy increases water quality concerns due to the potential lateral movement of nutrients and sediment.

Immediate soil coverage is an inherent advantage in sod establishments and even where complete installation is not possible due to cost, using sod strips in predominantly seed establishments is often an affordable way to slow the speed of water on slopes and reduce soil loss (figure 6.13).

Figure 6.13. Adding single strips of sod to seed establishments on sloped sites is a highly effective means of reducing soil erosion potential.

One nitrogen fertility strategy that promotes the development of newly established turfgrasses with less potential impact on water quality is to utilize "slowly available nitrogen" (SAN) sources during grow-in. The Virginia Department of Conservation and Recreations' Nutrient Management Training and Certification Regulations (4 VAC 5-15) (*http://www.dcr.virginia.gov/documents/nmtraincertregs.pdf*) define SAN as "sources that have delayed plant availability involving compounds which dissolve slowly, materials that must be microbially decomposed, or soluble compounds coated with substances highly impermeable to water, such as polymer-coated products, methylene urea, isobutylidene diurea (IBDU), urea formaldehyde based (UF), sulfur-coated urea, and natural organics." Ideally, these sources should contain 50 percent or more SAN in order to realize the full benefits of sustained nitrogen feeding with little nitrogen loss potential. Such sources should be the focal point of grow-in programs on sand-based soils. However, it is possible — and sometimes desirable due to cost or desired rate of turf coverage — to utilize predominantly water-soluble nitrogen (WSN) sources during grow-in by way of frequent, low-level (0.25 to 0.5 pound of nitrogen per 1,000 square feet) nitrogen applications. Many times, a successful grow-in program that combines both desirable turfgrass coverage and quality with environmental protection is one that employs a range of nitrogen sources with varying degrees of water solubility.

Grow-In Strategies for Lawns and General Turf

Nitrogen applications for establishment of home lawns and general turf areas should not exceed 1 pound of nitrogen per 1,000 square feet at planting, followed by one or two applications initiated at 30 days after planting, not to exceed a total of 2 pounds of nitrogen per 1,000 square feet for the establishment. Slow-release nitrogen sources containing 50 percent or greater SAN will reduce leaching potential and should be used whenever possible for establishments on sand-based soils. Split applications of WSN at 0.25 to 0.5 pound per 1,000 square feet per application on one- to two-week intervals will further improve nitrogen-use efficiency, but consider that these applications can be difficult given the likelihood of wet soils during the grow-in period.

Grow-In Strategies for Golf Course, Athletic Field, or Sod Production Systems

With the wide range of grasses that can be used and the diversity in soils found across the mid-Atlantic region, there is a great deal of variability in fertilization strategies for turfgrass establishments. Successful establishments are best achieved by planting grasses during their optimum establishment windows (late summer to early fall for cool-season grasses and late spring through midsummer for warm-season grasses). For any grass on any soil type, utilize a soil test to determine lime, phosphorus, and potassium needs and incorporate all needed amendments into the top 4 to 6 inches of the soil profile prior to planting.

First, consider nitrogen-based establishment fertility programs for cool- or warm-season grasses on heavier-textured, predominantly silt/clay soils. These programs apply to most soils used for golf fairways and roughs, athletic fields, and sod farms in the region. Up to 1 pound of nitrogen per 1,000 square feet can be applied in a single application at planting with a 50 percent or greater SAN source that will feed the turf for up to four weeks. For sources containing predominantly WSN, apply no more than 1 pound of nitrogen per 1,000 square feet over the first four weeks by splitting the applications into regular intervals. At four weeks after planting, apply 0.25 to 0.5 pound of WSN per 1,000 square feet per week for the next four weeks.

Next, consider nitrogen-based establishment fertility programs for cool- or warm-season grasses on naturally occurring or modified sand-based soils. In these highly leachable soils, it is important to use a 50 percent or greater SAN source at up to 1 pound of nitrogen per 1,000 square feet for the first four weeks of establishment for either type of grass. For warm-season grasses, apply 0.25 to 0.50 pound of WSN per 1,000 square feet per week for the next four weeks. On cool-season grasses, apply up to 0.25 pound of nitrogen per 1,000 square feet per week (or 0.5 pound of a 50 percent or greater SAN source every two weeks) after germination is complete for the next eight weeks.

Large-scale grow-ins on golf courses are sometimes achieved with fertigation systems (the application of low levels of nutrients through an inground irrigation system). For a properly installed and functioning irrigation system, fertigation is an extremely efficient method of nutrient delivery through the irrigation water.

Irrigation and Water Conservation Strategies for Establishments

Light and frequent irrigation is required for optimal seed establishments. Keep the seedbed moist but don't apply so much water that the seed might drown or be washed away. A somewhat more aggressive watering strategy is required for sprig establishments, as these tissues are particularly prone to rapid desiccation. Initiate irrigation as soon as possible on newly planted sprigs and keep the sprigs moist but not saturated. Excessive watering can drown plants and promote fertilizer losses, due to either runoff or leaching loss. Even with immediate irrigation, anticipate a possible total loss of color due to leaf desiccation on the sprigs, but don't let this deter watering as healthy sprigs will almost always rapidly initiate new roots and shoots if their planting is appropriately timed and irrigation and fertility requirements are met. As establishment progresses, gradually reduce irrigation to a deep and infrequent strategy recommended for established turf.

Sod and rooted plugs provide more flexibility in supplemental irrigation requirements for establishment, not requiring nearly as much attention as seed or sprig plantings. As a rule of thumb, sod installations during optimal establishment periods should receive up to 1 inch of water (either from irrigation or rainfall) during establishment. However, the ideal water management approach is to keep the soil moist and not saturated; during periods of low evapotranspiration, supplemental water needs will be greatly reduced. Roots require both water and oxygen to establish properly, and overwatering sod greatly reduces establishment. Periodically tugging on the sod or plugs to assess root development is a good way to monitor moisture needs, and as rooting progresses, reduce supplemental irrigation to a deep and infrequent strategy as one would for an established turf.

An important way to conserve moisture and reduce soil-erosion potential for seed establishments (and it could work for sprig plantings as well) is to mulch the seedbed. Small-grain (e.g., wheat, barley, etc.) straw is an ideal mulch for seed establishments (figure 6.14). A general application level is one bale of straw per 1,000 square feet, and it can be applied by hand or by power equipment that chops and blows the straw. Avoid using hay as a mulch source; a clean (weed-free) wheat straw is a preferred mulching material. Straw can simply be mulched right back into the canopy as the new grass establishes, and any of the small-grain seed that germinates can be mowed and will die during the first summer season.

Figure 6.14. Mulching newly seeded areas with weed-free straw is very effective in conserving moisture for seed establishments.

There are numerous paper-based and wood-fiber mulches available for mulching as well. Shredded paper mulch is very popular when turf is established by "hydroseeding" — a motorized, pump-driven planting strategy that applies a fertilizer, seed, mulch, and tackifier slurry to a prepared seedbed. There is also a wide variety of erosion control blankets that are primarily designed for vegetation establishments on sloped sites. These materials and their application strategies are further discussed in chapter 11.

Seeding Levels and Planting Strategies

Seed provides the most popular means of establishment because of the availability of improved cultivars for many species and the relative affordability of seed. Many improved varieties of bermudagrass do not produce viable seed and must be established vegetatively. Seed is readily available for many improved varieties of cool-season turfgrasses. Select certified (blue-tag) seed whenever possible, as this ensures that what is indicated on the tag is what is in the bag. Apply fertilizers and lime as detailed above, utilizing soil tests whenever possible to best correct deficiencies. For lawns, seed at the recommended levels detailed in table 6.2, using the higher seeding levels during suboptimal establishment periods.

Establishment Methods

The most common equipment to deliver seed in surface applications to prepared seedbeds is either rotary (often referred to as "broadcast" or "centrifugal") or drop (gravity-fed) spreaders. A rotary spreader can be used for large-scale plantings because it can cover a lot of ground in a short period of time. However, uniform seed distribution can be disrupted on windy days. Drop spreaders allow for precision in seed application because the seed falls precisely over the area covered by the spreader. Seed distribution is not affected by the wind, but this delivery method takes a great deal more time because it covers a much smaller area in a single pass. Apply seed in at least two directions (especially

Table 6.2. Recommended seeding levels for turfgrasses used in home lawns.

Grass	Seeding level (lb pure live seed/1,000 sq ft)
Fine-leaf fescue	3-5
Kentucky bluegrass	2-3
Perennial ryegrass	3-5
Tall fescue	6-8
Perennial ryegrass	3-5
Bermudagrass	.5-1
Centipedegrass	.25-.50
Zoysiagrass	2-3
Cool-season mixtures depend on percent of individual species in mix.	Use recommendations on the bag. For example, a 90/10 (percent by weight) mixture of tall fescue/Kentucky bluegrass is seeded at 3-4 lb/1,000 sq ft.

Table 6.3. Recommended establishment levels for specific uses of grasses for golf and sports turfs.

Grass and use	Seeding level (lb pure live seed/1,000 sq ft)
Creeping bentgrass (golf putting greens and tees)	.5-1
Creeping bentgrass (golf fairways)	.25-.50
Kentucky bluegrass (golf fairways and tees, sports fields)	2-3
Perennial ryegrass (golf fairways and tees, sports fields)	3-5
Perennial ryegrass/Kentucky bluegrass mixtures, 90%-10% by weight (golf fairways and roughs, sports fields)	2-4
Tall fescue (golf roughs)	4-6
Tall fescue (sports fields)	6-8
Tall fescue/Kentucky bluegrass mixtures, 90%-10% by weight (golf roughs)	2-4
Tall fescue/Kentucky bluegrass mixtures, 90%-10% by weight (athletic fields)	3-4
Bermudagrass (golf fairways and tees, athletic fields)	.5-1
Bermudagrass (golf roughs)	.25-.50
Zoysiagrass (fairways or tees)	2-3

with drop spreaders) to avoid skips. The previously mentioned method of hydroseeding is an excellent means of rapidly covering large areas of prepared soil with a seed, fertilizer, and mulch slurry using water as a carrier.

There also are a host of mechanized seeders that slice or lightly till the soil in front of a seed hopper that drops the seed into the soil, thus ensuring soil-to-seed contact. The primary concern with mechanized planters is being sure the seed is not planted so deep in the soil that it cannot emerge. Smaller-seeded grasses (bluegrass, bermudagrass, bentgrass, zoysiagrass, centipedegrass) should be planted on or just below the soil surface. Larger-seeded grasses (tall fescue, perennial ryegrass, fine-leaf fescues) can be planted into the top 0.5 inch of soil.

Sodding

An inherent advantage of sodding is that the soil attached to the sod serves as a nutrient and moisture reservoir to aid in establishment. Another consideration in the choice of sod is that it is an extremely effective means of almost eliminating soil erosion (and potential movement of sediment into waterways) during turf establishment. Appropriate use of a high-phosphorus starter fertilizer can benefit initial rooting, but the responses are not likely to be as significant as those encountered from seed establishments. Fertilizers can also be applied postestablishment to the sod itself. Sod offers significant advantages in lower water requirements (and attention to watering during establishment), has virtually no soil-erosion potential, and provides almost immediate gratification and use potential. Roll the sod after planting to ensure soil-to-plant material contact. Water frequently enough to maintain a moist (not saturated) sod. Periodically check for rooting by tugging on sod to see how well it is tacked to the soil; reduce irrigation frequency and amount after establishment is complete.

Plugging or Sprigging

Any grass that produces lateral stems (rhizomes and/or stolons) can be established by plugging or sprigging (planting stems directly into the soil, figure 6.15). However, due to the ready availability of seed for many cool-season grass varieties and their slower lateral growth rates, only warm-season grasses are commonly established by plugs or sprigs. Plugs of 2 inch to 4 inch in diameter are planted on 6- to 12-inch centers. Rapidly spreading grasses like bermudagrass and St. Augustine-

Figure 6.15. Bermudagrass sprigs (i.e., shredded stems) planted in rows on a sand-based athletic field.

grass can be planted on 12-inch centers and will achieve complete coverage within one summer growing season; faster coverage rates of 30 to 60 days are likely with plugging on 6-inch centers. Slow-spreading grasses like centipedegrass and zoysiagrass should be planted on 6-inch centers and even then might not cover within one growing season. Plugs have the advantage of usually being fully rooted, and therefore, they require less-intensive maintenance at establishment.

The shredded stems used as sprigs require regular and frequent irrigation until the growing points on the stems have produced a functioning rooting system. The moisture requirement for sprigs is very high during the first seven to 14 days of establishment.

For those who have never established turf in this manner, the first impression is that the stems have died because most of the leaf material at planting browns and decays. Be persistent with providing regular irrigation during this seven- to 14-day window, and new leaves and roots will emerge. Logically, the more plant material used at establishment, the quicker the establishment rate. Sprigging levels of 10 to 25 stems per square foot are typical planting levels, but higher levels of up to 50 stems per square foot will likely be required to establish slower-growing grasses, such as zoysiagrass or centipedegrass in one growing season (table 6.4).

It is common for sprigging specifications to be presented in units of bushels of sprigs per acre. However, there is no clear definition of what constitutes a bushel. As a point of reference, numerous custom planting company personnel equate 25 stems per square foot to a planting rate of 500 bushels per acre. Specifying a precise number of stems per square foot is the easiest way to quantify a vegetative planting rate of stems per unit area.

Table 6.4. Vegetative planting recommendations for various grasses and their respective uses.

Grass and intended use	Stems/sq ft
Bermudagrass (lawns)	10-25
Bermudagrass (golf fairways)	10-50
Bermudagrass (golf greens)	35-50
Zoysiagrass (lawns)	25-35
Zoysiagrass (fairways and tees)	35-50

Winter Overseeding

Winter overseeding is defined in this publication as the early-to-midfall seeding of an adapted cool-season turfgrass into an existing warm-season turfgrass for the purpose of winter color and possibly improved playability of sports fields. Note that overseeding is sometimes used as a general term to describe any general seeding or renovation event that is conducted on existing stands of turfgrass.

Most often, the choice in cool-season turf for overseeding is an annual, perennial, or intermediate ryegrass. For most purposes, only bermudagrass is recommended to be overseeded, because other warm-season grasses are generally not viewed as being competitive enough the following season to outcompete the winter overseeding. The bermudagrass might be lightly vertical-mowed or slightly scalped prior to overseeding in order to enhance seed movement through the canopy to the soil. Obviously, this is potentially detrimental to the bermudagrass, and the level of vertical mowing should be kept to a minimum and not used as a dethatching event late in the bermudagrass growing season. Optimum soil-to-seed contact can be achieved by topdressing the overseeded grass with sand or a similar topsoil material. For winter overseeding of bermudagrass, home lawns are seeded at 5 to 10 pounds of pure live seed per 1,000 square feet. Athletic fields or golf fairways and tees are typically seeded at 10 to 20 pounds of pure live seed per 1,000 square feet.

Fertilization strategies for overseeded turfs can be problematic in trying to balance the needs of the germinating, cool-season grass seedlings with those of a warm-season grass that will soon enter winter dormancy. Overly aggressive nitrogen fertilization during fall overseeding periods can reduce ryegrass establishment by promoting excessive late-season bermudagrass competition, and high nitrogen levels can also reduce the winter hardiness of the bermudagrass. Using reduced nitrogen application levels of 0.25 pound of nitrogen per 1,000 square feet per week during establishment allows the manager to maintain control of the growth rates of bermudagrass and the establishing ryegrass seedling. Nitrogen fertilization levels totaling from 0.5 to 1 pound of nitrogen per 1,000 square feet in early September should suffice to feed the germinating ryegrass seedlings while not excessively stimulating the bermudagrass. Apply an additional 0.5 pound of nitrogen per 1,000 square feet in October or November and then again in February or March of the following year. These levels should suffice to promote ryegrass growth with limited effects on the bermudagrass turf.

While overseeding is generally considered to negatively affect the health and quality of warm-season grasses, there are inherent advantages to its use in grassing systems. Color and playability of golf and sports turfs might warrant the necessity of winter overseeding in some golf-turf and sports-turf situations. Another possible reason to overseed is if the turf is irrigated with reclaimed water. The ryegrass can effectively serve as a sink for nutrients applied in the reclaimed water that the dormant bermudagrass turf otherwise would not utilize.

Maintenance Fertility Programs

Phosphorus and Potassium

Applications of phosphorus and potassium in maintenance application programs for cool- and warm-season turfgrasses should be based on soil tests. Soil tests should be conducted at least every three years on high silt/clay soils and every year on high sand-content soils. Table 6.5 provides recommended fertilization levels for phosphorus and potassium.

Table 6.5. Phosphorus and potassium levels applied to established turf on the basis of soil testing.

	Nutrient needs (lb/1,000 sq ft)	
Soil test level*	**Phosphorus** (P_2O_5)	**Potassium** (K_2O)
Low	2-3	2-3
Medium	1-2	1-2
High	.5-1	.5-1
Very high	0	0

*For low soil test levels within a category (e.g., L-), use the higher side of the range of nutrient needs. For high soil test levels (e.g., H+), use the lower side of the range of nutrient needs.

Nitrogen

As detailed previously in this chapter describing the predominant grasses of the region and their uses, the annual nitrogen requirement varies greatly depending on the species of grass being grown, site characteristics, intended use of the grass, and expectations of the clientele growing the turf. The following tables detail general seasonal nitrogen fertilization strategies for both cool- and warm-season turfgrasses.

Table 6.6. General seasonal nitrogen fertilization strategies for cool-season turfgrasses.

Time of year	Relative N rate/ application, per growing month	Comments
Early spring	None to low (.25 lb N/1,000 sq ft)	- Never apply to frozen ground. - If following aggressive fall fertilization, probably not necessary.
Mid-late spring	Low to medium (.25-.5 lb N/1,000 sq ft)	- Have been shown to benefit root growth with responsible applications. - Exceeding these levels promotes shoots at expense of roots.
Summer	None to low (.25 lb N/1,000 sq ft)	- In general, refrain from N fertility, but small amounts can aid recovery from stress/pest pressures. - Avoid applications during high heat/drought pressures.
Late summer through early winter	Medium to high (.5-1 lb N/1,000 sq ft)	- Promotes recovery from summer stress with early fall applications. - Continue program (while grass is still green without much shoot growth) to promote roots, color, turf density, and carbohydrate levels.

Table 6.7. General seasonal nitrogen fertilization strategies for warm-season turfgrasses.

Time of year	Relative N rate/ application, per growing month	Comments
Early spring	None to low (.25 lb N/1,000 sq ft), pending emergence from winter dormancy	- Never apply to frozen ground. - Ideally, wait until complete greening, but strategy doesn't fit standard weed and feed products designed for PRE-crabgrass control
Mid-late spring	Low to medium (.25-.5 lb N/1,000 sq ft)	- Excessive levels promote shoots at expense of roots. - Be aware of average "last frost" dates for the area.
Summer	Medium to high (.5-1 lb N/1,000 sq ft)	- Primary season for fertilization, but still wise to avoid applications under severe environmental stress.
Late summer to winter dormancy	Low (.25-1 lb N/1,000 sq ft)	- Maintaining active growth until dormancy promotes late-season rooting and carbohydrate storage, but N applications terminated prior to first frost date.

Lawns and Commercial Turf

Cool-season grasses can receive up to 3.5 pounds of water-soluble nitrogen (WSN) per 1,000 square feet or 4 pounds of slowly available nitrogen (SAN) per 1,000 square feet on an annual basis. Warm-season grasses can receive up to 4 pounds of WSN per 1,000 square feet or 5.5 pounds SAN per 1,000 square feet. Applications of water-soluble nitrogen should not exceed 1 pound of nitrogen per 1,000 square feet every 30 days. When using WSN on sandy soils, split applications to no more than 0.5 pound of nitrogen per 1,000 square feet every 15 days. Slowly available nitrogen sources (defined as any nitrogen source containing 50 percent or more SAN) can be applied at up to 1.5 pounds per 1,000 square feet on heavier-textured (high clay or silt) soils per application at a recommended timing or 1 pound of nitrogen per 1,000 square feet on predominantly sand soils. However, remember that the seasonal requirements of varying species are highly variable and some of the region's turfgrasses would actually decline in health and/or quality if aggressively fertilized. Table 6.8 details typical seasonal nitrogen requirements to achieve anticipated levels of desirable turfgrass performance.

Table 6.8. Seasonal nitrogen requirements to deliver satisfactory levels of turfgrass performance for cool- and warm-season lawns.

2.5-5.5 lb N/1,000 sq ft annually	1-2 lb N/1,000 sq ft annually
Kentucky/hybrid bluegrass	Fine-leaf fescues
Creeping bentgrass	Centipedegrass
Bermudagrass*	Zoysiagrass
Tall fescue*	Bermudagrass*
Perennial ryegrass	Tall fescue*
St. Augustinegrass*	St. Augustinegrass*

*Certain varieties within species perform well under either annual nitrogen program.

Golf Courses

Golf turf is some of the most intensively managed grass grown, requiring maintenance cutting heights as low as 0.1 inch for some putting greens with expectations to deliver a dense, smooth-playing surface. Furthering the need for additional nutrition is that clippings are collected on all greens, most tees, and even some fairways. For sand-based greens and tees, care especially needs to be taken regarding the potential for leaching loss of nitrates and phosphates due to the sandy soil and the likelihood that the greens contain subsurface drains that likely channel leachate to a water source. When greens are mature and healthy, nitrate and phosphate leaching concerns are minimal. When greens are immature (i.e., being grown-in) or are stressed due to pest or environmental pressures, the potential for nutrient loss is greatly increased. Table 6.9 presents general seasonal nitrogen applications for all aspects of golf turf management. Consider that while the total annual nitrogen rates stay the same, the maximum nitrogen rate per application (and therefore, the number of applications) might vary when 50 percent or more SAN sources are used on heavier-textured (predominantly clay or silt) soils, and levels of up to 1.5 pounds of nitrogen per 1,000 square feet can be applied in a single application.

Table 6.9. General seasonal nitrogen strategies for golf turf management.

Turf use	Grass type	Maximum N rate/ application (lb/1,000 sq ft)[a]	Total annual N rate (lb/1,000 sq ft)[b]
Greens		.5-1	3-6
Tees		.5-1	2-5
Fairways (standard management)[c]	Cool-season	1	2-3
	Warm-season	1	2-4
Fairways (intensive management)[d]	Cool-season	.5-1	3-4
	Warm-season	.5-1	3.5-4.5
Overseeding fairways[e]	Warm-season	.5	1.5
Roughs		1	1-3

[a]For naturally occurring sand or modified sand-based soils on greens and/or tees, apply no more than 0.5 lb water-soluble nitrogen per 1,000 sq ft every 15 days, or 1 lb nitrogen from sources containing 50 percent or greater SAN every 30 days.
[b]Use the higher levels for intensively managed turf where accelerated growth and/or rapid recovery are required; use lower rates for maintenance of lesser used areas.
[c]Standard management fairways may or may not have irrigation and likely are mowed at heights of 0.75-1.25 inch, one to two times per week.
[d]Intensively managed fairways are irrigated and are likely mowed at heights of 0.75 inch or shorter, three or more times per week.
[e]Initiate nitrogen applications of no more than 0.5 lb per 1,000 sq ft after ryegrass is well-established and bermudagrass has entered dormancy. In spring, up to two applications of nitrogen at 0.5 lb per 1,000 sq ft can be used in February or March if growth and color enhancement are required.

Athletic Fields

There is likely no turf management situation more challenging than maintaining a safe, high-quality playing surface on an athletic field. A fertility program is only one component of a successful management program, because appropriate cultivation, irrigation, and field use management strategies have similar importance. However, applying fertilizer at the appropriate levels and timing pending the grass, soil, and field use is critical to sustain turf coverage and encourage its recovery. The following tables (adapted from Goatley et al. 2008, and the 2005 Virginia DCR Standards and Criteria) provide general recommendations for nitrogen fertility strategies on cool-season athletic fields in this region. As stated previously, the maximum nitrogen rate per application (and therefore, the number of applications) might vary when 50 percent or more SAN sources are used on heavier-textured (predominantly clay or silt) soils and levels of up to 1.5 pounds nitrogen per 1,000 square feet can be applied in a single application. The application timing and frequency would be adjusted accordingly.

Table 6.10. Suggested nitrogen fertility programs for a cool-season athletic field.

	Maintenance program[a] (lb N/1,000 sq ft)		
Application timing	**Normal** (predominantly silt/clay soil)[b]	**Intensive** (predominantly silt/clay soil)[b]	**Sandy or modified sand soil**[c]
After August 15	–	.5	.5
September	1	1	1
October	1	1	1
November	.5	1	1
April 15-May 15	.5	.5	.5
June 1-15	–	.5	.5
Seasonal N total	Up to 3 lb	Up to 4.5 lb	Up to 4.5 lb

[a]Intensively managed native soil- and sand-based fields require supplemental irrigation.
[b]These nitrogen levels can be applied with either water-soluble nitrogen (WSN) or slowly available nitrogen (contains 50 percent or more SAN) sources.
[c]On sand-based systems, any application more than 0.5 lb nitrogen per 1,000 sq ft should be made with 50 percent or more SAN sources on a 30-day minimum interval. Where WSN is used, levels should not exceed 0.5 lb per 1,000 sq ft every 15 days.

Table 6.11 Suggested nitrogen fertility programs for a bermudagrass athletic field.

Application timing	Maintenance Program[a] (lb N/1,000 sq ft) Predominantly silt/clay soil[b]	Sandy or modified sand soil[c]
April 15-May 15	.5-1	.5
June	1	1
July	.5-1	1
August	.5-1	1
Sept 1-15[d]	.5-1	–
Seasonal N total for non-overseeded fields	3-5	Up to 3.5
If overseeded with ryegrass[e]		
October-November	.5	.5-1
February-March	.5-1	.5-1
Seasonal N total for overseeded fields	4-6.5	4.5-5.5

[a]Intensively managed native soil- and sand-based fields require supplemental irrigation.
[b]These nitrogen levels can be applied with either water-soluble nitrogen (WSN) or sources containing 50 percent or more SAN.
[c]Any application more than 0.5 lb nitrogen per 1,000 sq ft should be made with a SAN source (containing 50 percent or more SAN) on a 30-day minimum interval. When WSN is used, levels should not exceed 0.5 lb per 1,000 sq ft every 15 days.
[d]The September application is suitable only if anticipated first fall killing frost date is after Oct. 20.
[e]Use the higher nitrogen levels on intensively trafficked fields only.

Sod Production Systems

Growing sod is quite simply a specialized form of "production agriculture," with a similar goal (i.e., yield) of any other crop. A harvestable sod of acceptable turf quality (high density, dark green and uniform color, pest-free, etc.) is the sign of a successful crop. Revenues are optimized by achieving rapid coverage of the turf; to accelerate harvest, it is common to net the sod either prior to planting or at harvest. As for any growing system, proper timing and appropriate application levels of nutrients are crucial to optimize nutrient use efficiency. Prior to seed or sprig establishment, soil tests should be performed to adjust pH and supplemental nutrient requirements (phosphorus and potassium, etc.) at planting using the standard guidelines presented in table 6.1. Netted sods can likely be produced within a calendar year, whereas non-netted sods will likely require some portion of a second growing season to complete establishment. Recommended nitrogen levels at the establishment of both cool- and warm-season turfgrasses were presented earlier in this chapter. Tables 6.12 and 6.13 detail seasonal nitrogen levels in the production of cool-season or warm-season sods.

Table 6.12. Recommended nitrogen levels for production of a cool-season turfgrass sod.

Timing of planting	Actual N (lb/acre)
At seeding[a]	40-60[b]
In seeding year of fall planting[c]	
Nov. 15-Dec. 15	40-60
First full year of establishment	
April 1-June 15	20-40
Aug. 15-Oct. 1	40-60
Nov 1-Dec. 1	40
Second year[d]	20-40/growing-month as needed to complete coverage

[a]Fall planting dates are optimal for rapid establishment; for spring plantings, continue first season fertility in August of that year.
[b]Apply no more than 40 lb of water-soluble nitrogen per acre in any single application; for levels more than 40 lb, use materials that are 50 percent or more SAN.
[c]Do not apply fertilizer to frozen soil.
[d]Second-year fertilization likely only required for non-netted sod.

Table 6.13. Recommended nitrogen levels for production of bermudagrass or zoysiagrass sods.

Timing of application	Bermudagrass	Zoysiagrass
	lb N/acre[a]	
Establishment by seed or sprigs in late spring/early summer	40-60	40-60
June	40	–
July	40	40
August	40	–

[a]Apply no more than 40 lb of water-soluble nitrogen per acre in any single application; for levels greater than 40 lb, use materials that are 50 percent or greater SAN.

Mowing

Standard Mowing Heights

The recommended mowing heights detailed in table 6.14 are recommendations for optimal growing periods and will vary depending on the cultivar and the use of the grass (lawn, golf or sports turf). In almost every instance, the listed grasses can be mowed taller than heights listed. However, maintaining turfgrasses within their recommended clipping height range during periods of optimal growth promotes turfgrass density by promoting lateral growth through tillers (i.e., daughter plants), rhizomes (belowground stems), or stolons (aboveground stems). Prior to and/or during environmental stress periods, raising the clipping height is a standard recommendation for all grasses in order to enhance survival. Therefore, prior to summer stress periods, the recommendation is to raise the cutting heights of cool-season grasses, and for non-irrigated turf, it is often suggested to refrain from mowing at all. For warm-season grasses, raise the cutting heights a few weeks prior to an anticipated frost date (and initiation of winter dormancy) in order to promote winter survival.

The standard recommendation is to never remove more than one-third of the leaf blade at any cutting event. Limiting leaf blade removal to this level prevents scalping and a drain on carbohydrate reserves to replenish the shoot system.

Table 6.14. Typical maintenance cutting heights for turfgrasses grown in the mid-Atlantic.[a]

Species	Cutting heights (inches)[b]
Creeping bentgrass	0.1-0.19, greens; 0.25-0.75, fairways
Fine-leaf fescues	1.5-2.5
Kentucky bluegrass, hybrid bluegrass	1.5-2.5
Perennial ryegrass	0.75-2
Bermudagrass	0.5-1 on athletic fields, golf fairways and tees; up to 2 on lawns and general-purpose turf
Centipedegrass	1.5-2.5
St. Augustinegrass	2-3
Zoysiagrass	0.5-1 on golf fairways and tees; up to 2 on lawns and general-purpose turf
Tall fescue	2-3

[a]Cutting height recommendations for optimal growing periods.
[b]Cutting heights shorter than 1 inch require a reel mower.

Equipment

Rotary mowers are the prevalent cutting units for the most acreage because they are generally inexpensive to both purchase and maintain. Rotary units clip grass by spinning a metal blade with a sharpened edge at high speed under a stationary deck. The cut is actually more of a “tear,” because the grass blades are removed simply by the impact of a solid object striking the leaf blade at a high speed. Maintaining a sharp and properly balanced blade is crucial to maintaining high turf quality and plant health. Mowing with a dull blade creates jagged wounds in the leaves that result in a low-quality turf that has increased potential for disease and environmental stress.

Flail mowers have multiple-levered blades on a spinning horizontal shaft. The blades are not intended to be sharpened and are designed to “give” if they hit a solid object; the deck is fully self-contained with no discharge point. Flail units are popular in maintaining unimproved turf areas such as highway rights of way where turf quality is not critical.

The cutting unit that provides the highest quality of cut is the reel unit that features a cylinder of curved blades that gathers and pinches leaves between the blade and a stationary, sharpened bedknife. Reel units are used on the highest-quality turf where cutting heights shorter than 1 inch are desired and the highest level of surface smoothness is required. Maintaining properly adjusted and sharpened blades and bedknives is crucial to achieving the high-quality cut desired with this type of cutting unit.

Clipping Management

Returning clippings is desirable whenever possible, and the only situation where clippings are recommended for collection is in putting green management for golf turf where they would disrupt playability of the putting surface. Clippings are essentially controlled-release fertilizer, containing approximately 4 percent nitrogen, 0.5 to 1 percent phosphorus and 2 percent potassium by weight.

A common misconception is that clippings contribute to thatch — a layer comprised primarily of slow-to-decay stems that forms between the turfgrass canopy and the soil surface. Thatch is primarily composed of stems (rhizomes, stolons, and crowns) that resist microbial degradation. Therefore, all grasses capable of lateral growth by way of rhizomes and/or stolons can become thatchy, especially if they are aggressively fertilized. If properly mowed (i.e., following the "1/3 mowing rule" of leaf removal), clippings readily degrade and do not contribute to thatch. However, if mowing is sporadic and the turf is allowed to produce seedheads, thatch buildup is likely to occur over multiple seasons. Another tempting reason to collect clippings is to reduce the potential of spreading weeds or diseases throughout the lawn. However, research has shown that the advantages of returning clippings far exceed any concerns with promoting weed or disease pressure in the turf.

It is now common that many versions of the standard rotary mowers can serve as "mulching mowers" by way of modifications of their decks and blades (figure 6.16).

Figure 6.16. A mulching mower chops turfgrass clippings into fine particles that are quickly decomposed by microbes in the soil.

The ability to chop clippings into very small leaf pieces accelerates leaf decomposition in the soil, thus improving lawn appearance and promoting a healthy soil microbial population. If the 1/3 rule cannot be followed for a mowing event and piles of clippings remain on the lawn (figure 6.17), it is important to remove them because they block sunlight and encourage disease due to the elevated temperature and moisture under the pile. In all cases where clippings are collected, they should be properly composted (detailed in chapter 9) rather than piled in waste areas and/or bagged for deposit in landfills.

Figure 6.17. When the "1/3 mowing rule" is violated, it is important not to leave the piled clippings on the lawn because they can damage the underlying turf. Collect and compost this material.

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Chapter 7. The Ornamental Landscape

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Introduction

Fertilization is an important part of landscape management. Plants need nutrients to survive, and while many of the essential elements are already in the soil, fertilizer is often added to supplement those nutrients. Fertilization is a common cultural practice often made complex and confusing by the wide variety of fertilizer products on the market. The simple objective is to supply plants with nutrients in a form they can use at the time they most need them in a way that produces a healthy, attractive landscape while being environmentally sound.

Site Assessment and Environmental Design

Site Assessment

A site assessment provides critical information for any landscape nutrient management plan. The information from a site assessment supports short- and long-term nutrient planning as well as the environmental sustainability of the overall plan. A site assessment should be conducted every five to seven years and should include information that will assist the landscape manager in making the best nutrient management decisions. Information to include in a site assessment:

- Site boundaries.
- Rainfall amount and distribution throughout the year.
- Water movement (on and through/off site for runoff and leaching potential).
- Management area delineation and size (e.g., turf, annuals, natural areas, etc.).
- Categories of plants (both existing and future additions; see "Plant Categories," later in this chapter).
- Condition of existing plants (healthy, stressed, etc.).
- Previous management strategies.
- Results of soil test(s).
- Site accessibility.
- Site management goals, short- and long-term.
- Special landscape situations.
- Overall site goals and objectives.
- Location relative to environmentally sensitive areas or proximity to storm drainage and bodies of water.

Urban Soils

There are many special situations to consider in the ornamental landscape, and one of the most pressing issues is the fact that the growing medium is usually a drastically altered urban soil where much of the native topsoil is removed during development (see chapter 3). Subsoil — deficient in essential nutrients and lacking desirable physical properties — becomes the new topsoil in many situations. Or perhaps soil of unknown origin and composition is brought onto the site. Construction is also a factor affecting the performance of these soils. Urban soils tend to be heavily compacted, poorly aerated, poorly drained, and low in organic matter. Fertilization of landscape plants will not be effective until these adverse growing conditions are corrected. In fact, unhealthy soil cannot sustain healthy plants and can lead to nutrient pollution of surface and groundwater through runoff and leaching of the applied nutrients.

Site Design

Nutrient management is also affected by proper environmental design. Plants with similar nutrient needs should be grouped together in the landscape when possible to avoid improper rates of fertilizer application and to utilize fertilizer most efficiently. Landscape areas with mixed categories of plants are more challenging to manage. These areas may need to be subdivided into smaller management areas based on plant category and nutrient needs, or they may need to be fertilized using a "middle-of-the-road" approach where all plants get some nutrients but none is managed optimally because of the diverse plant mix.

BMPs

Special landscape design features such as buffers, bioretention or rain gardens, and green roofs are commonly used in landscapes to manage stormwater (see chapter 12). They are called landscape best management practices (BMPs) and are used to slow down stormwater and provide an opportunity for it to be filtered by the plants, soil, and microorganisms before it either runs into natural surface water sources or percolates down to recharge groundwater sources. Plants in these BMPs should be fertilized only once when they are planted (usually in the individual planting hole) in order to get them established. These plants act as biofilters, absorbing nutrients from the stormwater; they DO NOT need any additional nutrient applications.

Correct Plant Selection and Planting

Plant Selection

Correct plant selection is the first critical step to a successful landscape.

- Choose plants that are adapted to the environmental and site conditions.
- Select plants that naturally have few pest problems or are pest-resistant.
- Choose plants that meet the landscape goals and design parameters.
- Install plants at the correct spacing to account for their mature size, avoid crowding, and reduce long-term maintenance.

Plant Categories

Following are some basic definitions that apply specifically to landscape plants:

- **Annuals** are plants that complete their entire life cycle in one growing season. They germinate from seed, flower, set seed, and die in the same year.
- **Biennials** are plants that live for two years. They usually form vegetative growth in the first year and flowers and fruit/seed the second year.
- **Perennials** are plants that live for three or more years.
- **Bulbs** are short, modified, underground stems surrounded by (usually) fleshy, modified leaves that contain stored food for the shoot within.
- **Herbaceous plants** lack a permanent woody stem and die back to the ground every winter.
- **Woody plants** have permanent woody stems, are perennial, and go dormant in the winter but do not die back to the ground. These plants grow from aboveground stems year after year and include shrubs, trees, and some vines.

Planting

No amount of fertilizer will improve a plant's health or growth if that plant is installed incorrectly. Correct planting is essential for growing healthy roots and getting a plant established quickly in a landscape. Without a healthy root system, a plant can't absorb nutrients efficiently or effectively. In addition, many nutrient applications are made at the time of planting, either in the planting hole or to the planting bed area. See Appendix 7-A, *Tree and Shrub Planting Guidelines*, Virginia Cooperative Extension publication 430-295 for details on correct planting.

Determining the Need to Fertilize

Plants need 17 elements for normal growth. These are divided into two groups based on the amount of each needed by plants. Carbon, hydrogen, and oxygen are found in air and water. Nitrogen, potassium, magnesium, calcium, phosphorous, and sulfur are found in the soil. The six elements found in soil are used in relatively large amounts by plants and are called macronutrients. There are eight other elements that are used in much smaller amounts and are called micronutrients, or trace elements. The micronutrients, which are found in the soil, are iron, zinc, molybdenum, manganese, boron, copper, cobalt, and chlorine. All 17 elements — both macronutrients and micronutrients — are essential for plant growth. See chapter 4 for more detailed information.

Fertilizer should be applied when plants need it, when it will be most effective, and when plants can readily absorb it.

How and when to fertilize landscape plants depends on factors like:

- Maintenance objectives: stimulate new versus maintain existing growth.
- Plant age: generally more for younger and less for older woody plants.
- Plant stress levels: stressed plants can sometimes benefit from additional fertilizer.

In addition to soil testing (see chapter 5), a visual inspection of plants is often used in making fertilization decisions. Look for:

- Poor or chlorotic leaf color (pale green to yellow).
- Reduced leaf size and retention.

- Premature fall coloration and leaf drop (shrubs and trees).
- Overall reduced plant growth and vigor.

Foliar or tissue analysis can also be used to help determine whether supplemental fertilization is needed (see chapter 5). Avoid late-summer or early-fall fertilization while plants are still actively growing because this stimulates late-fall growth, which can be killed by freezing temperatures.

Soil Tests (See chapter 5.)

The purpose of a soil test is to provide information to make wise choices regarding fertilizer and soil amendment. An initial soil test will provide baseline information on the condition of the soil and can include soil type; pH; available phosphorus, potassium, calcium, and magnesium; organic matter; and soluble-salt levels. Soil tests can also provide fertilizer and lime recommendations based on the specific crop being grown. Subsequent tests can be used to monitor changes and improvements in soil health.

For ornamental landscape areas, soil testing should be done every three to five years. Each management area in the landscape should have its own test in order to customize the nutrient management plan for that area and avoid incorrect applications. For example, separate tests should be done for the turf, perennial beds, tree and shrub or naturalized areas, and annual beds. Soil test guidelines should be closely followed to assure the greatest plant response with the least chance of plant damage or possibility of water pollution. Many soils in Virginia have adequate phosphorus levels, making it unnecessary to apply more through fertilizers.

Soil sample kits are available at local Extension offices and most libraries. There are private companies that also do soil testing. Fees vary. For best results, carefully follow the instructions given in the soil sample kit. The accuracy of the test is a reflection of the soil sample taken. Be sure the sample is representative of the area to be treated.

Soil pH, a measure of acidity, has a significant impact on the plant's ability to use nutrients. Most ornamental landscape plants prefer a pH range of 5.5 to 7.0. Within this range, the essential nutrients are available to most plants, and soil microorganisms can carry out their beneficial functions.

If the soil is too acidic (i.e., low pH), the pH can be raised by adding lime. Lime applications can be made at any time of the year, but it is ideal to apply lime in the fall and winter months when there are several weeks to months for the chemical reactions to take place before the next growing season.

If the soil is too alkaline (i.e., high pH), the pH can be lowered by adding sulfur. It is not practical or advisable to change the soil pH more than one to two levels. Whenever possible, it is best to select plants that grow well in the existing conditions.

Factors Affecting Nutrient Uptake

Numerous factors affect nutrient uptake by plants. The most important factors include:

- Fertilizer form: inorganic, fast-release, or liquid forms are usually absorbed faster than organic, slow-release, or dry forms.
- Soil type: clay particles and organic matter adsorb or bind more nutrients than sand, so fertilizer application needs to be more frequent in sandy soils but with lower rates each time due to leaching potential.
- Soil moisture content and soil temperature: nutrient uptake is faster in moist, warm soils.
- Fertilizer placement and application timing and method.
- Plant vigor: plants under stress are less able to take up available nutrients due to damaged or reduced root systems.

Fertilizers

Forms (See chapter 8.)

All fertilizers are labeled with three numbers that give the percentage by weight of nitrogen (N), phosphate (P_2O_5), and potash (K_2O).

1. **Nitrogen** is important for leaf and stem growth and provides the rich green color in a plant.
2. **Phosphorous** (derived from phosphate) provides for root, flower, and fruit growth.
3. **Potassium** (derived from potash) helps build plant tissue and aids in disease resistance, cold hardiness, and the production of chlorophyll.

Proper use of nutrients can control rate and character of plant growth.

The analysis, or grade, of a fertilizer refers to the minimum amounts of nitrogen, phosphorus (in the form

P_2O_5), and potassium (in the form K_2O) in the fertilizer. The analysis is always printed on the fertilizer label. A fertilizer with a 10-10-10 analysis contains 10 percent nitrogen, 10 percent P_2O_5, and 10 percent K_2O. For example, in 100 pounds of 4-8-12, there are 4 pounds of nitrogen, 8 pounds of P_2O_5, and 12 pounds of K_2O.

Fertilizers may be divided into two broad categories: natural and synthetic. Natural fertilizers generally originate from unprocessed organism sources such as plants or animals. Synthetic fertilizers are manmade or processed. Synthetic fertilizers can be organic (e.g., urea) or inorganic (e.g., superphosphate). Natural fertilizers commonly misnamed "organic" can also contain inorganic ores such as rock phosphate.

Most nutrients from living or once-living organisms are not readily available for plant growth because they are bound in organic molecules such as proteins and amino acids and in structures such as cell walls. These nutrients are released only by microorganisms decomposing the organic matter. Cottonseed meal, blood meal, bone meal, hoof and horn meal, fish emulsion, and all manures are examples of organic fertilizers. Organic fertilizers usually contain relatively low concentrations of actual nutrients, but they perform other important functions that the synthetic formulations do not. These functions include increasing organic content of the soil, improving physical structure of the soil, and increasing bacterial and fungal activity.

"Slow-release" fertilizers may be synthetic or natural. Because nutrients are released over an extended period of time, slow-release fertilizers do not have to be applied as frequently as other fertilizer types. Also, higher amounts of slow-release fertilizer can be added at each application without risking injury to plant roots. Slowly released nitrogen is used more efficiently because a higher percentage is absorbed by plants. The higher efficiency of slow-release fertilizers means less nitrogen is available to contribute to pollution of surface and groundwater. While slow-release fertilizers are generally more expensive, when an analysis is done to determine the cost of the nitrogen absorbed by the plant, the unit cost is actually less for slow-release materials.

"Water-soluble" or "liquid" fertilizers (which are not the same) are applied either to the soil or foliage. Numerous water-soluble fertilizer formulations are available, from plant starter, high-nitrogen fertilizers to minor element formulations. Chelated iron is used extensively for prevention and control of iron deficiency in azalea, rhododendron, and other popular ornamentals.

"Combination" products that contain fertilizer mixed with a herbicide, insecticide, or fungicide should be considered carefully. Herbicides, insecticides, and fungicides should be selected and applied based on the crop being grown and the pest(s) being managed. Often, the timing for a fertilizer application does not coincide with that of another product, and off-target or unintentional injury to the plant could result from a combined application.

Placement

Because most landscape plant roots grow in the top 12 inches of soil, surface or shallow application (6 to 9 inches) is recommended. Fertilizer can be added to an individual planting hole, incorporated into the planting hole backfill or into an entire bed area, or spread over the plant's root zone. With the last method, the fertilizer should not be concentrated around the stem or trunk of a plant but where the majority of the absorbing roots are actively growing. For annuals, this is from the canopy edge extended out by 6 inches. For perennials, this is from the canopy edge extended out 6 to 12 inches. For trees and shrubs, fertilizer should be applied over an area extending two to three times the canopy spread. Research has shown that tree roots grow far beyond the drip line of established trees. Do not concentrate fertilizer in holes drilled under the tree canopy, but instead use a broadcast application beyond the tree canopy for better growth.

Application Timing

Research shows that plants actively absorb nutrients from the soil during the growing season and require few nutrients during the dormant winter season. In general, apply fertilizer as soon as plants begin breaking dormancy in the spring and avoid fertilizing after the first fall frost, which signals plants to slow growth in preparation for winter dormancy. Late-summer and early-fall fertilization may stimulate new growth that is not winter hardy.

Do not fertilize during stressful environmental conditions. Drought causes plants to slow their growth. That, combined with insufficient soil moisture, reduces nutrient absorption and could increase the potential for root injury from fertilizers. Too much rainfall or irrigation can cause nutrients to run off or leach, potentially contaminating water sources. Incorporate the fertilizer into the bed or planting hole when there is frequent rain or irrigation to avoid runoff or leaching problems.

The frequency of fertilization depends on the type of plants being fertilized and the type of fertilizer used. Slow-release fertilizers are commonly recommended so that one application lasts for the entire growing season. If general-purpose, water-soluble fertilizers are used, two or three applications applied four to six weeks apart may be needed to make it through the growing season. Fertilizer should be applied to newly planted landscape ornamentals to help them establish quickly.

Application Methods

Five methods — (1) liquid injection, (2) drill hole or punch bar, (3) surface application or fertilizer stakes or spikes, (4) foliar spraying, and (5) tree-trunk injection or implants — are discussed here. Each serves a specific role depending on the site and plant health. Table 7.1 summarizes the advantages and disadvantages of the five application methods. Regardless of the method selected, the soil should be moist at the time of fertilization to prevent fertilizer injury to the plant.

1. **Liquid injection** (primarily for trees). Through liquid injection into the soil, fertilizer solutions are placed in the root zone. This is an excellent method for correcting nutrient deficiencies. Injection sites should be 2 to 3 feet apart — depending on pressure — and 6 to 9 inches deep. Fertilizing deeper than 9 inches may place the fertilizer below the absorbing roots, preventing plant use. When using this method in summer or during periods of drought, the soil should be moist before application.

2. **Drill hole or punch bar** (primarily for trees). A major advantage of the drill-hole system is the opening of heavy, compacted soils, which allows air, moisture, and fertilizer to move into the soil. The drill holes should be placed in concentric circles or in a grid system around the main stem beginning 3 to 4 feet from the main stem and extending beyond the drip line (see figure 7.1). Space the holes 2 feet apart and drill them 6 to 9 inches deep. The recommended rate of fertilizer for the area should be uniformly distributed among the holes and is based on the root-zone space under the tree (and not the trunk diameter). The holes can be filled either with organic material such as compost or inorganic materials such as gravel, sand, or calcined clay.

3. **Surface application.** A broadcast application of granular fertilizer at the appropriate rate and time is made to the ground surface or on top of mulch in landscape beds. It is best to water the fertilizer in slowly, soon after application. This method is very common, but the results can be slow because it takes time for the nutrients to filter into the soil and to the absorbing roots.

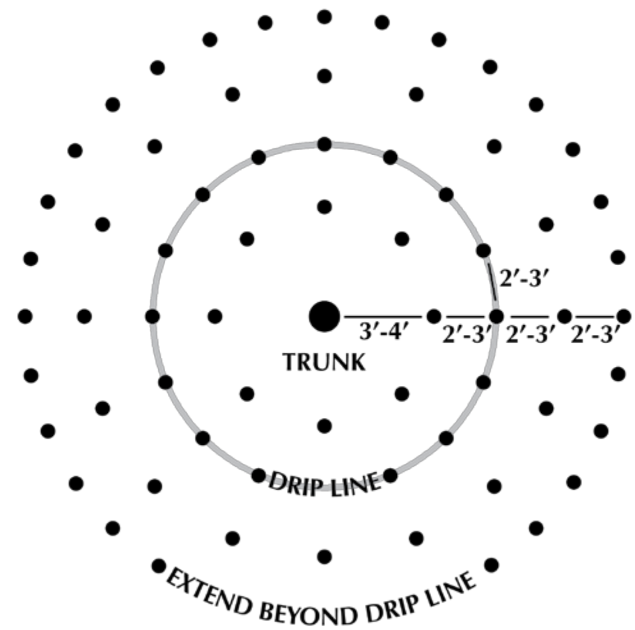

Figure 7.1. Liquid injection drill hole or stake diagram.

4. **Fertilizer stakes or spikes.** Fertilizer in the form of stakes or spikes, is driven into the soil in a grid pattern similar to that made with liquid injection fertilizer applications. Because lateral fertilizer movement is limited in soil, root system to fertilizer contact is reduced with this method. The general product recommendation of one or two stakes per inch of trunk diameter often does not provide an adequate fertilizer amount or efficient distribution.

5. **Foliar spraying.** Spraying liquid or water-soluble fertilizer on the foliage is best for correcting deficiencies of minor elements, especially of iron and manganese. Absorption begins within minutes after application, and with most nutrients, it is completed within one to two days. Foliar nutrition can be a supplement at a critical time for the plant but cannot replace soil fertilization. This method should not be used as a means of providing all the nutrients required by plants. Several applications during a growing season may be necessary. This method is generally not practical for large landscape trees.

6. **Tree-trunk injection or implants.** The infusion of liquid or implants of fertilizer directly to the tree trunk is often the best method for correcting iron and manganese problems in large landscape trees. This method is especially useful in areas of adverse soil pH, high moisture, or where other means of applica-

tion are not practical. The wounds or holes caused by the injections to the trunk should close within a growing season. Monitoring the wounds until they are healed is recommended to make sure insects or diseases do not become a problem.

Table 7.1. Advantages and disadvantages of application methods.

Application method	Advantages	Disadvantages
Subsurface	• Aerates soil. • Convenient.	• Special fertilizer and drilling or soil injection equipment needed.
Foliar sprays	• Relieves symptoms of micronutrient deficiencies.	• Temporary benefits. • Doesn't address underlying soil problem.
Injection and implantation	• Relieves deficiency symptoms.	• Temporary benefits. • Wounds create entry for insects/ diseases.

Source: Virginia Cooperative Extension publication 430-018 (VCE 2009a).

Overfertilization

Many synthetic fertilizers are salts, much like our familiar table salt, except that they contain various plant nutrients. If the concentration of fertilizer is too high, and if tender plant roots are close to the fertilizer granules, water is drawn from these roots. Plant cells in these roots begin to dehydrate and collapse. The plant roots are "burned" or dried out to a point where they cannot recover. Foliar injury, often in the form of marginal leaf burn, is also a result of too much fertilizer. Newly transplanted ornamentals are under stress while they are trying to adapt to their new location, and they can be easily injured by overfertilization. Reduce fertilizer rates when plants are growing in restricted areas (sidewalk cuts, parking lot islands) or where roots of multiple plants overlap. It is important to apply fertilizer at the proper time and rate.

Overfertilization can cause other problems in addition to plant injury. Avoid getting fertilizer on sidewalks and driveways where it can easily wash into storm drains and, eventually, into creeks, streams, and rivers. Nutrients, particularly nitrogen, become a water quality problem through leaching or run-off.

Specific Fertility Needs

Annuals and Bedding Plants

Generally, a slow-release, complete fertilizer at a rate of 2 to 4 pounds of nitrogen per 1,000 square feet is incorporated into the bed at planting time for season-long nutrients. Sometimes a liquid or water-soluble fertilizer is applied at 0.5-1.0 pound of nitrogen per 1,000 square feet at planting to jump-start the annuals until the slow-release fertilizer takes effect. Additional over-the-top fertilizer applications are not recommended because damage can occur to the plants when fertilizer contacts the stems, blooms, or foliage.

Bulbs

Avoid high-nitrogen fertilizers, which can cause foliage growth at the expense of blooms. A single fall application of 1 to 2 pounds of nitrogen per 1,000 square feet of a slow-release, complete fertilizer incorporated into the bed or planting hole at planting time is best. Several formulations of bulb fertilizer are available, like 9-9-6, 4-10-6, 5-10-20, or 10-10-20. They often go by names like "bulb food," "bulb booster," or "bulb tone." The common formulation 9-9-6 is ideal for most types of bulbs, including garden lilies, tulips, etc. For daffodils, use slow-release 5-10-20 or 10-10-20, if it is available. A topdressing of well-rotted manure or compost applied in the fall is also beneficial for bulbs (see chapter 9).

Perennials

Generally, a slow-release, complete fertilizer at a rate of 1 to 4 pounds of nitrogen per 1,000 square feet is incorporated into the bed or planting hole at planting time. If planting in the fall (September through November), use 1 pound of nitrogen incorporated, followed by a second application of 2 to 3 pounds of nitrogen broadcast the following spring (March or April). Always water the bed after applying fertilizer to established plants to wash the fertilizer off the foliage and prevent injury. If planting in the spring, use 3 to 4 pounds of nitrogen per 1,000 square feet incorporated. This should be enough to carry plants through the summer. Do not exceed 4 pounds of nitrogen per 1,000 square feet per year.

Shrubs and Trees

Generally, a slow-release, complete fertilizer at a rate of 1 to 4 pounds of nitrogen per 1,000 square feet is incorporated into the bed or planting hole at planting time or surface-applied around the canopy edge or drip line of the plant. If planting in the fall (September through November), use 1 pound of nitrogen per 1,000 square feet, followed by a second application of 2 to 3 pounds of nitrogen the following spring (March or April).

Additional applications of 2 to 3 pounds of nitrogen can be made each spring for the first three to five years, particularly on young trees to encourage establishment and quick growth. For established shrubs and trees, use 2 to 4 pounds of nitrogen per 1,000 square feet in the spring (March or April), every three years. Do not exceed 4 pounds of nitrogen per 1,000 square feet per year. Trees growing in turf areas will obtain nutrients from the fertilizer that is applied to the turfgrass. Do not apply excess fertilizer to turf in an effort to fertilize trees because injury to the turf may occur.

Some species such as roses (*Rosa* spp.), red-tip photinia (*Photinia* x *fraseri*), and English laurel (*Prunus laurocerasus*) are more demanding, while others like ornamental grasses, silver maple (*Acer saccharinum*), willow (*Salix* spp.), privet (*Ligustrum* spp.), forsythia (*Forsythia* spp.), hollies (*Ilex* spp.), and junipers (Juniperus spp.) require less fertilization. Species like azalea, dogwood, hemlock, and rhododendron have shallow root systems that are easily damaged by fertilizers. Here, split- or low-rate applications of slow-release fertilizers are recommended. A low-rate application (1 pound of nitrogen per 1,000 square feet) may also be appropriate for shrubs and trees under stress, such as from disease, drought, construction, or storm damage.

Plants growing in shade generally require less fertilizer than those growing in the sun, while those growing in sandy soils generally require more frequent fertilization than those in clay soils, due to nutrients leaching from sandy soils. Water-soluble fertilizers should be applied in split applications to minimize leaching potential and, where possible, use slow-release nitrogen sources on sandy soils.

Fertilizer Calculations (See chapter 10.)

The quantity of fertilizer applied on established ornamentals depends on:

- The analysis of the fertilizer used.
- The area fertilized.
- The amount of growth desired.

Nitrogen controls vegetative growth, so application rates are based on this primary nutrient. Low rates of fertilizer are recommended, particularly for a lower maintenance landscape. As the application rate of fertilizer increases, so does the amount of new growth, which requires more water, more fertilizer, and more pruning.

Area

To determine how much fertilizer to apply, first measure the area to be fertilized. This involves measuring the length and width of a bed in linear feet and multiplying the two numbers to obtain the square footage. Landscape beds can be addressed individually, or several can be added together for total square footage. Few plant beds are perfectly square or rectangular, so square off the rounded areas to simplify the calculations. See Appendix 7-B, Maryland Cooperative Extension publication, *How to Measure Your Yard* for additional information (*www.hgic.umd.edu/_media/documents/hg306.pdf*).

Trees growing within a bed can be included in the bed estimate or, if they require special fertilization, estimate their canopy area by measuring the distance from the trunk to the drip line (this is called the radius). Then use the geometric formula for the area of a circle to calculate the area of the canopy (3.14 x radius^2). For example, if the distance from the main trunk to the drip line of a tree is 20 feet, the area beneath the canopy is 3.14 x (20 x 20) = 1,256 square feet. See the guidelines above for additional recommendations on tree fertilization amounts and placement.

Conversions

To convert from actual amount of nitrogen recommended to amount of fertilizer, divide the amount of nitrogen desired per 1,000 square feet by the fertilizer analysis or grade. For example, if you have an 18-6-12 fertilizer, how much is needed to apply 3 pounds of nitrogen per 1,000 square feet? Divide 3 pounds of nitrogen by 0.18 (percentage of nitrogen in fertilizer) to get 17 pounds of fertilizer.

Fertilizer Selection

Fertilizers differ in nutrient content and release duration. The type of fertilizer selected is based on:

- Cost.
- The types of plants being fertilized.
- The type of growth response desired.
- Time of year.
- Application methods.

- Equipment cost.
- Proximity to water sources.
- Effect of soil type and pH.
- Type of deficiency.
- The existing nutrient content of the soil.

To determine whether a granular fertilizer has slow-release properties, check the analysis label. Nitrogen listed in the form of ammoniacal nitrogen indicates that the product probably isn't slow-release. If the nitrogen is listed as being derived from urea, urea-formaldehyde, IBDU (isobutylenediurea), or sulfur-coated urea, the release duration of the product will be increased. Granular slow-release fertilizers can last from three to twelve months after application.

Other commonly available, slow-release fertilizers on the market include Osmocote granules, Osmocote tablets, Jobe's Spikes, Woodace briquettes, Agriform tablets, and Milorganite. These fertilizers generally cost more per pound than general-purpose granular fertilizers such as 10-10-10 or 12-4-8, but they also last longer and don't need to be applied as frequently. Organic fertilizer sources such as bone meal, cottonseed meal, and animal manures can also be used. Compost is another good source of slowly available nutrients.

Tables 7.2 - 7.5 will help with fertilizer selection.

Table 7.2. Chemical fertilizers, analysis, speed of reaction, and effect on soil pH.

Fertilizer	Analysis	Speed of reaction and leaching	Soil reaction	Pounds of each fertilizer required to get 1 lb N/1,000 sq ft
Ammonium nitrate	33-0-0	Rapid	Acidic	3.0
Ammonium sulfate	20-0-0	Rapid	Very acidic	5.0
Urea	46-0-0	Rapid	Slightly acidic	2.0
Ureaformaldehyde	38-0-0	Slow	Slightly acidic	2.5
Di-ammonium phosphate	18-46-0	Rapid	Acidic	5.5
Calcium nitrate	15-0-0	Rapid	Alkaline	6.5
Potassium nitrate	13-0-44	Rapid	Neutral	7.5
10-10-10	10-10-10	Rapid	Varies with N source	10.0
Osmocote	18-6-12	Slow	Acidic	5.5

Source: Virginia Cooperative Extension publication 430-018 (VCE 2009a).

Table 7.3 Average nutrient content of various organic fertilizer sources.

Fertilizer source	% Nitrogen (N)	% Phosphorus (P_2O_5)	% Potash (K_2O)
Blood, dried	13.0	—	—
Bone meal, raw	3.5	22.0	—
Bone meal, steamed	2.0	28.0	—
Cottonseed meal	6.6	2.5	1.5
Fish scrap, dried	9.5	6.0	—
Soybean meal	7.0	1.2	1.5
Horse manure	0.7	0.3	0.6
Cow manure	0.6	0.2	0.6
Pig manure	0.5	0.3	0.5
Sheep manure	0.8	0.3	0.9
Chicken manure	1.1	0.8	0.5
Duck manure	0.6	1.4	0.5

Source: Georgia Cooperative Extension bulletin 1065 (2009).

Table 7.4. Recommended fertilization rates for newly planted ornamental plants during the first growing season (use only one of the fertilizers listed at the rate recommended).

Plant type/size	12-4-8	16-4-8	10-10-10	Application frequency
	Application rate/plant*			
1-gallon shrubs	1 tsp	1 tsp	1 tbsp	March, May, July
3-gallon shrubs	2 tsp	2 tsp	2 tbsp	March, May, July
5-gallon shrubs	3 tsp	3 tsp	3 tbsp	March, May, July
Trees under 4 feet	1 tbsp	1 tbsp	2 tbsp	March, July
Trees 4-6 feet	3 tbsp	3 tbsp	5 tbsp	March, July
Trees 6-8 feet	4 tbsp	4 tbsp	6 tbsp	March, July
	Application rate 100/sq ft			
Ground covers, annuals, and herbaceous perennials	0.5 lb	0.5 lb	1.0 lb	Each 4-6 weeks

Source: Georgia Cooperative Extension bulletin 1065 (2009).* When using slow-release or soluble fertilizers, follow label recommendations for application rate.

Table 7.5. Recommended application rates of various general-purpose granular fertilizers on established ornamental plants in the landscape.

	Application rate[a]				
	1,000 sq ft		**100 sq ft**		**10 sq ft**
Source	**Pounds**	**Cups**	**Pounds**	**Cups**	**Tablespoons**
10-10-10	10.0	20.0	1.0	2.0	4.0
8-8-8	12.5	25.0	0.5	2.5	5.0
13-13-13	6.0	12.0	0.75	1.5	3.0
12-3-6	6.0	12.0	0.75	1.5	3.0
12-4-8	6.0	12.0	0.75	1.5	3.0
12-6-6	6.0	12.0	0.75	1.5	3.0
16-4-8	6.0	12.0	0.5	1.0	2.0
4-12-12	25.0	50.0	2.5	5.0	10.0
5-10-10	20.0	40.0	2.0	4.0	8.0

Source: Georgia Cooperative Extension bulletin 1065 (2009).

[a]This rate will supply 1 pound of actual nitrogen per 1,000 square feet. For optimum growth of young shrubs, ground covers, and trees, three to five applications are recommended at six- to 10-week intervals from March to August. Application frequency varies with the amount of slow-release nitrogen in the product, so consult the label for specific recommendations. Established trees and shrubs will benefit from one to two applications during the growing season. Annual flowers and roses should receive applications at four- to six-week intervals from March to August. When using slow-release or specialty fertilizers, follow the manufacturer's recommendation on the container.

Organic and Other Soil Amendments (See chapter 9.)

Amendments can improve soil structure, drainage, and nutrient-holding capacity, making the soil a more favorable place for root development and nutrient uptake. Soil improvement or building is a continual process in the landscape. The regular addition of manures, compost, cover crops, other organic matter, and amendments can raise the soil nutrient level to a point where the addition of synthetic fertilizers is greatly reduced, and in some cases, no longer needed. This highly desirable soil quality does not come about with a single or even several additions of organic material, but rather requires a serious, long-term program.

Nutrient Deficiencies

Each of the 17 essential elements has a specific role in plant growth. A deficiency or an excess of any one will impair plant growth until the problem is corrected. Iron and manganese are the micronutrients most often deficient in landscape plants. An adjustment in soil pH usually corrects deficiencies of the micronutrients. Some symptoms of nutrient deficiency in woody plants are listed below (North Carolina Cooperative Extension Service 1996).

Table 7.6. Element and foliar deficiency symptoms.

Element	Foliar deficiency symptoms
Nitrogen (N)	• General yellowish-green; more severe on older leaves. • Stunted growth with small and fewer leaflets. • Early leaf drop. • Dark green to blue-green; slightly smaller leaves. • Veins, petioles, or lower surface may become reddish-purple, especially when young. • Death of lower needles in pines.
Potassium (K)	• Partial chlorosis of most recently matured leaves in interveinal area beginning at tips, followed by necrosis. • Older leaves may become brown and curl downward.
Calcium (Ca)	• Death of terminal buds. • Tip die-back. • Chlorosis of young leaves. • Leaves may become hard and stiff. • Root injury is the first apparent symptom.
Magnesium (Mg)	• Marginal chlorosis on older leaves, followed by interveinal chlorosis. • Margins may become brittle and curl upward.
Sulfur (S)	• Uniform chlorosis of new leaves. • Older leaves are usually not affected.
Iron (Fe)	• Interveinal chlorosis of young leaves (sharp distinction between green veins and yellow tissue between veins). • Older basal leaves greener, exposed leaves blanched.
Manganese (Mn)	• Interveinal chlorosis of young leaves beginning at margins and progressing toward midribs, followed by necrotic spots.
Zinc (Zn)	• Young leaves may be yellow, small, deformed, or mottled with necrotic spots. • May be a tuft of leaves at shoot tips.
Boron (B)	• Terminal growth dies; later growth that develops has sparse foliage. • Young leaves may be red, bronzed, or scorched. • Leaves may be small, thick, distorted, or brittle.
Copper (Cu)	• Rosetting of foliage, terminal growth may die. • Leaf symptoms not usually pronounced, but veins may be lighter than blades.
Molybdenum (Mo)	• Cupping of the older leaves. • Marginal chlorosis followed by interveinal chlorosis.

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Appendix 7-A

Original publication available at: *http://pubs.ext.vt.edu/430/430-295/430-295.html*

Virginia Cooperative Extension

PUBLICATION 430-295

Tree and Shrub Planting Guidelines

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Plant and Site Selection

Select trees and shrubs well-adapted to conditions of individual planting sites. Poorly-sited plants are doomed from the start, no matter how carefully they're planted.

Test soil drainage before planting. Dig a test hole as deep as your planting hole and fill with water. If water drains at a rate of less than one inch per hour, consider installing drainage to carry water away from the planting hole base, or moving or raising the planting site (berm construction).

Also consider using more water-tolerant species. For trees, try red maple, sycamore, bald cypress, willow oak, or river birch. For shrubs, try inkberry, redtwig dogwood and buttonbush. Avoid dogwoods, azaleas, boxwoods, Japanese hollies, and other plants that don't like "wet feet" where drainage is poor.

Examine soil for compaction before planting. If soils are compacted, consider replacement with a good loam soil, or incorporation of several inches of an organic material such as composted yard waste to a depth of at least 8 inches over the entire planting area. Do not incorporate small quantities of sand - compaction will increase and drainage decrease.

Site Preparation

Dig shallow planting holes two to three times as wide as the root ball. Wide, shallow holes encourage horizontal root growth that trees and shrubs naturally produce.

In well-drained soil, dig holes as deep as the root ball. In poorly-drained heavy clay soil, dig holes one to two inches shallower than the root ball. Cover the exposed root ball top with mulch.

Don't dig holes deeper than root balls or put loose soil beneath roots because loose soil will compact over time, leaving trees and shrubs planted too deep. Widen holes near the soil surface where most root growth occurs. Score walls of machine-dug (auger, backhoe) holes to prevent glazing.

Backfill holes with existing unamended soil. Do not incorporate organic matter such as peatmoss into backfill for individual planting holes. Differences in soil pore sizes will be created causing problems with water movement and root growth between the root ball, planting hole, and surrounding soil.

Backfill half the soil, then water thoroughly to settle out air pockets. Finish backfilling, then water again. Cover any exposed root ball tops with mulch.

Incorporate slow-release granular fertilizers into backfill soil to provide nitrogen, or if a soil test indicates a need for phosphorus or potassium. Avoid using fast-release agronomic fertilizers that can dehydrate tree roots. Use no more than 1# actual nitrogen per 1,000 ft. of planting hole surface. (Example - if using 18-6-12 with a 5' diameter hole, incorporate 0.3 oz. per planting hole.)

Tree and Shrub Preparation

Closely inspect the wrapping around root balls of B&B (balled and burlapped) trees and shrubs. Growers use many synthetic materials, as well as burlap treated to retard degradation, to wrap root balls. Many of these materials will not degrade. To insure root growth into surrounding soil, remove pinning nails or rope lacing, then cut away or drop the wrapping material to the bottom of the planting hole, backfilling over it.

Wire baskets used to protect root balls degrade very slowly underground. Remove the top 8-12 inches of wire to keep equipment from getting caught in wire loops, and surface roots from girdling.

Remove all rope, whether jute or nylon, from trunks. Again, degradation is slow or nonexistent, and ropes can girdle trunks and roots.

Remove plastic containers from container-grown trees and shrubs. For plants in fiber pots, break away the top or remove the pot entirely. Many fiber pots are coated to extend their shelf life, but this slows degradation below ground and retards root extension.

If roots are circling around the root ball exterior, cut through the roots in a few places. Cutting helps prevent circling roots from eventually girdling the trunk. Select trees grown in containers with vertical ribs or a copper-treatment on the interior container wall. These container modifications and treatments minimize circling root formation.

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Tree Care After Planting

Remove tags and labels from trees and shrubs to prevent girdling branches and trunks.

Good follow-up watering helps promote root growth. Drip irrigation systems and water reservoir devices can facilitate watering.

Mulch, but don't over mulch newly planted trees and shrubs. Two to three inches of mulch is best - less if a fine material, more if coarse. Use either organic mulches (shredded or chunk pine bark, pine straw, composts) or inorganic mulches (volcanic and river rocks).

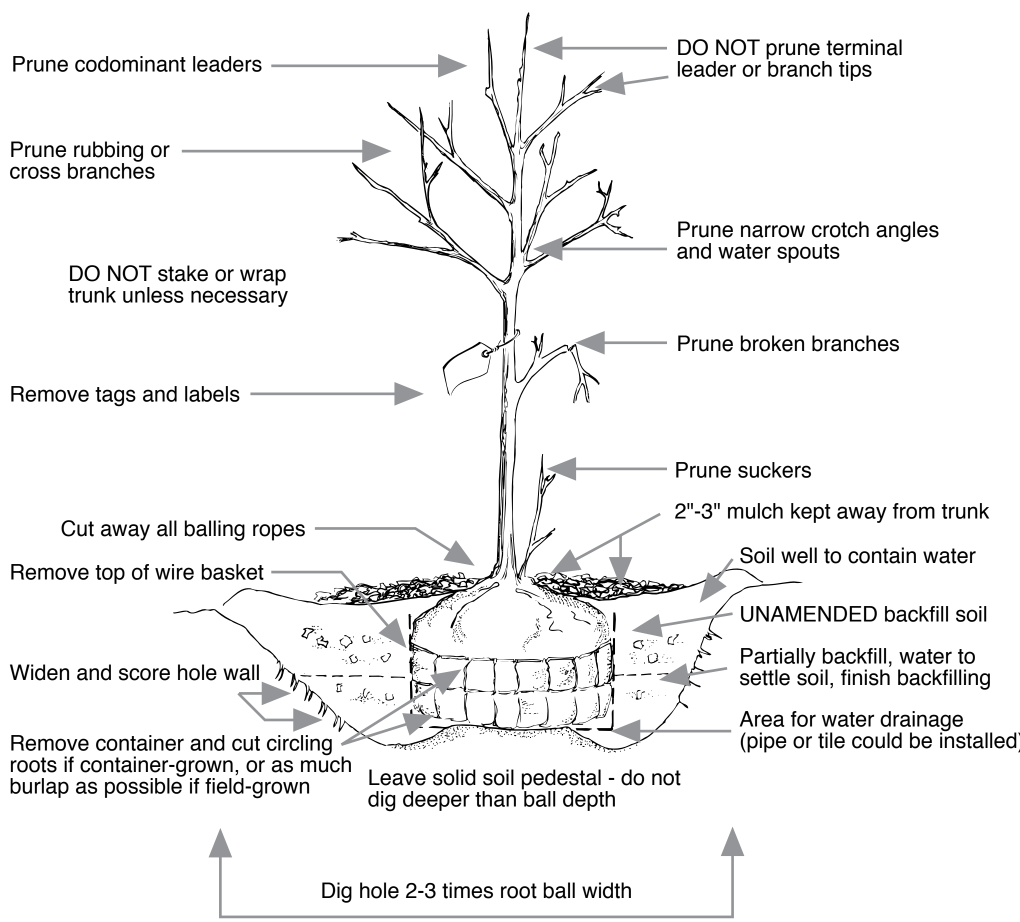
Keep mulch from touching tree trunks and shrub stems. This prevents disease and rodent problems if using organic mulches, and bark abrasion if using inorganic mulches.

Don't use black plastic beneath mulch around trees and shrubs because it blocks air and water exchange. For added weed control, use landscape fabrics that resist weed root penetration. Apply only one to two inches of mulch atop fabrics to prevent weeds from growing in the mulch.

Only stake trees with large crowns, or those situated on windy sites or where people may push them over. Stake for a maximum of one year. Allow trees a slight amount of flex rather than holding them rigidly in place. Use guying or attaching material that won't damage the bark. To prevent trunk girdling, remove all guying material after one year.

Most trees should not have their trunks wrapped. Wrapping often increases insect, disease, and water damage to trunks. Thin-barked trees planted in spring or summer into hot or paved areas may benefit from wrapping if a white wrap is used. To avoid trunk girdling, do not attach wraps with wire, nylon rope, plastic ties, or electrical tape. If wraps must be used, remove within one year.

For protection against animal or equipment damage, install guards to protect the trunk. Be sure the guards are loose-fitting and permit air circulation.



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Appendix 7-B

Original PDF file available at: *http://www.hgic.umd.edu/_media/documents/hg306.pdf*

MARYLAND COOPERATIVE EXTENSION
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COLLEGE PARK • EASTERN SHORE

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Home & Garden Mimeo # HG 306

How to Measure Your Yard

To apply the correct amount of fertilizer on your lawn, you need to know its surface area.

First, determine the total area of your property. Second, subtract the areas not to be fertilized. The remaining square footage is the number needed to determine how much fertilizer is needed. (See Figure 1)

Total lot:	Lot, 125’ x 100’	= 12,500 sq. ft.
Subtract:	House, 44’ x 26’	= 1,144 sq. ft.
	Deck, 12’ x 12’	= 144 sq. ft.
	Drive, 40’ x 10’	= 400 sq. ft.
	Garden, 25’ x 15’	= 375 sq. ft.
	Walk, 4’ x 20’	= 80 sq. ft.
Total to subtract		= 2,143 sq. ft.
Remainder: Yard		= 10,357 sq. ft.

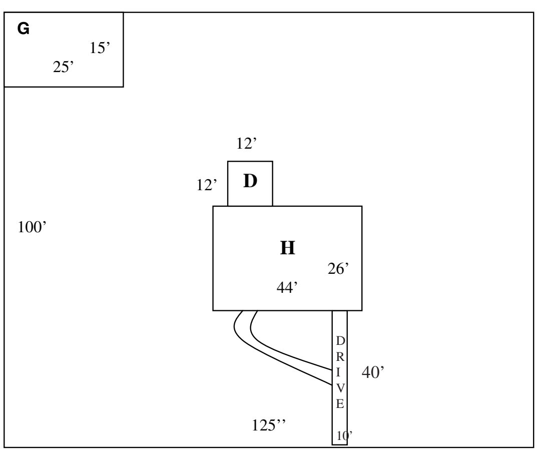


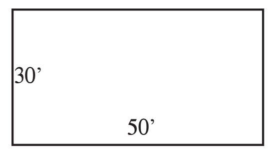
Figure 1.

How to determine the square footage of some familiar shapes

Squares, rectangles

Area = Length x width

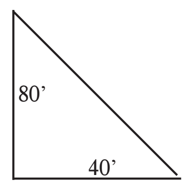
Length = 50’
Width = 30’
Area: 50’ x 30’ = 1,500 sq. ft.



Triangles

Area = .5 x base x height

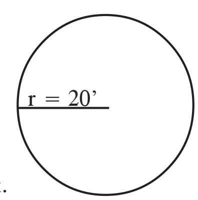
Base = 40’
Height = 80’
Area: .5 x 40’ x 80’ = 1,600 sq. ft.



Circles

Area = Ð x r^2
(Ð = 3.14)

r (radius) = 20’
Area; 3.14 x (20’ x 20’) = 1,256 sq. ft.



Educating People To Help Themselves

Chapter 8. Fertilizer and Lime Sources for Turf and Landscapes

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Introduction

Soil or tissue test results provide the basis for fertility programs in the management of turf and landscape materials. A standard soil test (described in chapter 5) provides information on soil pH and the levels of the macronutrients phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). The test will also likely provide levels of the micronutrients iron (Fe), zinc (Zn), copper (Cu), and boron (B). Missing from soil test results by nature of its constant fluctuations from plant-available to -unavailable forms and back is nitrogen (N). However, depending on the plant material being grown, the soil test will provide a recommendation for nitrogen levels and timing of application.

Defining Fertilizers

State regulatory agencies ensure the integrity of fertilizer sources. For example, in Virginia, the Office of Product and Industry Standards in the Department of Agriculture and Consumer Services analyzes samples of fertilizer and agricultural lime sources to ensure that labeling guarantees are met and that the product is safe for the environment. A labeled fertilizer has five criteria that must be met: brand, grade, guaranteed analysis, net weight, and name and address of the registrant and licensee (figure 8.1). This information applies whether the source is in liquid or granular form.

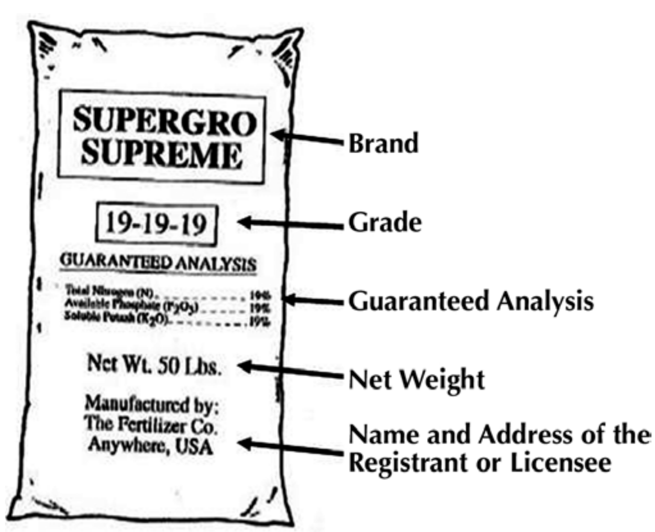

Figure 8.1. The five components required on a fertilizer label.

The information of most importance to end users in fertilizer selection is usually the grade (e.g., 19-19-19) and the guaranteed analysis. The grade presents the percentages by weight of nitrogen, phosphate (P_2O_5), and potash (K_2O). Note that the grade is not nitrogen, phosphorus, and potassium; the percentages of the actual (or elemental) phosphorus and potassium nutrients can be determined by multiplying the P_2O_5 level by a constant of 0.44, and the K_2O level by 0.83. While most soil test recommendations for these nutrients will be provided in units of P_2O_5 and K_2O per 1,000 square feet, sometimes levels are given in pounds of the actual nutrient instead. The guaranteed analysis will detail all nutrients in the product (in addition to nitrogen, phosphate, and potash) on a percentage-by-weight basis. These rules apply regardless of whether the product is a granular or liquid material.

Another common way of defining fertilizers is to classify them as either inorganic or organic. By definition, "organic" fertilizers contain carbon, and those defined as "inorganic" contain no carbon. Strictly following these definitions reveals that an organic fertilizer source may be composed of naturally occurring animal or plant byproducts/waste materials or synthetic products such as urea and any urea-based compound (ureaformaldehyde, methylene urea, isobutyraldehyde urea, etc.). This distinction is very important in both defining and developing what are commonly referred to as "organic fertilizer programs." In almost all instances where organic fertilizer programs are desirable, the intent for the program is very likely to be the utilization of "naturally occurring" organic sources and not the synthetic organic products.

At this time, the U.S. Department of Agriculture (USDA) does not offer specifications on what defines a "certified organic program" in turfgrass management as it does for crop production programs. The Northeast Organic Farming Association of Connecticut (*www.ctnofa.org*) offers a program that certifies organic lawn care practitioners but not their programs. This program might be of interest for lawn care managers interested in defining their overall fertility, cultural, and pest management programs as "organic."

Other ways of describing fertilizers include those defined as complete or incomplete and balanced or unbalanced sources. There are a host of possibilities in developing various analyses of fertilizer sources in terms of nutrient content.

"Complete" fertilizers contain some level each of nitrogen, phosphate, and phosphate, while "incomplete" fertilizers are designed to address only one or two specific nutrient needs (45-0-0, 0-20-0, 0-0-50, and 18-46-0 are all examples of incomplete fertilizers).

A "balanced" fertilizer contains equal amounts of nitrogen, phosphate, and potash (products such as 8-8-8, 10-10-10, or 19-19-19 and so forth). Often, balanced fertilizers are referred to as "garden fertilizers" because they are traditionally used in gardening applications and the plants respond to the additional phosphate and potassium in order to optimize bloom or fruit yield. An "unbalanced" fertilizer will have varying levels of nutrients (analyses such as 29-3-7 are common in many turf-specific products). Unbalanced fertilizers are very common in turfgrass management programs because nitrogen is the focal point of seasonal fertility programs. Additional P_2O_5 and K_2O are often not needed and their applications should be based on soil testing, particularly phosphate, because misapplication and overapplication are possible concerns for water quality. Other unbalanced fertilizers are developed for specific uses. Consider the classic "starter" fertilizers, such as 5-15-10 (discussed further in chapter 6). Sources that emphasize P_2O_5 are ideal for establishing plants because they provide an additional boost of phosphorus that can be important for the developing root system.

Nitrogen Sources

Nitrogen sources are frequently categorized according to their water solubility, which will be detailed in this chapter as "readily available" and "slowly available." A fertilizer label must state the percentage of total nitrogen as well as the varying percentages of water-soluble and slowly available nitrogen (SAN). Slowly available nitrogen can also be identified as water-insoluble nitrogen (WIN) or controlled-release nitrogen (CRN), depending on the nitrogen source. If there is no detail regarding SAN, WIN, or CRN, it is assumed that all nitrogen is water-soluble.

Because turf and landscape plant materials are usually not being grown for yield (the exception being sod and container/field landscape production systems) and are confined to relatively small land areas as compared to row crop production systems, slowly available nitrogen sources often provide sensible management, cost, and environmental advantages to readily available nitrogen sources. It is important to understand that all nitrogen sources will gradually lower soil pH. However, readily available nitrogen sources will drop pH much more quickly than slowly available nitrogen sources — a management point that needs to be addressed by soil testing. Each source has different strengths and weaknesses.

Readily Available Nitrogen

Readily available sources are also referred to as "water-soluble," "quick-release," or "fast-acting" to designate how quickly they become available following application. The rapid conversion of the fertilizer to the plant-available forms of ammonium (NH_4+) and nitrate (NO_3-) is why they provide such a quick growth and color response. As described previously regarding soil test information for nitrogen, these forms are readily transformed by chemical and microbial processes into plant-unavailable forms as well.

Readily available sources are less expensive than slowly available sources of nitrogen and can be applied as either liquid or dry formulations. Light and frequent applications of 0.25 to 0.50 pound of nitrogen per 1,000 square feet are desirable, but up to 1 pound of nitrogen per 1,000 square feet in a single application is suitable. The level and frequency of the application typically depends on the grass being grown, its intended use, the soil, and the climate (detailed in chapters 6 and 7).

In order to optimize nutrient utilization by the turf, reduce potential injury due to their high salt concentrations, and lessen potential environmental impact from nutrient leaching (especially the highly leachable nitrate), an increased frequency of application at lower levels is often desirable. Excessive salt accumulations in the soil can damage roots and/or reduce their function; however, because most areas of the mid-Atlantic receive periodic rainfall, concerns about salt accumulations in the soil from quickly available fertilizers are limited. The primary concern with turf damage from quickly available, high-salt-content fertilizers is the potential for "foliar burn" caused by tissue desiccation. In this scenario, the water-soluble, typically high-salt-content fertilizer that remains on the turfgrass leaves actually attracts water from the cells of the plant; this causes cell and leaf tissue desiccation in localized areas, resulting in the visual foliar burn.

Some of the most common forms of inorganic, readily available nitrogen sources used in turf and landscape management are ammonium nitrate, ammonium sulfate, potassium nitrate, calcium nitrate, diammonium phosphate, and monoammonium phosphate. The sources with the highest water solubilities (ammonium nitrate, urea, and ammonium sulfate) are often dissolved in water and are foliar-applied. The water solubilities and salt indices for these sources are provided in table 8.1.

Table 8.1. The grade, salt index, and water solubility of the most common, readily available nitrogen sources used in turf and landscape management fertility programs (after Turgeon 1985).

Fertilizer	Grade	Salt index[a]	Water solubility[b] [g/l (lb/gal)]
Ammonium nitrate	34-0-0	3.2	1810 (15.0)
Ammonium sulfate	21-0-0	3.3	710 (5.9)
Potassium nitrate	13-0-44	5.3	130 (1.1)
Monoammonium phosphate	11-48-0	2.7	230 (1.9)
Diammonium phosphate	20-50-0	1.7	430 (3.6)
Urea	45-0-0	1.7	780 (6.5)

[a] The salt index scale is: <1.0 = low, 1.0 to 2.5 = moderate, and >2.5 = high.

[b] Water solubility expressed in grams per liter (pounds per gallon in parentheses).

Ammonium nitrate is the most soluble of the quickly available nitrogen sources, providing the fastest growth and color response potential due to its rapid conversion to plant-available ammonium and nitrate. Its high water solubility also means it has the greatest potential for foliar burn and leaching. Ammonium nitrate supplies for the turf and landscape market are restricted because it may also be used as a strong oxidizing agent for explosives.

Ammonium sulfate is significantly less water-soluble than ammonium nitrate and was a popular alternative to ammonium nitrate in professional lawn care management long before supplies of ammonium nitrate dwindled. This source provides a rapid growth and color response from two macronutrients — nitrogen and sulfur. Its lower water solubility is advantageous, particularly for lawn applicators who ask their homeowner clientele to water the applied fertilizer into the soil but recognize that this simply does not happen soon enough to minimize foliar burn potential. Due to its high sulfur content (24 percent) and the fact that all nitrogen is in the ammoniacal form, ammonium sulfate causes the quickest decline in soil pH.

Potassium nitrate is a popular lawn and landscape fertilizer due to its combination of nitrogen and potassium nutrients. This source is frequently used in spring and fall applications as a treatment to increase potassium levels in plant material. Potassium — the second-highest nutrient content in plant tissues that is typically supplemented by fertilizer applications — regulates water movement into and out of cells. Its function is often described as the "summer coolant" and "winter antifreeze" of plants due to its ability to improve environmental stress tolerance. Its low water solubility results in much less foliar burn and leaching potential, but it is also difficult to dissolve and apply as a liquid.

Monoammonium phosphate (commonly called MAP) and diammonium phosphate (DAP) are popular sources for preparing blended fertilizers, but they also are used in turf and landscape applications, particularly for establishment situations. DAP has the greater water solubility of the two, but even its water solubility is so low that it is not a concern for fertilizer burn.

Urea has the unique property of being a synthetic organic (i.e., carbon-containing) source with a low salt index. Urea is available in granular and prilled forms that have the same chemical composition, but the granular forms are larger and harder while the prilled forms are softer and easier to blend with other fertilizers. Due to the high nitrogen content and water solubility, urea is often sprayed on turf provided there is adequate moisture available following application. In the presence of the enzyme "urease" (commonly present on leaves and dead plant residues), urea is rapidly converted to ammonium-nitrogen. Some volatile losses may occur under windy or hot, dry conditions if not watered into the soil. Approximately 60 percent will be converted the first day, with the remainder converted within a week. There is ongoing interest in ways to improve nitrogen-use efficiency of quickly available urea.

Row-crop production systems have had a great deal of research devoted to chemical additives with the urea that reduces the rate of its conversion to plant-available nitrogen (nitrification inhibitors) or gaseous loss (volatilization). The additives are extremely effective in the laboratory setting, but their levels of effectiveness in the field are variable and the factors affecting response not yet clearly understood. Research in this area continues in order to better understand chemical approaches to improve the nitrogen-use efficiency of urea. While these products affect the rate of conversion to plant-available nitrogen, they do not alter the water solubility of the urea, and they are still defined as readily available nitrogen sources.

Slowly Available Nitrogen

A unique aspect of nitrogen fertilization programs in turf and ornamental management is the use of a vast array of slowly available nitrogen sources that provide very controlled growth and color responses, along with inherent environmental advantages due to the slow-release characteristics. Their use in turf and ornamental systems is typically more economically viable than in production agriculture systems because "yield" is generally not a consideration (except in sod or nursery production systems) and quality, appearance, and playability (in the case of turf) are the driving factors in management programs. The incremental release characteristics of these materials are particularly valuable in turfgrass systems with completely modified, sand-

Table 8.2. A list of slowly available nitrogen[a] (SAN) sources, their typical chemical analyses, and general comments regarding the source.

Nitrogen source	Typical analyses	General comments about the fertilizer
Natural organics	6-2-0[b, d]	• Derived from waste byproducts. • Very low N analyses usually contain some phosphate and other micronutrients. • Very controlled release that is dependent on microbial activity.
Sulfur-coated urea (SCU)	32-0-0[c]	• Urea granules coated with molten sulfur. • Analyses and release rate varies depending on amount of coating. • N release due to osmosis, so moisture and temperature govern release rate. • Relatively inexpensive compared to other SAN sources. • Will reduce soil pH. • Handling is important because scratching the coat removes the controlled-release characteristic.
Polymer-coated urea (PCU)	32-0-0[c]	• Polymer coating of urea (sometimes also combined with sulfur). • N analyses variable depending on coating thickness. • Noted for very predictable release characteristics, and handling is not as much of a concern as for SCU.
Isobutylidene diurea (IBDU)	31-0-0	• Most readily available N source with highest water solubility. • High foliar burn potential, declining availability.
Methylene urea	30-0-0[b, d]	• Synthetic organic that can have varying levels of SAN defined by their solubility in hot or cold water. • N-release rates are dependent on the chain length of the carbon polymers (higher percentage of short chains increases water solubility). • N availability based on microbial activity.
Ureaformaldehyde (UF)	38-0-0	• Synthetic organic with predominantly long-chain carbon polymers and very controlled N release. • N availability based on microbial activity. • Very limited response in cold temperatures.

[a] Slowly available nitrogen (SAN) is used as a comprehensive term regarding nitrogen availability and includes sources also identified as water-insoluble nitrogen (WIN) and controlled-release nitrogen (CRN).

[b] N analyses vary depending on the source.

[c] N analyses vary depending on the coating thickness.

[d] The percentage of SAN varies depending on the source.

based soils (e.g., sand-based golf greens, tees, and athletic fields) that possess inherently low cation exchange capacities (CEC; discussed in chapter 2) and high nitrogen leaching potential.

Slowly available sources of nitrogen are also referred to as water-insoluble, controlled-release, slow-release, and slow-acting to designate their ability to meter out nitrogen over a certain length of time, similar to timed-release cold capsules. Using the Virginia Department of Conservation and Recreation's (VDCR 2005) Nutrient Management Training and Certification Regulations 4 VAC 5-15 criteria, SAN is defined as "nitrogen sources that have delayed plant availability involving compounds that dissolve slowly, materials that must be microbially decomposed, or soluble compounds coated with substances highly impermeable to water such as polymer-coated products, methylene urea, isobutylidene diurea (IBDU), urea formaldehyde based (UF), sulfur (S)-coated urea, and natural organics."

Slowly available nitrogen sources provide a sustained growth and color response that lasts for weeks to months rather than providing a quick surge in growth and greening response. Slowly available nitrogen sources also have a very low salt index; hence, they do not contribute to a buildup of soluble salts in the soil that might affect root system development. These sources also have minimal foliar burn potential. Because of the added steps involved in their production, they are typically more expensive than quick-release fertilizers.

The primary SAN sources used in turf management systems and a further description of the products are listed in table 8.2.

Natural Organic

These fertilizer sources are byproducts of plant and animal industries or waste products such as municipal sewage sludge; hoof, horn, seed, bone, and feather meal; and chicken and cow manures, among others. They can be categorized by their low (typically less than 10 percent) nitrogen content and the presence of mostly water-insoluble nitrogen. They are highly dependent on microbial activity for breakdown and release of nitrogen. For this reason, neutral pH, adequate moisture and oxygen, and temperatures above 55 degrees Fahrenheit enhance release.

A specialty organic product that also has activity as a pre-emergent herbicide is corn gluten. This product — approximately 8 percent nitrogen by weight — is applied on the basis of its pre-emergent herbicide activity and delivers approximately 1 pound of nitrogen per 1,000 square feet. It is an extremely effective, broad-spectrum herbicide but is relatively short-lived in its weed control activity.

Ureaform and Methylene Urea

Ureaformaldehyde is made by reacting urea with formaldehyde to produce nitrogen fertilizers that vary in release rate. UF products, like natural organic fertilizers, are dependent on microbial activity and subject to similar environmental conditions. Defining these products can become quite technical, but the information has value in making an informed decision regarding the selection of these very specialized SAN sources.

The term "water-insoluble nitrogen" (WIN) found on fertilizer bags containing UF refers to the amount of cold-water-insoluble nitrogen (CWIN) and hot-water-insoluble nitrogen (HWIN) present in the bag. Both CWIN and HWIN represent the slow-release portion of the fertilizer. The CWIN typically releases over several months while the HWIN can continue to release at a slower rate over several years. Products with the same WIN value can differ in the amount of CWIN and HWIN present, which in turn determines their release characteristics.

The activity index (AI) can be used to distinguish different UF fertilizers with identical WIN values. The AI represents the amount of CWIN that is soluble in hot water. In other words, AI is a measure of relative solubility with solubility increasing as AI values increase. According to the Association of the American Plant Food Control Officials (AAPFCO), UF fertilizers should contain at least 35 percent nitrogen and have an AI of at least 40 percent.

The remainder of the products are composed of cold-water-soluble nitrogen (CWSN) as free urea (quick-release nitrogen) and short-chain polymers that provide a quick response, yet offer some degree of safety regarding salt injury compared to quick-release fertilizers. Higher AI values represent sources that will provide faster nitrogen responses.

Ureaform is manufactured by reacting urea with formaldehyde using a 1.3-1.0 ratio. It consists of equal fractions of CWSN, CWIN and HWIN. It is often necessary to supplement the ureaform with quick-release nitrogen or increase the rate the first couple of years because of the extremely slow release of nitrogen. This is especially true in the cooler portions of the season because it might require three to four weeks to achieve a significant turf greening response.

Methylene urea is manufactured by reacting urea with less formaldehyde using a 1-9-1 ratio. This results in more CWSN (64 percent) and less CWIN (23 percent) and HWIN (13 percent). The difference results in quicker response yet shorter residual nitrogen compared to ureaform.

Other UF products are made with higher ratios of urea to formaldehyde. These products contain 35 to 40 percent nitrogen and are classified as "slowly available" by the AAPFCO. They provide a much quicker response compared to methylene urea and ureaform, but the response is shorter. Some products are available in liquid formulation as flowable products (they require tank agitation). These products contain no WIN, but instead contain short-chain reaction products that give a response somewhat comparable to free urea, though the chance of salt injury to turf is much less. Products claiming controlled-release nitrogen will also release nitrogen quickly.

IBDU

Isobutylidene diurea is made by reacting isobutyraldehyde and urea and is slowly soluble in water. Approximately 90 percent of the nitrogen is in the WIN form. Higher soil moisture and smaller particle size result in more rapid release. Nitrogen release is somewhat depressed in alkaline soils and is independent of microbial activity. For this reason, IBDU will release more readily during cooler temperatures than will UF products.

Triazones

These products are water-soluble, liquid, cyclic compounds derived by combining ammonia with urea and formaldehyde. Although considered to be slow-release by the AAPFCO, they act much like the "slowly available" UF products described above rather than IBDU, ureaform, or methylene urea because the greening response is quicker and the residual time is shorter. The major benefit is that salt injury is lessened using these products compared to using urea. Triazones have not established a major role in turfgrass fertilization programs, but they have the potential to expand in use in the turf and landscape industry.

Sulfur-Coated Urea

Sulfur-coated urea (SCU) products are made by spraying molten sulfur on urea particles. A sealant (wax or oil) is usually added to seal the imperfections, followed by a conditioner to reduce stickiness. Particles often contain a nitrogen-to-sulfur ratio of 2-to-1. Nitrogen is released by the microbial degradation of the coating and/or diffusion through the coating. Sulfur-coated urea products without sealants often release slower because of the thicker sulfur coating. Release rate increases as coating thickness decreases and temperature increases. It is the variability in coating thickness and particle size differences that allow for initial greening residual response.

Breaking of particles (with a spreader, traffic, or mower) results in the immediate release of nitrogen. A seven-day dissolution rate in water (lab procedure) is commonly used to characterize the quickly available fraction of SCU products. Most products have dissolution rates in the range of 25 to 35 percent. Controlled-release soluble urea nitrogen (CRSUN) is a term used on certain SCU labels and refers to the total percentage of nitrogen as SCU in the product. Another term, "controlled-release nitrogen," refers to the amount or percentage of SCU particles that are not broken and at least covered with a sealant.

Polymer-Coated Nitrogen

These products are coated with a synthetic polymer coating that is sometimes plastic-like in its composition. Sometimes the polymer coating is also supplemented with sulfur coating. Polymer-coated urea products are not microbially dependent because there is no wax sealant. Nitrogen is released through cracks in the sulfur and diffusion through the plastic. In plastic-coated urea, nitrogen is dissolved by water absorbed through the coating. Nitrogen is then gradually released through the coating by osmosis. Release increases with temperature and is influenced very little by soil moisture content, irrigation, soil pH, or microbes. Coating thickness determines the release rate for polymer-coated products.

Combinations of Quickly and Slowly Available Nitrogen

Many manufacturers combine quick- and slow-release sources of nitrogen to take advantage of the strengths of both. The quick-release source provides quick green up, but it is at a sufficiently low rate to prevent salt injury and reduce the potential for leaching. The slow-release source is available to provide a greening response for a longer duration.

Practical Considerations in Interpreting and Applying Slowly Available Nitrogen Sources

The slowly available nitrogen sources offer advantages from an environmental perspective as well as reductions in application frequency and controlled plant response. In cooperation with the Virginia Department of Conservation and Recreation, the following application criteria were developed for SAN sources (all categories and combinations of WIN, CRN, etc., apply) in order to optimize plant nutrient use efficiency and environmental responses.

If the fertilizer is 50 percent SAN or more, then up to 1.5 pounds of nitrogen per 1,000 square feet is acceptable in a single application during optimal growing periods.

If the fertilizer is 25 to 49 percent SAN, then up to 1.25 pounds of nitrogen per 1,000 square feet is acceptable in a single application during optimal growing periods.

If the fertilizer is less than 25, then no more than 1 pound of nitrogen per 1,000 square feet should be applied in a single application during optimal growing periods.

Determining the percentage of SAN in a fertilizer source that contains varying forms of water-soluble and slowly available nitrogen can be tricky. As an example, use the guaranteed analysis of a complete, balanced fertilizer detailed in figure 8.2 to determine its SAN percentage and a recommended maximum application rate. The material is 32-4-4 with the two forms of readily available (water-soluble) nitrogen being ammoniacal (3.5 percent) and urea (17.2 percent), for a total of 20.7 percent of the total nitrogen being readily available. For the SAN sources, 5.7 percent is clearly defined as WIN. The remaining 5.6 percent is where the analysis can be confusing. The top of the analysis details the 5.6 percent as "other water-soluble nitrogen," and an asterisk indicates that more information is provided in a footnote. The footnote specifies that the "other water-soluble nitrogen" is derived from methylene urea. As previously discussed, this SAN source contains highly variable percentages of nitrogen solubilities, ranging from very slowly available to readily available (which, because it contains readily available nitrogen, is why it is classified as "other" water-soluble nitrogen).

Therefore, the total SAN in this source is:

5.7 percent + 5.6 percent = 11.3 percent SAN.

The percentage of SAN is:

11.3 percent ÷ 32 percent = 35 percent SAN,

and this product could be applied at up to 1.25 pounds per 1,000 square feet in a single application. Note that for some states, the only thing required by law on the label is percentage of total nitrogen, but for most specialty turf fertilizer materials, there likely will be a listing of the percentages of varying nitrogen sources according to their solubilities.

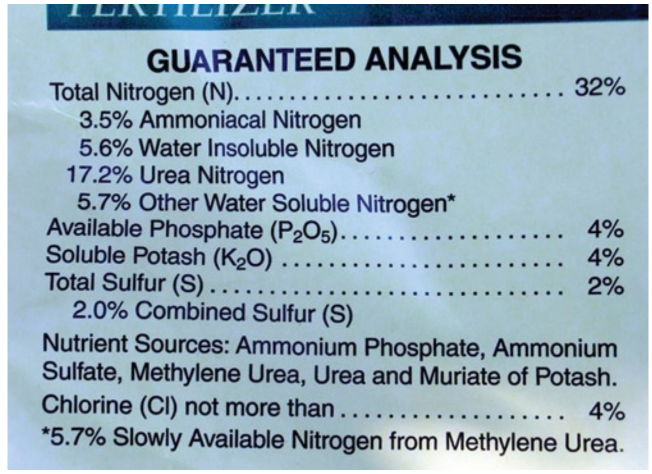

Figure 8.2. A fertilizer label detailing the guaranteed analysis of some of the various sources of slowly available nitrogen and how it is defined.

Phosphorus Fertilizer Sources and Fertility Guidelines

As previously defined, phosphorus does not actually occur as phosphate in the fertilizer or the soil. (This is an artifact from early analytical methods and laws used to assess phosphorus content and regulate fertilizer sales that has remained in use to keep records comparable across years.) Most scientific literature now uses percentage of elemental phosphorus (percentage of phosphorus) instead. To convert from percentage of P_2O_5 to percentage of phosphorus, multiply by 0.44. The standard phosphorus fertilizer sources are provided in table 8.3. Natural organic fertilizer sources are usually 0.5 percent to 2.0 percent P_2O_5 by weight. One of the most significant changes in lawn fertilization programs in the 21st century is the ready availability of phosphate-free fertilizers.

In most soils, phosphorus quickly binds with other elements to form water-insoluble compounds that are slowly released into the soil solution as phosphate anions (HPO_4^{2-} or $H_2PO_4^-$) on an "as needed" basis due to plant uptake. Water quality issues bring phosphorus applications to the forefront of environmental concerns due to the potential for eutrophication in water sources affected by phosphorus. Phosphorus is critical for energy transformations in plants and root development; therefore, it is an extremely important nutrient to optimize establishment. Typical application rates for turf and landscape plant establishment might be 1 to 2 pounds of phosphorus per 1,000 square feet. For maintenance of a healthy canopy, it should be applied as recommended by soil test results. Many soils in the southeastern United States are inherently low in phosphorus, and appropriate phosphorus applications that support a healthy turfgrass will actually improve water quality because the turf minimizes sediment losses.

On the other hand, on heavier-textured soils where phosphorus has been regularly applied for many years, additional phosphorus is not likely required. When present in its anionic form, phosphate is highly leachable, but due to its immobilization with other compounds, its mobility is much less than that of NO_3-. However, phosphate leaching can and does occur in two situations: (1) soils that contain excessive phosphorus levels, likely due to persistent overapplication of synthetic or organic phosphorus sources, and (2) modified sand-based soils, particularly during turfgrass establishment. All this being said, the major source of phosphate contamination in our waterways comes from fertilizer misapplications where granules are erroneously applied to hardscapes. This material quickly and easily enters water supplies through stormwater drains.

Table 8.3. The typical grade, salt index, and water solubility of the most common phosphorus sources used in turf and landscape management fertility programs (after Turgeon 1985).

Fertilizer	Grade	Salt index[a]	Cold-water solubility[b] [g/l (lb/gal)]
Superphosphate	0-20-0	0.4	20 (0.16)
Treblesuperphosphate	0-45-0	0.2	40 (0.32)
Monammonium phosphate	11-48-0	3.2	230 (1.8)
Diammonium phosphate	20-50-0	1.7	430 (3.4)
Rock phosphate	0-30-0[c]	NA	NA
Bone meal	4-12-0	NA	NA

Note: NA = not applicable.

[a] The salt index scale is: <1.0 = low, 1.0 to 2.5 = moderate, and >2.5 = high.

[b] Water solubility expressed in grams per liter (pounds per gallon in parentheses).

[c] Rock phosphate levels of P_2O_5 can range from 27 to 41 percent.

Potassium Fertilizer Sources and Fertility Guidelines

The most common forms of potassium fertilizer sources are presented in table 8.4. Remember that the last of the three numbers that appear in the fertilizer grade represents potash; to convert this value to elemental potassium, multiply by 0.83.

Table 8.4. The typical grade, salt index, and water solubility of the most common potassium sources used in turf and landscape management fertility programs (after Turgeon 1985).

Fertilizer	Grade	Salt index[a]	Cold water solubility[b] [g/l (lb/gal)]
Potassium chloride (muriate of potash)	0-0-60	1.9	350 (2.8)
Potassium sulfate (sulfate of potash)	0-0-50	0.9	120 (1.0)
Potassium nitrate	13-0-44	5.3	130 (1.0)

[a] The salt index scale is: <1.0 = low, 1.0 to 2.5 = moderate, and >2.5 = high.

[b] Water solubility expressed in grams per liter (pounds per gallon in parentheses).

Potassium is involved in a host of biochemical responses in a plant but is not a direct component of any organic compound. In particular, potassium is recognized as the nutrient that most impacts water relations within the plant, sometimes being referred to as the "antifreeze" and "coolant" nutrient of the plant world.

There are many unrefined and manufactured sources of potassium, but plants always absorb potassium in the same form: K^+. Potassium is required in the second-highest quantity by plants after nitrogen. As a cation, K^+ can be temporarily bound and exchanged for other cations in soils that contain significant anionic (negatively charged) exchange sites (i.e., soils with significant amounts of clay and/or organic matter). Even as a cation, K^+ can still leach depending on soil type (especially sand-based soils) and under heavy rainfall and/or irrigation. In general, application rates of potassium should not exceed 1 pound of K_2O per 1,000 square feet. Lower rates and more frequent applications are desired on sandy soils low in organic matter.

At this time, potassium is not considered to be an environmental concern that negatively impacts water quality, so it does not receive as much attention as nitrogen and phosphorus from this perspective. Potassium chloride (KCl) is the most commonly used potassium source, primarily because it is a cheaper material. The other sources (potassium sulfate, potassium magnesium sulfate, and potassium nitrate) contain other macronutrients that can provide additional desirable plant responses. Potassium sulfate has a very low salt index and is less water-soluble than the other sources, meaning it has low foliar-desiccation potential. Potassium nitrate is a popular spring and fall fertilizer material used to prepare landscape plants for the environmental extremes of the summer and winter. Potassium magnesium sulfate (commonly called sul-po-mag) is somewhat underutilized in turf management programs as compared to production agriculture systems. It promotes turfgrass color without a lot of growth, but it is a very water-soluble product that must be quickly watered in to prevent foliar burn.

Calcium, Magnesium, and Sulfur Fertilizer Sources and Fertility Guidelines

There are numerous sources of calcium, magnesium, and sulfur detailed in table 8.5; the table lists the most common fertilizer sources. In addition, materials such as bone meal, wood ash, manures, and sludge can contain significant amounts of these elements.

Many of these sources will be recognized also as chemicals applied to alter pH. Therefore, if calcium, magnesium, or sulfur is required due to nutrient deficiency but a pH change is not desired, standard liming sources and elemental sulfur should be avoided.

Calcium and magnesium are often overlooked regarding their importance as macronutrients because they are most commonly associated with adjusting pH levels. However, both have important activities in the plant, with calcium serving as a primary component of cell walls and magnesium being the central atom of the chlorophyll molecule. They behave very much the same in the soil due to similar chemical properties, but magnesium is typically much lower in soils than calcium. Both are divalent cations (Ca^{2+} and Mg^{2+}) and are of very similar size. It is important to monitor the balance of magnesium, calcium, and potassium and many soil test reports will include this information as part of their results. The mobility of both calcium and magnesium is relatively low, especially compared to anions or even other cations, such as sodium or potassium. Therefore, loss of these two cations through leaching is relatively low, especially when applied in the form of lime. Leaching is primarily limited to sandy soils with low CEC and is enhanced by low pH. Applications of these nutrients to soils do not result in any known water quality problems in this region.

Similar to nitrogen, sulfur is highly mobile in the soil because its plant-available form is the sulfate (SO_4^{2-}) anion. Tissue sampling is usually the best way to diag-

Table 8.5. Common inorganic sources of calcium, magnesium, and sulfur.

Material	Chemical formula	Ca (%)	Mg (%)	S (%)
Calcium chloride	$CaCl_2$	36.0	0	0
Burned lime or calcium oxide	CaO	70.0	0	0
Calcitic limestone	$CaCO_3$	32.0	3.0	0.1
Dolomitic limestone	$CaCO_3$, $MgCO_3$	21.0 -30.0	6.0 -12.0	0.3
Gypsum	$CaSO_4$	22.0	0.4	17.0
Hydrated lime	$Ca(OH)_2$	50.0	0	0
Magnesium ammonium phosphate	$MgNH_4PO_4.6H_2O$	0	15.0	0
Magnesium oxide	MgO	0	45.0	0
Magnesium sulfate	$MgSO_4.7H_2O$	2.0	10.0	14.0
Potassium magnesium sulfate	$K_2SO_4.2MgSO_4$	0	11.0	22.0
Ammonium sulfate	$(NH_4)_2SO_4$	0.3	0	24.0
Ammonium thiosulfate	$(NH_4)_2S_2O_3$	0	26.0	0
Elemental sulfur	S	0	52.0 -70.0	0
Flowable, wettable flowers			90.0 -100.0	
Potassium sulfate	K_2SO_4	0.7	1.0	18.0
Sulfuric acid	H_2SO_4	0	0	20.0 -33.0

nose sulfur deficiency, but deficiencies are most common on sand-based, low-organic-matter soils. For landscape plants that require an acidic soil pH (for instance, achieving a certain bloom color of hydrangea), elemental sulfur is often used to lower pH. For lawn applications intended to lower pH, elemental sulfur applications should not exceed 5 pounds per 1,000 square feet and should promptly be watered in.

Micronutrient Fertility Sources and Fertility Guidelines

Micronutrients are required in very small quantities but they are equally important to overall plant health as the macronutrients. The list of plant-required micronutrients comprises iron, manganese (Mn), boron, copper, zinc, chlorine (Cl), and molybdenum (Mo). Micronutrients are rarely deficient in terms of soil quantities with the only exception being very sandy soils (natural or modified) with low organic matter or high turnover systems, such as sod farms. Maintaining an appropriate soil pH is the most important factor in managing soils to ensure adequate micronutrient availability.

Iron is by far the most important micronutrient in turfgrass management programs, having uses in all segments of the turfgrass industry. The most popular sources of iron are detailed in table 8.6.

Table 8.6. Standard iron fertilizer sources used in lawn and landscape settings.

Source	% iron
Iron sulfates	19-23
Iron oxides	69-73
Iron ammonium sulfate	14
Iron chelates	5-14

Whereas nitrogen deficiencies are often uniform across the turf, iron deficiencies are often scattered randomly throughout the turf, and appear more severe on closely mowed surfaces. The most severe deficiencies occur with warm days and cool nights, when shoot growth is favored over root growth. Total iron levels in most mid-Atlantic soils range from 0.5 percent to 5.0 percent. Yet iron is the micronutrient most likely to be deficient. Iron occurs primarily as oxides and hydroxides that are sparingly soluble in well-aerated soils above pH 4.0. Root exudates from deeply rooted plants are generally able to solubilize sufficient iron to optimize plant growth, but high nitrogen rates and close mowing decrease root growth relative to shoot growth and limit uptake capability. The inherently low levels of iron in high-sand green mixes and some of our native sandy sands, along with the relatively high supply of nitrogen and phosphorus in these management systems can further complicate iron uptake.

The most popular forms of iron applied in turf and landscape applications are the chelates applied as sprays over the top of the turf canopy. Granular iron sources are beneficial in increasing soil iron levels where needed, but they do not provide rapid color response. These liquid organic chelates are easy to handle, mix, and apply, and they can be tank-mixed with most pesticides. Chelation reduces the rate of complexing of iron into insoluble compounds in the soil, thereby improving plant uptake. However, the benefit most turf managers seek from foliar applications of any form of iron is a rapid, deep-green color without a surge in shoot growth. The immediacy of the "iron response" is mostly due to "staining" of the foliage, but there also will be a promotion of internal chlorophyll production within the leaves over time. The color response from foliar applications is relatively short-lived (might last up to two weeks) and is lost as the turf is clipped. Typical iron application levels are 5 to 10 pounds per acre (0.12 to 0.25 pounds per 1,000 square feet).

Deficiencies of other micronutrients are rare except on mostly sand soils. Maintaining appropriate soil pH is of utmost importance in ensuring satisfactory availability and/or preventing potential phytotoxicity issues. For instance, where copper or galvanized zinc roofs are used, there is the potential for metal toxicity to lawn and landscape plants, particularly where water from the roof is concentrated near a downspout. The easiest way to manage the elevated soil copper or zinc content is to reduce their solubility by liming to maintain the pH above 6.0. Where supplemental micronutrient applications are needed (most often indicated by tissue testing), chelated formulations are very effective.

Liming Materials and Chemical Composition

Why is there such a constant need for lime in this region? Most of the soils of the mid-Atlantic essentially act as weak acids, with only a small portion of their potential acidity present in the active, or soil solution, form. Exchangeable aluminum (Al), manganese, and iron metals, along with pH-dependent charges on organic matter and clay edge sites, constitute the major sources of potential acidity (also called the reserve or total acidity). The reserve acidity, in conjunction with the exchangeable bases, helps to buffer or to enable the soil to resist rapid changes in soil solution pH. Plants growing in acid soils must be able to contend with high levels of aluminum and manganese, and low availability of phosphorus, calcium, and magnesium. Because most turfgrasses are intolerant of these conditions, acidic soil must be limed to make the rooting environment hospitable for root exploration and development.

A number of materials are available for liming acid soils (table 8.7). The selection of a liming material should be based on its ability to neutralize soil acidity, chemical composition, fineness of grind, ease of handling, and cost. Limestone is a naturally occurring sedimentary rock rich in the minerals calcite (CaCO3) or dolomite [$CaMg(CO_3)_2$]. Most limestone is formed in thick, compacted deposits of calcareous skeletons and shells of sea animals on the ocean bed. Relatively pure deposits of calcite are called "calcitic" limestone, while materials containing more magnesium are called "dolomitic" limestone. Dolomitic limestone is widely used as a lime (and magnesium) source in the mid-Atlantic. When either calcitic or dolomitic lime is heated, the carbonate is driven off and calcium (magnesium) oxide is formed. When treated with water, or "slaked," calcium oxide forms $Ca(OH)_2$, also called slaked or hydrated lime. These are very reactive and caustic materials and are seldom if ever used for turf. These materials are occasionally used when very rapid changes in pH are needed, such as immediately prior to planting.

Table 8.7. The neutralizing value (calcium carbonate equivalent, CCE) of the pure forms of commonly used liming materials.

Lime material	Neutralizing value (%)
CaO (calcium oxide)	179
$Ca(OH)_2$ (calcium hydroxide)	136
$MgCO_3$ (magnesium carbonate)	119
$CaMg(CO_3)_2$ (dolomitic limestone)	109
$CaCO_3$ (calcium carbonate)	100

Source: Data from Tisdale, Nelson, and Beaton 1985.

As with most sedimentary materials, limestone varies in purity and chemical composition. In order to compare the acid-neutralizing value of various liming materials of differing purity levels, the calcium carbonate equivalent (CCE) test uses pure calcite ($CaCO_3$) as the standard, with an arbitrarily assigned value of 100 percent. A CCE value greater than 100 is possible and simply indicates that the material has a higher neutralizing capacity than pure calcite. Note that the neutralizing values for magnesium carbonate ($MgCO_3$), dolomitic limestone [$CaMg(CO_3)_2$], calcium hydroxide ($CaOH_2$), and calcium oxide (CaO) are all greater than 100 percent (table 8.7).

Apply this information in the selection and application of the lime source as recommended by the soil test. For example, if the soil test recommendation indicates that 50 pounds of lime is recommended per 1,000 square feet (the recommendation is on the basis of pure calcite) and the lime source available has a CCE of 90 percent, 55.5 pounds of the source (50 pounds per 0.9 = 55.5 pounds) per 1,000 square feet will be necessary to achieve the recommended liming rate. Conversely, if dolomitic limestone (with a CCE on the label of 109 percent) is selected, only 46 pounds (50 pounds per 1.09 = 46 pounds) per 1,000 square feet are required.

Fineness of Grind

Because liming materials have a limited solubility, the rate of reaction is largely determined by the amount of surface area exposed to acid soil. As fineness increases, the rate of reaction increases. Agricultural lime (having a wide variety of particle sizes) is particularly cost-effective for new establishment sites where it can be incorporated into the seedbed prior to planting. Ag-lime is more difficult to apply because of its nonuniform particle size. Powdered lime provides a rapid response but is extremely difficult to handle and apply. Pelletized lime — finely ground limestone made into pellets by using a binding agent — is commonly used in turf settings. The large pellets retain the quick reaction time of fine particles but without the dust of the powdered form. Pelletized forms are more expensive than powdered lime, but the ease in handling and application makes it a very popular choice. Pellets break down when wetted to release the finely ground particles. When applied to bare ground, pelletized lime should be wetted and allowed time for particles to break down prior to tillage or incorporation. Otherwise, the particles will be in contact with much less of the soil surface and will not be as effective in neutralizing soil acidity.

Managing Lime Applications

The general recommendation is to apply no more than 50 pounds of lime per 1,000 square feet at any one time to established turf (25 pounds per application to golf putting greens). If the soil test suggests more, then the amount should be applied monthly in incremental amounts.

All the beneficial effects of liming occur only where lime and soil are in contact. Liming materials are sparingly soluble and react strongly with the soils with which they come in contact. As a result, lime is relatively immobile in the soil and surface applications generally affect no more than the surface 2 or 3 inches during a growing season. For this reason, it is imperative to adjust the pH of soils prior to establishment and to incorporate the lime early enough so that neutralization of the acidity has time (two to four weeks for finely ground lime) to take place. Thorough incorporation throughout the rooting zone increases the rate of reaction and treats a larger volume of the soil, maximizing the benefits of lime.

Attempting to change the pH in the deep rooting zone of an established turf is difficult at best. One method of getting lime somewhat deeper in established turf areas is to apply lime in conjunction with core aeration events. Applying lime in the fall and winter months is also possible because the foliar burn potential (i.e., leaf desiccation) is very low and the freezing and thawing of the soil aid in mixing lime throughout the root zone.

Overliming

In this region, the target pH for turf and most ornamentals is 6.0 to 6.5. Overliming dramatically reduces availability of micronutrients and can result in deficiencies that are very difficult to correct. Turfgrass areas that have excessively high pH can be amended over time with use of an acid-forming fertilizer such as ammonium sulfate. Where pH is too high, the only alternative is to reduce the pH using elemental sulfur or aluminum sulfate.

Lime application should be based on soil tests to ensure that excessive lime is not added. While a good liming program usually provides adequate levels of calcium and magnesium, there are times when lime is not recommended but additional calcium and/or magnesium are required. Sources such as gypsum (calcium sulfate), magnesium sulfate, and potassium-magnesium sulfate should be used in this instance to supply needed nutrients without the addition of pH-increasing lime.

Best Management Practices for Water Quality Protection

The following list details steps that can reduce the impact of nutrient management practices on water quality.

- Base fertilization practices on a soil test.
- Supplement the soil test with a plant tissue test when necessary.
- Core or aerate compacted soil to reduce runoff and aid phosphorus and lime in entering the soil.
- Minimize fertilizer rates on slopes. If using quickly available sources of nitrogen on deep, sandy soils or near shallow water tables, use no more than 0.25 to 0.50 pound of nitrogen per 1,000 square feet per application.
- Establish and maintain a buffer zone of reduced- to zero-input vegetation around bodies of water (figure 8.3). In some cases, native vegetation might be appropriate, but whatever plant material is selected, it must persist indefinitely to serve as a functional buffer zone. Florida has established a very successful public awareness campaign called the "Ring of Responsibility" that promotes best management practices in maintaining and fertilizing turf near water resources (Florida Department of Environmental Protection 2008). In Oklahoma, researchers simulated intensively managed golf fairway turf bordering water sources and reported that a graduated buffer system where turf cutting heights were raised from 1 to 2 inches as the slope approached the water significantly reduced total runoff volume as well as nitrogen and phosphorus movement (Moss et al. 2006). This approach utilizing a simple graduated buffer improves water quality protection and still meets playability needs from a golfer's perspective.
- Consider using iron as a supplement to nitrogen for greening response.
- Use at least 50 percent slowly available sources of nitrogen on soils subject to leaching.
- Time applications carefully. Do not apply fertilizer before a heavy rainfall.
- Irrigate lightly (0.10 to 0.25 inch) after each application of quick-release fertilizer so it is washed off the foliage and moved into the soil.
- Avoid overirrigation.
- Return grass clippings to the lawn to improve nutrient cycling and reduce the amount of fertilizer needed to produce healthy plants (figure 8.4). Use a mulching mower whenever possible and consider that a mulching mower can even be used to manage fall leaves (Goatley 2006).
- When collected, compost grass clippings rather than disposing of them in landfills.


Figure 8.3. This buffer zone near the water's edge features low-input native grasses and shrubs.


Figure 8.4. A mulching mower being used to recycle both grass clippings and tree leaves in a single mowing event.


Figure 8.5. Sweeping or blowing fertilizer and/or grass clippings on hardscapes back into the turf canopy is one of the most important steps in protecting water quality.

- Use a drop (gravity) spreader near bodies of water or impenetrable areas to lessen the chance of spreading material on these surfaces.
- Perhaps the most important best management practice toward improving water quality is to simply sweep or blow fertilizers and grass clippings off hardscape surfaces and back into the turf (figure 8.5).

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Chapter 9. Organic and Inorganic Soil Amendments

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Introduction to Organic Amendments

Organic amendments can be applied to soils to provide nutrients and/or as soil conditioners. The nutrients in organic amendments can either be readily available or complexed in organic forms that must first undergo mineralization in order to become plant-available. Because the nutrient concentrations in many organic amendments are often low (relative to inorganic fertilizers) and are typically less than 100 percent plant-available, higher application rates than those of inorganic fertilizers are necessary to supply a plant's nutrient requirements. Therefore, organic amendments are often not applied to supply a plant's entire nutrient needs.

Organic amendments can also be applied as soil conditioners, relying on the organic matter content to improve such soil physical properties as water-holding capacity, plant-available water, aggregation, tilth, bulk density, porosity, drainage, and hydraulic conductivity. Chemical property improvements from organic matter include pH buffering, increased cation exchange capacity, and increased nutrient availability. Organic matter is also a source of energy for soil microbes that increases aeration, reduces bulk density, and facilitates nutrient cycling.

Sources of Organic Amendments

Organic amendments are produced from agricultural, municipal, and industrial byproducts (table 9.1). Agricultural sources of organic amendments include poultry and livestock manure and rotten or unusable animal feed, hay, and forage plants. Municipal wastes include sewage sludge/biosolids, landscape trimmings (e.g., leaves, grass clippings, brush), and food waste (postconsumer or preconsumer). Industrial byproducts such as paper mill sludge, food processing sludge, and brewery waste can also be converted to organic amendments appropriate for use on turfgrass and landscapes. Such byproducts require treatment that enables the finished amendment to be used in a safe, nuisance-free, and environmentally sound manner in areas where human contact is frequent and/or constituents in the amendment may pose environmental risks if not managed correctly.

Table 9.1. Sources of organic amendments.

Type	Examples of byproducts
Agricultural	• Livestock and poultry manures. • Rotten/unusable plant material such as feed, hay, silage, and forages. • Wood chips. • Slaughterhouse wastes and animal mortalities.
Municipal	• Wastewater sewage sludge/biosolids. • Water treatment residuals. • Landscape trimmings such as leaves, brush, and grass clippings. • Food waste. • Newspaper and other paper waste.
Industrial	• Paper mill sludge. • Food processing sludge such as poultry dissolved air flotation sludge, brewery waste, and peanut hulls. • Wood shavings, sawdust.

Processes for Generating Organic Amendments

Byproducts generated from animal manures and biosolids used in landscapes with public contact must first be treated to eliminate disease-causing organisms (pathogens) and vector attraction factors (viz., odors), which can exacerbate nuisance and health issues. Most biosolids applied to agricultural lands are termed "Class B" and have reduced (but detectable) levels of pathogens. Class B products are generated by processes to significantly reduce pathogens, such as aerobic and anaerobic digestion and lime stabilization. The land application of Class B products requires site restrictions to ensure that disease organisms do not pose health or environmental problems (*http://pubs.ext.vt.edu/452/452-302/452-302.html*).

Class A products have undetectable levels of pathogens and can be used without restriction as long as regulated pollutant concentrations meet appropriate standards. Class A biosolids are treated by processes to further reduce pathogens. Such commonly used processes include heat treatment (i.e., pasteurization), drying, advanced alkaline stabilization, and composting. Animal manures can also be treated by the same processes to enable their use on lands with high public contact.

Waste residuals that are physically and chemically homogenous — such as some manures, biosolids, and industrial sludges — are well-suited to be heat-treated, dried, and pelletized/granulated or alkaline-stabilized. The end product can be applied at rates marginally above inorganic fertilizer rates and often with fertilizer- or lime-spreading equipment. Residuals that are physically and chemically heterogeneous, on the other hand, are usually processed in large volumes to enable uniformity in the end product. Composting is well-suited for such treatment processing and application because the low-analysis nutrient content of the finished product is typically applied at considerably higher rates than heat-treated, dried, and pelletized or granulated products.

Heat Treatment, Drying, and Pelletizing or Granulating

This process can be used for treating liquid sewage sludge obtained from a wastewater treatment plant or from animal manure for the development of an organic fertilizer pellet or granule. Heat treatment produces an organic fertilizer by combining a dewatered sludge with dry fines and simultaneously drying and pelletizing the mixture. Alternatively, animal manures may be dried and pasteurized by heating and then either pelletized or granulated to produce a fertilizer. Such sludge- and manure-based products typically have low carbon (C)-to-nitrogen (N) ratios; thus, a high portion of their organic nitrogen is rapidly mineralized.

Advanced Alkaline Stabilization

This process involves mixing a waste byproduct, typically sewage sludge, with a dry, pH-raising material such as lime, kiln dust, or fly ash to meet Class A pasteurization criteria (i.e., maintain a pH of 12.0 or more for at least 72 hours, with a temperature of 52°C for at least 12 hours or with a temperature of 70°C for 30 minutes) via exothermic reaction. A similar process — except that it does not use heat — can be used to process animal manures into Class A products. In this process, high concentrations of gaseous ammonia that form at the high pH level disinfect the manure. The resulting products contain essential plant nutrients but are often applied as liming agents.

Composting

Composting is the controlled, aerobic, thermophilic, biological decomposition of organic materials that results in a stable end product that can be used as a soil amendment called "compost." Compost contains essential plant nutrients in low concentrations and is typically applied as a soil conditioner or mulch.

Composition of Organic Amendments

Heat-Treated Biosolids

The concentrations of constituents in typical heat-treated biosolids are presented in table 9.2. These materials are very dry (i.e., more than 90 percent solids), and their fine particle size permits their application as commercial fertilizer. The total Kjeldahl nitrogen (TKN) concentrations in such products are usually between 4 and 6 percent, nearly all of which is in the organic nitrogen form; thus, little of the nitrogen is readily plant-available.

Water-insoluble and water-soluble nitrogen are similar indicators of slowly available organic nitrogen forms and readily available inorganic nitrogen forms, respectively. These residuals are largely organic (40 percent carbon, 70 percent organic matter) and possess carbon-to-nitrogen ratios that favor rapid mineralization of the organic nitrogen. Biosolids products are typically rich in phosphorus (P), but the phosphorus solubility is often lower than in manure products because of the presence of high concentrations of phosphorus-binding iron (Fe), manganese (Mn), and other metal oxides in biosolids. Potassium (K) is low in biosolids products because the soluble K^+ is separated from the solids during wastewater treatment and exits the system with the treated wastewater effluent. Such materials are usually near-neutral in pH because the heating process drives off pH-elevating ammonia (NH_3).

Electrical conductivity (EC) is an indirect measurement of soluble-salt concentration. It is lower in heat-treated biosolids than in synthetic fertilizer and similar to that of compost. Organic residuals are good sources of sulfur (S) and other secondary and micronutrients, including such regulated plant-essential trace elements as copper (Cu) and zinc (Zn). The byproducts must meet the Code of Federal Regulations Title 40 (40 CFR) Part 503 pollutant concentration limits (PCL) set by the U.S. Environmental Protection Agency (EPA 1993) for the inorganic trace elements arsenic (As), cadmium (Cd), chromium (Cr), copper, mercury (Hg), molybdenum (Mo), nickel (Ni), lead (Pb), selenium (Se), and zinc.

Table 9.2. Concentrations of constituents in typical heat-treated and pelletized biosolids
(Pinegro, Winston-Salem, N.C.; Tuscarora, Leesburg, Va.; Granulite (Synagro), Houston, Texas).

Parameter	Pinegro	Tuscarora	Granulite
Solids (%)	93.00		96.00
pH	7.12		6.00
EC (dS/m)[a]	3.62		
TKN[b]/total N (%)	5.51	6.00	5.00
(NH_4-N)[c] (%)	0.26		
Organic N (%)	5.25		
Water-soluble N (%)	0.56	1.00	1.00
Water-insoluble N (%)	4.95	5.00	4.00
Total organic C (%)	40.00		
C:N ratio	7.30:1		
P (%)	2.32	2.62	1.30
K (%)	0.17	0.50	
Ca (%)	2.26	2.00	1.00
Mg (%)	0.36	0.40	
(SO_4-S)[d] (%)	1.68	2.25	0.40
Fe (%)	2.86	1.00	1.00
Cu (ppm[e])	262		300
Zn (ppm)	1,830	200	400
Mn (ppm)	1,030	100	100

[a]dS/m = deciSiemens per meter.
[b]TKN = total Kjeldahl nitrogen.
[c]NH_4-N = ammonium nitrogen.
[d]SO_4-S = sulfate sulfur.
[e]ppm = parts per million.

Heat-Treated Manures

With the excessive concentrations of nutrients, especially phosphorus, in areas dominated by confined-animal feeding operations, manure is frequently being processed via heating, drying, pasteurizing, and pelletizing or granulating. This is particularly true for poultry manures, which contain especially unbalanced concentrations of nitrogen and phosphorus that necessitate their transport from regions with phosphorus-saturated soils. The analytical data for typical pelletized poultry litter in table 9.3 can be used to compare and contrast with the composition of heat-dried biosolids (table 9.2).

Table 9.3. Concentrations of constituents in typical heat-treated and pelletized manure.

Parameter	Perdue Agrirecycle Microstarter 60 Plus	Pelletized poultry litter (Hammac et al. 2007)
Solids (%)	>85.00	
TKN (%)	3.00	3.51
NH_4-N (%)		0.20
(NO_3-N)[a] (%)		0.10
Total organic C (%)	36.0	
C:N ratio	12:1	
P (%)	2.00	2.45
WSP[b] (%)		0.25
K (%)	3.00	
Ca (%)	2.50	
Mg (%)	0.50	
SO_4-S (%)	0.76	
Fe (%)	0.13	
Cu (ppm)	0.07	
Zn (ppm)	0.07	
Mn (%)	0.07	

[a] NO_3-N = nitrate nitrogen.
[b] WSP = water-soluble phosphorus.

All heat-dried, pelletized or granulated products are very dry, permitting easy spreading with fertilizer equipment. Nitrogen and phosphorus contents are similar, but manures are significantly higher than biosolids in potassium. It is difficult to estimate plant-available nitrogen (PAN) in organic fertilizers that do not list various inorganic and organic nitrogen fractions, but the nitrogen availability should be similar to that of unpelletized manure (Hammac et al. 2007). Manure products usually contain less iron and, thus, bind phosphorus less strongly than biosolids. Manure products, like heat-dried biosolids, contain other macronutrients (e.g., calcium, magnesium, sulfur) and micronutrients (e.g., copper, zinc, iron, manganese, etc.).

Advanced Alkaline-Stabilization Products

- Advanced alkaline-stabilized (AAS) products have high **pH** values (i.e., more than 12.0) due to their strong alkalinity.

- Much of the content of such materials that utilize calcium oxide (CaO) as the liming agent is **calcium**. One such example is N-Viro Soil (table 9.4), whose calcium concentration can be as high as 40 percent of the product.
- The **carbon** concentration of AAS biosolids is about half that of digested biosolids due to dilution by the liming agent.
- Nearly all of the **nitrogen** in AAS products is in the organic form because the inorganic nitrogen has been driven off as ammonia due to the high pH.
- **Phosphorus** is present as a mixture of organic phosphorus and calcium phosphates.
- **Potassium** content can vary widely depending on the potassium content in the source of alkalinity used to treat the biosolids.
- **Sulfur** is present as a combination of gypsum and organic sulfur.
- **Trace element** concentrations are lower than digested biosolids due to the dilution of the biosolids by the liming agent and are typically lower than 40 CFR Part 503 pollutant concentration limits (EPA 1993; table 9.5).
- The **calcium carbonate** equivalent of such AAS products typically ranges from 40 to 50 percent.

Compost Properties and Quality Standards

Compost is used primarily as a soil conditioner and secondarily as a supplier of nutrients. Thus, the properties of compost that are usually tested and listed include those that improve soil conditions for plant growth and environmental effects (e.g., water quality; table 9.6). Composting is a pH-neutralizing process; therefore, most high-quality composts have pH values near 7.0 (table 9.7). Stabilized organic matter tends to buffer soil pH, so adding compost to soil often reduces the need for frequent liming. Only where acid-loving plants are grown are such compost application effects not desirable.

Electrical conductivity can vary greatly in compost, depending on the source of the feedstock(s) (table 9.6). Composts produced primarily from animal manures are usually higher in soluble salts and hence, higher in EC than yard and woody waste-based composts (table 9.7). High soluble salts and EC can impair the growth of sensitive plants, particularly seedlings; thus, it is important

Table 9.4. Typical composition of N-Viro Soil (advanced alkaline-stabilized biosolids) produced in Toledo, Ohio.

Property	Value
pH	12.2
N (%)	1.0
P (%)	0.2-1.1
K (%)	1.0
Ca (%)	10.0-40.0
Mg (%)	1.0
S (%)	5.0
Na (%)	<0.2
As (ppm)	27.4
Cd (ppm)	<1.4
Cr (ppm)	65.4
Cu (ppm)	74.0
Hg (ppm)	<0.7
Mo (ppm)	9.2
Ni (ppm)	61.1
Pb (ppm)	28.4
Se (ppm)	8.5
Zn (ppm)	188.0
Calcium carbonate equivalent (%)	45.0

Table 9.5. Biosolids trace element pollutant concentration limits (EPA 1993) **and mean concentrations from the National Sewage Sludge Survey** (NSSS; EPA 1990)**.**

Class A products must meet pollutant concentration limits in order to be deemed "exceptional quality" for uses in areas of frequent public contact.

Pollutant	**PCL** (ppm)	**NSSS** (ppm)
As	41	10
Cd	39	7
Cu	1,500	741
Pb	300	134
Hg	17	5
Mo	*	9
Ni	420	43
Se	100	5
Zn	2,800	1,202

* No current federal EPA pollutant concentration limits (PCL), but the Virginia Department of Environmental Quality has adopted a limit of 40 parts per million.

to limit the portion of high soluble-salt-containing compost mixed with soil when seeding or transplanting will occur soon after soil amending.

The higher the concentration of organic matter in compost, the greater will be the beneficial soil physical and chemical property effects. The water-holding capacity of the compost can vary depending on the quality and particle size distribution of the organic matter (table 9.6). The compost's water-holding capacity is directly proportional to the water-holding capacity of compost-amended mineral soil. Bulk density of the compost is an indirect measure of the proportion of organic to mineral matter in the compost (mineral matter having a higher specific density than organic matter) and particle size distribution. An intermediate bulk density will have a balance between coarse and fine particles.

Because the primary purpose of compost used in landscapes is as a soil conditioner, there are no ideal concentrations of nutrients. Normal landscape application rates of compost do, however, provide considerable amounts of nutrients, even at the low concentrations that typically occur in compost (table 9.6). For instance, 1 inch of compost (3 cubic yards or approximately 1,350 pounds of dry matter per 1,000 square feet) having a nitrogen-to-phosphorus-to-potassium ratio of 1-to-1-to 1 (1:1:1) will provide 13.5 pounds each of nitrogen, phosphorus, and potassium per 1,000 square feet. Only a small portion of the nitrogen — but most of the phosphorus and potassium — will be plant-available.

Carbon-to-nitrogen ratios can provide useful information (e.g., potential degree of nitrogen mineralization or immobilization) about compost and other organic waste byproducts, although by themselves, they are not good indicators of compost quality. Most stabilized composts that are produced from well-designed starting recipes have carbon-to-nitrogen ratios between 12:1 and 20:1.

Table 9.6. Typical and preferred values of compost properties.

Property	Typical	Preferred
pH	5.0-8.5	6.0-7.5
EC (dS/m)	1-10	≤5
Organic matter (%)	30-70	≥50
Water-holding capacity (%)	75-200	≥100
Moisture content (%)	30-60	40-50
Bulk density (lb/cu yd)	700-1,200	800-1,000
Nutrients	0.5-2.5% N 0.2-2% P 0.3-1.5% K	No minimum required for ideal compost.
Inorganic trace elements		As, Cd, Cu, Hg, Mo, Ni, Pb, Se, and Zn must meet 40 CFR Part 503 pollutant concentration limits.
Stability		Should be measured as "stable" to "highly stable" by appropriate tests.
Growth screening		Should pass seed germination and plant growth assays.

Table 9.7. Properties of various composts.

Feedstocks	No. of samples	pH	EC (dS/m)	Soluble P (mg/kg)	Water-soluble N (mg/kg)	C:N ratio
Biosolids and woodchips	6	6.20	5.49	236	1,936	14.9:1
Yard waste	1	6.75	6.40	139	534	32.2:1
Dairy manure	3	7.50	8.52	204	448	14.6:1
Poultry litter	5	7.53	19.80	1,092	979	9.9:1
Various combinations of manures, yard and woody waste	11	6.57	11.50	94	1,359	12.9:1

Source: Data from John C. Bouwkamp and Catherine Ku. Unpublished data. University of Maryland.

Most feedstocks contain concentrations of inorganic trace elements (e.g., heavy metals, arsenic, and selenium; see tables 9.5 and 9.6) that will not pose a food chain, phytotoxicity, or direct ingestion concern, but the concentrations of these potential pollutants should be reported for all composts, particularly those produced from manure, biosolids, and other sludges. The concentrations of these pollutants should be lower than the EPA (1993) 40 CFR Part 503 pollutant concentration limits (table 9.5).

Because the ultimate purpose of compost application to soil is often to improve plant growth response, compost quality can also be assessed by the product's ability to support plant growth (i.e., biological properties). Incomplete and/or improper composting can generate a product with properties that can adversely affect plant growth and vigor. Incompletely composted material may possess bioactive carbon and a high carbon-to-nitrogen ratio; its continued decomposition upon addition to soil can deplete plant root-zone oxygen (O_2) and/or immobilize plant-available soil nitrogen via rapid microbial respiration.

The biological property "stability" should be assessed to ensure that only stabilized compost is used where plant growth is important. Stability is a measure of the degree of decomposition of carbon, where greater decomposition (i.e., greater stability) prevents high rates of oxygen-depleting, carbon-dioxide-producing (CO_2) microbial respiration and net soil nitrogen immobilization. Stability can be tested via various microbial respiration techniques that measure oxygen assimilation or carbon dioxide production. The Dewar's self-heating test employs an insulated container to measure the difference in temperature between ambient air and a compost sample maintained under conditions conducive to microbial activity (i.e., 50 to 60 percent moisture, optimal bulk density, and porosity). The extent of temperature change between ambient air and the "finished" compost provides an indirect test of the respiratory potential of the organic matter.

A second biological assessment method involves direct measure of such plant-growth parameters as seed germination and seedling vigor. Electrical conductivity was previously discussed as an abiotic property that could reduce plant vigor. Feedstocks being composted under anaerobic (i.e., oxygen-free) conditions can produce simple organic acids such as acetic (vinegar), butyric (rancid butter), and propionic that are the products of fermentation rather than composting. Such organic acids can be phytotoxic. Immature compost may also contain phytotoxic concentrations of ammonia and unstable, oxygen-depleting carbon.

Various chemical tests or bioassays can be used to evaluate compost or soil-compost mixes for the media's potential to support plant growth. There are several quick test methods that measure carbon dioxide and ammonia production, such as the Solvita compost maturity test (*www.solvita.co.uk/products/compost-maturity-test-kit.htm*). Specialized compost laboratories offer tests for stability and growth screening in addition to the previously discussed physical and chemical properties. A list of some compost laboratories can be found on the U.S. Composting Council website at *www.compostingcouncil.org/programs/sta/labs.php*. These laboratories are also certified to perform analyses for the Composting Council's Seal of Testing Assurance Program (*www.compostingcouncil.org/programs/sta/*), a compost-testing, labeling, and information-disclosure program designed to provide information needed to maximize benefit from the use of compost.

Woods End Research Laboratory (*www.woodsend.org/index.html*) also performs testing of compost and natural soil amendments for certified organic farming acceptance. The Organic Materials Review Institute in Oregon conducts an independent review process according to the standards established in the U.S. Department of Agriculture's (USDA) National Organic Program of October 2002.

Factors That Affect Nutrient Availability

Nitrogen

Nitrogen in organic residuals is present in organic and inorganic (ammonium nitrogen: NH_4-N; nitrate nitrogen: NO_3-N) forms. Inorganic nitrogen is immediately plant-available, although nitrogen in the ammonium (NH_4) form can be lost via volatilization as ammonia (NH_3) if the residual has an alkaline pH and is applied to the soil surface.

Most of the nitrogen in heat-treated residuals and nearly all of the nitrogen in compost is organically complexed. Such nitrogen requires the organic matter to be mineralized in order to transform the nitrogen into plant-available nitrogen. The main factor that affects the portion of the organic nitrogen that mineralizes to PAN is the byproduct carbon-to-nitrogen ratio, which is inversely related to the fraction of PAN. Typically, net nitrogen mineralization occurs at a carbon-to-nitrogen ratio of less than 20:1, and net nitrogen immobilization occurs at a carbon-to-nitrogen ratio of more than 30:1. Little-to-no mineralization/immobilization occurs between carbon-to-nitrogen ratios of 20:1 and 30:1.

The form of the carbon in the residual also affects the extent and rate of mineralization. The mineralization rate decreases in relation to the stability of the organic matter in the residual. For example, the organic nitrogen in sewage sludges that have undergone waste activation and biosolids that have been decomposed by microbial (anaerobic, aerobic) digestion processes will mineralize slower than the organic nitrogen in livestock and poultry manures that have not first been subjected to microbial decomposition. Composted manures and sludges undergo intensive decomposition that reduces mineralization rates even further.

The data in table 9.8 summarize measured values for carbon-to-nitrogen ratios and calculated (estimated) values for total plant-available nitrogen (100 percent of inorganic nitrogen forms plus the plant-available fractions of the organic nitrogen in the various residuals). The higher PAN fractions are found in residuals that have a higher portion of their nitrogen in inorganic forms and a lower portion of their carbon in less decomposed (stable) forms.

Table 9.8. Typical carbon-to-nitrogen ranges and first-year organic nitrogen mineralization rates of organic residuals in the mid-Atlantic states.

Residual	C:N range	Nmin* (first year %)
Manure, uncomposted	6-25	35-60
Biosolids, uncomposted	5-16	25-35
Biosolids and manure, heat-treated, dried, and pelletized or granulated	6-8	35-50
Compost	12-20	5-15

* Nitrogen mineralization rate.

Phosphorus

Phosphorus in organic byproducts is largely 100 percent plant-available, but the phosphorus in byproducts that contain considerable amounts of iron, manganese, and aluminum will be less-available than the phosphorus in byproducts containing lower amounts of these phosphorus-binding elements. The phosphorus in organic wastes is typically present in greater concentrations, relative to plant needs, than nitrogen. The application of organic wastes at rates to supply a plant's nitrogen need will usually supply more phosphorus than required by the plant. Therefore, organic waste byproducts must be applied judiciously to prevent soil phosphorus buildup to concentrations that promote phosphorus runoff and resulting surface-water impairment.

Other Macronutrients and Micronutrients

Organic wastes, being the eventual products of plant materials, contain every plant-essential element. The application of organic waste byproducts is rarely based on fertilizer elements other than nitrogen, phosphorus, or sometimes lime. However, there can be value to vegetative growth and quality by increasing the soil content of potassium, calcium, magnesium, sulfate sulfur (SO_4-S), and micronutrients with such byproducts. One caveat is that byproducts could contain elements in concentrations that may be phytotoxic (e.g., boron).

Uses of Organic Amendments

Pelletized and Granulated Products

Heat-treated, dried, and pelletized or granulated products are essentially low-grade, organic fertilizers that can be applied in the same manner as inorganic fertilizers. Because such materials have fixed nitrogen-to-phosphorus-to-potassium ratios (unlike specially blended inorganic fertilizers), care must be taken not to overapply phosphorus when applying these products to meet nitrogen needs.

Advanced Alkaline-Stabilized Materials

Advanced alkaline-stabilized products can be used as liming agents, as topsoil blends, and to supply essential plant nutrients. These products are often physically granular and can be applied with standard fertilizer applicators.

Compost and Blended Products

Compost as a Soil Amendment

Residential soils are typically low in organic matter and have high bulk density because their topsoil has usually been removed and the underlying soil horizons compacted by earth-moving equipment. Such soils typically support poor vegetation, even when fertilized and watered (figure 9.1). For incorporation into disturbed or degraded soils as a soil conditioner and nutrient source for establishment of turfgrass, ornamentals, trees, and shrubs, a thickness of 1 to 2 inches of compost (3 to 6 cubic yards per 1,000 square feet or 135 to 270 cubic yards per acre) is recommended. Such rates can be surface-applied (figures 9.2 and 9.3) and incorporated into the soil surface prior to planting (figure 9.4). Turfgrass and other plants can then be established by seeding, sprigging, sodding, or transplanting. Seed germination and seedling vigor are typically improved with the use of compost (figure 9.5).

Compost can replace topsoil, peat, sand, and woody fines mix in conjunction with core aeration and reseeding or as a topdressed treatment only (figure 9.6). Compost should be applied at a depth of 0.125 inch to 0.250 inch after aeration and moved into the holes by raking or dragging a chain. Such use of compost promotes seed germination and improves soil properties by placing compost several inches into the soil (figure 9.7).

In a review of 21 short- and long-term research studies, Shiralipour, McConnell, and Smith (1992) summarized the quantitative soil benefits of applications of 10 to 30 tons of mature municipal solid waste (MSW) compost per acre. The physical and chemical properties of most soils were improved with MSW (table 9.9; McConnell, Shiralipour, and Smith 1993). These studies demonstrate the consistent beneficial effects of compost as a soil amendment, especially for degraded environments. Additional benefits have been summarized by Alexander (2001).

Figure 9.1. Ramifications of poor soil quality.
Upper: Poor soil preparation.
Lower: Poor turf establishment.
Photos courtesy of John Sloan, Texas A&M.

Figure 9.2. Applying compost to disturbed soil using a hand-operated spreader. *Photo courtesy of Greg Evanylo.*

Figure 9.3. Close-up of compost application.
Photo courtesy of Greg Evanylo.

Figure 9.4. Applying turfgrass seed to compost-mulched disturbed soil. *Photo courtesy of Greg Evanylo.*

Figure 9.5. Comparison of turfgrass establishment on disturbed soil with various compost and standard treatments. *Photo courtesy of Greg Evanylo.*

Figure 9.6. Effect of compost on athletic field. Inset showing compost being topdressed. Main picture showing difference between turfgrass color with and without compost. *Photos courtesy of Mike Goatley.*

Figure 9 7. Topdressing compost after core aeration is a good practice for getting organic matter into soil under established turfgrass. *Photo courtesy of Ron Alexander, Alexander and Associates.*

Table 9.9. Effects of various rates of municipal solid waste (MSW) on soil properties (McConnell, Shiralipour, and Smith 1993).

Soil property	**Compost application rate** (cubic yards/ 1,000 sq ft)	**Change in soil property**
Organic matter	1.0-6.5	6.0-163.0% ↑
Cation exchange capacity	2.5-10.5	31.0-94.0% ↑
pH	1.0-6.5	0.8-1.4 ↑
Bulk density	1.0-6.5	4.0-71.0% ↓
Water-holding capacity	0.5-6.5	5.0-143.0% ↑
Essential plant elements	1.0-20.0	0-500.0% ↑

Composts and other organic amendments have also been shown to provide beneficial biological effects, particularly suppression of plant disease. Nelson and Boehm (2002) summarized the results of studies that quantified turfgrass disease control from various organic amendments (table 9.10). While the maximum disease-control percentages were often high, there was considerable variation in control among different compost feedstocks, different batches of the same feedstock, and at different experiment locations.

Compost can be used as an amendment for various in-ground infiltration and filtration systems, such as bioretention systems and pervious pavement. Bioretention systems are shallow, landscaped depressions designed

Table 9.10. Turfgrass disease control by various organic amendments (Nelson and Boehm 2002).

Amendment	Disease controlled	Maximum % control
Activated sewage sludge	Dollar spot	99
Composted biosolids	Brown patch	42
	Dollar spot	40
	Pythium root rot	63
	Red thread	51
	Typhula blight	70
Composted brewery sludge	Brown patch	25
	Dollar spot	15
	Pythium root rot	68
	Red thread	36
	Typhula blight	70
Composted cow or horse manure	Brown patch	25
	Dollar spot	73
	Pythium root rot	31
	Red thread	9
	Typhula blight	55
Composted poultry litter	Brown patch	75
	Dollar spot	55
	Necrotic ringspot	86
	Pythium root rot	94
	Red thread	79
	Typhula blight	15
Composted yard trimmings	Brown patch	39
	Dollar spot	5
	Red thread	0
Composted grass clippings	Brown patch	50-80
Spent mushroom compost	Brown patch	25
	Dollar spot	0
	Red thread	0
Uncomposted organic fertilizer (consisting of soybean meal, feather meal, blood meal, bone meal, etc.)	Brown patch	75
	Dollar spot	74
	Necrotic ringspot	96
	Pythium root rot	56
	Red thread	57
	Typhula blight	0

to receive and filter stormwater runoff (figure 9.8). Such systems are typically incorporated into parking lot islands and residential landscapes. As the stormwater infiltrates the bioretention media, pollutants such as sediment, nutrients, polycyclic aromatic hydrocarbons, heavy metals, and bacteria are removed by filtration, adsorption, ion exchange, biological degradation, and volatilization (Davis 2007). Bioretention rain gardens are commonly composed of a natural well-drained soil (sandy loams or loamy sands are best) underlaid with coarse sand or gravel and covered with an organic mulch layer (compost). The role of the compost is to protect the soil bed from erosion, provide a medium that holds moisture in the plant root zone for vegetative growth, biological decomposition, volatilization of organics, treatment of bacteria, and pollutant filtering.

Use of pervious pavement is a practice for increasing the permeability of surfaces in residential and urban areas to increase infiltration and reduce stormwater runoff. Compost can be used as a partial amendment in pervious pavement for reducing erosion and filtering pollutants (figure 9.9).

Figure 9.8. Bioretention rain garden.
Photo courtesy of A. P. Davis, University of Maryland.

Figure 9.9. Compost can be used as partial growth and filtering medium in pervious pavement.
Photo courtesy of Dwayne Stenlud, MnDOT.

Using Compost as Landscape Mulch

Compost can be used to mulch landscape vegetation to conserve soil moisture and prevent runoff and erosion. As an alternative to ground wood pallets, mulch compost conserved soil moisture and increased soil organic matter equally well as the woody waste; however, the soil nitrogen mineralization rate, plant-available nitrogen, and plant growth were higher with the compost (Lloyd et al. 2002). The benefits of compost were due largely to its lower carbon-to-nitrogen ratio (20:1) than that of the ground pallets (100:1).

Other well-researched uses of compost as mulch are for erosion and sediment control and as a cellulosic hydromulch substitute for highway roadsides. Roadsides and construction site "cut and fill" areas often leave steep, erosion-prone, low-fertility soils that can be difficult to vegetate and to physically stabilize. Applying compost (figure 9.10) at thicknesses of 1 to 2 inches to such sites can provide erosion- and runoff-reducing mulch whose organic matter and nutrient content reduce the long-term risk of vegetation establishment and maintenance failure (figure 9.11).

Even level, disturbed soils can be difficult to vegetate owing to the poor physical and chemical properties of such soils. Compost has also been used successfully to revegetate such highway roadsides with application thicknesses of 1 to 2 inches (figure 9.12).

Using Compost as Filtering Amendment

Due to its high organic matter content and variable distribution of particle-sized fractions, compost possesses a suite of attributes (e.g., porosity, chemical adsorption, biological activity) that permit its use as a filtering and processing agent for waterborne pollutants.

Filter berms are small windrows that can be constructed around disturbed land to reduce the transport of suspended and dissolved inorganic and organic solids and biological agents (figure 9.13). Compost filter berms can be used as recyclable, biodegradable, "living" filter silt fence substitutes. Upon stabilization of the adjacent disturbed land, compost berms present no disposal costs and are excellent growth media for vegetating the site perimeter.

Filter socks are mesh (sausage-like) containment systems into which can be stuffed compost possessing the appropriate physical and chemical properties to permit water flow, suspended solids filtering, and dissolved constituents' adsorption and biological degradation (figure 9.14). The EPA has touted such products

Figure 9.10. Compost applied pneumatically to steep slopes adjacent to highway to establish medium for erosion controlling and hillside stabilizing vegetation. *Photo courtesy of Greg Evanylo.*

Figure 9.11. Compost-mulched roadside hill. *Photo courtesy of Greg Evanylo.*

Figure 9.12. Applying compost to highway roadside to revegetate poorly established turfgrass. *Photo courtesy of Greg Evanylo.*

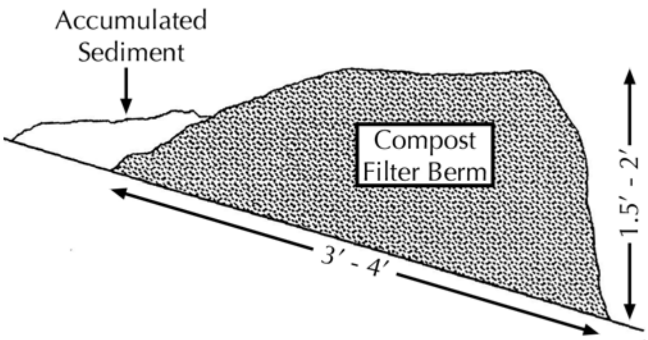

Figure 9.13. Compost filter berms can reduce the transport of suspended and dissolved water-borne constituents.
Illustration courtesy of Ron Alexander, Alexander and Asssociates.

Figure 9.14. Compost in filter socks reduces runoff and protects stormwater quality.
Photos courtesy of Rod Tyler, Filtrexx International LLC.

revolutionized by Filtrexx International LLC (*www.epa.gov/waste/conserve/rrr/greenscapes/projects/filtrexx.htm*). The environmental value of a specific compost source used in these systems is quantified in table 9.11, where certified test pollutant reductions have been listed. The compost removed most of the suspended solids and significant portions of dissolved pollutants via filtering and adsorption, while allowing a flow rate adequate to prevent excessive ponding behind the Soxx.

Additional uses of compost from yard waste can be found in *The Virginia Yard-Waste Management Manual* (VCE publication 452-055).

Compost Application Rates

Desirable application rates for compost vary depending on the purpose for its use and the cost of the product.

Table 9.11. Filtrexx International-certified results for a specific compost product used as a filtering medium in a Filtrexx Soxx product.

Parameter	Numeric value
Flow-through rate	16 gpm*
Leach test	NPK: none
Chemical removal	Total N: 29.0% reduction
	Total P: 14.0% reduction
	Total K: 14.0% reduction
Motor oil test	98.5% reduction (absorption)
Turbidity	27.0% reduction
Large solids removal	100.0% reduction
Suspended solids removal	52.0% reduction
Suspended solids w/ floculant	96.0% reduction

*gpm = gallons per minute.

The U.S. Composting Council (1996) published a valuable field guide for using compost, but the guide did not account for concentrations of potentially water-impacting nutrients that could be transported to surface water. Because composts produced from different feedstocks have different concentrations of soluble and potentially soluble carbon, nitrogen, and phosphorus, the composition of total and readily available, potentially water-impairing nutrients in the compost and the proximity to water bodies must be assessed prior to planning application rates.

An understanding of how compost use affects soil properties that influence nutrient transport is also important. For instance, despite the application of considerably higher-than-needed phosphorus in five consecutive years of compost application, Spargo et al. (2006) measured no significant increase in runoff phosphorus compared to a control treatment fertilized according to soil testing recommendations because the high rates of compost increased infiltration and decreased runoff and erosion.

The conversions in table 9.12 can be used to estimate the volume of compost needed to apply varying thicknesses of compost to a given area. The required mass of compost can be calculated from the measured bulk density, which normally varies between 700 and 1,200 pounds per cubic yard. A general rule of thumb is that there are approximately 2 cubic yards in 1 ton of compost. Additional conversions are listed in *The Field Guide to Compost Use* (U.S. Composting Council 1996).

Table 9.12. Compost use estimator.

Compost thickness (inches)	**Cubic yards/1,000 sq ft**	**Cubic yards/ acre**
0.25	0.75	34.00
0.50	1.50	67.00
1.00	3.00	134.00
2.00	6.00	269.00

How compost quality affects its fitness for use

Although use of the highest quality compost will ensure the fewest agronomic/horticultural problems, all uses do not require compost of the highest quality. The information in table 9.13 shows the relative importance of quality attributes for various compost uses. For example, compost properties that influence plant growth are very important if the compost will be used where establishing vegetation is the primary purpose (e.g., land reclamation, soil amendment for horticultural crop), but such properties are not important if the primary purpose of the compost is as a vegetation-free, soil-erosion-controlling mulch. Conversely, particle size is important when considering compost as mulch, but not so for amending drastically disturbed soils for reclamation purposes.

Table 9.13. Relative importance of quality attributes for various uses.

Attribute	**Land reclamation**	**Soil amendment for horticultural crop**	**Mulch**
Plant growth	++	++	—
Nutrient content	+	+	—
pH and soluble salts	+	+	—
Maturity	—	+	—
Particle size	—	+	+

++ = very important, + = important, — = not important

Organic Byproduct Summary With Regard to Water Quality

1. The slow nitrogen-release nature of organic amendments can either reduce or increase water contamination risk. Although nitrogen from most organic byproducts will not be supplied in such high concentrations in the soil water as nitrogen from inorganic fertilizers, organic sources may continue to slowly release nitrogen during the season (i.e., winter) when plant uptake is greatly reduced or has ceased.
2. Organic amendments typically supply more phosphorus than is required by the growing vegetation when the amendment is applied at a rate to supply the plant's nitrogen needs. This can result in an accumulation of soil phosphorus at concentrations that may increase the risk of phosphorus runoff and surface-water impairment.
3. The increase in soil organic matter with the application of organic amendments increases soil tilth (including aggregation), infiltration, and water-holding capacity, which reduces runoff volume and decreases the risk of surface water impairment by sediment, nitrogen, and phosphorus.
4. The increase in soil infiltration and water-holding capacity with the application of organic amendments increases vegetative biomass production and nutrient utilization, thus decreasing the risk of water impairment by nitrate leaching and nitrogen and phosphorus runoff.

Inorganic Materials for Amending Soils

There are a variety of inorganic materials used to amend soils, with the most common source being sand (Bigelow 2006). Based on particle size, sand is classified into five textural classes: very fine, fine, medium, coarse, and very coarse (see chapter 3). There are many possibilities in both composition and particle shape that further define sand and its particular uses. In the mid-Atlantic, calcareous and silica sands predominate, and they have varying shapes ranging from spherical to angular. Sand composition and shape is extremely important when selecting sands for completely modified root zones for golf putting greens or athletic fields. Consult the U.S. Golf Association's *USGA Recommendations for a Method for Putting Green Construction* (2004) if interested in putting green construction, or refer to a book such as *Sports Fields: Design, Construction* *and Maintenance* (Puhalla, Krans, and Goatley 2010) for recommendations in building a sand-based sports field.

Calcined and vitrified clays (also called porous ceramics) are naturally occurring materials that are mined in various parts of the country. The clays are heat-treated in a rotary kiln where they expand to significantly larger end products, similar to the size of sands. The end products are physically very stable and both retain some degree of cation exchange capacities (e.g., nutrient-holding capacity), but the temperature differences in their formation result in very different moisture-retention properties. Calcined clays, fired to temperatures up to 760° C, are noted for strong water-absorption properties. On the other hand, vitrified clays, fired at temperatures up to 1,100° C, have significantly less water-holding capacity. Combinations of these products as wetting and drying agents are the staple for managing the skin (grass-free) areas of baseball and softball fields with calcined clay products serving as a wetting agent and vitrified clays serving as a drying agent. These materials can also be used in completely modified, sand-based soils if they meet particle size specifications.

Zeolites are either synthetic or naturally occurring mined aluminosilicates that provide greater cation exchange capacity than calcined clays but not quite as high a water-holding capacity. Zeolite compounds have been used as amendments in modified sand-based soils since the mid-1980s and their ability to capture and hold NH_4^+ and K^+ ions enhance turfgrass establishment and reduce nutrient leaching.

Diatomaceous earth is mined from deposits of the fossilized shell remains of diatoms — single-celled aquatic organisms whose shells are primarily silica. These fossilized remains contain a high percentage of micropores and have the ability to hold significant amounts of water. The physical stability of diatomaceous earth is questionable if used as an amendment on heavily trafficked soils, but calcining the product improves its strength.

Another inorganic amendment that has application primarily on sports turfs but could be utilized on any heavily trafficked area is crumb rubber. Use of crumb rubber presents a recycling opportunity because it is produced from ground-up tires. Developing a turfgrass canopy up to a 0.75-inch depth has improved turf wear tolerance, reduced surface compaction, and improved shear resistance of the sod (Sorochan and Vanini 2003; Goddard et al. 2008). However, no more than 0.25 inch should be applied as a topdressing application, and the crumb should be sized to no more than 10- to 20-mesh material. It can float to the surface during heavy rain events and it is not a replacement strategy for implementing regular, hollow-tine, core cultivation programs to relieve compaction.

Incorporating crumb rubber into the existing soil has not been as successful as its benefits when used as surface topdressing. The best results on reducing surface compaction have been obtained when it is used preventively (pre-traffic) rather than as a curative (post-traffic) treatment. Given its black color, the heating of crumb rubber from radiant energy can benefit early- and late-season turfgrass growth but can result in excessive heating in thin turfgrass canopies during the hottest months of the year, especially on cool-season turfgrasses.

Inorganic Amendment Use Strategies

Based on its comparatively large particle size, it is logical that sand can be added to fine-textured soils to improve drainage and soil aeration. Many potential mistakes and/or concerns exist about amending soils with inorganic materials. What is the size and uniformity of the proposed amendment? In general, uniform medium-to-coarse-textured amendments are desired, and well-graded materials (e.g., concrete sand that contains equal percentages of fine-, medium-, and coarse-textured materials) are discouraged.

Next, just how much of the amendment is required to achieve the desired results? The only way to precisely determine this is to conduct a physical analysis of mixtures of the existing soil material and proposed amendments, something that will likely have to be done by consulting with a soil testing laboratory.

The most common mistakes in modifying existing soils with sands (or other coarse-textured amendments) are (1) using an inappropriately sized material, and (2) not adding enough coarse-textured amendment to affect the desired changes in porosity. As a rule of thumb, uniform, medium-to-coarse-textured inorganic materials are desirable for amending soils. Well-graded amendments such as “concrete sand” have very limited potential in increasing porosity when added to heavier-textured soils because the relatively equal percentages of fine, medium, and coarse aggregates are intended to produce a firm medium.

A quick review of the soil textural triangle (figure 9.15) demonstrates how specified ranges in the percentages of sand, silt, and clay are used to define soil texture. Soils that are very high in percentage of silt and clay will require large additions of sand to change their textures; for any soil to even have "sand" in its textural name (sandy clay, sandy clay loam, etc.), it will have to contain approximately 50 percent sand by volume.

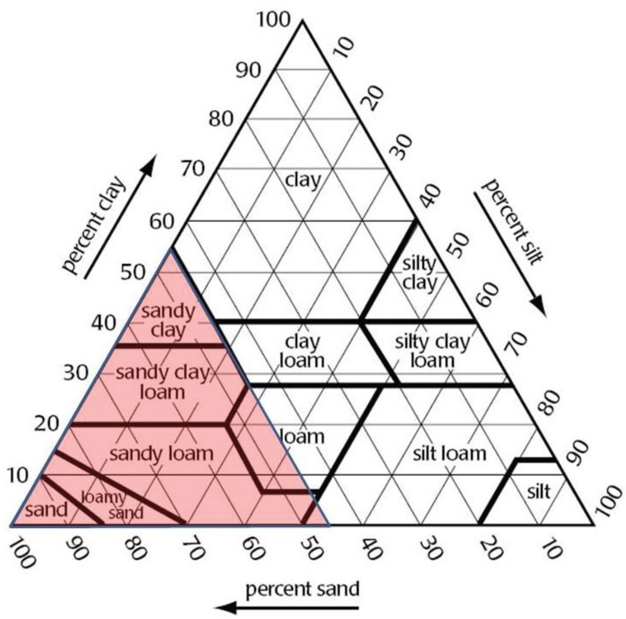

Figure 9.15. The soil textural triangle.

Table 9.14 demonstrates how adding up to 40 percent by volume of either a uniform medium-textured sand or calcined clay to a silt loam soil alters porosity and water-holding capacity. In this example, adding either the medium sand or the calcined clay essentially doubles the percentage of air porosity and reduces the percentage of plant-available water by one-third as compared to the silt loam soil. However, the two amendments vary widely in their effects on the percentage of plant-unavailable water and total porosity. The calcined clay doubles the percentage of plant-unavailable water (water is held so tightly by the calcined clay particles that plants cannot utilize it) but increases the percentage of total porosity. The sand-modified soil has virtually no change in the percentage of plant-unavailable water and an actual decrease in the percentage of total porosity (table 9.14). The data reveal the difficulty in predicting how adding what seems to be an appreciable amount of coarse-textured amendment actually affects the physical properties of the soil. A physical soil test is required to precisely determine how much amendment is needed to blend with a specified depth of the existing soil. Even with these data, the actual performance of the blended soil in the field will still be greatly influenced by how thoroughly the mixing of amendment and existing soil is conducted.

Topdressing With Inorganic Amendments

Periodic (one to two times annually), light (0.25-inch depth or less) topdressing (i.e., surface applications) of inorganic amendments offers the potential benefits of surface smoothing and improved thatch control in turf. It is ideal to conduct the topdressing event with hollow-tine core aeration events in order to better incorporate the material into the soil profile. Topdressing is a cultural practice that is quite common on sand-based golf greens and athletic fields. Although not common in lawn turf management, the benefits are the same. Due to economics, sand is the logical inorganic material of choice. In general, a uniform, medium-to-coarse-textured material is preferable, but even well-graded concrete sands have been successfully used in topdressing lawn turf if they are applied one to two times annually at depths of 0.25 inch or less. The possibilities of topdressing with crumb rubber on heavily trafficked sites are detailed above.

Table 9.14. Alterations in soil porosity and available water percentages of a silt loam topsoil amended with inorganic materials.

Amendment added (% by volume)	Air porosity (%)	Plant-available water (%)	Plant-unavailable water (%)	Total porosity (%)
None	9	35	9	53
40% medium sand	18	22	8	48
40% calcined clay	16	25	20	61

Source: Data provided by D. V. Waddington, professor emeritus of soil science, Pennsylvania State University.

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Chapter 10. Equipment Calibration and Fertilizer Application Methods

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Introduction

After determining the source and form of nutrients that best fit the situation, it is necessary to have an accurate assessment (size, surrounds, plant materials, etc.) of the area planned for fertilization. Square footage of areas can usually be calculated by assessing site characteristics for typical shapes and using some basic geometric formulas for the different shapes detailed in figure 10.1 to calculate square footage. For example, using the formula for the circle below, one could calculate the square footage of a circular courtyard with a diameter of 25 feet as having a total square footage of

$$3.14 \times (12.5)^2 = 490.6 \text{ square feet.}$$

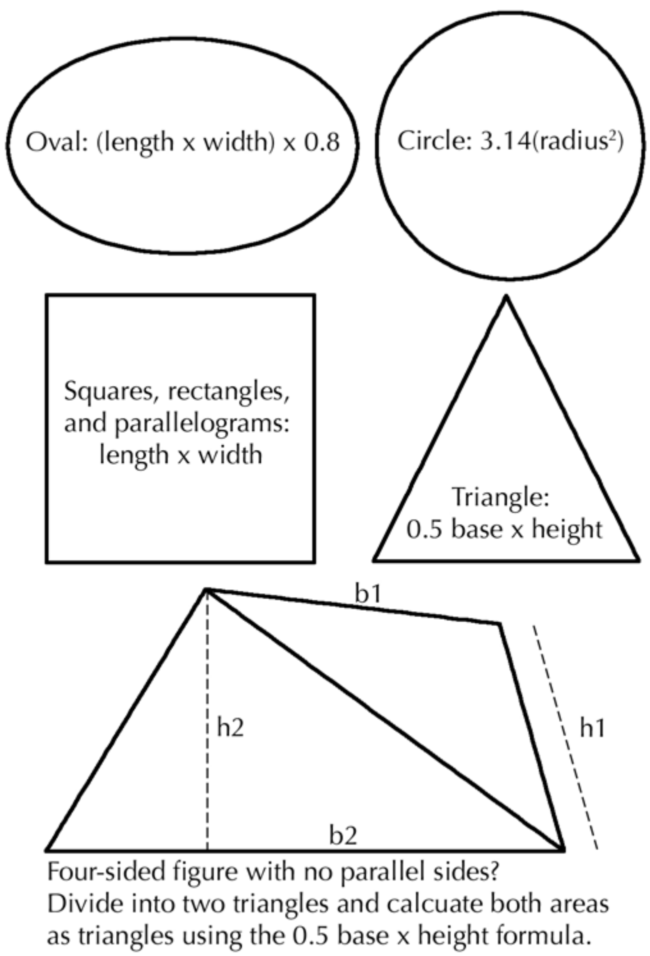

Figure 10.1. Mathematical formulas for calculating the square footage of various shapes found in turf and landscape management situations.

The next step to consider is the basic calculation of how much product is needed to deliver the desired amount of nutrient. The three numbers that make up the fertilizer grade on the label represent the percentages of nitrogen (N), phosphate (P_2O_5), and potash (K_2O) by weight, and the label will list any other nutrients contained within the fertilizer on a percentage-by-weight basis as well.

Dry Fertilizer and Application Methods

Fertilizers are available in either dry or liquid formulations. First, consider dry formulations and their standard delivery methods. For dry formulations, the percentage of each nutrient by weight will be indicated in the Guaranteed Analysis section of the label. To determine the amount needed for a given area, use the following basic formula (and note that nitrogen is generally used because it is usually the most limiting nutrient).

$$\text{Pounds of fertilizer per area} = \frac{\text{Pounds of N needed per area}}{\text{N from fertilizer formula as a decimal (i.e., the number divided by 100)}}$$

Example: Using a 16-4-8 fertilizer to supply 1 pound of nitrogen per 1,000 square feet gives:

$$\text{Pounds of fertilizer per area} = \frac{\text{1 lb of N per 1,000 sq ft}}{0.16}$$

$$= \text{6.25 lb of fertilizer per 1,000 sq ft}$$

Because the numbers on the fertilizer grade represent their percentage by weight, the amounts of phosphate and potash that would be delivered to the area would be:

$$6.25 \times 0.04 = 0.25 \text{ lb of } P_2O_5 \text{ per 1,000 sq ft}$$

$$6.25 \times 0.08 = 0.50 \text{ lb of } K_2O \text{ per 1,000 sq ft}$$

Notice that the proportion of the nutrients remains constant: A 16-4-8 product has a 4-1-2 proportion of nitrogen to phosphate to potash.

Product requirements for larger or smaller areas can simply be made by calculating standard proportions.

Using the basic algebraic steps of "cross multiply, divide, and solve for the unknown" is a popular way to perform fertilizer calculations. For example, for the proportion of 1/2 = Y/4, cross-multiplying results in:

$$(1 \times 4) = (2 \times Y)$$

$$4 = 2Y$$

Dividing each side by 2 results in Y = 2. Apply this same proportion concept to fertilizer calculations with the only requirement being that the units in the numerators (top number in the proportion) and the denominators (bottom number of the proportion) must match.

Assume the goal is to deliver 1 pound of nitrogen per 1,000 square feet to a 10,000-square-foot area with the 16-4-8 fertilizer previously considered. The previous calculation determined that 6.25 pounds of 16-4-8 total are needed to deliver a desired level of 1 pound of nitrogen per 1,000 square feet to the 10,000-square-foot area. Carefully keeping the proportion rules for similar units in numerators and denominators in place, the basic proportion is:

$$\frac{6.25 \text{ lb of 16-4-8}}{1{,}000 \text{ sq ft}} \times \frac{Y \text{ lb of 16-4-8}}{10{,}000 \text{ sq ft}}$$

$$52{,}500 = 1{,}000\,Y$$

$$Y = 62.5 \text{ lb of 16-4-8}$$

Drop Spreader Calibration

Drop spreaders (figure 10.2) allow granules to drop out of a hopper by gravity and provide the most accurate distribution because the material falls directly below its release point. Wind is of minimal concern with distribution uniformity, but applications take longer because only limited areas are being covered in a single pass. Drop spreaders are preferred when applying very fine material or a mix of nutrients of differing sizes, and they are ideal to use around impervious surfaces as a means of ensuring that the product is kept off hardscapes.

Figure 10.2. A typical 3-foot-wide drop (gravity-fed) spreader.

To calibrate the spreader, you will need to collect and weigh the amount of product actually dropped in a known area at a given spreader setting. It is strongly recommended to apply material at one-half the desired rate in perpendicular directions to reduce the possibility of skips and to avoid fertilizer application disasters such as the example in figure 10.3.

Figure 10.3. Striping is evidence of either a poorly calibrated drop spreader or an inexperienced operator who did not properly apply the fertilizer.

Steps in Drop Spreader Calibration

1. Determine a known area for the calibration: Measure the width of your spreader (feet) and the distance you will walk during the calibration process (figure 10.4). For this example, assume a 2-foot-wide spreader (drop width, not overall width of spreader) and plan on walking a 50-foot length for a calibration area of 2 feet by 50 feet = 100 square feet.

2. Prepare a collection device: A huge timesaver in calibrating a drop spreader is to hang a "catch pan" from the base of the spreader frame to collect all product that falls through the hopper. A catch pan made by cutting an appropriate length of 4-inch-diameter PVC pipe and fitting it with two end caps is shown in figure 10.5. An alternative method to collect product is to drop the material on a piece of plastic or on a clean, hard surface that can be swept to collect the product after it is dropped. (Note: For lengths longer than 10 feet, you will want to use a catch pan rather than dropping it on plastic or a hard surface and collecting.)

3. Ensure normal spreader operation: Place enough of your dry product in the spreader to completely cover the base and make sure the particle size is small enough to readily flow through the spreader. Specialty turf fertilizers usually work well, but many agricultural-grade materials (for example, 10-10-10) are too large to flow through a drop spreader.

4. Make the calibration “run”: Select a low-to-medium setting on the spreader (figure 10.6). Begin walking a few paces behind the calibration starting point in order to establish a consistent speed. Open the spreader as you reach the starting point and walk the desired, known length. Collect the product in the catch pan, sweep it off the hard surface or collect it off the plastic, and place it in a container of a known weight.

5. Weigh the product (figure 10.7) and calculate the amount of product (total weight minus weight of the container) being delivered per unit area: If the amount delivered does not match the amount you are trying to apply, adjust the spreader setting and repeat the calibration steps until you collect the desired amount. Note: One of the biggest limitations when using a small area for calibration is the accuracy of the scales. Accurate calibrations are possible in small areas with very precise scales as pictured in figure 10.7, but if you want to use standard scales from around the house, the calibration area (and therefore, the amount of product collected) will have to be much larger.

Figure 10.4. A calibration run length of 20 feet has been marked with paint in this photo.

Figure 10.5. A homemade catch pan made from a piece of PVC pipe.

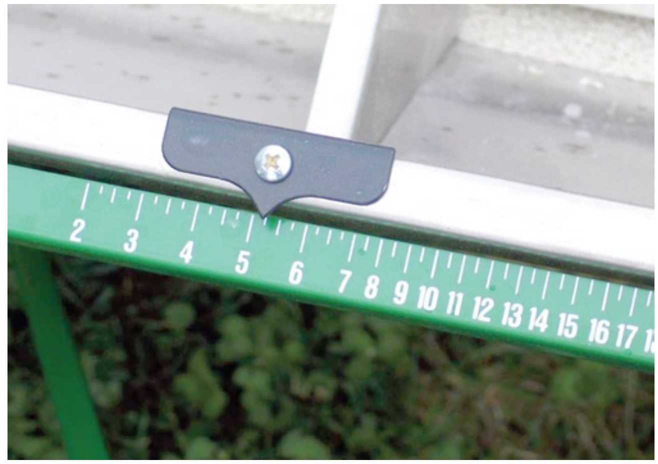

Figure 10.6. Adjusting the setting on the spreader will increase or decrease the size of the openings at the base of the spreader.

Figure 10.7. Scales that measure in units of ounces or grams allow for accurate spreader calibration on relatively small areas.

Example: The fertilizer selected for application is a 6-2-0 organic material (containing 6 percent nitrogen, 2 percent phosphate, and 0 percent potash by weight). The desired level of application for this slowly available nitrogen source is 1.5 pounds of nitrogen per 1,000 square feet, so the formula is 1.5 ÷ 0.06 = 25 pounds of 6-2-0 fertilizer required per 1,000 square feet. The spreader is 2-feet wide (and is equipped with a catch pan) and a length of 25 feet has been measured, resulting in a 50-square-foot calibration area (25 feet in length x 2-foot drop spreader width = 50 square feet of area covered in a single pass). The setup for the proportion is:

$$\frac{25 \text{ lb of 6-2-0}}{1{,}000 \text{ sq ft}} \times \frac{Y \text{ lb of 6-2-0}}{50 \text{ sq ft}}$$

$$1{,}250 = 1{,}000\,Y$$

$$Y = 1.25 \text{ lb of 6-2-0}$$

Continue to adjust the setting on the spreader until 1.25 pounds of 6-2-0 is collected during the calibration run. (If you want to work in ounces or grams, the calculations will be 1.25 pounds x 16 ounces per pound = 20 ounces of the product, or 1.25 pounds x 454 grams per pound = 567.5 grams.)

To avoid skips in application, it is recommended to calibrate for one-half rate and make two perpendicular passes over the treatment area in order to improve application uniformity. Therefore, the calibration for a one-half-rate application that will be made in two directions would be:

$$1.25 \div 2 = \text{approx } 0.63 \text{ lb of 6-2-0}$$

Broadcast (Rotary) Spreader Calibration

Broadcast spreaders (figure 10.8) deliver product by dropping a dry granule onto a spinning impeller. The spread pattern of a broadcast spreader is not as precise as a drop spreader but it is usually the preferred means to rapidly deliver fertilizer to a large area. A consistent walking speed is important to optimize uniform delivery, and wind is much more of a concern for distribution uniformity — especially with lightweight materials.

The potential for materials landing on hardscapes is much greater with broadcast spreaders due to the wide throw of the materials in the spread pattern. Particular care needs to be taken when using these spreaders near sidewalks, streets, etc., to ensure that product does not land on hardscapes and potentially end up in a nearby water source. Many of these spreaders have deflector attachments that should be employed around hardscapes to minimize the potential for fertilizer ending up on the hard surfaces; however, even when deflectors are used, the site should be inspected after application and product should be swept up or blown back onto the turf.

Spreading mixed materials of different sizes can be a problem because larger, heavier particles are thrown farther than smaller particles, thus reducing even distribution of nutrients. As with drop spreaders, application uniformity can often be improved by applying one-half rates in two directions (detailed in the following).

Figure 10.8. A broadcast spreader can hold relatively large volumes of fertilizer and is a useful tool to rapidly apply granular fertilizers to large areas.

Steps in Broadcast (Rotary) Spreader Calibration

1. Ensure that the spreader is operating normally: Place enough product in the spreader to completely cover the base of the spreader.

2. Determine uniformity and the effective spreader width (ESW): Product can be propelled 15 feet or more in a semicircle around the spreader, with the amount delivered decreasing with distance from the spreader. It is important to know how the spreader distributes product. Use catch pans (inexpensive aluminum baking pans as pictured in figure 10.9) spaced uniformly every 2 to 3 feet from the center of the spreader and perpendicular to its line of motion. Depending on the size of the spreader, anticipate product spread distance to range from 12 to 20 feet. Begin walking a few paces behind the calibration starting point in order to establish a consistent walking speed prior to opening the hopper (figure 10.10). Open the spreader in time to distribute product across the catch pans and close it as soon as you pass the line of pans.

3. Collect results: Collect the fertilizer that is captured in each pan and place the product in small clear cups or tubes to make a visual evaluation of the spreader pattern (figure 10.11). Be sure to keep the samples in the same order — by distance from the spreader — as the pans. The desired distribution for a standard application should be essentially a bell-shaped pattern, with the largest amount of product in the middle catch pan and uniform amounts extending away from the center.

Figure 10.9. Fertilizer catch pans are being placed at regular intervals in order to determine the fertilizer's effective distribution width.

Figure 10.10. Establish a consistent walking speed prior to fertilizer delivery in the calibration run.

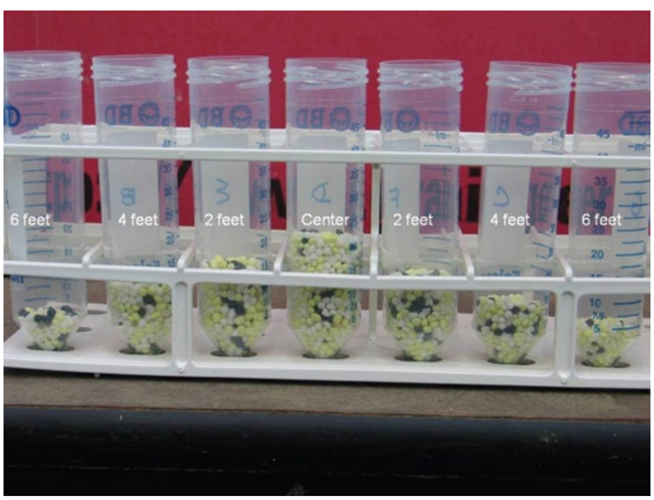

Figure 10.11. The collection of fertilizer from catch pans at 2-foot spacing from the center demonstrates an effective spreader width of 12 feet in this example.

4. Evaluate spread pattern and determine effective spreader width: By visually evaluating the fertilizer collected from the catch pans, the effective spreader width can be determined as being that distance where the fertilizer product is approximately 50 percent of the total collected from the center catch pan. Using the example in figure 10.11, that point occurs at approximately 6 feet, so in this example, the ESW is 6 feet on either side of center, for a total ESW of 12 feet. The application strategy will be to overlap distribution by 6 feet in order to uniformly achieve 100 percent coverage. If the distribution is not uniform, the spreader might need an adjustment or repair or the nonuniform distribution will have to be accounted for in the delivery of the product. Note that some professional spreaders intentionally have adjustments and/or shields to deflect granular products from being discharged in a certain direction (e.g., in order to restrict fertilizer from being thrown onto a hardscape).

5. Calibrate weight delivered: Now that the ESW and the overlap width of the spread are known, the spreader will be calibrated to determine an appropriate setting to deliver a desired amount of material. The use of a collection bag — an attachment that encloses the impeller and captures the product as it is being delivered (figure 10.12) — greatly speeds the calibration process and prevents product from repeatedly being delivered to an area during the calibration run. Consider the goal in this example is to deliver a total of 1 pound of nitrogen per 1,000 square feet using urea (45-0-0). If possible, perform the calibration using a calibration run length that results in 1,000 square feet of coverage. If the ESW is 12 feet, then the desired calibration length is 83.3 feet (1,000 square feet ÷ 12 feet ESW = 83.3 feet in length). If 45-0-0 is the fertilizer of choice, the formula for how much product is needed is (1 x 100) ÷ 45 = 2.2 pounds urea per 1,000 square feet to deliver 1 pound of nitrogen per 1,000 square feet. Set the spreader setting to a low-to-medium range; establish a comfortable, repeatable walking speed that is initiated several feet before the beginning of your calibration course; and collect fertilizer in the collection bag over the 83-foot distance. Weigh the material collected and adjust the spreader setting up or down depending on the amount collected. Repeat the process until approximately 2.2 pounds of urea are collected. Just as for drop spreaders, the uniformity in distribution can be improved by applying the fertilizer in two directions. If this strategy were employed, the calibration run would collect 1.1 pounds of urea (one-half the full rate).

Figure 10.12. This rotary spreader is equipped with a collection bag to capture all granular product that is applied during calibration.

In the absence of a collection bag, it is possible to simply weigh out a known amount of fertilizer to place in the hopper, apply product to a length of at least 25 feet, and then determine how much fertilizer remains in the hopper in order to determine the level of nutrient applied. For example, 2 pounds of urea is placed in the fertilizer hopper with a previously determined ESW of 12 feet and a calibration run length of 25 feet. The total area covered in a single pass is 12 feet x 25 feet = 300 square feet. It was previously determined that 2.2 pounds of urea per 1,000 square feet was required to deliver 1 pound of nitrogen per 1,000 square feet. The proportion would be:

$$\frac{2.2 \text{ lb of 45-0-0}}{1{,}000 \text{ sq ft}} \times \frac{Y \text{ lb of 45-0-0}}{300 \text{ sq ft}}$$

$$660 = 1{,}000\,Y$$

$$Y = 0.66 \text{ lb of 45-0-0}$$

Choose a low spreader setting, apply the fertilizer over the 25-foot calibration run length, and collect and weigh the remaining fertilizer in the hopper. If 2 pounds of urea was placed in the hopper before the application, then the desired amount remaining in the hopper is 2.00 pounds – 0.66 pounds = 1.34 pounds of urea. Repeat the process until you determine the appropriate spreader setting. The obvious disadvantage of this method is the application of product in the calibration area.

Another method is to apply the dry product to a clean, paved area where the product can be collected by sweeping after delivery. Again, determine a suitable length based on the ESW. Of course, having to sweep up product over an 83.3-foot length is quite labor intensive; therefore, a shorter length is typical but some precision in calibration is likely sacrificed. Apply the product, collect it with a broom and dust pan, and weigh to determine a rate of product per unit area covered in the calibration run. Because all the product is collected, it is not necessary to start with a known quantity. As before, keep adjusting the spreader settings until the appropriate amount of product is delivered per unit area.

Finally, a fourth method of delivery that does not involve calibration is what is sometimes referred to as the "exercise method." For this method, divide the lawn up into logical areas of known square footage. Next, weigh precise amounts of fertilizer to cover the known area. For example, if an area measures 5,000 square feet and the goal is to deliver 2.2 pounds of urea per 1,000 square feet (i.e., 1 pound of nitrogen per 1,000 square feet), then 11 pounds of urea are needed for the lawn based on the following proportion:

$$\frac{2.2 \text{ lb of 45-0-0}}{1{,}000 \text{ sq ft}} \times \frac{Y \text{ lb of 45-0-0}}{5{,}000 \text{ sq ft}}$$

$$11{,}000 = 1{,}000\,Y$$

$$Y = 11 \text{ lb of 45-0-0}$$

Weigh 11 pounds of urea and place it in the spreader. Select a very low spreader setting and cover the lawn in multiple directions until the spreader hopper is emptied. No calibration is required, but the only way to ensure uniform spread is to get plenty of exercise covering the lawn in multiple directions, delivering small amounts of product. This method is very suitable for someone who infrequently fertilizes small lawn areas but obviously is not an efficient use of time for professional applicators who may be fertilizing several acres per day.

Spread Patterns

The spread pattern with a rotary spreader will never be completely uniform because of the variability in spread due to wind, speed, equipment operation, and for some fertilizers, the different sizes and weights of particles. To manage the lack of spread uniformity, most textbooks suggest calibrating the spreader to deliver one-half the desired rate of product and apply the product in two passes at right angles to each other. Other published information suggests that similar (if not better) delivery results can be obtained by applying granular products at one-half application rates in a parallel delivery pattern (figure 10.13).

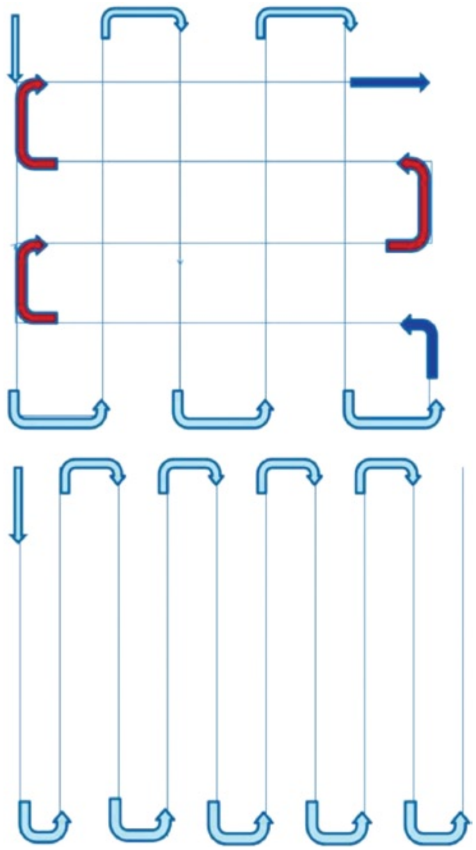

Figure 10.13. Standard right-angle application method (top) and the overlap delivery method (bottom).

Final Thoughts on Spreader Calibration

Several national lawn product retailers sell spreaders specifically designed for their products. Part of the advantage of using these specialty products is the "cookbook" nature of the application instructions. However, it is still wise to use their recommended settings only as guidelines for beginning your own calibration steps rather than taking the suggested spreader settings and application levels as guarantees. Not all spreaders deliver product alike, and over time (and with use), spreader performance is likely to change. Record all information involved in calibration steps (amount and type of product, spreader settings, etc.) for future reference. This will make future calibrations that much quicker and easier.

Liquid Fertilizers and Sprayer Calibration

Many specialty products are marketed as liquid formulations that quickly go into solution or are easily suspended in water. Many micronutrient formulations are sold as chelates — organic forms of the nutrient that are in a liquid formulation. Also, several common granular forms of fertilizers are highly water-soluble and can be quickly dissolved in water to make their own spray solution, while others are quite insoluble and unsuitable for liquid feeding (see the water solubility information in tables 8.1, 8.3, and 8.4 in chapter 8).

Before adding different fertilizers and/or pesticides to a tank, check the label very carefully for specific comments regarding tank mixing and/or conduct a test of the compatibility of the two products by adding small, proportional amounts of the products that simulate what will be added to the spray tank. If the product blends into a uniform solution, mixing in the tank should be fine. If the combination becomes a sludge-like consistency, tank-mixing should be avoided.

Sprayer Components

All spray systems will have a tank, a pump, a boom, nozzles, and sprayer tips. The system will logically be mobile, whether it is by way of someone walking or a motorized vehicle. While it is beyond the scope of this handbook to provide exhaustive detail on all these components, there are some basic elements about the sprayer components that will suffice in obtaining accurate calibration. Additional information is available in *Fine Tuning a Sprayer with "Ounce" Calibration Method*, Virginia Cooperative Extension publication 442-453 (Grisso et al. 2009).

The pump is used to create pressure (whether the pump is powered by hand or by an engine), and it is important that the pressure be optimal for the system and the product and that it is consistent and repeatable. Most products will have pressure and spray-volume recommendations on their labels.

Next, choose an appropriate nozzle and tips for the system and the application. Again, this information is usually provided on the product label or as a recommendation provided by the sprayer system and/or the nozzle and tip supplier. True foliar feeding of nutrients that are intended to primarily enter a plant through the leaves is accomplished with spray volumes of 45 gallons per acre (GPA) or less. In other situations where a liquid fertilizer might be mixed with an insecticide intended to enter the soil in order to control a ground-borne pest, the recommended volume of liquid delivery might be 100 to 200 GPA.

Other factors to consider when selecting and optimizing the use of nozzles and tips for multinozzle booms (often used in golf turf management) are their appropriate spacing and height off the ground. Some tips require up to a 33 percent overlap of the spray pattern to ensure 100 percent coverage. The manufacturers of the nozzles and tips provide helpful charts for these criteria, with much of the information being available on the Internet.

Routinely check the system and its components to ensure proper working condition. Check that hoses and fittings are securely attached, nozzles and tips are not clogged, and spray pressure generated by the pump is constant. A great place to run a preliminary inspection of the system is to conduct a sprayer test by applying water on a driveway or parking lot that makes it easy to evaluate that boom height, nozzle selection, and nozzle spacing are all appropriate to provide uniform application (figure 10.14). After this initial check, gather all the equipment you will need for the calibration: a stopwatch, measuring tape or wheel, flags to mark your course, and containers to collect and measure the liquid discharge (figure 10.15).

Figure 10.14. Evaluating nozzle and tip performance prior to calibration is easily accomplished by spraying water on a road or driveway to evaluate boom nozzle height and overlap.

Figure 10.15. The basic equipment needed for sprayer calibration.

The "Ounce" Calibration Method

This method of calibration is very popular because it eliminates a lot of the math in the calibration calculations. A gallon equals 128 ounces, so if a sprayer is calibrated on an area of 1/128th of an acre (1 acre = 43,560 square feet ÷ 128 = 340 square feet), then the ounces collected during calibration equate to gallons per acre.

Begin by measuring the nozzle spacing on the boom (figure 10.16) because this determines the course length required to cover 1/128th of an acre. For example, with a 20-inch nozzle spacing as depicted in figure 10.16 (20 inches equals 1.67 feet), the calculation will be 340 square feet ÷ 1.67 feet nozzle spacing = approximately 204 linear feet (see table 10.1 for course lengths based on standard nozzle spacing). When calibrating a single nozzle such as for a hose end or backpack sprayer, determine the spray width (in feet) for the single nozzle and divide this into 340 square feet to determine the course length for calibration.

Figure 10.16. Nozzles should be equally spaced on the boom according to manufacturer recommendations. By measuring the spacing, you can then calculate the test course length in order to calibrate the sprayer according to the ounce calibration method.

Table 10.1. Course lengths required to calibrate 1/128th of an acre (340 square feet)**.**

Boom nozzle spacing (inches)	**Course length** (feet)
12	340
16	255
20	204
24	170
28	146
32	127
36	113
40	102

If the boom has 20-inch nozzle spacings, then table 10.1 indicates that a course length of 204 feet is required to cover 1/128th of an acre. Fill the tank at least half way with water, determine an optimum speed for the terrain and product delivery (usually 3 to 4 mph), set the power takeoff (PTO) at an appropriate rate of RPMs for the pump to deliver the desired pressure and volume of spray solution, and operate the sprayer system as if product was being applied. Be sure the test course terrain is comparable to the area that you will be treating so your calibration run equates well with the actual area to cover.

Time how long it takes to travel the 204 feet for this particular spray system setup. Then, operate the sprayer in a stationary position, capturing the discharge from a single nozzle for the time period it took to drive the 204-foot test course in this example (figure 10.17). Using a measuring cup marked in ounces, what is collected in ounces simply equals gallons per acre.

Figure 10.17. Capture the discharge from a nozzle for the same time duration it took to drive the test course.

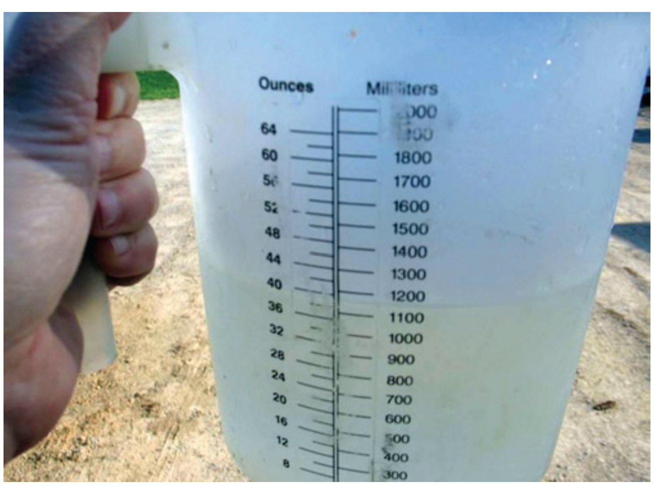

Figure 10.18. The amount captured in ounces equals the gallons per acre the sprayer is delivering. In this example. the sprayer is calibrated to deliver 40 GPA.

In the example presented, the 40 ounces of discharge collected for the known time period equates to a sprayer calibrated to deliver 40 GPA. Catch the output from at least three nozzles for the required duration to ensure that all nozzles are performing comparably. If a nozzle does not deliver an output that is within plus/minus 5 percent of the average nozzle output, check the filter and tip to see if they are clogged and/or damaged. Replace any suspect nozzle or tip.

Example of How Much Product to Add

The label of a popular 15-0-0 liquid fertilizer that is also 4 percent sulfur and 6 percent iron by weight recommends an application range of 2 to 8 fluid ounces per 1,000 square feet. If 4 ounces per 1,000 square feet is selected, how much is added to the sprayer system that was just calibrated in the preceding example?

If relatively large areas are to be treated, it is logical to prepare full tanks of spray solution. Assume the system has a 100-gallon tank. As calibrated at 40 GPA, then a full tank can cover 100 gallons ÷ 40 GPA = 2.5 acres. How many square feet are in 2.5 acres? One acre is 43,560 square feet, so 2.5 x 43,5460 = 108,900 square feet. Using a basic proportion, the setup is:

$$\frac{\text{4 fluid oz of product}}{\text{1,000 sq ft}} \times \frac{\text{Y fluid oz of product}}{\text{108,900 sq ft}}$$

$$435{,}600 = 1{,}000\,\text{Y}$$

$$\text{Y} = \text{approx 436 fl oz of product}$$

$$\frac{\text{436 fluid oz}}{\text{128 fl oz/gal}} = \text{approx 3.4 gal of 15-0-0}$$

So, 3.4 gallons is the amount of 15-0-0 liquid fertilizer to be added to the tank of a sprayer calibrated to deliver 40 GPA. To prepare a full tank, fill the tank partially with water, add the fertilizer, and then add the remaining water to bring the tank to the 100-gallon level.

What if the goal were to cover only 20,000 square feet of area? It was just calculated that a full sprayer holding 100 gallons will cover 108,900 square feet. There would be no point in mixing a full tank but instead, just enough to cover 20,000 square feet. A simple proportion would be:

$$\frac{\text{100 gal}}{\text{108,900 sq ft}} \times \frac{\text{Y gal}}{\text{20,000 sq ft}}$$

$$2{,}000{,}000 = 108{,}900\,\text{Y}$$

$$\text{Y} = \text{approx 18.4 gal of water}$$

How much fertilizer is needed to treat the 20,000-square-foot area using a rate of 4 fluid ounces per 1,000 square feet?

$$\frac{\text{4 fluid oz of product}}{\text{1,000 sq ft}} \times \frac{\text{Y fluid oz of product}}{\text{20,000 sq ft}}$$

$$80{,}000 = 1{,}000\,Y$$

$$Y = \text{80 fluid oz of product}$$

Add a few gallons of water to the tank, add the 80 fluid ounces of fertilizer, and then fill the tank to a final volume of approximately 18.4 gallons.

How about adding dry products or powders? Many commercially available powdered fertilizers are highly water-soluble and even some bulk fertilizer materials may be sufficiently soluble to deliver in liquid form (see chapter 8, table 8.1). For example, up to 6.5 pounds of urea is soluble in a gallon of water (from table 8.1; note that rapid mixing and even heat may be needed to speed dissolution of some materials unless dilute solutions are desired). Consider an example where the goal is to use the calibrated sprayer above to provide a nitrogen level of 0.25 pound per 1,000 square feet (using urea) to 20,000 square feet of turf.

It will take 0.25 pounds of nitrogen ÷ 0.45 = 0.56 pounds of urea per 1,000 square feet to deliver the desired level of nitrogen. The area to be covered is 20,000 square feet.

$$\frac{\text{0.56 lb of 45-0-0}}{\text{1,000 sq ft}} \times \frac{\text{Y lb of 45-0-0}}{\text{20,000 sq ft}}$$

$$11{,}200 = 1{,}000\,Y$$

$$Y = \text{11.20 lb of 45-0-0}$$

It was previously determined (see above) that a sprayer calibrated to deliver 40 GPA would need approximately 18.4 gallons of total spray volume to treat 20,000 square feet. Fill the tank with approximately 9 gallons of water, add the 11.2 pounds of urea (stirring or agitating to ensure the product fully dissolves), and bring the final tank volume to approximately 18.4 gallons. The sprayer is calibrated to deliver 0.25 pound of nitrogen per 1,000 square feet.

Other Considerations With Sprayable Fertilizers

Because of the high volumes applied and the relatively dilute concentration of nutrients, liquid fertilizer applications are often very uniform and precise. However, you should pay very close attention to the label recommendations regarding spray volume, nozzles, and tips and the requirement for sprayer agitation. Also, be sure to record your own observations regarding sprayer performance and plant response for future reference. Watering in of many liquid fertilizers may be recommended after application to reduce leaf burn potential or to improve uptake efficiency. Be very careful regarding the compatibility of tank mixtures of fertilizers, pesticides, and other spray additives because they can cause undesired changes in physical and/or chemical properties of the materials.

Literature Cited

Grisso, R., P. Hipkins, S. D. Askew, L. Hipkins, and D. McCall. 2009. *Nozzles: Selection and Sizing*. Virginia Cooperative Extension Publication 442-032. *http://pubs.ext.vt.edu/442/442-032/442-032.html.*

Grisso, R., M. Weaver, K. Bradley, S. Hagood, and H. Wilson. 2009. *Fine Tuning a Sprayer with "Ounce" Calibration Method*. Virginia Cooperative Extension Publication 442-453. *http://pubs.ext.vt.edu/442/442-453/442-453.html.*

Chapter 11. Soil-Water Budgets and Irrigation Sources and Timing

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Introduction

The successful establishment and management of turfgrass and landscape plantings are highly dependent on the maintenance of adequate soil moisture over time, particularly during periods of drought. Ideally, the soil's physical properties allow for rapid infiltration and retention of rain and applied irrigation waters. When adverse soil properties such as excessive compaction and lack of aggregation (see chapters 2 and 3) limit soil infiltration rates, valuable water is lost to runoff and may carry excess nutrients away with it in stormwater discharge.

Conversely, when excess soil water percolates down through the soil profile, particularly during the winter, it may also carry away soluble nutrients such as nitrate-nitrogen to local groundwater. Thus, the relative risk of nutrient movement to groundwater and surface waters in any managed soil landscape is strongly controlled by the physical nature of the soil profile coupled with the nature of the vegetation and associated management practices. These site-specific factors then interact with local climate — particularly rainfall intensity and snowmelt — resulting in different infiltration and runoff rates.

In this chapter, we will focus on understanding how water applied as rainfall or irrigation moves into and out of the soil profile on a local (e.g., home lot) basis. Greater detail on larger scale (e.g., subdivision or watershed level) stormwater and nutrient runoff issues and best management practices is presented in chapter 12.

The Hydrologic Cycle and Soil-Water Budgets

A basic understanding of the hydrologic cycle (illustrated in figure 11.1) is necessary to understand nutrient loss mechanisms and to develop management strategies to reduce nutrient losses to groundwater and surface water. The primary components of the hydrologic cycle that are most important to nutrient transport in surface water and groundwater are:

- Precipitation.
- Interception of rainfall on plants.
- Surface runoff.
- Evapotranspiration (evaporation plus plant transpiration).
- Net leaching to groundwater and eventual discharge into streams (base flow).

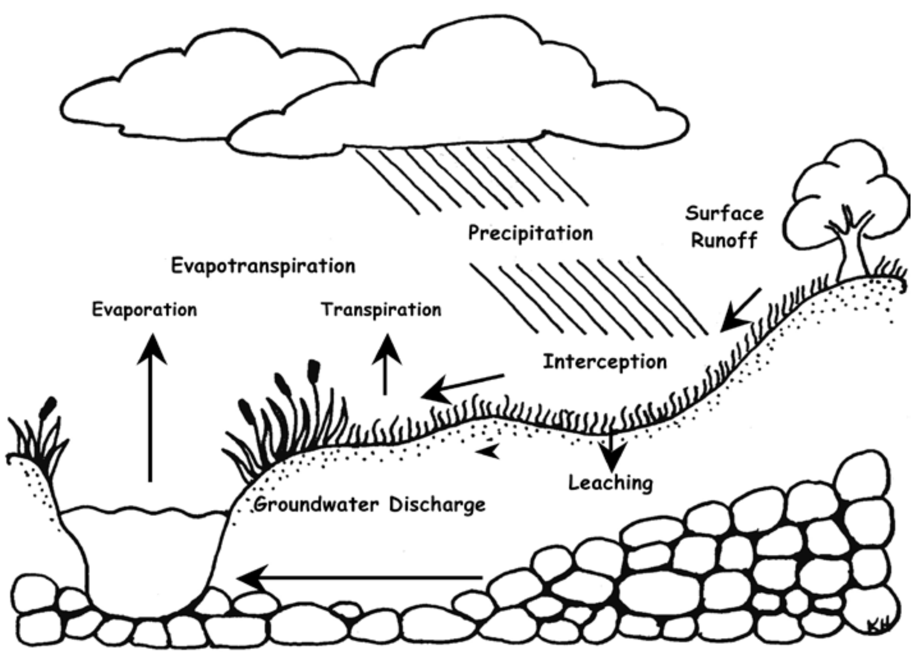

Figure 11.1. The hydrologic cycle. *Figure by Kathryn Haering.*

Nutrients move into the groundwater system via leaching and to surface water via runoff or groundwater discharge to springs and seeps. Any contaminants dissolved in surface runoff, such as nitrate (NO_3^-) or ortho-phosphorus, can contribute to surface water contamination. In addition, discharge of groundwater into surface water often occurs in stream beds and tidal portions of the Chesapeake Bay system.

Precipitation

Long-term annual precipitation averages range from 35 inches to more than 50 inches in different areas of the mid-Atlantic region. Although timing and amount of precipitation will vary in each individual year, these deviations from the average cannot be reliably predicted.

Interception

From 5 percent to 40 percent of precipitation is intercepted by the leaves of plants, depending on the intensity of rainfall and the morphology of the canopy. This water never reaches the soil surface to contribute to either infiltration or runoff, but it does cool and wet the plant's leaves, which can decrease transpiration losses over the short term. Higher interception rates are associated with light rains falling on dense multistoried canopies (e.g., mature woody trees over complete herbaceous groundcovers), while lower interception rates are associated with heavy rains on thinly vegetated surfaces, such as newly established lawns.

Surface Runoff

Precipitation that falls onto the soil surface in excess of the infiltration rate will run off to lower portions of the landscape or to surface streams. Soil infiltration rates vary widely, from several inches of rainfall per hour on gently sloping, well-vegetated, and aggregated surfaces to less than 0.10 inch per hour on sloping, compacted, clayey, poorly vegetated areas. Infiltration is also affected by whether or not the soil surface is wet or dry at the start of the rainfall event (antecedent moisture conditions).

Evapotranspiration

Evapotranspiration (ET) is the sum of surface evaporation of moisture (from puddles, ponds, etc.) plus the removal of soil moisture by the root uptake and subsequent transpiration of water through the leaves of living vegetation. For example, ET accounts for 25 to 40 inches of the total precipitation in Virginia and is highest in Eastern Virginia, where the long growing season and higher air temperatures combine for maximum plant water demand. The removal of soil water by ET decreases significantly when air temperatures drop below 45 degrees Fahrenheit (F) and/or when the active vegetation goes dormant for the winter. Long-term average rainfall by month does not vary significantly throughout the year for most areas, but it is slightly higher in the late summer and early fall due to infrequent (but extreme) effects of hurricanes. Evapotranspiration, however, is much greater during the late spring, summer, and early fall because water use by vegetation is much higher during this period (see figure 11.2).

Leaching and Groundwater Discharge

Water that infiltrates upland soils during the growing season is largely removed by evapotranspiration (figure 11.2); water losses beyond the rooting zone to groundwater are very rare. Consequently, the risk of leaching or runoff losses of water and soluble nutrients is much less during the summer than during the winter. However, during the late fall and winter, any added or remaining soil water — particularly that held in large macropores — is subject to leaching below the rooting zone and will eventually reach groundwater.

During leaching, soluble nutrients such as nitrate percolate through the soil with water because they are not readily bound to soil surfaces. The relative amounts of surface runoff, interception, and leaching from an area are influenced by storm intensity, storm duration, slope, soil type, type of vegetation, and amount of plant or crop residue on the soil surface.

During the winter months, the amounts of rainfall and snowmelt that infiltrate most upland soils greatly exceeds the rate of evapotranspiration. During this period (nominally November to March), water leaches completely through the soil profile and contributes to local groundwater "recharge." Groundwater that infiltrates upland soils as recharge eventually discharges into local streams and is also termed "base flow."

Figure 11.3 depicts an example of a landscape-level water budget and net groundwater discharge to streams for a typical Ridge and Valley Province watershed. In this area, long-term leaching and discharge accounts for about 5 inches per acre of watershed area, while direct-surface runoff losses account for 7 inches per acre annually. Surface runoff contributions to stream water occur during and after rainfall events or snowmelt and are therefore highly variable over time.

In contrast, base flow is usually a continuous contributor to stream flow throughout the year. During dry periods, base flow is the primary contributor to stream flow, which vividly demonstrates the interconnection of groundwater and surface waters.

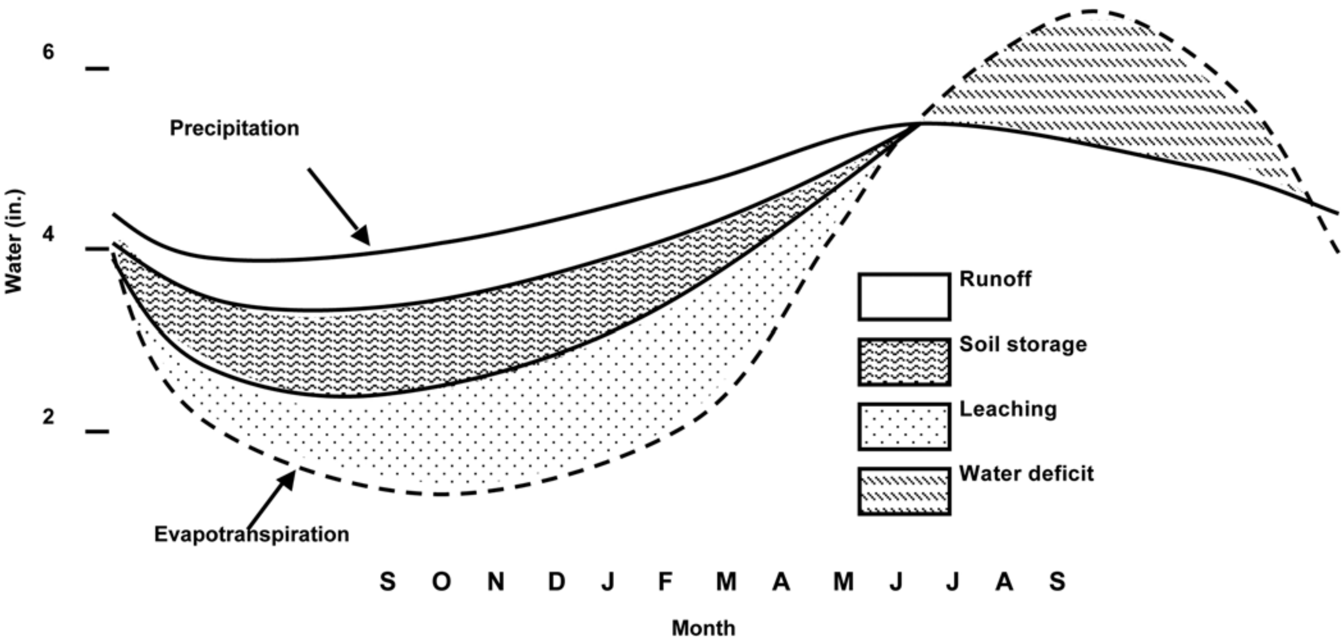

Figure 11.2. The soil water budget. This figure depicts the overall balance of water inputs (as precipitation) and losses (as runoff, evapotranspiration, and leaching) for a typical upland soil in the mid-Atlantic region. The annual period shown here runs from September (S) to September. Note that while average precipitation inputs are fairly even across the year, net evapotranspiration demand varies directly with the season as driven by temperature and day length. In midsummer (J, J, and A), potential evapotranspiration greatly exceeds rainfall and the difference between the two results in a soil water deficit that must be made up via supplemental watering/irrigation for optimal plant growth. By late fall (N and D), however, evapotranspiration drops with falling temperatures and the soil holds and stores water against leaching up to its water-holding capacity as soil storage. Once that capacity to retain water is exceeded, additional infiltrating rainwater and snowmelt is transmitted down through the soil and is lost as leaching to groundwater recharge. *Figure by Kathryn Haering; based on data from Carroll County, Va.*

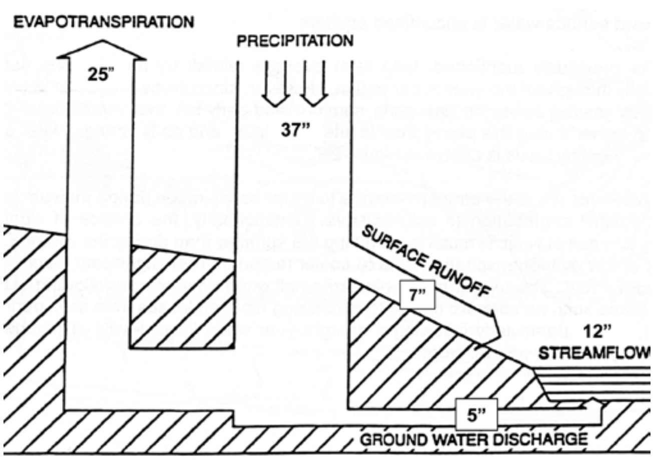

Figure 11. 3. General water budget, Upper South Fork of the Shenandoah River (adapted from Virginia Department of Conservation and Recreation 1993).

Base flow and subsurface seepage of groundwater contribute more than surface runoff to surface water bodies in the Atlantic Coastal Plain Province due to much flatter terrain, highly permeable soils, and relatively high water table levels. In some areas of the Coastal Plain, groundwater discharge may account for as much as 80 percent of total annual contributions to surface water. Groundwater in the Coastal Plain Province typically moves in a downwardly arcing path from uplands toward discharge points at a rate of several inches to as much as 2 feet per day.

Watering Basics for Turf and Landscape Plantings

As pointed out in the preceding section, plant transpirational demands for water during the summer usually exceed rainfall, which can lead to water stress, poor plant growth, and even death of established turf and landscape plantings. Water stress is amplified in urban soils that are limited by compaction and poor aggregation/infiltration (chapter 3) and in very sandy or rocky native soils with inherently low water-holding capacities (chapter 2). Therefore, we commonly supplement rainfall with watering/irrigation during the summer and early fall months.

Water Application Rate, Timing, and Frequency

The amount of water needed by established turf or ornamental plants depends on the type of turf or plant, the soil type, the amount of existing moisture in the soil, and the time of year. Overwatering is a leading cause of problems with landscape plants and can also damage established turf — especially when applied to soils with limited permeability that locally perch shallow, saturated zones in soils (see chapter 3) or cause local ponding. Where feasible, rain sensors should be installed on large or commercial irrigation systems to prevent overwatering and waste and to reduce costs.

Application Rate

One-time irrigation rates for turf should be sufficient to wet, but not saturate, the entire rooting depth as described below. This may vary from 0.5 to 1.5 inches or more of water per event, depending on the porosity, aggregation, and bulk water-holding capacity of the soil. An easy way to check this is to use a shovel to examine the wetting depth approximately 30 minutes after the irrigation event ends. Obviously, the application rate will also need to be managed to ensure complete infiltration and limited runoff.

As a general guide, water should be applied to landscape plantings at the rate of 1.0 inch per week (60 gallons per 100 square feet) in a single application. This amount will wet most soils to a depth of about 12 inches (the area containing 80 percent of the roots of most landscape plants). Because water moves readily within the plant, you do not need to water the entire root zone. Twenty-five percent of the root area can absorb enough water for the entire plant. Irrigation should stop when water begins to run off. If necessary, 0.5 inch of water can be applied, followed by an additional 0.5 inch several hours later to prevent runoff. This rate is a general recommendation for established annuals, perennials, and woody plants in landscape beds.

Application Timing

The best time to water is in the early morning, whether using a hand-held hose, drip or trickle system, microsprinklers, soaker or ooze hose, or overhead sprinklers. As much as 30 percent of the water applied overhead during midday can be lost to interception and evaporation. Also, overhead applications made early in the day allow time for the foliage to dry, which prevents diseases.

Application Frequency for Landscaping Plants

For established turfgrass, the watering regime should be managed to provide enough water to wet the soil throughout the normal rooting zone (i.e., 6 to 12 inches) but not more than twice per week to avoid overwatering. Deep, infrequent watering promotes downward turfgrass root proliferation while more frequent, shallow irrigation events are detrimental to long-term turf rooting patterns and the sod's inherent ability to withstand drought in the absence of watering.

Slow, deep, soaking applications once a week are best for landscaping plants. Avoid short, frequent, shallow applications that can actually stress landscape plants or cause a buildup of ions or salts from the water in the soil that may be toxic to certain plants. Newly installed plants may require more frequent irrigation. This depends mainly on the plant species, soil type, and mulch.

In general:

- Water annuals every two days for the first two weeks.
- Water perennials and woody plants every three to four days for the first three weeks.
- Irrigation frequency should return to once a week as needed after the plants have been established.

Water Reuse: Using Reclaimed Water for Irrigation

"Reclaimed water," also known as "recycled water," is water recovered from domestic, municipal, and industrial wastewater treatment plants that has been treated to standards that safely allow most uses except human consumption (figure 11.4). "Wastewater" (untreated liquid industrial waste and/or domestic sewage from residential dwellings, commercial buildings, and industrial facilities) is not reclaimed water. "Gray water," or untreated wastewater from bathing or washing, is one form of wastewater. Wastewater may be land-applied, but this is considered to be land treatment rather than water reuse.

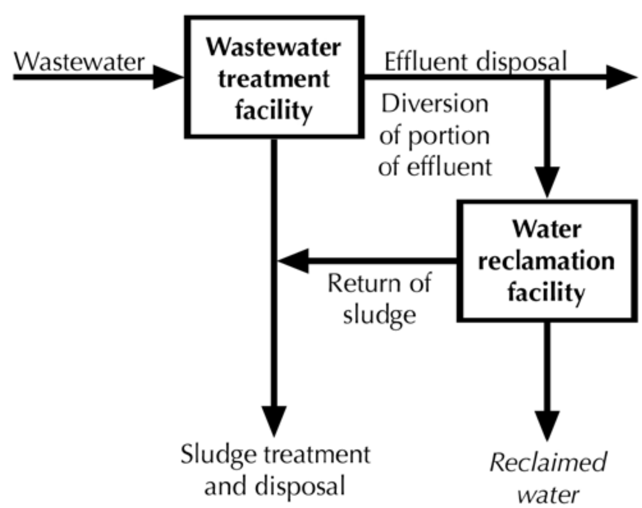

Figure 11.4. Water reclamation process at a wastewater treatment facility. (adapted from Environmental Protection Agency [EPA] 2004).

How Is Reclaimed Water Produced?

During primary treatment at a wastewater treatment plant, inorganic and organic suspended solids are removed from plant influent by screening and settling. The decanted effluent from the primary treatment process is then subjected to secondary treatment, which involves biological decomposition of organic material and settling to further separate water from solids. If a wastewater treatment plant is not equipped to perform advanced treatment, water is disinfected and discharged to natural water bodies following secondary treatment.

Advanced treatment or tertiary treatment consists of further removal of suspended and dissolved solids, including nutrients, and disinfection. Advanced treatment can include:

- Nutrient (nitrogen and/or phosphorus) removal by biological or chemical methods.
- Removal of organics and metals by carbon adsorption or chemical precipitation.
- Further removal of suspended and dissolved solids by filtration, coagulation, ion exchange, reverse osmosis, and other techniques.
- Removal of organic chemicals by oxidation with hydrogen peroxide or ozone.

Water that has undergone advanced treatment is disinfected prior to being released or reused. Reclaimed water often requires greater treatment than effluent that is discharged to local streams or rivers, because users will typically have more direct contact with undiluted, reclaimed water than with undiluted effluent.

Why Reuse Water?

The demand for fresh water can potentially exceed supply during times of even moderate drought. The potential for developing new sources of potable water is limited. Conservation measures such as irrigating with reclaimed water are one way to help ensure existing water supplies are utilized as efficiently as possible.

Water Reuse Regulations

There are no federal regulations governing reclaimed water use, but the Environmental Protection Agency (EPA; 2004) has established guidelines to encourage states to develop their own regulations. The primary purpose of federal guidelines and state regulations is to protect human health and water quality. To reduce disease risks to acceptable levels, reclaimed water must meet certain disinfection standards by reducing the concentrations of constituents that may affect public health and/or limiting human contact with reclaimed water.

The EPA (2004) recommends that water intended for reuse should:

- Be treated to achieve biochemical oxygen demand and total suspended solids levels of less than 30 milligrams per liter (mg/l) during secondary or tertiary treatment.
- Receive additional disinfection by means such as chlorination or other chemical disinfectants, UV radiation, ozonation, and membrane processing.

Biochemical oxygen demand (BOD) is an indicator of the presence of reactive organic matter in water. Total suspended solids (TSS) are measures of the amount of organic and inorganic particulate matter in water.

In Virginia, water reuse means direct beneficial reuse, indirect potable reuse, or a controlled use in accordance with the Water Reclamation and Reuse Regulation (9 VAC 25-740-10 et seq.; available at the Virginia Administrative Code website at *http://leg1.state.va.us/000/reg/TOC09025.htm*, chapter 740).

The Virginia Water Reclamation and Reuse Regulations are designed to protect both water quality and public health while encouraging the use of reclaimed water. The primary determinants of how reclaimed water of varying quality can be used are based on treatment processes to which the water has been subjected and on quantitative chemical, physical, and biological standards. Further detail on the water reclamation process and reclaimed water quality standards can be found at *http://pubs.ext.vt.edu/452/452-014/452-014.html*.

Reclaimed Water Quality Considerations for Irrigation

Water quality must be considered when using reclaimed water for irrigation. The following properties are critical to plant and soil health and environmental quality.

Salinity Levels

Salinity, or salt concentration, is probably the most important consideration in determining whether water is suitable for reuse (EPA 2004). Water salinity is the sum of all elemental ions (e.g., sodium, calcium, chloride, boron, sulfate, nitrate) and is usually measured by determining the electrical conductivity (EC; units =

deciSiemens per meter [dS/m]) or total dissolved solids (TDS; units = mg/l) concentration of the water. Water with a TDS concentration of 640 mg/l will typically have an EC of approximately 1 dS/m.

Most reclaimed water from urban areas is slightly saline (TDS ≤ 1,280 mg/l or EC ≤ 2 dS/m). High salt concentrations reduce water uptake in plants by lowering the osmotic potential of the soil. For example, residential use of water adds approximately 200 to 400 mg/l dissolved salts (Lazarova, Bouwer, and Bahri 2004a). Plants differ in their sensitivity to salt levels, so the salinity of the particular reclaimed water source should be measured so that appropriate crops and/or application rates can be selected. Most turfgrasses can tolerate water with 200 to 800 mg/l soluble salts, but salt levels above 2,000 mg/l may be toxic (Harivandi 2004). For further information on managing turfgrasses when irrigating with saline water, see Carrow and Duncan (1998).

Many other crop and landscape plants are more sensitive to high soluble-salt levels than turfgrasses and should be managed accordingly. See Wu and Dodge (2005) for a list of landscape plants with their relative salt tolerance and Maas (1987) for information on salt-tolerant crops.

Concentration of Sodium, Chloride, and Boron

Specific dissolved ions may also affect irrigation water quality. For example, irrigation water with a high concentration of sodium (Na) ions may cause dispersion of soil aggregates and sealing of soil pores. This is a particular problem in golf course irrigation (Sheikh 2004), because soil compaction is already a concern due to persistent foot and vehicular traffic. The sodium adsorption ratio (SAR), which measures the ratio of sodium to other ions, is used to evaluate the potential effect of irrigation water on soil structure. For more information on how to assess and interpret SAR levels, see Harivandi (1999).

High levels of sodium can also be directly toxic to plants, both through root uptake and accumulation of plant leaves following sprinkler irrigation. The specific concentration of sodium that is considered to be toxic will vary by plant species and type of irrigation system. Turfgrasses are generally more tolerant of sodium than most ornamental plant species.

Although boron (B) and chlorine (Cl) are necessary at low levels for plant growth, dissolved boron and chloride ions can cause toxicity problems at high concentrations. Specific toxic concentrations will vary depending on plant species and type of irrigation method used. Levels of boron as low as 1 to 2 mg/l in irrigation water can cause leaf burn on ornamental plants, but turfgrasses can often tolerate levels as high as 10 mg/l (Harivandi 1999). Very salt-sensitive landscape plants such as crape myrtle (*Lagerstroemia* sp.), azalea (*Rhododendron* sp.), and Chinese privet (*Ligustrum sinense*) may be damaged by overhead irrigation with reclaimed water containing chloride levels more than 100 mg/l, but most turfgrasses are relatively tolerant to chloride if they are mowed frequently (Harivandi 1999; Crook 2005).

Nutrient Levels

Reclaimed water typically contains more nitrogen and phosphorus than drinking water. The amount of nitrogen and phosphorus provided by the reclaimed water can be calculated as the product of the estimated irrigation volume and the nitrogen and phosphorus concentration in the water. To prevent nitrogen and phosphorus leaching into groundwater, the Virginia Water Reclamation and Reuse Regulation requires that a nutrient management plan be written for bulk use of reclaimed water not treated to achieve biological nutrient removal (BNR), which the regulation defines as treatment which achieves an annual average of 8.0 mg/l total nitrogen and 1.0 mg/l total phosphorus. Water that has been subjected to BNR treatment processes contains such low concentrations of nitrogen and phosphorus that the reclaimed water can be applied at rates sufficient to supply a crop's water needs without risk of surface or groundwater contamination.

Other Plant Growth and Water Quality Concerns

- High suspended solids (TSS) concentrations may clog irrigation systems and can fill pore spaces near the soil surface, resulting in reduced drainage. Acceptable TSS levels will vary depending on the type of suspended solids and type of irrigation system. Generally, TSS levels less than 50 to100 mg/l are safe for drip irrigation.
- Free chlorine (Cl_2) is necessary for disinfection, but can damage plants at high concentrations (> 5 mg/l). Storage for a short time reduces the residual free-chlorine concentration in water.
- High or low pH is an indicator of the presence of phytotoxic ions, and pH should be approximately 6.5 to 7.0, if possible.

- High bicarbonate (> 120 ml) and carbonate (15 mg/l) levels can clog sprinklers and cause white lime deposits on plant leaves; it may increase soil pH and decrease permeability.
- Heavy metals can be a concern in wastewater that has high industrial input, but such metals (for example, cadmium, copper, molybdenum, nickel, and zinc) are typically strongly bound to the solid fraction, or biosolids portion, of the wastewater and are rarely found in high enough concentrations to pose a reclaimed water quality problem.

(Harivandi 1999; Landschoot 2007; Lazarova et al. 2004a)

Application Rates

Irrigation rates for reclaimed water are site- and crop-specific and will depend on the following factors (EPA 2004; Lazarova, Papadopoulous, and Bahari 2004b).

1. Seasonal irrigation demands must be determined. These can be predicted with:
   - An evapotranspiration estimate for the particular crop being grown.
   - Determination of the period of plant growth.
   - Average annual precipitation data.
   - Data for soil permeability and water-holding capacity.

   Methods for calculating such irrigation requirements can be found in the U.S. Department of Agriculture's (USDA) *National Engineering Handbook* at *http://www.info.usda.gov/CED/ftp/CED/neh-15.htm* (USDA 2003) and in Reed, Crites, and Middlebrooks (1995). Turfgrass irrigation rates in Virginia can also be calculated using the website *http://www.turf.cses.vt.edu/Ervin/et_display.html*. These calculations are more complicated for landscape plantings than for agricultural crops or turf because landscape plantings consist of many different species with different requirements.
2. The properties of the specific reclaimed water to be used, as detailed in the section above, must be taken into account because these may limit the total amount of water that can be applied per season.
3. The availability of the reclaimed water should also be quantified, including:
   - The total amount available.
   - The time of year, when available.
   - Availability of water storage facilities for the non-growing season.
   - Delivery rate and type.

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Chapter 12. Principles of Stormwater Management for Reducing Nutrients From Urban Landscaped Areas

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Introduction

The objective of this chapter is to provide a summary of current urban stormwater management issues and practices relevant to the mid-Atlantic region. One of the goals of a nutrient management plan is to reduce nutrient loads in stormwater runoff from urban landscaped areas. Nutrient management efforts have typically addressed agricultural, industrial, and commercial sites and impervious or paved surfaces. There appeared to be very little, if any, overlap with urban stormwater management.

However, Virginia's regulatory approach to stormwater management now includes urban stormwater runoff from **both** pervious and impervious areas, so many of the newer, "greener" stormwater management practices may become part of the landscape of an average urban site. Thus, a background in stormwater quantity and quality may be beneficial for the nutrient management planner.

This chapter provides an introduction to stormwater and discusses aspects related to stormwater quality, with an emphasis on nutrient loading to downstream receiving waters. The current regulatory approach and available practices for managing urban stormwater runoff are summarized. A list of practices and an assessment tool to examine the risk of urban water quality problems from a single site are provided in appendix B of this chapter.

Introduction to Stormwater Management

What Is Stormwater?

Stormwater is a hybrid term used to describe runoff (usually from urban areas) caused by precipitation in the form of rain, snow, or ice. In urban areas, runoff can occur from both impervious and pervious areas, although much more runoff comes from impervious areas.

Factors that affect stormwater runoff:

- Quantity and intensity of precipitation.
- Amount of impervious surface on the site (rooftops, driveways, patios and decks, roadways, parking lots, etc.).
- Type and condition of soil: Water infiltrates clay soils slower than sandy soils.
- Soil saturation level at the time of the precipitation: More runoff from pervious areas can occur if soil is already saturated before precipitation.
- Vegetative canopy layers and coverage: Runoff is reduced on sites with a higher percentage of vegetative coverage and multiple canopy layers.
- Extent and steepness of slopes.

Figure 12.1 describes a simplified hydrologic cycle for a residential lot. Precipitation, usually in the form of rainfall, falls on the land. On pervious areas, infiltration occurs until soil saturation has been reached. Runoff occurs almost immediately from impervious surfaces and after saturation from pervious land. Living vegetation creates water vapor that is released to the atmosphere; this is known as evapotranspiration (ET).

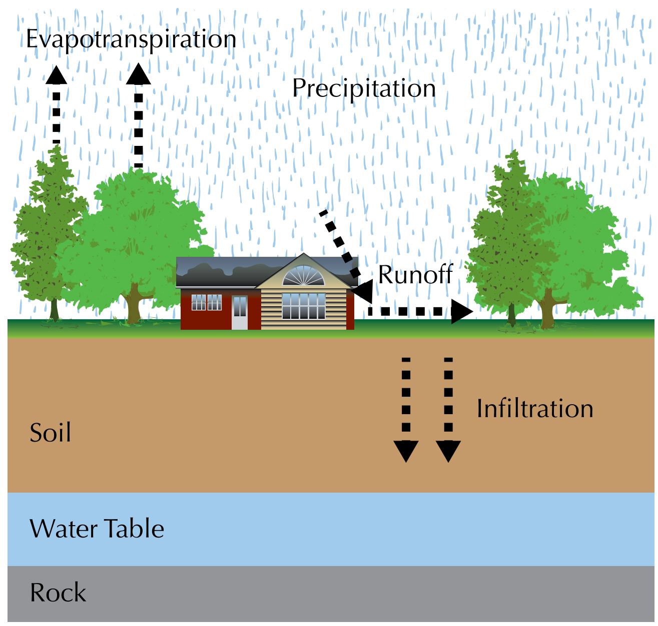

Figure 12.1. Simplified hydrologic cycle of a residential lot.

Where Does Stormwater Go?

Figure 12.2 illustrates the water pathways in a typical urban system. Potable water is shown entering homes (blue water system) while wastewater is shown leaving homes. Wastewater from laundry, bathroom sinks, and showers is often classified as "gray water" and can be recycled; however, in most homes, gray water is discharged to the wastewater or "black water" system. Typical stormwater from streets and impervious areas enters a catch basin and is transported to a storm sewer. In some cases, stormwater is also classified as a gray water system.

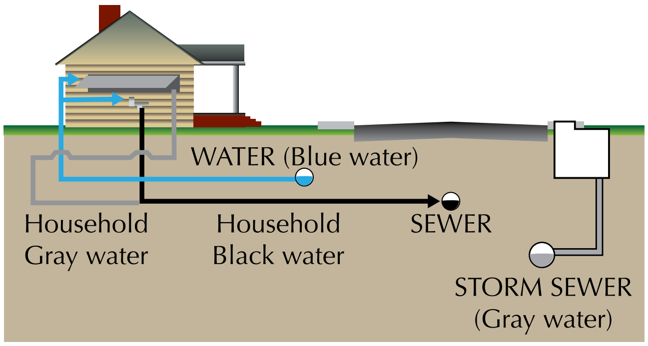

Figure 12.2. Definitions of urban water systems.

Many people who live in urban areas believe that stormwater flows through storm drains to a treatment facility. This is only the case in a "combined sewer system" (CSS), where one pipeline is used to convey both stormwater and wastewater (gray and black water). This type of system is often found in older urban areas. A major problem of a CSS is overflows of partially treated wastewater that occur when peak runoff exceeds storage capacity in the system. This discharge is known as a "combined sewer overflow." The more common type of system is a "separate storm sewer system." Here, one pipeline conveys stormwater from storm drains directly into receiving waters, which are usually smaller streams and/or lakes, wetlands, bays, estuaries, or reservoirs. A separate pipeline conveys sanitary wastewater — household water and waste from toilets, sinks, and showers — to a wastewater treatment facility. Wastewater receives treatment and is discharged to receiving waters as authorized with permit conditions in the National Pollutant Discharge Elimination System (NPDES). Stormwater discharges from urbanized areas are also regulated via an NPDES permit; a system of this type is known as a "municipally separate storm sewer system," or MS4.

Watersheds

A key concept necessary for understanding how water flows to receiving waters is a watershed. A watershed is a contiguous portion of land that sheds water into a single lowest point called an outlet or pour point. Ridgelines or areas of higher elevation separate one watershed from another.

Figure 12.3 illustrates a typical watershed. All upstream land uses and practices contribute to downstream water quality. Parks, open spaces, "low-impact development"

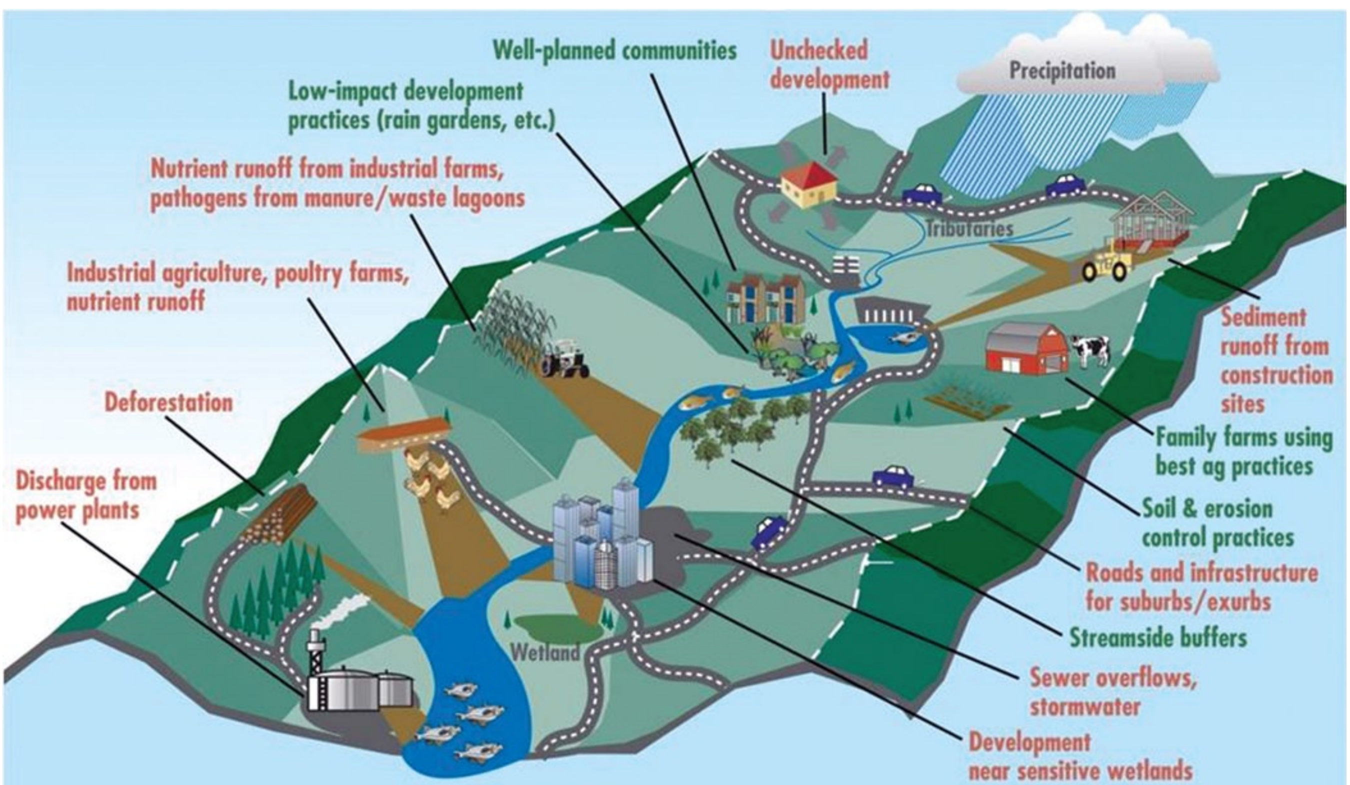

Figure 12.3. Watershed model. Green = positive factors; red = negative factors. *Source: Potomac Conservancy 2007.*

(LID) areas, riparian buffers, streams, and wetlands connect aquatic and forested ecosystems within the watershed. This connected natural system is also known as "green" infrastructure. In essence, urban nutrient planners are stewards of the green infrastructure system.

For more information on watersheds, see *What is a Watershed?* (Gilland et al. 2009), Virginia Cooperative Extension publication 426-041, in appendix 12-A of this chapter or at *http://pubs.ext.vt.edu/426/426-041/426-041.pdf.*

Stormwater Quantity and Quality Issues

In undisturbed areas, stormwater runoff is generally not an issue because rainwater is quickly absorbed into the soils or utilized by vegetation. Water that infiltrates the soil is either released into the atmosphere by plants through the evapotranspiration process or percolated down through the soil profile to recharge the groundwater aquifers.

During urban development, the land is impacted in two ways:

1. During site preparation, when vegetation is stripped away leaving exposed soils that easily erode during rainfall events, causing an increase in sediment loading and downstream deposition. Sediment- and erosion-control practices and products are used at this stage of development.
2. During construction, as impervious surfaces are created (roofs and paved surfaces), infiltration is reduced and runoff is increased. Best management practices (BMPs) are used at this stage of development to offset the increased runoff. Because runoff is the primary transport mechanism for pollutants including sediment and nutrients, these pollutants will increase with the runoff increase if nothing is done to prevent it.

Both point and nonpoint source pollution are regulated under the federal Clean Water Act (CWA).

- "Point sources" may be classified as publicly owned treatment works, privately owned treatment facilities, industrial discharges, and sometimes, agricultural operations. Point sources are regulated through the National Pollutant Discharge Elimination System permitting program.
- "Nonpoint sources" consist primarily of runoff from urban, suburban, and developing areas and some agriculture sites. Because of the numerous and diffuse nature of these sources, they have not previously been regulated. In order to achieve the goals of the CWA, pollution from urban runoff is now becoming more strictly regulated through the municipally separate storm sewer system NPDES stormwater permits. Other nonpoint source pollution problems have also been addressed through a variety of incentive programs.

Stormwater Quantity Issues

Figure 12.4 illustrates one of the most fundamental concepts in urban stormwater — a hydrograph — which is a plot of stream discharge over time during a rainfall event. Urban development causes multiple impacts on the stormwater hydrograph.

1. The peak runoff rate increases due to lack of infiltration.
2. Water travel time decreases, resulting in a shortening of the hydrograph when compared to predevelopment hydrology.
3. After the storm event is over, base flow does not recover when comparing postdevelopment with predevelopment curves. This is due to the lack of infiltration and recharge from impervious areas.

Traditional stormwater management functions by providing a facility with additional storage volume that slowly releases water at the predevelopment rate of discharge. However, the volume of this discharge is greater than before development. This is shown as the dotted green line in figure 12.4. The increased stormwater volume causes an increase in sheer stress as it reaches a stream, which then causes erosion and increased transport capacity for pollutants. Low-impact development attempts to replicate the predevelopment hydrograph by increasing infiltration volume. A perfect LID system would therefore be very close to the blue line on figure 12.4 or the predevelopment hydrograph.

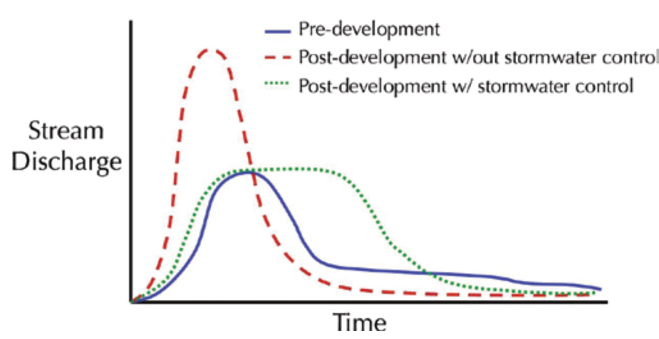

Figure 12.4. A typical urban hydrograph.

Figure 12.5 illustrates the net impact of these changes across an annual hydrologic cycle in Virginia. The horizontal portion shows the continuum of urbanization from left to right, with natural groundcover on the left, moving through suburban, then urban development to 75 to 100 percent imperviousness on the right. The top part of the figure shows the annual change in the typical year's water budget. Significant changes occur with recharge decreasing from 11 to 2 inches and runoff increasing from 4 to 23 inches. A moderate decrease in ET from 17 to 13 inches occurs.

Figure 12.6 illustrates the subsequent geomorphic effects of urbanization on a receiving stream. A continuum of urbanization is shown from left to right. As development increases, significant changes occur in stormwater runoff peak flows and frequencies. The resultant stream shape changes are also shown. Urban streams are subjected to more frequent and increased peak flows and have much higher sheer stresses during bankfull events. This results in increased erosion of the channel. Also, urban streams tend to dry out due to the lack of recharge, resulting in a loss of stream length. The urban stream widens, deepens, and dries out, seriously impacting or destroying aquatic ecosystems and associated green infrastructure.

Stormwater Quality Issues

Higher stream flows cause increased stream erosion and higher loads of sediment, nutrients, and other pollutants in downstream receiving waters. The pollutants are present due to practices on the land but are carried by storm runoff and adversely impact downstream receiving waters. When receiving waters deteriorate to the point of not meeting their designated use, they are listed as "impaired." A current map of impaired streams for Virginia is provided in figure 12.7.

For each of these impacted streams, the Virginia Department of Environmental Quality (VDEQ) has or is establishing a Total Maximum Daily Load (TMDL) of the identified pollutant to the receiving stream. Once a TMDL has been established, the VDEQ develops an allocation amount for each of the identified sources for the pollutant in the upstream watershed. VDEQ then revises the surface water discharge permits from identified point sources at the time of permit renewal. Then, the Virginia Department of Conservation and Recreation (VDCR) develops an implementation plan for how these allocations will be achieved for nonpoint sources, including stormwater discharges.

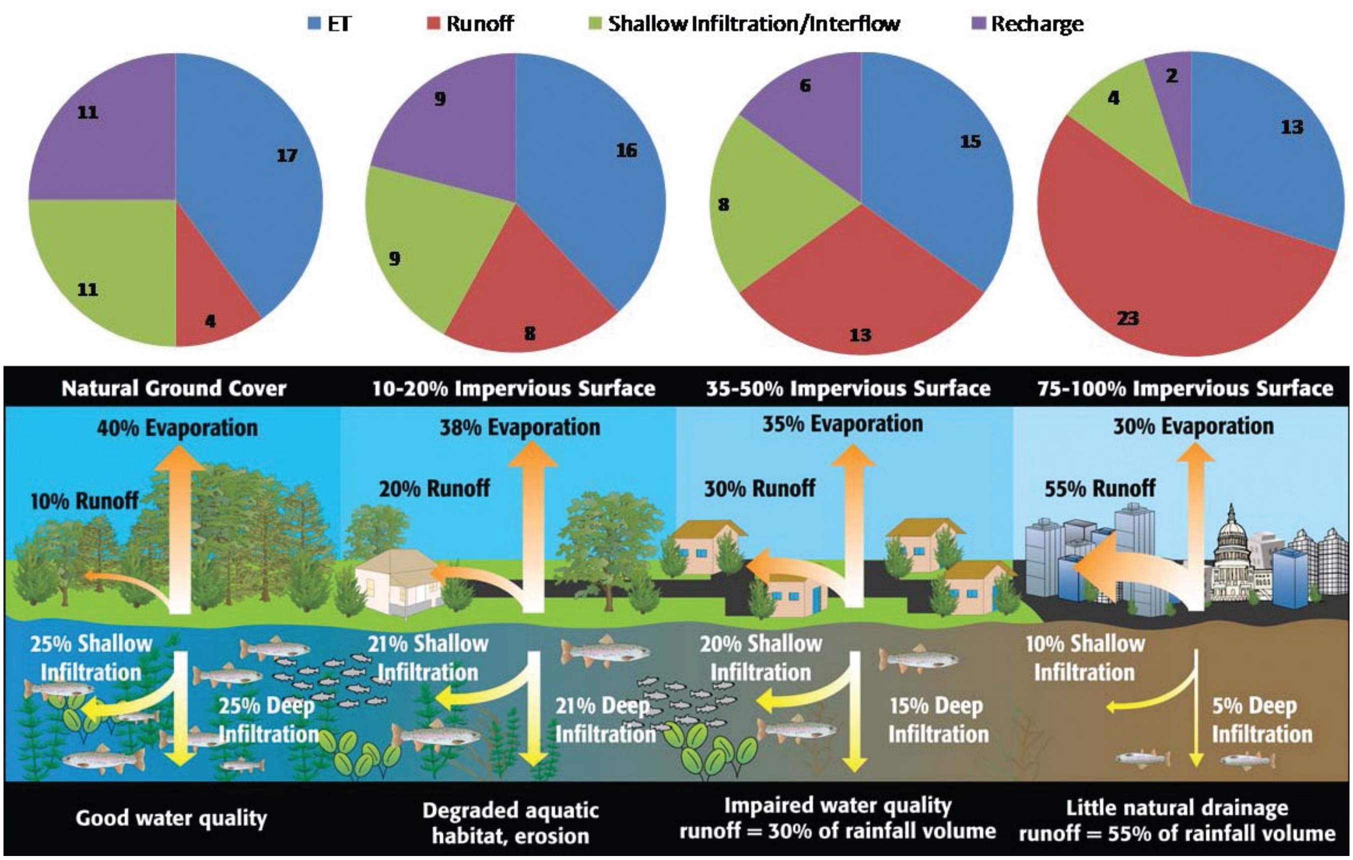

Figure 12.5. Virginia average annual water budget with urbanization. *Source: Potomac Conservancy 2008.*

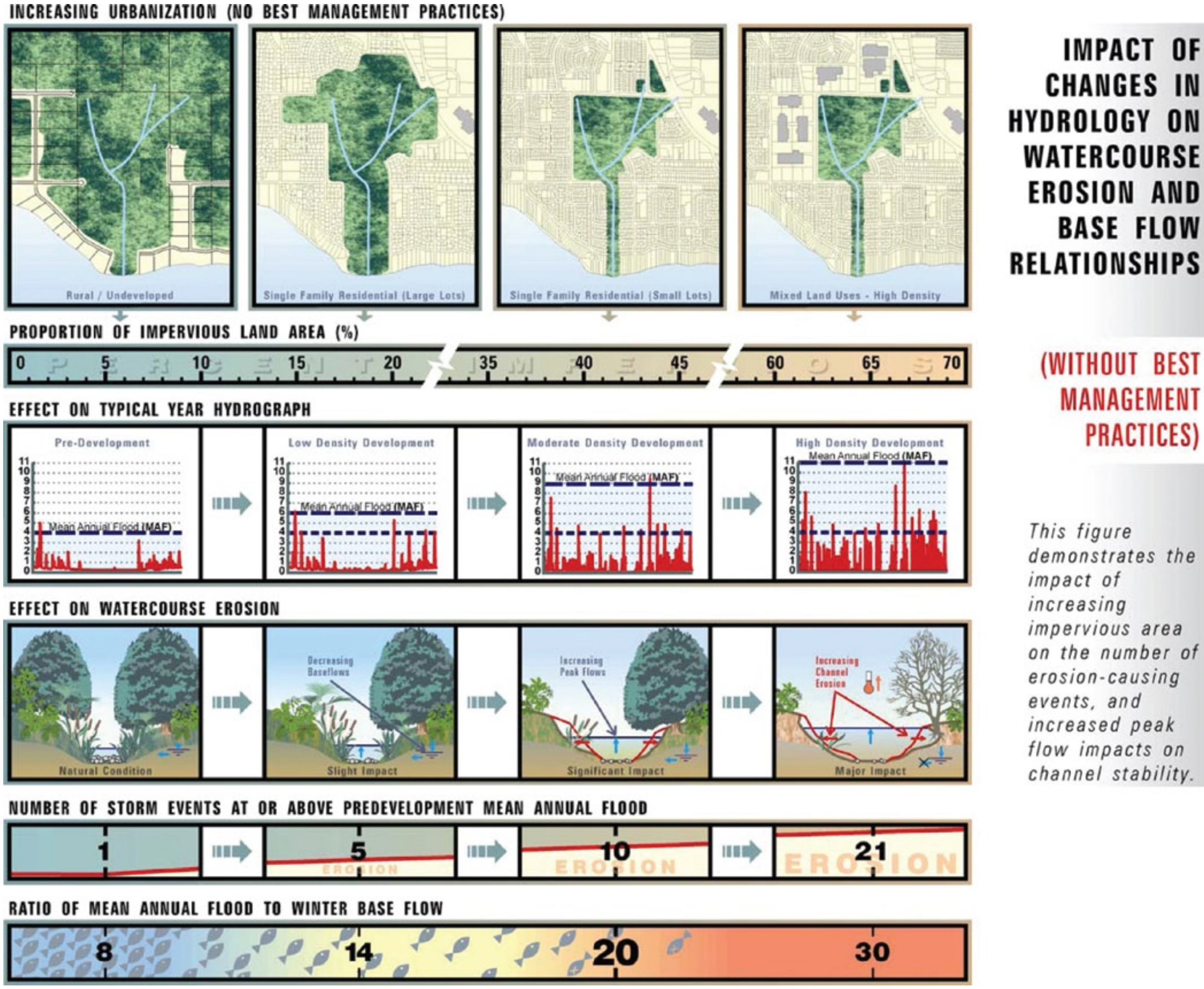

Figure 12.6. Urbanization and its effect on stream geomorphology.

Source: Ministry of Water, Land and Air Protection, Copyright 2002 Province of British Columbia. All rights reserved. Reprinted with permission of the Province of British Columbia.

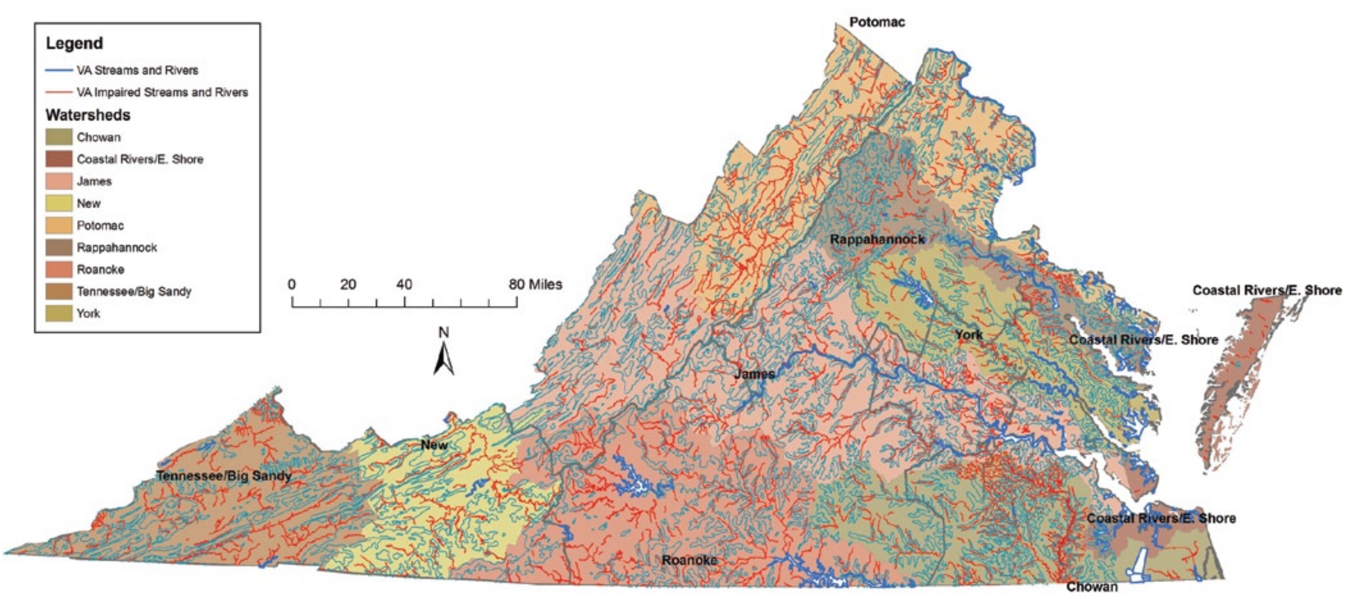

Figure 12.7. Currently impaired water bodies, Virginia.

Source: Virginia Department of Environmental Quality 2008.

Regional water quality issues can also significantly affect local water quality programs. The Chesapeake Bay receives runoff from most of Virginia, including the watersheds associated with the Shenandoah, Potomac, Rappahannock, James, and York rivers. These watersheds are shown in figure 12.7. The bay also receives runoff from the states of Maryland, Pennsylvania, Delaware, and New York, creating a watershed of 64,000 square miles.

An assessment of the health of tributary streams to the bay is provided in figure 12.8. Once a rich and productive estuary, the Chesapeake Bay has declined due to pollution generated from urban and industrial development and agricultural practices. Within the bay, sediment, nutrients, and other pollutants cause a variety of problems such as excess algae growth, reduced dissolved oxygen levels, and decreased water clarity. These conditions cause changes in aquatic organisms, often decimating desirable species and creating dead zones in the bay (figure 12.9). A recent assessment of water quality and ecosystem health of the bay estuary is provided in figure 12.10.

Nitrogen and phosphorus are the primary nutrients of concern. As a benchmark, for illustrative purposes, existing loadings from various land uses were computed from the Chesapeake Bay Nutrient and Sediment Reduction Tributary Strategies (Commonwealth of Virginia 2005) and disaggregated for Virginia. Figures 12.11 and 12.12 depict nitrogen and phosphorus loadings, respectively, from different land uses, with urban areas separated into impervious and pervious (or landscaped) areas. These figures show that while urban impervious areas are the source of increased flows, urban pervious areas may be a source for excess nutrients, on par with loadings from agricultural areas. Thus, nutrient management in the landscape should reduce loadings from urban areas and eventual pollution to receiving waters and the Chesapeake Bay.

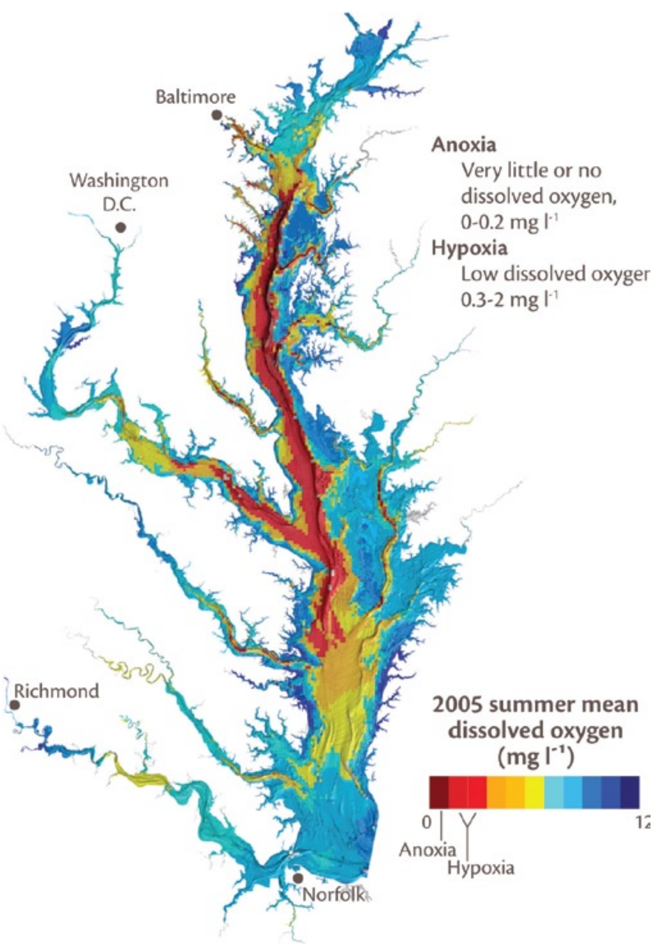

Figure 12.9. Chesapeake Bay dead zones, August 2005.
Source: Chesapeake Bay Program 2005.

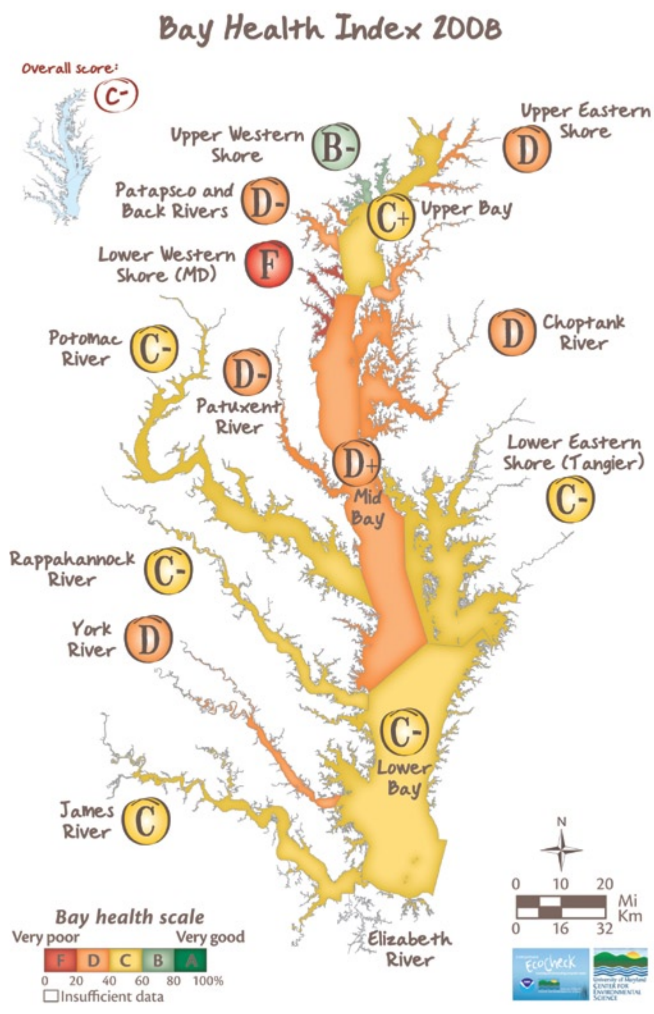

Figure 12.10. Chesapeake Bay Report Card 2008: Bay Health Index.
Source: University of Maryland Center for Environmental Science (UMCES) and EcoCheck 2008.

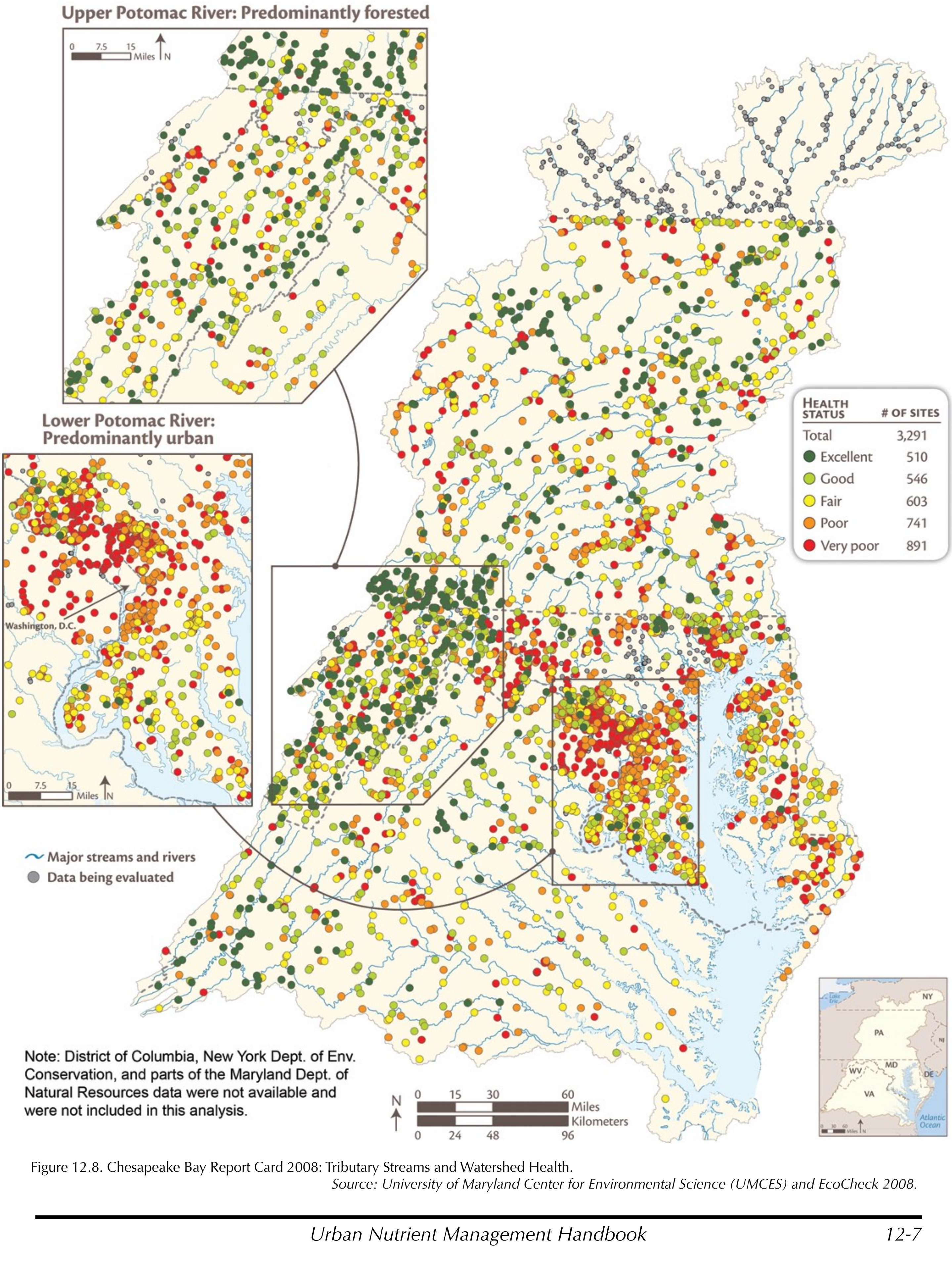

Figure 12.8. Chesapeake Bay Report Card 2008: Tributary Streams and Watershed Health.

Source: University of Maryland Center for Environmental Science (UMCES) and EcoCheck 2008.

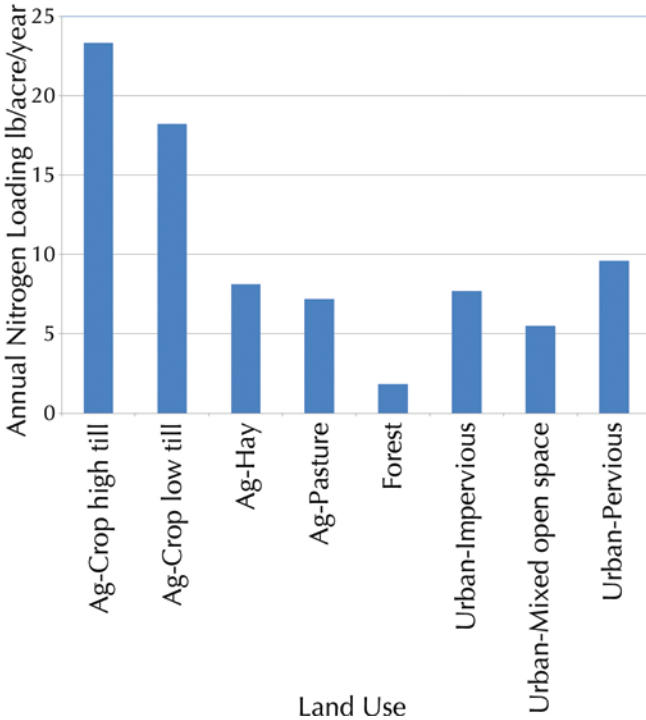

Figure 12.11. Average annual nitrogen washoff loadings for Virginia land uses. *Source: Commonwealth of Virginia 2005.*

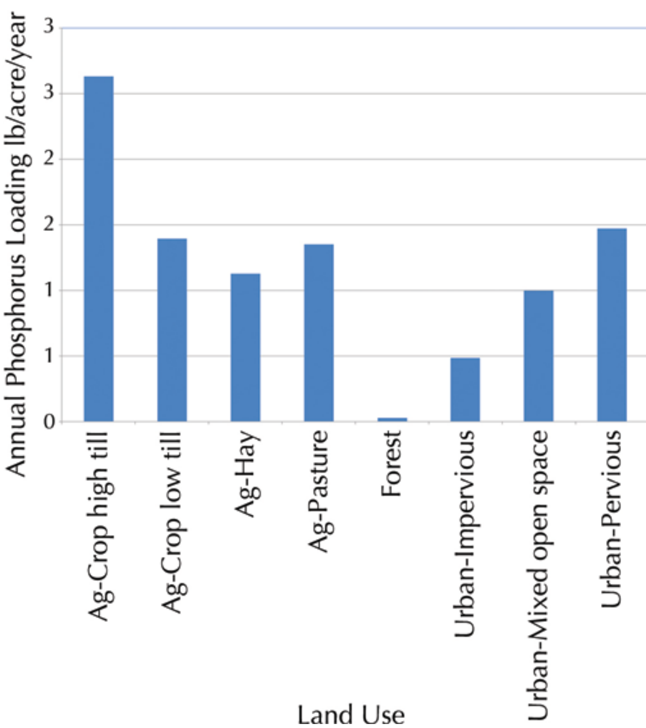

Figure 12.12. Average annual phosphorus washoff loadings for Virginia land uses. *Source: Commonwealth of Virginia 2005.*

Managing Urban Stormwater

The Virginia Stormwater Management Program (VSMP) is the regulatory program by which the state and local governments control nonpoint source pollution stemming from urban development. In 2009, in response to the issue of adverse impacts to receiving waters from urban runoff, the VDCR revised the VSMP regulatory program. The program focus shifted from mitigating peak runoff during urban development to managing stormwater volume and water quality. A new process known as the Virginia Runoff Reduction Method (VRRM) was developed by the Center for Watershed Protection (2009) in collaboration with VDCR. The intent of the VRRM is to fundamentally alter the land design process used in urban development through a three-tiered strategy that includes:

Environmental site design (ESD) practices. These are intended to minimize impervious surface area and maximize conservation practices. ESD practices can be employed to reduce runoff by restoring soil infiltrative capacities, restoring and/or preserving riparian buffers, and providing conservation subdivisions to protect critical habitats. The net impact from a stormwater perspective is that impervious surfaces and urban runoff are minimized.

Runoff reduction (RR) or volume control. This consists of implementing a variety of low-impact, density-based source controls on a site. Runoff reduction practices seek to reduce runoff prior to flowing offsite through a variety of mechanisms, predominately infiltration.

Pollutant removal (PR). This means using traditional, larger-scale best management practices to treat the reduced amount of runoff to remove nutrients and sediments.

Figure 12.13 illustrates the use of Virginia Runoff Reduction Method strategies in urban design, with the goal of increasing nutrient removal performance of a site after development.

Table 12.1 in appendix B lists the VDCR-approved BMPs. Each practice includes a brief description, diagram, photograph, and performance data, as well as their characterization as an ESD, RR, and/or PR device. The BMPs listed in this table are compiled from several sources, predominately the VDCR specifications from the Virginia Stormwater BMP Clearinghouse website (VDCR 2011), and are for public use. Most of these BMPs are intended for use in landscaped areas, so some familiarity with their functions may be beneficial.

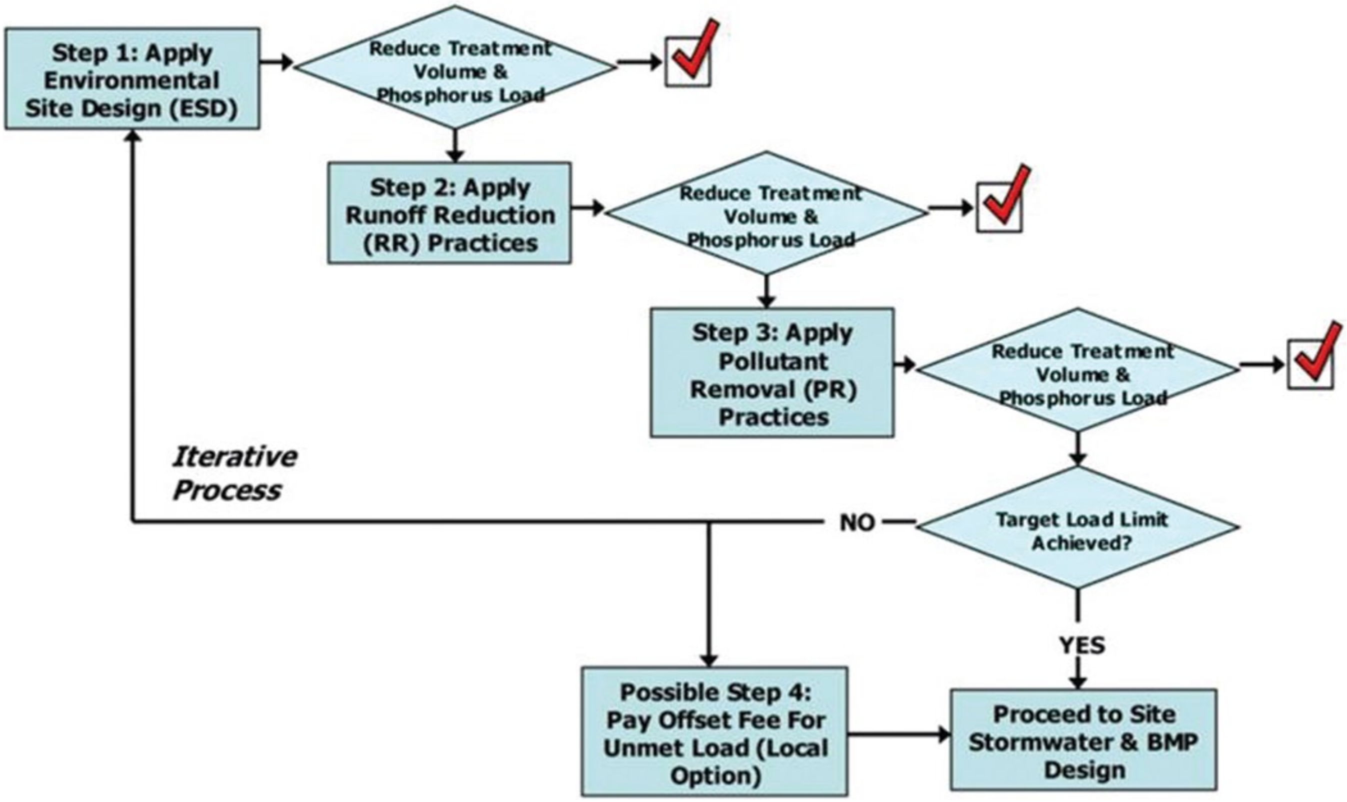

Figure 12.13. Virginia's runoff reduction methodology. *Source: Center for Watershed Protection 2008.*

Proprietary BMPs consist of systems developed by specific manufacturers that utilize a variety of treatment technologies to remove pollutants from urban runoff, usually at a smaller scale than public-use BMPs. Proprietary BMPs should be examined individually because limited unbiased information is available.

Managing Stormwater on a Residential Lot

Until recently, stormwater management focused exclusively on management of impervious areas. As the understanding of nonpoint source pollution from urban areas has improved, it has become apparent that a substantial portion of the pollutants may come from pervious or landscaped areas. So, programs have shifted toward management of both pervious and impervious urban areas at both watershed and single-lot scales.

Many practices are available to reduce nonpoint source pollution at the residential level. Water and nutrient use in both turf and ornamental bed areas should be addressed. These practices require participation from the homeowner, which can sometimes be challenging. The following sections provide an overview of the steps to characterize and reduce runoff and pollutants at a residential scale, identify landscape management practices that can be beneficial, and present a risk-based assessment tool for an owner or contractor to evaluate practices at a single lot scale. This information is based on Shelton and Feehan (2008), Thacker (2009), and the Washington Environmental Council (2009).

Source Control or Reducing Pollutants in Runoff

One of the most effective means of reducing pollutants in runoff is source control. Addressing the following questions and issues may assist in the characterization of the relative risk a single site poses on downstream urban water quality issues.

Where Does Stormwater Go?

In order to assess a site, develop a site plan using the following steps:

1. Measure lot boundaries and buildings or obtain a copy of a recent survey of the site. An example of a simple site plan without topography is provided in figure 12.14.
2. Include topographical information if it is available, but a visual survey of the high and low spots on the site can suffice.

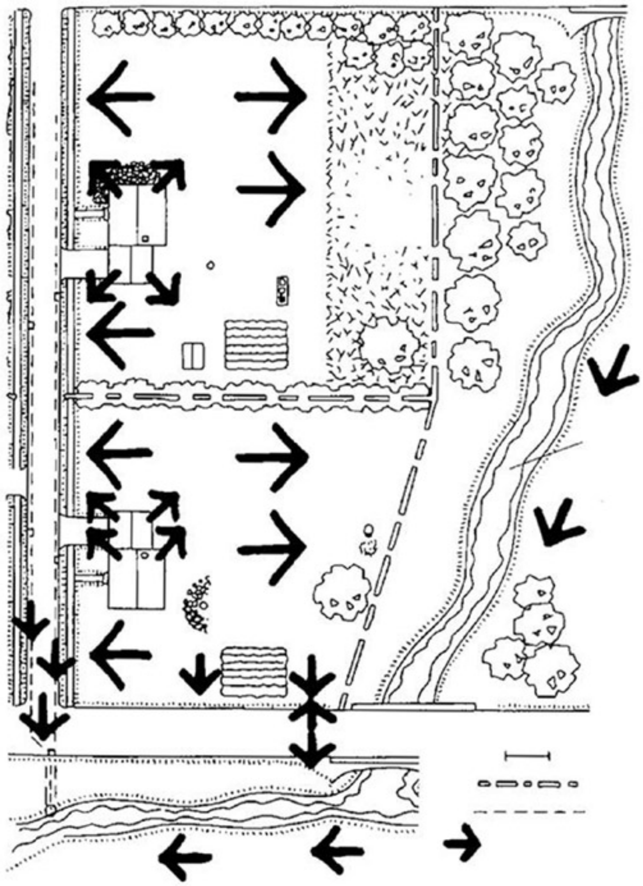

Figure 12.14. Site planning. *Source: Shelton and Feehan 2008.*

3. Identify impervious areas such as buildings, parking areas, sidewalks, patios, pools, decks, and driveways and how they drain (or if a drain is present).
4. Show areas of steep slopes.
5. Identify soil types based on soil test information or local soil maps.
6. Mark and characterize landscaped and vegetated areas.
7. Identify sensitive areas such as creeks, ditches, lakes, wetlands, storm drains, buffers, etc. Usually these would receive runoff from the site.
8. Mark stormwater runoff paths and flow directions.
9. Identify where the runoff leaves the site to adjacent receiving waters, storm drains, and neighboring sites.

It is always a good practice to reduce runoff, but it can also be a good social practice when water flows onto neighboring sites.

Keeping Yard and Garden Wastes

Disposing of leaves, grass, branches, and other yard debris in ditches and storm drains is a common practice that clogs drainage systems, causes flooding, and increases organic loading downstream. Previously, it was explained that for the most part, urban runoff is discharged untreated to receiving waters. As the organic matter from yard debris decomposes in streams, lakes, and estuaries, it depletes oxygen in water that can cause fish kills. Excess nutrients cause algal blooms and aquatic weed growth that lead to an imbalance in the ecosystem. To avoid these problems:

- Sweep/collect yard debris off streets, sidewalks, and driveways.
- Dispose of debris in a compost pile or through a curbside pickup service.
- Use a mulching mower to return grass clippings and their nutrients to the lawn.
- Use compost instead of fertilizer.

Handling Pesticides Safely

A wide variety of pesticides are available for use in landscapes.

- Keep an updated inventory list of the products stored on site.
- Store products in a dry, locked place.
- Always follow the label instructions. The label is the law!
- Hire certified pesticide applicators when necessary, especially when applying products near bodies of water.
- Avoid applications before a rain or irrigation cycle to prevent runoff contamination.
- Immediately clean up any spills or residues on impervious surfaces and dispose of them properly.
- Purchase only what is needed to avoid storing large amounts.
- Treat only when necessary with the least-toxic product.
- Consider alternative management practices to pesticides.
- Promote beneficial insects and natural predators in the landscape to minimize pesticide applications.

Fertilizers

An example of nutrient contamination can sometimes be seen in properties adjacent to stormwater ponds. Excess or misapplied fertilizer runs off before plants can absorb it and causes algae blooms and aquatic weed growth. These plants typically have short life cycles, and when they die and decay, they deplete oxygen needed for aquatic organisms and sometimes release substances that are toxic to aquatic organisms. Responsible fertilizer use can avoid many of these problems.

- See pesticide list above.
- Test soil to determine the fertilizer need (every three years is recommended).
- Use a slow-release fertilizer instead of multiple applications of a quick-release product.
- Apply the total amount recommended in a split application.
- Apply at the correct time for the plants to use it most efficiently.
- Don't use a complete fertilizer if it isn't necessary.
- Consider an organic product instead of a synthetic product.
- Remove fertilizer from impervious surfaces such as driveways and sidewalks.
- Contact the local cooperative Extension office for information on plants, environmental conditions, and educational programs.

Are Car and Truck Wastes Being Carried Away by Stormwater?

Fluids and residues from our vehicles can be significant pollutants. Used oil from a single oil change can contaminate a large quantity of runoff. Antifreeze is toxic to aquatic organisms and can shut down the kidneys of mammals. Brake dust and tire bits contain toxic metals. Soaps used in car washing contain surfactants that threaten aquatic habitat. These issues are easily addressed.

- Maintain vehicles to prevent leaks.
- Immediately and thoroughly clean up spills.
- Wash vehicles on the lawn or at a car wash with environmentally friendly products.
- Collect spent fluids, waste oils, solvents, etc., and dispose of properly. Many communities have household hazardous waste collection days for these materials.

Animal Waste Disposal

Domestic animals and pets provide companionship and recreation. However, animals produce waste that can contain high concentrations of nitrogen, phosphorus, and harmful pathogens. When this waste is exposed to rainfall, it can easily contaminate runoff and potentially cause human health hazards for recreational and drinking waters downstream. The economic impact on a community is significant when drinking water resources are compromised or recreational activities involving water are banned and beaches closed. Fortunately, this issue is easily resolved through good housekeeping practices.

- Pick up pet waste and dispose of it properly. Many communities have "scoop the poop" programs.
- Compost animal waste. Compost systems are good for treating waste from many animals or from larger animals such as horses.

Salt or Other De-Icing Products

In order to cope with winter weather, salt and de-icing products are often used. These can be toxic to aquatic organisms and plants. Salts can be corrosive to water pumps and pipes and build up in receiving waters. Because most salts are untreated except for dilution, they can cause issues in drinking water supplies downstream. Simple practices can be used to minimize these impacts.

- Manually clear snow from impervious surfaces and drains.
- Use alternative products such as sand or kitty litter.

Landscape Site Management for Control of Runoff

There are many practices that can be used in residential landscapes to reduce pollutants in runoff. The following questions are designed to assist in assessing their need and the relative risk of a site for urban water quality issues from erosion and other pollutants.

Are There Areas of Bare Soil?

Soil left exposed without vegetation easily erodes. When erosion occurs, sediment is transported downstream through runoff. Excess sediment clogs storm drains and reduces channel conveyance capacity, causing flooding. It also buries and destroys downstream underwater habitats, depriving fish of their food sources and living areas. These issues can be easily avoided.

- Overseed bare spots. Aeration may be necessary on compacted areas.
- Use groundcovers if turf will not grow.
- Use mulch if vegetation will not grow or is not desired.
- Vegetative buffers can be used along sloped or downhill portions of the site (appendix 12-B, table 12.1, BMP No. 2).

Can the Landscape Layout Be Changed to Reduce Runoff?

Reference the site analysis (figure 12.14). Determine if there are problem areas where the runoff is too concentrated (i.e., many arrows coming together). There are many practices that can be used to slow down and spread out the runoff.

- Improve the soil to improve water infiltration (appendix 12-B, table 12.1, BMP No. 4).
- Terrace slopes and/or add swales (appendix 12-B, table 12.1, BMP Nos. 3, 10, and 11).
- Increase vegetation and/or canopy layers. Add buffers.
- Incorporate a rain garden (appendix 12-B, table 12.1, BMP No. 9).

Adding a rain garden is an excellent BMP that can reduce runoff flows, treat contaminants in runoff, and encourage infiltration. Rain garden resources include:

- *Rain Gardens Technical Guide: A Landscape Tool to Improve Water Quality*, Virginia Department of Forestry. *www.dof.virginia.gov/mgt/resources/pub-Rain-Garden-Tech-Guide_2008-05.pdf.*
- Rain garden design templates, The Low Impact Development Center. *www.lowimpactdevelopment.org/raingarden_design/templates.htm.*
- *Urban Water Quality Management: Rain Garden Plants*, Virginia Cooperative Extension publication 426-043. *www.pubs.ext.vt.edu/426/426-043/426-043.pdf.*

Does Roof Water Flow Onto Pavement or Landscaped Areas?

The impact of a roof on the drainage of a site cannot be overstated. In many cases, roofs provide the majority of impervious areas. When roofs are directly connected via gutters and downspouts to pavement, runoff peak flows increase, along with the potential for downstream degradation.

- Disconnect gutters and drain them onto a vegetated area or into a rain barrel or rain garden (appendix B, table 12.1, BMP Nos. 1, 6, and 9). The rain barrel can provide a supplemental irrigation source during dry periods.
- Install a green roof (appendix B, table 12.1, BMP No. 5). Most buildings cannot be retrofitted for a green roof without structural improvements, so this practice applies mainly to additions or new buildings.

Can Paved Surfaces Be Reduced?

On most sites, the controllable impervious areas include walks, porches, patios, decks, and driveways.

- Reduce the total square footage of the impervious area.
- Consider a driveway that uses pavement for the tire tracks only, with turf or gravel in between.
- Use permeable pavement and/or paver systems (appendix B, table 12.1, BMP No. 7). There are many new products available that allow water infiltration through the pavement or joints.
- Consider using steppingstones or mulched or vegetated paths or walks. Some groundcovers can tolerate foot traffic.
- Use wider seams or joints on decks and patios for better water infiltration.

Self-Assessment Tool

Appendix 12-B, table 12.2 is a self-assessment tool constructed by Shelton and Feehan (2008) that is designed to evaluate a single site and identify water quality concerns for that site. The tool analyzes the relative safety of stormwater and landscape management practices using risk scoring and assists the user in determining which practices are safe and which need modification. Choose the description that best characterizes the site. Each choice has an associated risk level and corresponding score according to the following formula:

- Low risk (1): Ideal, but might not always be practical.
- Moderate-low risk (2): Provides reasonable water quality protection.
- High-moderate risk (3): Does not provide adequate water quality protection.
- High risk (4): Poses a serious danger to water quality.

The lower the individual and total scores, the better. Higher individual scores and a higher total score suggest that the site could be improved relative to stormwater management and the risk the site poses to downstream contamination.

Acknowledgements

Figures 12.1, 12.2, 12.3, and 12.5 were constructed using symbols courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (*http://ian.umces.edu/symbols/).*

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Appendix 12-A

Original publication available at: *http://pubs.ext.vt.edu/426/426-041/426-041.html*

Virginia Cooperative Extension

PUBLICATION 426-041

Urban Water-Quality Management

What Is a Watershed?

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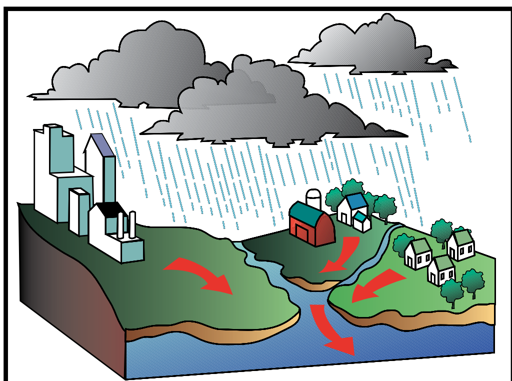


A Watershed Defined

A watershed is an area of land that drains to a lake, river, wetland, or other waterway. When precipitation occurs, water travels over forest, agricultural, or urban/suburban land areas before entering a waterway. Water can also travel into underground aquifers on its way to larger bodies of water. Together, land and water make up a watershed system.

Watersheds can be any size, but generally, the larger the body of water the larger the watershed. For example, the Chesapeake Bay Watershed covers 64,000 square miles and drains from six states, including Virginia. Smaller, local watersheds drain much smaller areas. Even a local stream has a watershed associated with it, perhaps only a few acres in size.

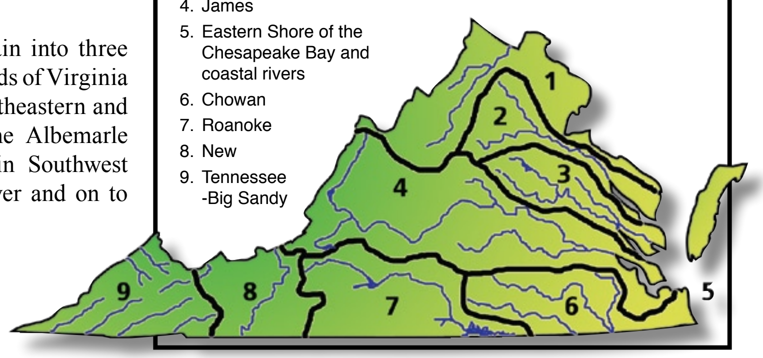
Virginia Watersheds

No matter where you live in Virginia you are part of one the state's nine major watersheds. You may have even noticed signs identifying the boundaries of each watershed while traveling through the state.

Virginia's watersheds ultimately drain into three main bodies of water. Nearly two-thirds of Virginia drains into the Chesapeake Bay. Southeastern and south-central Virginia drain into the Albemarle Sound in North Carolina. Rivers in Southwest Virginia flow to the Mississippi River and on to the Gulf of Mexico.

There are nine major watersheds in Virginia. Some flow to the Chesapeake Bay. Some go directly into the Atlantic Ocean. Others flow to the Albemarle Sound in North Carolina. Some rivers in Virginia even flow to the Mississippi River and then to the Gulf of Mexico.

1. Shenandoah-Potomac
2. Rappahannock
3. York
4. James
5. Eastern Shore of the Chesapeake Bay and coastal rivers
6. Chowan
7. Roanoke
8. New
9. Tennessee -Big Sandy



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Virginia Tech
Invent the Future

Produced by Communications and Marketing, College of Agriculture and Life Sciences, Virginia Polytechnic Institute and State University, 2009

VIRGINIA STATE UNIVERSITY

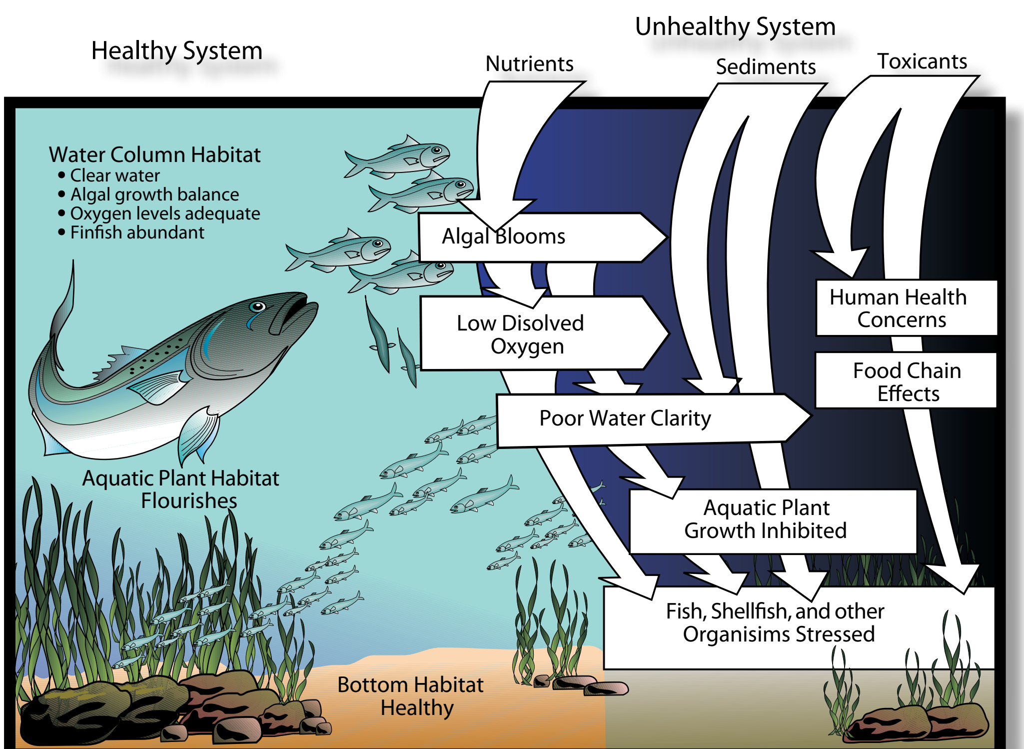
Why Are Watersheds Important?

Healthy watersheds are a vital component of a healthy environment. Watersheds act as a filter for runoff that occurs from precipitation and snowmelt, providing clean water for drinking, irrigation, and industry. Recreation and leisure are important components of watersheds, with many Virginians taking advantage of boating, fishing, and swimming in our waterways. Watersheds also support a variety of plant and wildlife communities.

Scientists and community leaders recognize the best way to protect our water resources is to understand and manage them on a watershed basis. Human activities as well as natural events that occur in a watershed can affect water quality throughout the entire system.

Human Impacts on Watersheds

Nearly all watersheds have something in common; they are populated by humans. With humans comes development and, unfortunately, pollution. As development encroaches on natural areas, the filtering system of the watershed is replaced by impervious surfaces such as concrete and asphalt. Water runs off these surfaces in sheets, carrying with it a variety of pollutants. This type of pollution is called non-point source pollution because it comes from multiple sources over a large area. Anything on the impervious surface, such as automobile fluids, litter, leaves, debris, sediments, or animal feces is swept away by the run-off. It is carried directly into a waterway by storm drains and culverts. These non-point source pollutants can have devastating effects on the health of Virginia waterways.



2

Fertilizer runoff from lawns and landscapes is another part of non-point source pollution. The overuse and incorrect use of fertilizers account for this type of pollution. The adage "if a little is good, then more is better" is not only false, but has serious detrimental effects on water quality. Excess fertilizer in the lawn is easily washed off by rain or irrigation. It travels into waterways, causing algal blooms that block sunlight, smother aquatic plants, and increase bacterial decay. As a result, dissolved oxygen is decreased and the water is unable to provide a healthy environment for aquatic life.

How can you help?

If everyone in Virginia would do a few simple things, we can greatly improve how our watersheds function in protecting water quality. Below are just a few ways you can help.

- Reduce your daily water usage.
- Never dispose of anything by dumping into a storm drain. Storm drains lead directly to waterways.
- Use the correct amounts of fertilizer at the correct time for your grass species.
- Reduce your use of pesticides and fertilizers by replacing grass with hardy trees and shrubs.
- Follow label directions carefully on all chemicals and use them only when necessary.
- Clean up after your pets.
- Maintain home septic systems.
- Create buffers along waterways on your property.
- Know your watershed address.
- Volunteer for clean up, restoration, and conservation programs.
- Promote sustainable land stewardship throughout your community.

For more details about watersheds and what you can to do to help, please refer to the following agencies.

- Virginia Department of Conservation and Recreation
  http://www.dcr.state.va.us/sw/index.htm
- Alliance for the Chesapeake Bay
  http://www.alliancechesbay.org
- Chesapeake Bay Program
  http://www.chesapeakebay.net/

Virginia Cooperative Extension offers a wide variety of publications regarding proper fertilizer and pesticide use, plant selection and buffers. Please see our website, *http://www.ext.vt.edu,* or contact your a local Extension agent for more details.

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Appendix 12-B

Table 12.1. Descriptions of best management practices (BMPs).

Rose ranges reflect current observations in the literature, not VDCR specifications and design practices.

Source: VDCR 2011. Efficiency ranges provided in Center for Watershed Protection, 2008. The Runoff Reduction Manual, Technical Memorandum.

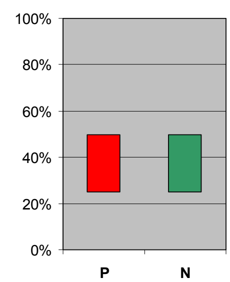
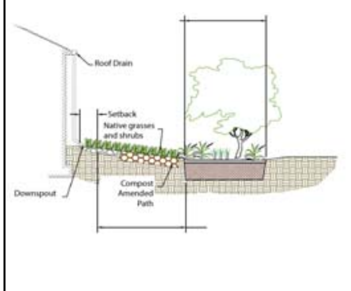
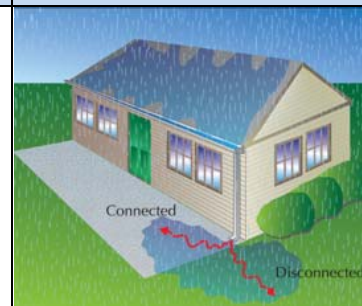
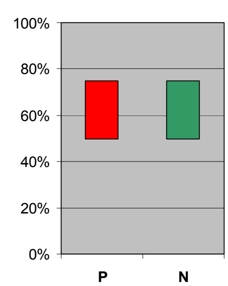
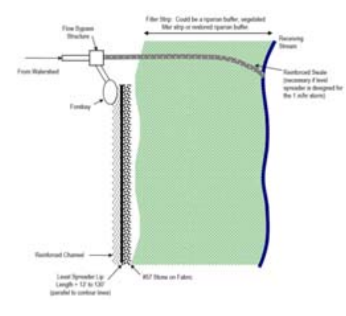
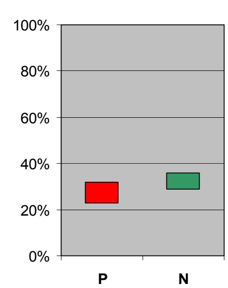
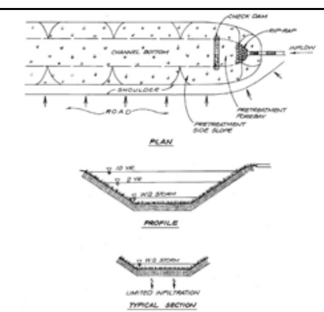
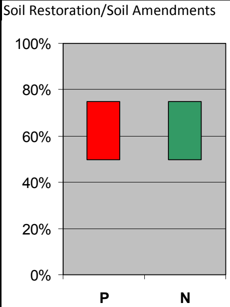
#	Treatment Type	Name/Performance	Description	Diagram or Photograph	Diagram or Photograph
1	Runoff Reduction	Impervious Surface Disconnection 	This is one of the simplest means of reducing urban runoff from residential lots, and involves taking rooftop runoff and redirecting it from impervious areas. The redirected runoff must be infiltrated, filtered, treated, or reused, prior to discharge into a storm drain system. If sufficient land area with good soils is available, simply disconnecting rooftop drains, and allowing them to sheet flow across the lot or directing flow to a grass channel or other BMP is acceptable. In other cases, with limited space, rooftop disconnection is combined with soil restoration, bioretention, a cistern, or a tree planter.	 *Source: VDCR Stormwater Design Specification Number 1: Rooftop (Impervious Surface) Disconnection Version 1.9, 2011.*	
2	Runoff Reduction	Sheetflow to Open Space 	Vegetated filter strips, also known as filter strips, grassed filters, and grass strips) are densely vegetated, uniformly graded areas that intercept sheet runoff from impervious surfaces. Turf grass is the most common planting, however, vegetation can also consist of meadows or small forest plantings. A filter strip can accept runoff from small contributing impervious areas; larger areas with higher flows are accommodated by the use of a gravel trench or other level spreader. Filter strips trap sediments very effectively, have some modest runoff reduction potential from infiltration, and reduce the velocity of the runoff by increasing surface roughness. Filter strips are frequently used to pretreat small areas, prior to discharge to a larger BMP such as a filters or bioretention system.	 *Source: VDCR Stormwater Design Specification Number 2: Sheet Flow to Filter Strip or Conserved Open Space, Version 1.9, 2011.*	 *Source: US EPA, 2009. Chesapeake Bay Program, http://www.chesapeakebay.net/photosearch.aspx?menuitem=14870.*
3	Runoff Reduction/Pollutant Removal	Grass Channels 	Grass channels are open channels with grass sides that can carry runoff with modest velocities. Grass channels provide treatment via filtering through vegetation and are considered part of a conveyance system. When compared with curb and gutter, inlets and pipes, grass channels provide a modest amount of runoff reduction and pollutant removal, the extent of which varies depending on the underlying soil characteristics. Unlike dry swales, they do not include a soil media and/or specific storage volume. When used as an alternative to traditional systems such as stormwater pipes and curb and gutter, a grass swales can provide significant environmental benefits.	 *Source: VDCR Stormwater Design Specification Number 3: Grass Channels, Version 1.9, 2011.*	 *Source: Fairfax County Department of Public Works and Environmental Services, 2011.*
4	Environmental Site Design/Runoff Reduction	Soil Restoration/Soil Amendments 	Soil restoration is the technique of using compost to amend soils to improve their porosity and improve their nutrient retention. Mature compost contains a mixture of complex organic matter that reduces soil compaction and enhances soil structure, infiltration, rooting and water holding capacity. Normal calculations for lawn areas that undergo soil restoration and do not receive runoff from other areas can absorb as much as 75% of runoff. Compost-amended soils may be used in conjunction with impervious surface disconnection, grass channels, and filter strips.	 *Source: VDCR Stormwater Design Specification Number 4: Soil Compost Amendment, Version 1.9, 2011.*	 *Source: Christian, AH., G.K. Evanylo, R. Green, (2009) Compost: What Is It and What's It To You, VCE Publication 452-231.*

Table 12.1. Descriptions of best management practices (BMPs). (cont.)

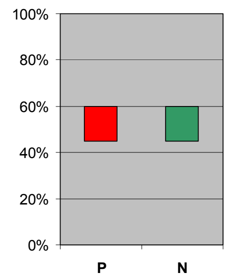
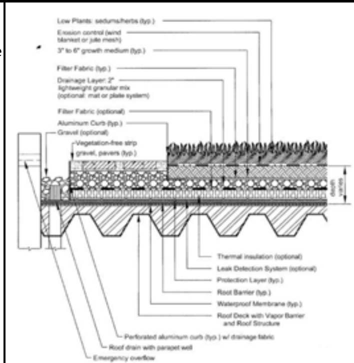
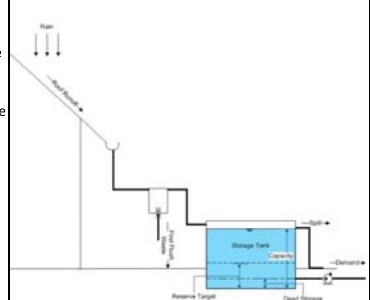
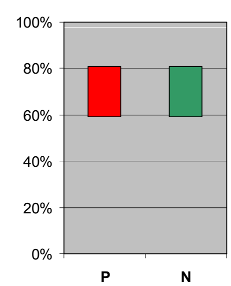
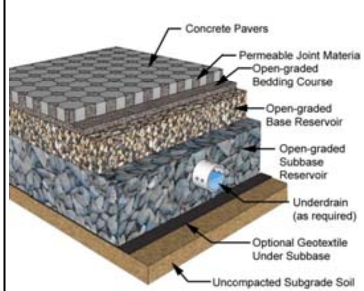
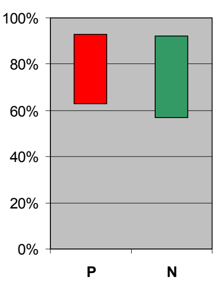
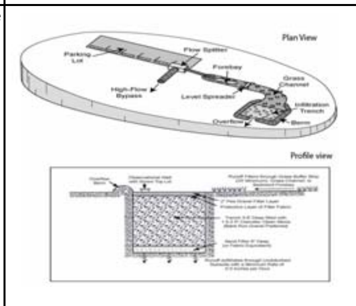
#	Treatment Type	Name/Performance	Description	Diagram or Photograph	Diagram or Photograph
5	Runoff Reduction	Vegetated Roofs 	Vegetated roofs, which are also known as green roofs, are roofs that are designed and constructed to support living vegetation. There are two main types of vegetated roofs, extensive, and intensive. Both roofs add weight to the structural load. Intensive green roofs have thicker media and can support long rooted shrubs and trees. The increased weight and associated structural load of the media can be high. The most common vegetated roof, the extensive roof, has a shallower media and smaller plantings, and is typically constructed of replaceable modular forms. For extensive roofs, rainfall is intercepted by the plantings, infiltrated into the media, and used by plants. Extensive vegetated roofs typically provide 0.5 inches of storage.	 *Source: VDCR Stormwater Design Specification Number 5: Vegetated Roof, Version 1.9, 2011.*	 *Source: Fairfax County Government Center, 2010, photo taken by D. Sample.*
6	Runoff Reduction	Rainwater Harvesting Based mainly upon its Runoff Reduction credits, receives a 40% of the credited volume (must determine credited volume through simulation).	Rainwater harvesting systems, also known as rain barrels and/or cisterns intercept, divert, store and release rainfall for later use as a water supply. These systems may also provide pollution reduction through stormwater volume control. Most systems are covered to avoid contamination and eliminate evaporative losses. In a typical system, rainfall falls on the roof, runs off, is captured in gutters, and flows to a simple device which eliminates the first flush containing organic materials that washes off the roof. Once the first flush volume is exceeded, the water enters a storage tank located either above or below ground. Once the tank's capacity is exceeded, water is diverted through an overflow near the top of the tank. Because a tank may remain full between rain events, water quality benefits may be reduced due to the potential for spillage.	 *Source: Sample, D. (2009) Stormwater Management Research, Assessing Improvements in Design and Operation on Performance, approved VT-CALS Hatch Proposal 2010-2015.*	 *Source: Wetland Studies and Solutions, Inc., Gainesville, VA, 2009., photo taken by D. Sample.*
7	Runoff Reduction/Pollutant Removal	Permeable Pavement 	Permeable pavement is a modified form of asphalt or concrete whose top layer is pervious to water due to voids within the mix design. Permeable or porous pavements include pervious concrete, porous asphalt, grid pavers and interlocking concrete pavers. These pavements consist of several layers, including the top pervious layer, an underlying storage layer composed of gravel or stone. This layer provides the storage reservoir needed for stormwater management. The depth and materials are determined by the amount of peak runoff and structural concerns. Runoff infiltrates, enters the lower layer, and either exfiltrates into the nearby soils or is collected in an underdrain system and later discharged to a conveyance system. Porous pavements are efficient for removal of sediments, nutrients, and some metals. However, sediment clogs the pores of these systems, leading to failure. Vacuum sweeping can remove sediment and restore clogged	 *Source: Smith, D. (2006) Permeable Interlocking Concrete Pavement-Selection Design, Construction and Maintenance. Third Edition. Interlocking Concrete Pavement Institute. Herndon, Virginia, cited in VDCR Stormwater Design Specification Number 7: Permeable Pavement, Version 1.9, 2011.*	 *Source: Wetland Studies and Solutions, Inc., Gainesville, VA, 2009, photo taken by D. Sample.*
8	Runoff Reduction/Pollutant Removal	Infiltration 	Infiltration practices provide temporary surface or subsurface storage, allowing exfiltration of runoff into soils. Implementation consists of an excavated trench filled with gravel or stone backfilled to the surface. Temporary storage volume is provided within pore spaces or voids between the stone. Sediment can be easily trapped within the pores and clog them, so pretreatment for sediment removal is advised. Designs can include or exclude a perforated drainage pipe near the bottom of the stone layer, depending upon the quality of the runoff and the infiltration rate; a minimum value of 0.5 inches/hour is recommended. These systems can reduce significant quantities of runoff by infiltration, and also provide filtration and adsorption of pollutants within the media and soil column. Infiltration practices should be avoided in industrial areas and other "hot spots" to avoid contamination of groundwater.	 *Source: Virginia DCR Stormwater Design Specification Number 8: Infiltration, Version 1.9, 2011.*	 *Source: Wetland Studies and Solutions, Inc., Gainesville, VA, 2009.*

Table 12.1. Descriptions of best management practices (BMPs). (cont.)

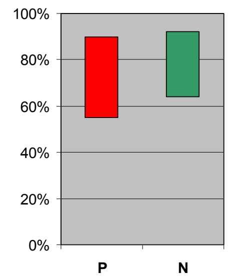
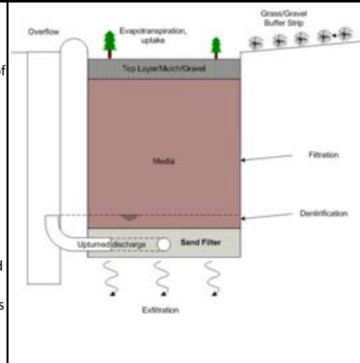
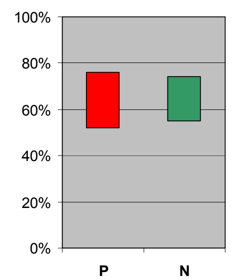
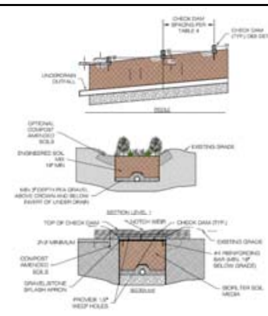
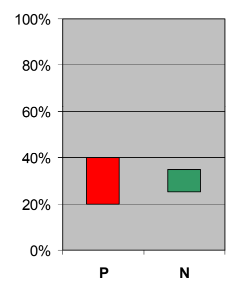
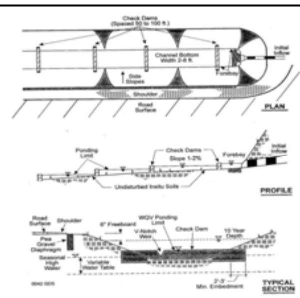
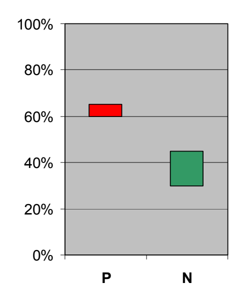
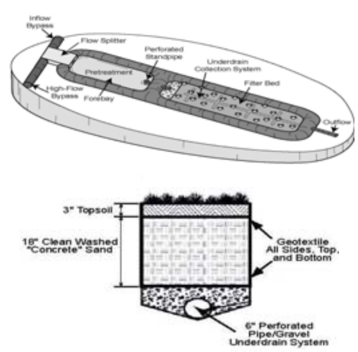
#	Treatment Type	Name/Performance	Description	Diagram or Photograph	Diagram or Photograph
9	Runoff Reduction/Pollutant Removal	Bioretention 	Bioretention cells, (small informal versions often called rain gardens), are stormwater BMPs consisting of a depression with a vegetated layer, a mulch layer, several layers of sand, soil, and organic media known as a filter bed, an overflow, and an optional underdrain. They typically small treat catchment areas of 5 acres or less. Within a bioretention cell, treatment is performed by filtration, infiltration, detention (overflow weir), adsorption, plant uptake and evapotranspiration. An underdrain consists of a perforated pipe in a gravel layer installed along the bottom of the filter bed; an upturned outlet promotes partial anaerobic conditions within the fluctuating water table which results in denitrification. In nonindustrial settings where soils have high infiltration rates, removal of the underdrain may be considered, thus increasing runoff reduction by exfiltration.	 *Source: Sample, D. (2009) Stormwater Management Research, VT-CALS Hatch Proposal 2010-2015. Diagram shows optional upturned elbow.*	 *Source: Wetland Studies and Solutions, Inc., Gainesville, VA, 2009.*
10	Runoff Reduction/Pollutant Removal	Dry Swale 	A vegetated swale is a shallow, gently sloping channel with broad vegetated side slopes, and low velocity flows. A dry swale provides temporary storage and filtering of a design treatment volume within vegetation and soil media. Dry swales are similar to bioretention except they are configured as linear channels. Dry swales are always located above the water table to provide drainage capacity. In highly permeable soils, typically no underdrain is used, while the reverse is true in impermeable soils. Underdrains are constructed with a perforated pipe fit within a gravel layer at the bottom of the swale. Vegetation species can include turf, meadow grasses, woody covers, and trees. Treatment processes generally include settling, adsorption and filtering, infiltration into native soils (if permeable), and plant uptake.	 *Source: VDCR Stormwater Design Specification Number 10: Dry Swales, Version 1.9, 2011.*	 *Source: Wetland Studies and Solutions, Inc., Gainesville, VA, 2009.*
11	Pollutant Removal	Wet Swale 	A wet swale is a shallow, gently sloping channel with broad vegetated side slopes, and low velocity flows. Wet swales typically stay wet by intercepting the shallow groundwater table. Vegetation is primarily wetland and other hydrophilic species. Wet swales function similar to linear constructed wetlands, and area functioning part of the stormwater conveyance system. Treatment is provided by settling filtering and biological processes, associated with microbial organisms. Soils are typically saturated; water depths do not usually exceed 6 inches. Because they are normally flat or gently sloped and exist in areas of high water table, wet swales are applicable only to coastal plain installations.	 *Source: VDCR Stormwater Design Specification Number 11: Wet Swales, Version 1.9, 2011.*	 *Source: VDCR Stormwater Design Specification Number 11: Wet Swales, Version 1.9, 2011.*
12	Pollutant Removal	Filtering Practices 	A stormwater filtering practice, also known as a stormwater filter captures, temporarily stores, and treats stormwater runoff by passing it through an engineered filter media, collecting it in an underdrain and then discharging the effluent to the stormwater conveyance system. Typical filter designs include a settling chamber and a filter bed chamber, which contain multiple layers of differing media. Common media types include various layers of sand, gravel, organic matter, geotextiles, packed bed, and/or ion exchange resins. Stormwater filters are useful for treating runoff from small, highly impervious sites, including "hot spots". Stormwater filters can work on most commercial, industrial, institutional or municipal sites and can be located underground if surface area is not available.	 *Source: VDCR Stormwater Design Specification Number 12: Filtering Practices, Version 1.9, 2011.*	 *Source: Center for Watershed Protection, Photo courtesy of David Hirschman, 2011.*

Table 12.1. Descriptions of best management practices (BMPs). (cont.)

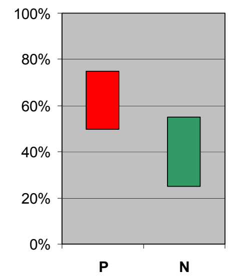
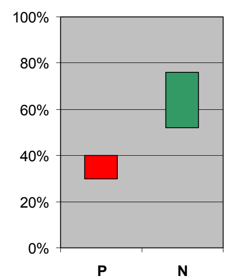
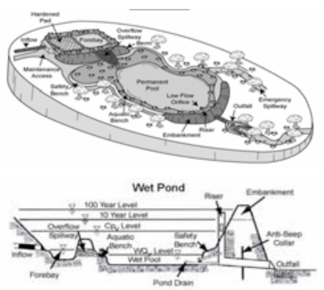
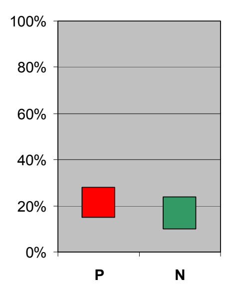
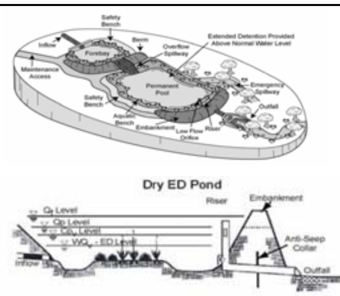
#	Treatment Type	Name/Performance	Description	Diagram or Photograph	Diagram or Photograph
13	Pollutant Removal	Constructed Wetlands 	Constructed wetlands, also known as stormwater wetlands, are BMPs that use wetland vegetation to provide physicochemical and biological treatment of urban stormwater. Constructed wetlands vary substantially in their microtopography from depressions of less than one foot to deeper micropools several feet deep. This variability diversifies wetland vegetation. There are several subtypes of constructed wetlands, including shallow marsh, extended detention, pond/wetland systems, pocket wetlands, and forested wetland systems. Treatment is provided by settling, filtration, adsorption, and biological uptake. Stormwater wetlands can be very effective at pollutant removal.	 *Source: VDCR Stormwater Design Specification Number 13: Constructed Wetlands, Version 1.9, 2011.*	 *Source: Hession, C., 2010, Biological Systems Engineering, Virginia Tech.*
14	Pollutant Removal	Wet Ponds/Retention Ponds 	Wet ponds (also known as stormwater ponds or retention ponds) are stormwater impoundments that have a permanent pool of water that is controlled to a specified elevation by an outfall structure. Treatment consists of settling of solids and biological uptake of nutrients. Inflow enters the pond and partially displaces water collected during previous storms. If additional freeboard is available above the outfall threshold, then attenuation of stormwater peak flows may also be provided through extended detention, which helps meet channel protection requirements. Because of their placement at the lowest point of a drainage area, wet ponds are the final treatment opportunity available. Therefore, other opportunities for runoff reduction and/or water quality treatment should be explored prior to resorting to this BMP.	 *Source: VDCR Stormwater Design Specification Number 14: Wet Ponds, Version 1.9, 2011.*	 *Source: Fairfax County Department of Public Works and Environmental Services, 2011.*
15	Runoff Reduction/Pollutant Removal	Extended Detention 	An Extended Detention (ED) Pond provides 12-24 hours of storage during peak runoff events. Releases from the ED Pond are controlled by orifices and/or weirs within the pond's outlet structure. As the outflow is restricted, water backs up into the ED Pond. The pool slows flow velocities and enables particulate pollutants to settle. Treatment of settleable nutrients and sediment is good, however, resuspension of the settled pollutants can occur, and dissolved nutrient removal is poor. ED Ponds have the lowest overall pollutant removal rate of any stormwater treatment option, so they are often combined with other upstream LID practices to better maximize pollutant removal rates.	 *Source: VDCR Stormwater Design Specification Number 15: Extended Detention Pond, Version 1.9, 2011.*	 *Source: Center for Watershed Protection, Photo courtesy of David Hirschman, 2011.*

Table 12.2. Site assessment tool.

Stormwater Management on Residential Lots: Assessing the Risk of Surface and Groundwater Contamination

1. For each category listed in the first column that is appropriate to your property, read across and circle the statement that best describes conditions on your property. If there is not a descriptive statement that exactly fits your situation, use your judgment to select the risk level that best applies. (Skip and leave blank any categories that don't apply to your property.)
2. Look above the description you circled to find your "Risk Level Number" (1, 2, 3, or 4) and enter that number in the right-hand column under "Your Risk Score."

Practice	**High Risk** (Risk Level 4)	**High-Moderate Risk** (Risk Level 3)	**Moderate-Low Risk** (Risk Level 2)	**Low Risk** (Risk Level 1)	**Your Risk Score**
Potential Contaminants in Runoff					
Grass clippings, leaves, and other yard waste	Grass clippings, leaves, and other yard wastes are dumped down a storm drain or near a surface water body.	Grass clippings, leaves, and other yard wastes are left on driveways, streets, and other paved areas to be carried off by stormwater.	–	Grass clippings, leaves, and other yard wastes are swept off paved surfaces and onto lawns away from water flow routes. Leaves and other yard wastes are composted.	
Handling and use of pesticides, fertilizers, and outdoor chemicals	Spills are not cleaned up. Products are used in greater amounts than what is recommended on the label.	Granules, etc., are left on driveway, sidewalks, or other paved areas to be carried off by stormwater.	–	Spills are cleaned up immediately, particularly on paved surfaces. Recommended amounts of chemicals are applied according to label instructions.	
Timing of pesticide, fertilizer, and outdoor chemical use	Application is made when heavy rain is forecast within the next 24 hours and on saturated soils or areas where runoff is likely.	Application is made when heavy rain is forecast within the next 24 hours and on unsaturated soils or areas with little slope.	Application is made when light rain is forecast within the next 24 hours and on saturated soils or areas where runoff is likely.	Application is made when no or only light rain is forecast within the next 24 hours and on unsaturated soils or areas with little slope.	
Storage of pesticides, fertilizers, and other potentially harmful chemicals	Chemicals are stored in nonwaterproof containers outdoors.	Chemicals are stored in waterproof containers outdoors, but within reach of stormwater.	Chemicals are stored in waterproof containers outdoors, out of the reach of stormwater.	Chemicals are stored in waterproof containers in a garage, shed, or basement that is protected from stormwater.	

Table 12.2. Site assessment tool. (cont.)

Practice	High Risk (Risk Level 4)	High-Moderate Risk (Risk Level 3)	Moderate-Low Risk (Risk Level 2)	Low Risk (Risk Level 1)	Your Risk Score
Potential Contaminants in Runoff (cont.)					
Automotive wastes	Used oil, antifreeze, or other wastes are dumped down a storm drain or on a paved surface.	Used oil, antifreeze, or other wastes are dumped in a ditch or on the ground.	Drips and spills are not cleaned up. Car parts and other vehicle wastes are left on unpaved areas outside.	Oil drips and fluid spills are cleaned up. Dirty car parts and other vehicle wastes are kept out of reach of stormwater runoff.	
Vehicle washing	Cars, trucks, or other items are washed on a driveway, street, or other paved area.	Cars, trucks, or other items are washed on a gravel or rocked area.	Cars, trucks, or other items are washed on a lawn.	Cars and trucks are taken to a commercial car wash.	
Animal and pet wastes	Animal and pet wastes are left on paved surfaces or dumped down a storm drain.	Animal and pet wastes are left to decompose on grass or soil. Wastes are concentrated in a small area, such as a pen.	Animal and pet wastes are left to decompose on grass or soil. Wastes are scattered over a wide area.	Animal and pet wastes are flushed down the toilet or wrapped and placed in the garbage for disposal.	
Landscaping and Site Management					
Landscaping	There is no landscaping to slow the flow of runoff. Soils are compacted, limiting infiltration. Yard is hilly, allowing runoff to occur.	No areas are landscaped to encourage water to soak in, and soils are compacted. Yard is relatively flat, reducing the amount of runoff that occurs.	Yard is landscaped and soils are amended to slow the flow of stormwater and provide areas where water soaks into the ground. Yard is hilly, allowing some runoff to occur.	Yard is landscaped and soils are amended to slow the flow of stormwater and provide areas where water soaks into the ground. Yard is relatively flat and little runoff occurs.	
Yard and gardens	Large areas of yard or garden are left without mulch or vegetation for long periods.	Small areas of yard or garden are left without mulch or vegetation for long periods.	Grass or other ground cover is used, but is spotty, particularly on slopes.	Bare spots in the lawn are promptly seeded and topped with a layer of straw or mulch. Bare soil in gardens is covered with mulch	
Paved surfaces	Large areas are paved for walkways, patios, and other areas.	Some small areas are paved for walkways, patios, and other areas.	Alternatives such as gravel, rock, paving blocks, brick, or flagstone are used for walkways, patios, and other areas.	Alternatives such as wood chips or mulch are used for walkways, patios, and other areas.	

Table 12.2. Site assessment tool. (cont.)

Practice	High Risk (Risk Level 4)	High-Moderate Risk (Risk Level 3)	Moderate-Low Risk (Risk Level 2)	Low Risk (Risk Level 1)	Your Risk Score
Landscaping and Site Management (cont.)					
Roof drainage	Most or all downspouts are connected directly to storm drains.	Most or all eave drip lines or downspouts discharge onto paved surfaces where water runs off.	Most or all eave drip lines or downspouts discharge water onto grassy or mulched areas where some water runs off.	Most or all eave drip lines or downspouts discharge water onto a grassy or mulched area or rain garden where water soaks into the ground.	
Lot during construction	Soil is left bare until construction is completed and no sediment barriers are used.	Soil is left bare until construction is completed. Sediment barriers are installed, but are poorly maintained allowing some muddy runoff to leave the site.	Soil is left bare until construction is completed. Sediment barriers are installed and maintained to detain muddy runoff until grass covers soil.	Bare soil is seeded and mulched as soon as possible (before construction is completed). Sediment barriers are used until grass covers soil.	
Buffer strips	Bare soil, sand, or gravel exists next to a stream bank or lakeshore. Stream banks or lakeshores are eroding.	Spotty mowed vegetation exists next to a stream bank or lakeshore.	Mowed grass exists next to stream bank or lakeshore.	Buffer strips of thick vegetation are left along a stream bank or lakeshore.	.

Source: Shelton and Feehan 2008

Chapter 13. Turf and Landscape Nutrient Management Planning

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Introduction

This chapter will emphasize the actual steps that a certified nutrient management planner will use to develop and implement a nutrient management plan (NMP). Utilizing the data and recommendations provided in an NMP promotes water quality protection. However, an equally important result of an NMP is its value as a comprehensive tool in planning fertilizer selections and application strategies in terms of optimizing plant responses, nutrient-use efficiency, and economics. While these criteria were specifically developed for the Commonwealth of Virginia, the principles will apply to any mid-Atlantic state.

The primary steps for nutrient management planning are:

1. Collect and evaluate information about the overall area to be planned.
2. Determine realistic expectations of the planting's performance with known conditions, such as soil fertility levels and adaptation of plant species to the area and for the intended use.
3. Establish nutrient requirements for the plant species in each area to be planned.
4. Evaluate planting area limitations based on environmental site sensitivity or other plan implementation concerns.
5. Allocate purchased and any on-site nutrient sources, if any, to available planned areas.
6. Identify nutrient timing and placement methods to maximize nutrient use by plantings and minimize environmental losses.

Prior to initiating plan development, it is critical to obtain some information about the current management practices used by your client. This process of inventorying your client's resources and needs is critical to developing an implementable plan, based on sound agronomics, that improves water quality.

Assessment of Planned Areas

Land

The obvious place to begin is with the land. This will vary from small management areas like an urban or residential setting to perhaps several hundred acres, such as golf courses, large parks, and recreation facilities. Planned areas will represent an area that will be managed and fertilized as one distinct unit. It will usually be defined by the type of planting it contains, such as turf, bedding plants, etc. How many planned areas will be needed to address various plant species? How much area is in each of these planned areas? What is the present use of these areas? If they are being used for turf or annual or perennial bedding plants, will that use continue or will the areas be renovated to something else?

Equipment Resources

Once you know what is normally done (or expected) in each planned area, knowing what type of equipment, if any, your client has will be helpful when developing recommendations. Does your client have seeding equipment, fertilizer spreaders, aerators, sprayers, or tillage equipment? What are the limitations of these machines? You need to consider the availability of equipment when recommending certain management operations and, if unavailable, is there an alternative operation that will be acceptable?

Past Methods of Fertilizer Application

The use of commercial fertilizer is a similar consideration. You need to know the client's current fertilization program. The rate and timing of applications are important considerations for plan development. Also, be certain to determine how much custom application is done and by whom. If the landowner is a steady customer of a particular dealer, his application capabilities and limitations should be considered, if possible, when developing the final plan.

Soil Resource Assessments

The most important resource to consider when developing a plan is the soil, or combination of soils, and the location within the landscape of each planned area. For undisturbed areas, a soil survey is used to determine the predominant soils in the planned areas. Consider the expected outcomes in trying to grow the various plant species your client wants. If the soils in the planned area have been heavily excavated, what type of soil is present and how deep is it? This may come down to identifying the soil by its texture and physically assessing the soil horizons and any restrictive characteristics that will limit or even prohibit successful plantings.

Steep slopes that are prone to erosion or light-textured soils subject to leaching are two possible examples. These types of factors obviously affect satisfactory seeding but are also additional considerations in developing a thorough plan. Of course, a current soil test will also be important as part of this evaluation.

Nutrient Resources

Soil testing is critical to nutrient management planning in determining the plant's likely response to applied nutrients and the pH of the soil for lime needs. The use of water-soluble fertilizer, slow-release materials, and even manures, wastewater, and biosolids needs to be considered in your recommendations regarding timing and rate of applications. You will have preferred materials you would like used; however, your client may have products in stock or a source of these materials he has to use. Know the options you have available to use various materials in the following years and educate your client about the advantages and disadvantages of available materials for his operation. Ultimately, what is used will be the client's decision, so to facilitate plan implementation, try to use as many client-preferred materials as possible.

Nutrient Requirements for Species in Each Planned Area

Once soils are tested, nutrient recommendations for the plant species in each planned area can be determined by utilizing the tables in *Virginia Nutrient Management Standards and Criteria*, revised October 2005 (Virginia Department of Conservation and Recreation-VDCR). If the plant species is not contained in Standards and Criteria, use Virginia Cooperative Extension publications or other sources that specifically address management of that species. When a publication is used for this purpose, it should be noted in the plan narrative or noted as a recommendation source on the worksheet for the plan. There are numerous examples of plant materials and their anticipated nutrient requirements presented in preceding chapters of this manual.

Environmentally Sensitive Sites

An important item to consider in evaluating your client's operation is the presence of environmentally sensitive sites. An environmentally sensitive site is any managed area that is particularly susceptible to nutrient loss to ground or surface water because it contains (or drains to areas that contain) sinkholes, or where at least 33 percent of the area in a specific management area contains one, or any combination of, the following features:

1. Soils with high potential for leaching based on soil texture or excessive drainage.
2. Shallow soils less than 41 inches deep that are likely to be located over fractured or limestone bedrock.
3. Subsurface tile drains.
4. Soils with high potential for subsurface lateral flow based on soil texture and poor drainage.
5. Floodplains as identified by soils prone to frequent flooding in county soil surveys.
6. Land with slopes greater than 15 percent.

Existing best-management practices (BMPs) installed to protect such areas should be noted to ensure their protection and maintenance. The plan writer should also consider the need for recommending additional measures to protect water quality whenever necessary. It is critical that an actual site visit be made to all planned areas that will receive any type of nutrient applications. This is necessary to check for environmentally sensitive areas and to check the general terrain of the application sites. Maps in the plan should clearly identify all environmentally sensitive sites.

Allocation of Nutrients to Planned Areas

After considering nutrient needs for each planned area and the environmentally sensitive areas, fertilizer applications should be made to meet nutrient needs or to supplement deficiencies in meeting the nutrient needs when other sources of nutrients have been applied first.

Plans shall be written on a nitrogen (N) and phosphorus (P) basis. It is important that nutrient applications be prioritized to meet plan requirements. Nitrogen recommendations should not exceed the need determined by the *Virginia Nutrient Management Standards and Criteria* (2005) or other appropriate resource as discussed. Soil test levels should be used to make phosphorus and potassium (K) recommendations.

Initial Client Visit

Collecting Background Information

This visit is very important. The complete and detailed information you collect at this time will reduce the number of return visits or calls needed. Plan ahead and be organized. Make an appointment with your clients and let them know this may take several hours or more so that they can schedule the time required. Also let them know what information you will need so they can have it ready when you arrive. The following pages contain an example of an approach for collecting background information (figures 13.1-13.4). It may not be necessary in all cases but could be helpful when working with a client for the first time.

General Information

Date of visit _____ /_____ / _____

Owner name ____

Phone ____________________________ E-mail ____________________________

Manager/superintendent ___________________________________

Phone ____________________________ E-mail ____________________________

Address ____

City/state/zip ____

Extension agent ____

Phone ____________________________ E-mail ____________________________

Fertilizer supplier ____

Phone ____________________________ E-mail ____________________________

Salesman ____

Phone ____________________________ E-mail ____________________________

Consultant ____

Phone ____________________________ E-mail ____________________________

Are you scheduled to receive biosolids or other organic nutrient sources? ❏ Yes ❏ No

If yes, supplier: ____

Field representative: _______________________________________

Phone ____________________________ E-mail ____________________________

Who takes soil samples? ❏ Client ❏ Fertilizer dealer ❏ Consultant ❏ Other

At what interval are soil samples taken? ❏ 1 year ❏ 2 years ❏ 3 years

Do you have current samples of all areas to be included in plan? ❏ Yes ❏ No

What lab is used? ❏ VT ❏ A&L ❏ Spectrum ❏ Waters ❏ Other

Who makes recommendations? ❏ Extension ❏ Laboratory ❏ Fertilizer dealer ❏ Consultant ❏ Yourself

Are tissue samples taken? ❏ Yes ❏ No

What plant species? ____

Figure 13.1. Sample form to collect background information.

Nutrient Application

Plant species	**Rate/month**	**Rate/month**	**Rate/month**	**Rate/month**
Bermudagrass				
Turf-type tall fescue				
Flowering annuals				

Figure 13.2. General nutrient application for each plant species (pound per acre plant food).

Management Area Information

Owner: ____ Date _____ /_____ / _____

Operation name: ____________________________ Location: ______________________________

Management area designation ID	**Sq ft or acres**	**Present plant species**	**Renovate to new species**	**Last lime application rate** (month/year)

Figure 13.3. Clearly define and label each management area.

Components of a Nutrient Management Plan

A nutrient management plan designates proper management of nutrients using proper application rates and timing specific for the species of plant in each management area. Following the plan will result in a cost-effective and environmentally sound use of plant nutrients. A plan may also be used to document the proper rate and timing of nutrient applications. This is used to report the urban community's progress in protecting and improving water quality. A description of the components of an NMP is outlined in Virginia's Nutrient Management Training and Certification Regulations (available at *www.dcr.virginia.gov/soil_and_water/nutmgt.shtml*). The following information offers a brief outline and explanation of the various parts of a plan. All plans must be written to the criteria set forth in the regulations.

Plan Identification Sheet

The plan identification sheet is a page at the front of the plan that contains information such as the client's name and address, the planner's name and certificate number, and the county and watershed code for the operation. Information about the square footage or acreage of each plant species is included to give a snapshot view of the plan.

Narrative

Use this section to describe the operation and to assist with tailoring the plan to the individual.

- Describe the type of operation (athletic field, golf course, recreation area, etc.).
- Describe the location, naming common landmarks or route numbers; this will be helpful to identify the operation on a map or for another planner to drive to the operation.
- Include a general description of the management of each plant species in the operation.
- Make note of the proximity of management areas to streams, erosion control, environmentally sensitive areas, etc., and what precautions address each issue.
- Give directions on where additional help can be obtained for other operation management and water quality objectives that are beyond the scope of this plan.
- Write clear, concise statements that are to the point.

If some information is already included on the balance sheet (e.g., timing, testing, renovation), it is not necessary to include it in the narrative.

Plan Map

Use a copy of an aerial photograph whenever possible. Generally, these photographs will show established, planned area boundaries and should be a good reference to identify these areas as they are listed in the plan. If aerial photos are not available, take the time to draw a clear, neat map. This map should show planned area identification designations, environmentally sensitive areas (e.g., wells, erosion control structures, drainageways, etc.), and any other features of the landscape that need to be addressed in the plan to minimize the impact of nutrient application to the environment.

Plan Map Legend

Use a legend to explain any symbols used on the plan map. It can be on the map itself or included on a separate sheet directly following the map.

Soil Map

Include soil maps for the operation when there is considerable acreage in the plan and the land, for the most part, is undisturbed. Delineate the outside boundaries of the operation matching those used on the plan maps.

Nutrient Application Window

Timing of nutrient applications is very important. *Spring and Summer Lawn Management Considerations for Cool-Season Turfgrasses*, Virginia Cooperative Extension (VCE) publication 430-532 (VCE 2009a), and *Spring and Summer Lawn Management Considerations for Warm-Season Turfgrasses*, VCE publication 430-533 (VCE 2009b) are two publications that give the client a quick view of when various operations in turf maintenance should occur throughout the year. This information may be helpful when clients are putting together a plan implementation strategy.

Organic Nutrient Sources

Calculating nutrient availability from land-applied organic materials is an important component of an NMP. Most organic materials will either be animal manures or biosolids. A detailed discussion and examples of calculating nutrient availability is covered in *Standards and Criteria*, pages 109-10, and 117 (VDCR 2005). Refer to this section to become familiar with the formulas and proper coefficients to be used on each planned management area receiving organic nutrient sources. Once the plant-available nitrogen, phosphate, and potash have been calculated, the nutrients supplied from the organic material application are deducted from the nutrient needs for the plant species to which the material was applied, and subsequent residual nitrogen credit is given to following spring plant species nitrogen needs.

Nutrient Application Worksheet Header

(figure 13.4)

- The property owner's name.
- The date the plan is prepared and the date it expires.
- Identification of the managed area. The managed area identification needs to exactly match the labeling as it appears on the plan map. Areas can be grouped in any order you think best suits the client's operation. Separate recommendations should be made for each individual planned area unless two or more areas are managed similarly and soil test levels are similar.
- The area of the space identified, either per 1,000 square feet or per acre.
- The plant species in the management area, as either turf or landscape materials.

Nutrient Application Worksheet

Name: ______________________________

Prepared: ____ /____ / ____ Expires: ____ /____ / ____

Management Area Identification: ______________________________

Square Feet: ______________________________

Landscape Plants: ______________________________

Turf Species: ______________________________

*Column 1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Nutrient needs N-P_2O_5-K_2O (lb/1,000 sq ft)	**Application month/day**†	**Fertilizer material N-P_2O_5-K_2O** (lb/1,000 sq ft)	**% slowly available nitrogen**	**Nitrogen** (lb/1,000 sq ft)	**P_2O_5** (lb/1,000 sq ft)	**K_2O** (lb/1,000 sq ft)	**Lime recom-mendation** (lb/1,000 sq ft)

Notes:

†The month and day designations may not always be followed due to weather, etc. Apply as close to the month as possible, using the day designation to determine the interval between applications.

Figure 13.4. Worksheet used to provide client with a ready reference for nutrient management recommendations.

* Row of column numbers added for ease of identification; it is not on worksheet.

Nutrient Application Worksheet Table

The columns used in the worksheet table (figure 13.4) are explained below. All recommendations should be designated on a "per 1,000 square feet" or "per acre" basis.

1. **Nutrient needs:** This is where nutrient needs are shown. The nutrient needs represent the total nitrogen, phosphate, and potash for an annual application. Recommendations should be based upon soil test results for phosphorus and potassium for each plant species. Nitrogen recommendations should be based on those contained in *Standards and Criteria* (VDCR 2005) or a referenced resource document.

2. **Application** month/day: There may be several applications of nutrients per year depending on the species being fertilized. This column allows the planner to designate the months in which the nutrient applications should be applied and allows the planner to use the worksheet in two ways:

   a. If the management areas are small and will receive the same applications for each year of the plan, only the month and day for the application needs to be entered, along with a note on the worksheet explaining that this annual application program is applicable for all the years of the plan.

   b. If the recommendations will vary from year to year, then each **year** of the plan should be entered into the "Prepared" and "Expires" dates. This will probably increase the number of worksheets in the plan, but it is acceptable when needed to convey the specific applications needed to achieve desired soil fertility levels in the management area.

   Note: The month and day designations may not always be followed due to weather, etc. Apply as close to the month as possible, using the day designation to determine the interval between applications.

3. **Fertilizer material** N-P_2O_5-K_2O: This column identifies the fertilizer material and the rate that it should be applied at the designated time period.

4. Percent slowly available nitrogen: This column is used to identify the amount of slowly available nitrogen in the material recommended (Note: slowly available N is defined in chapter 8 of this manual).

5. **Nitrogen** (lb/1,000 square feet or lb/acre): This is the amount of plant-available nitrogen supplied by the designated fertilizer material application.

6. **P_2O_5** (lb/1,000 square feet or lb/acre): This is the amount of plant-available phosphorus — expressed as phosphate — that is supplied by the designated fertilizer material application.

7. **K_2O** (lb/1,000 square feet or lb/acre): This is the amount of plant-available potassium — expressed as potash — that is supplied by the designated fertilizer material application.

8. **Lime recommendation** (lb/1,000 square feet or lb/acre): This is the amount of lime recommended for the management area. Most times this recommendation may be the only material application designated; thus, it will have its own "application month/year" because it will probably be applied at a different time than fertilizer materials.

9. **Notes:** Special considerations regarding nutrient application, special conditions in the managed area, tillage practices, etc., can be footnoted here.

Assistance Notes

These notes record what transpired during your first and follow-up client visits. Write about such things as alternatives you provided, decisions made based on unusual circumstances, progress on plan implementation, or unusual circumstances anyone should be familiar with when visiting the client. These notes will help you or your successor understand what has already been discussed and what needs further discussion. These notes should only be kept in **your** copy of the NMP.

Personal Plan Notes

This is where **your** personal notes and calculations should be recorded. This will be important and very helpful to you because in some cases you may not update plans for two or three years, depending on the plan's expiration date. You may need some reminders of how and why you wrote the plan. You should keep a record showing details of how the recommendations were derived. Any special condition or unusual circumstances that existed at the time the plan is written should be documented so the information can be referred to when you review the plan at a later date or to justify specific recommendations during an inspection. These notes should only be kept in **your** copy of the NMP.

Sample Nutrient Management Plan

Nutrient Management Plan Identification

Owner
Fairfax County
1100 Cub Run Lane
Manassas, VA 22025
(804) 555-1212

Land Manager
Mr. William DuPont

Watershed Summary
Watershed: PL45
County: Prince William

Nutrient Management Planner
John Smith
Courthouse Plaza, Suite #5
Hanover, VA 22555
Certification code: 100

Acreage Use Summary
Total acreage in this plan: 15
Athletic fields: 3.5
Supporting areas: 2
Picnic/recreation: 7
Other turf: 2.5

Plan written 3/18/10
Valid until 3/18/13

Planner signature: ________________________________

Narrative for
Cub Run Valley Park
Manassas, Virginia

Cub Run Valley Park is located off Rt. 29 in Fairfax County between Rt. 609 and Rt. 620. The park entrance is off of Stillfield Place Road. This park is open to the public from March 1 through November 30. The park consists of three athletic fields — two baseball and one football field, a primitive picnic area, and an adjoining recreation area maintained for the public to use for recreational activities such as pick-up games, Frisbee tossing, and general exercise and play activities. No pets are allowed in the park. Cub Run stream runs through the park and Field No. 3; the football field is accessed from the parking areas by a large cement culvert crossing over the stream. This crossing is used by cars, maintenance equipment, and foot traffic to access this area of the park.

The athletic fields are mainly used for community Little League baseball and elementary football games on weekends, with practices being conducted throughout the season. Field No. 1 has restricted use and is used mainly for weekend games through early summer. Field No. 3 is used for baseball practice in the late summer, with the majority of the baseball season games played on Field No. 2. During the football season, Field No. 2 is used for practices as well. These fields are managed at a high level, with special attention given to mowing heights and intervals, weed control, and compaction. Soil tests are taken regularly to monitor nutrient needs, and nitrogen is applied on a set schedule to keep grass growing as vigorously as possible through the open season. When possible, play is rotated to different areas of the fields to minimize damage to the field in any one area due to concentrated use.

The recreation area is used for all activities while the park is open to the public.

Condition of the athletic fields is usually good at the opening of the park and remains fairly good through the season. If the field conditions deteriorate too much, the park may be closed earlier in November to minimize damage done to the grass stands and keep costs down to renovate and re-establish fields for the next year.

A buffer area of 50 feet on each side of Cub Run is untreated and is mowed occasionally at about 6 to 8 inches to discourage activities in the buffer area.

Because very little excavation was done to build the fields and other park areas, the native soils are still in place for the most part. Athletic Field No. 1 is constructed on Dulles silt loam, which is somewhat poorly drained. Athletic Field No. 2 is constructed on Ashburn silt loam, which is moderately well-drained. The paved parking lot is built on Jackland and Haymarket soils, which are very stony; fortunately, the entrance area to the park runs through a Dulles silt loam.

Field No. 3, the overflow parking area, and the picnic/recreation area are on a Rowland silt loam. This soil is environmentally sensitive because it is listed as “frequent” for the chance of flooding. Application of nutrients in these areas are not scheduled when heavy rainfall events are expected within a week’s time. Any soil disturbance associated with renovation or construction is usually stabilized with straw mulch covered with anchored netting after final grading and seeding are completed. In areas where water flow could possibly be more concentrated, soil stabilization blankets may be installed to protect the planting until the grass is fully established.

The park is maintained by the county, which has a minimal budget for fertilizer, lime, and reseeding. Nutrient applications, particularly fall nitrogen applications, may be slightly reduced to save money — especially if the turf has a good appearance.

The worksheets in this plan represent recommendations for each management area for the next three years. Applications will be repeated each year at the same designated times. Lime recommendations are only for one application and the designated date includes the year to be applied. This plan is written for a three-year period and will need to be revised at that time to remain current. Revising a plan takes some time, so the process should begin at least four weeks or more prior to the plan expiration date.

The following management practices should be utilized where appropriate to protect water quality and enable the client to better implement a nutrient management plan.

1. Soil samples should be analyzed at least once every three years for pH, phosphorus, potassium, calcium, and magnesium in order to maximize the efficient utilization of nutrients. A representative soil sample of each management area should be composed of at least 20 cores randomly sampled from throughout the area. Soil sampling core depth will be 6 inches from the surface. Soil pH should be maintained at appropriate agronomic levels to promote optimum plant growth and nutrient utilization.
2. Spreader calibration is extremely critical to ensure proper application rates.
3. A protective cover of appropriate vegetation should be established and maintained on all disturbed areas. Vegetation such as trees, shrubs, and other woody species are limited to areas considered to be appropriate, such as wind breaks or visual screens.
4. This nutrient management plan should be revised **at least once every three years** to make adjustments for needed renovations, re-establishment of turf around construction projects, and updated soil test information.
5. If clippings are collected, they should be disposed of properly. They may be composted or spread uniformly as a thin layer over other turf areas or areas where the nutrient content of the clippings can be recycled through actively growing plants. They should not be blown onto impervious surfaces or surface waters, dumped down stormwater drains, or piled outside where rainwater will leach out the nutrients, creating the potential for nutrient loss to the environment.
6. Iron applications (particularly foliar applications) may periodically be used for enhanced greening as an alternative to nitrogen. These applications are most beneficial if applied in late spring through summer for cool-season grasses and in late summer/fall applications for warm-season grasses.
7. Do not apply fertilizers containing nitrogen or phosphorus to impervious surfaces (sidewalks, streets, etc.). Remove any granular material that lands on impervious surfaces by sweeping and collecting it, and either putting the collected material back in the bag or spreading it on the turf and/or using a leaf blower, etc., to return the fertilizer back to the turfgrass canopy.
8. These conditions do not override any local or county ordinances that may be more restrictive.

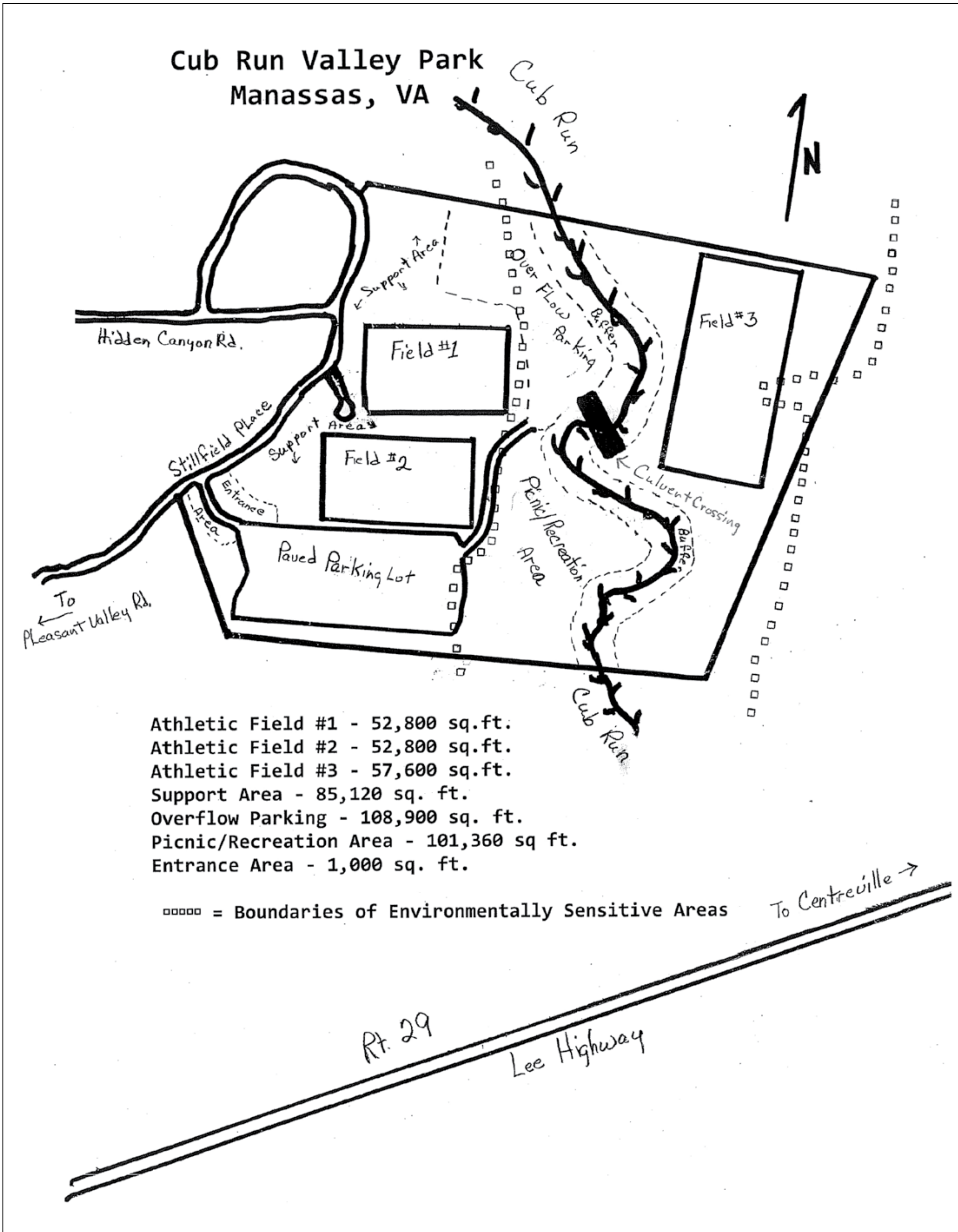
Cub Run Valley Park

Soil Test Summary Report

Lab: Virginia Tech

Sample date: March 9, 2010

Managed area I.D.	Area (sq ft)	P_2O_5 (lb/ac)	K_2O (lb/ac)	Soil pH	Buffer index	Turf species
Athletic Field No. 1	52,800	14/M	40/L	6.2	—	Bluegrass
Athletic Field No. 2	52,800	33/M+	161/M+	6.3	—	Bermudagrass
Athletic Field No. 3	57,600	35/M	148/M	5.9	6.18	Bermudagrass
Support area	85,120	10/L+	59/L+	6.2	—	Bermudagrass
Overflow parking	108,900	8/L	51/L+	5.7	6.12	K-31 fescue
Picnic/recreation area	101,360	14/M-	78/M-	6.0	6.21	Tall fescue
Entrance area	1,000	10/L+	73/L+	5.8	6.14	Perennials


Cub Run Valley Park
Manassas, VA
Cub Run
N
Hidden Canyon Rd.
Support Area
Field #1
Field #2
Field #3
Over Flow Parking
Buffer
Culvert Crossing
Stillfield Place
Support Area
Entrance Area
Paved Parking Lot
Picnic/Recreation Area
Buffer
Cub Run
To Pleasant Valley Rd.
Athletic Field #1 - 52,800 sq.ft.
Athletic Field #2 - 52,800 sq.ft.
Athletic Field #3 - 57,600 sq.ft.
Support Area - 85,120 sq. ft.
Overflow Parking - 108,900 sq. ft.
Picnic/Recreation Area - 101,360 sq ft.
Entrance Area - 1,000 sq. ft.
▫▫▫▫▫ = Boundaries of Environmentally Sensitive Areas
To Centreville
Rt. 29
Lee Highway


Soil Map—Fairfax County, Virginia
(Cub Run Valley Park)
4/21/2010
Page 1 of 3
Map Scale: 1:8,060 if printed on A size (8.5" x 11") sheet.
Meters
Feet
Natural Resources
Conservation Service
Web Soil Survey
National Cooperative Soil Survey
38° 50' 53"
38° 50' 17"
38° 50' 52"
38° 50' 15"
77° 27' 18"
77° 27' 16"
77° 28' 28"
77° 28' 26"
Cub Run
Green Park Way
Basingstoke Loop
Basingstoke Ct
Wycombe St
Wealdstone Ct
Regents Park Rd
Wycoff Sq
Stone Rd
Seasons Dr
Gatwick Sq
Lynhodge Ct
Millicent Ct
Billingsgate Ln
Smethwick Pl
Hancock Ct
Ealing Ct
Bentley Sq
Golfwalte Dr
Cardigan Sq
Maidstone Ct
Ridge Haven Ct
Stillfield Pl
Hidden Canyon Rd
Martins Brandon Way
Oakengate Way
Welton Dr
Wetherburn Dr

Soil Map–Fairfax County, Virginia | Cub Run Valley Park

Map Unit Legend

Fairfax County, Virginia (VA059)			
Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
2B	Ashburn silt loam, 0 to 7 percent slopes	26.0	11.2%
11B	Catlett gravelly silt loam, 2 to 7 percent slopes	2.2	1.0%
11C	Catlett gravelly silt loam, 7 to 15 percent slopes	3.2	1.4%
25B	Chantilly-Penn complex, 2 to 7 percent slopes	5.0	2.2%
25C	Chantilly-Penn complex, 7 to 15 percent slopes	1.3	0.5%
30A	Codorus and Hatboro soils, 0 to 2 percent slopes, occasionally flooded	0.3	0.1%
34A	Dulles silt loam, 0 to 2 percent slopes	8.5	3.7%
34B	Dulles silt loam, 2 to 7 percent slopes	1.0	0.4%
64B	Jackland and Haymarket soils, 2 to 7 percent slopes, very stony	6.2	2.7%
80D	Nestoria channery silt loam, 15 to 25 percent slopes	6.8	2.9%
84B	Panorama loam, 2 to 7 percent slopes	0.9	0.4%
85B	Penn silt loam, 2 to 7 percent slopes	0.5	0.2%
85C	Penn silt loam, 7 to 15 percent slopes	16.5	7.1%
89A	Rowland silt loam, 0 to 2 percent slopes, frequently flooded	120.0	51.9%
97	Urban land-Chantilly complex	32.6	14.1%
99	Urban land-Hattontown complex	0.0	0.0%
Totals for Area of Interest		**231.1**	**100.0%**

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Nutrient Application Worksheet

Name: Fairfax County

Prepared: 3 / 18 / 10 Expires: 3 / 18 / 13

Management Area Identification: Athletic Field No. 1

Square Feet: 52,800 - 7,000* (infield) = 45,800

Landscape Plants: Bluegrass

Turf Species: none

Nutrient needs $N\text{-}P_2O_5\text{-}K_2O$ (lb/1,000 sq ft)	Application month/day†	Fertilizer material $N\text{-}P_2O_5\text{-}K_2O$ (lb/1,000 sq ft)	% slowly available N	Nitrogen (lb/1,000 sq ft)	P_2O_5 (lb/1,000 sq ft)	K_2O (lb/1,000 sq ft)	Lime recommendation (lb/1,000 sq ft)
3.5-2.0-3.0	4/15	18-24-12 2.76 lb	50%	0.5	0.66	0.33	—
	6/1	18-24-12 2.76 lb	50%	0.5	0.66	0.33	—
	8/15	18-24-12 2.76 lb	50%	0.5	0.66	0.33	—
	9/1	23-0-23 4.35 lb	50%	1	0	1	—

Notes:

*7,000 square feet deducted from treated area for infield, which does not receive any fertilization.

†The month and day designations may not always be followed due to weather, etc. Apply as close to the month as possible, using the day designation to determine the interval between applications.

Nutrient Application Worksheet

Name: Fairfax County

Prepared: 3 / 18 / 10 Expires: 3 / 18 / 13

Management Area Identification: Athletic Field No. 2

Square Feet: 52,800 - 7,000* (infield) = 45,800

Landscape Plants: Bermudagrass

Turf Species: none

Nutrient needs $N-P_2O_5-K_2O$ (lb/1,000 sq ft)	Application month/day†	Fertilizer material $N-P_2O_5-K_2O$ (lb/1,000 sq ft)	% slowly available N	Nitrogen (lb/1,000 sq ft)	P_2O_5 (lb/1,000 sq ft)	K_2O (lb/1,000 sq ft)	Lime recom-mendation (lb/1,000 sq ft)
4.5-1.5-1.0	4/15	18-24-12 2.76 lb	50%	0.5	0.66	0.33	—
	6/1	30-6-10 3.33 lb	50%	1.0	0.20	0.33	—
	7/1	30-6-10 3.33 lb	50%	1.0	0.20	0.33	—
	9/1	18-24-12 1.83 lb	50%	0.33	0.44	0.22	—
	9/15	40-0-0 1.25 lb	85%	0.50	0.00	0.00	—
	10/1	Overseed ryegrass 2 lb	—	—	—	—	—
	10/15	40-0-0 1.25	85%	0.5	0.00	0.00	—

Notes:

*7,000 square feet deducted from treated area for infield, which does not receive any fertilization.

10/15 application date is approximate; nitrogen should be applied as soon as ryegrass has germinated and there is adequate moisture to promote vigorous growth.

†The month and day designations may not always be followed due to weather, etc. Apply as close to the month as possible, using the day designation to determine the interval between applications.

Nutrient Application Worksheet

Name: Fairfax County

Prepared: 3 / 18 / 10 Expires: 3 / 18 / 13

Management Area Identification: Athletic Field No. 3

Square Feet: 57,600

Landscape Plants: Bermudagrass

Turf Species: none

Nutrient needs N-P_2O_5-K_2O (lb/1,000 sq ft)	Application month/day†	Fertilizer material N-P_2O_5-K_2O (lb/1,000 sq ft)	% slowly available N	Nitrogen (lb/1,000 sq ft)	P_2O_5 (lb/1,000 sq ft)	K_2O (lb/1,000 sq ft)	Lime recommendation (lb/1,000 sq ft)
4.5-1.5-1.5	4/15	18-24-12 2.76 lb	50%	0.5	0.66	0.33	—
	5/1	Pulverized lime	—	—	—	—	57 lb
	6/1	30-6-10 3.33 lb	50%	1.0	0.20	0.33	—
	7/1	30-6-10 3.33 lb	50%	1.0	0.20	0.33	—
	9/1	18-24-12 1.83 lb	50%	0.33	0.44	0.22	—
	9/15	40-0-0 1.25 lb	85%	0.50	0.00	0.00	—
	10/1	Overseed ryegrass 2 lb	—	—	—	—	—
	10/15	40-0-0 1.25 lb	85%	0.5	0.00	0.00	—

Notes:
10/15 application date is approximate; nitrogen should be applied as soon as ryegrass has germinated and there is adequate moisture to promote vigorous growth.

†The month and day designations may not always be followed due to weather, etc. Apply as close to the month as possible, using the day designation to determine the interval between applications.

Nutrient Application Worksheet

Name: Fairfax County

Prepared: 3 / 18 / 10 Expires: 3 / 18 / 10

Management Area Identification: Support Area/Overflow Parking

Square Feet: 194,020

Landscape Plants: Tall Fescue

Turf Species: none

Nutrient needs **N-P_2O_5-K_2O** (lb/1,000 sq ft)	**Application month/day**†	**Fertilizer material** **N-P_2O_5-K_2O** (lb/1,000 sq ft)	**% slowly available N**	**Nitrogen** (lb/1,000 sq ft)	**P_2O_5** (lb/1,000 sq ft)	**K_2O** (lb/1,000 sq ft)	**Lime recom-mendation** (lb/1,000 sq ft)
3.0-2.5-2.0	9/1	10-20-15 10 lb	—	1.0	2.0	1.5	—
	10/1	30-6-10 3.33 lb	50%	1.0	0.2	0.33	—
	11/1	40-0-0 2.5 lb	50%	1.0	0.00	0.00	—
	4/11/10	Pulverized limestone	—	—	—	—	69 lb Overflow parking only

Notes:

†The month and day designations may not always be followed due to weather, etc. Apply as close to the month as possible, using the day designation to determine the interval between applications.

Nutrient Application Worksheet

Name: Fairfax County

Prepared: 3 / 18 / 10 Expires: 3 / 18 / 10

Management Area Identification: Picnic/Recreation Area

Square Feet: 101,360

Landscape Plants: Tall Fescue

Turf Species: none

Nutrient needs N-P_2O_5-K_2O (lb/1,000 sq ft)	**Application month/day†**	**Fertilizer material N-P_2O_5-K_2O** (lb/1,000 sq ft)	**% slowly available N**	**Nitrogen** (lb/1,000 sq ft)	**P_2O_5** (lb/1,000 sq ft)	**K_2O** (lb/1,000 sq ft)	**Lime recom-mendation** (lb/1,000 sq ft)
3.0-2.0-2.0	9/1	10-20-15 10 lb	—	1.0	2.0	1.5	—
	10/1	23-0-23 4.3 lb	50%	1.0	0.00	1.0	—
	11/1	40-0-0 2.5 lb	50%	1.0	0.00	0.00	—
	4/1/11	Pulverized limestone	—	—	—	—	46 lb

Notes:

†The month and day designations may not always be followed due to weather, etc. Apply as close to the month as possible, using the day designation to determine the interval between applications.

Nutrient Application Worksheet

Name: Fairfax County

Prepared: 3 / 18 / 10 Expires: 3 / 18 / 10

Management Area Identification: Entrance Plantings

Square Feet: 1,000

Landscape Plants: Herbaceous Perennials

Turf Species: none

Nutrient needs N-P$_2$O$_5$-K$_2$O (lb/1,000 sq ft)	**Application month/day**†	**Fertilizer material N-P$_2$O$_5$-K$_2$O** (lb/1,000 sq ft)	**% slowly available N**	**Nitrogen** (lb/1,000 sq ft)	**P$_2$O$_5$** (lb/1,000 sq ft)	**K$_2$O** (lb/1,000 sq ft)	**Lime recom-mendation** (lb/1,000 sq ft)
1.25-1.0-1.0	3/1	10-10-10 5 lb	—	0.5	0.5	0.5	—
	3/15	Pulverized limestone	—	—	—	—	39 lb
	4/15	10-10-10 5 lb	—	0.5	0.5	0.5	—
	5/30	30-6-10 2.5 lb	50%	0.75	0.15	0.25	—
	6/15	Pulverized limestone	—	—	—	—	39 lb

Notes:
A 3-1-1 fertilizer ratio is suggested, but based on low soil test results for phosphorus and potassium, this ratio for P and K was increased based on an annual N rate of 1.25 lb. Lime applied in two applications to adjust pH to 6.2.

†The month and day designations may not always be followed due to weather, etc. Apply as close to the month as possible, using the day designation to determine the interval between applications.

References: *Perennials: Culture, Maintenance, Propagation; Fertilizing Landscape Trees and Shrubs.*

Plan Discussion

The following information is **NOT** part of an actual plan; its purpose is to help the reader understand what information was used to write this plan and the reasoning behind some of the recommendations.

When you begin to work with clients, they may have some fertilizer materials on hand that they want to use before buying other products, so you may be forced to use some analysis that does not exactly match your recommendations. Try to use as few products as possible to make the plan a little easier for your client to follow. To aid in understanding the recommendations in the example plan, the specimen labels that follow (figure 13.5) were used.

40-0-0 Slow-Release Nitrogen Fertilizer

Guaranteed Analysis	
Total Nitrogen (N)*	40%
Urea Nitrogen 6%	
Slowly Available Water Soluble 20%	
Water Insoluble Nitrogen 14%	
Derived from: methylene urea	

*20% slowly available Nitrogen from methylenediurea and dimethylenetriurea.

10-20-15

Guaranteed Analysis	
Total Nitrogen (N)	10%
Ammoniacal Nitrogen 7.8%	
Urea Nitrogen 2.2%	
Available Phosphorus (P_2O_5)	20%
Soluble Potash (K_20)	. 15%
Iron (Fe)	.1%
Water-Soluble Iron (Fe) 0.1%	
Derived From: Ammonium Phosphate, Urea, Muriate of Potash, Ferric Oxide, Ferrous Sulfate	
Chlorine (CL) not more than	13%

Notice: This product contains the secondary nutrient iron. Iron may stain concrete and should be removed from these areas promptly after application by sweeping or blowing. Do NOT wash off with water.

18-24-12 50% SCU

Guaranteed Analysis	
Total Nitrogen (N)	18%
Urea 0%	
Coated Slow Release 9%	
Water Insoluble Nitrogen 0%	
Water Soluble Nitrogen 0%	
Ammoniacal Nitrogen 9%	
Stabilized Urea Nitrogen 0%	
Total Phosphate Acid (P_2O_5)	24%
Soluble Potash (K_2O)	12%
Iron Sulfate (FE)	0%
Sulfate Sulfur (S)	0%

23-0-23

Guaranteed Analysis	
Total Nitrogen (N)	23%
Urea 11.5%	
Coated Slow Release 11.5%	
Water Insoluble Nitrogen 0%	
Water Soluble Nitrogen 0%	
Ammoniacal Nitrogen 0%	
Total Phosphate Acid (P_2O_5)	0
Available Potash (K_20)	.23%
Iron Sulfate (FE)	.2%

30-6-10 50% SCU

Guaranteed Analysis	
Total Nitrogen (N)	30%
Urea 13.1%	
Coated Slow Release 15%	
Ammoniacal N 1.9%	
Total Phosphate Acid (P_2O_5)	6%
Available Potash (K_2O)	.10%
Iron Sulfate (FE)	0%
Sulfate Sulfur (S)	0%

Figure 13.5. The five sample specimen labels, as stated earlier, may not be part of a plan you would take back to your clients. They are provided here as a reference to help in your understanding of how to interpret the information contained in them to make recommendations.

How do I know if my fertilizer material is considered slowly available, and if so, how do I calculate the percentage of slowly available nitrogen to use in making recommendations? To determine this, divide the percentage of slowly available nitrogen material by the percentage of total nitrogen listed on the label. Slowly available nitrogen will be listed on the label as “coated slow release,” “water insoluble nitrogen,” etc.

Looking at the materials used on Athletic Field No. 2 and from the label information, here are the calculations:

18-24-12: 9% ÷ 18% = 50%

30-6-10: 15% ÷ 30% = 50%

40-0-0: (20% + 14%) ÷ 40% = 85%

In the last fertilizer, there are two different materials making up the slowly available component of the total nitrogen. (Note: A complete discussion on slowly available nitrogen sources, their characteristics, and their uses is provided in chapter 8 of this manual.)

For athletic fields No. 1, 2, and 3, the nutrient needs were determined using the Virginia Nutrient Management Standards and Criteria (2005; available through the Virginia Department of Conservation and Recreation website at *www.dcr.virginia.gov/soil_and_water/nutmgt.shtml*). The nitrogen program followed the “intensive” maintenance program shown on page 102 of *Standards and Criteria*. How an area is managed determines whether you should use the normal or intensive program. You determine how an area is managed by talking to your client about the nitrogen rate they have been using, how much play the fields have to handle, and how quickly they heal in season and postseason. The phosphorus and potash recommendations are from soil test results. Those recommendations for athletic fields are found on page 104 of *Standards and Criteria*.

Because the financial budget is always tight at the county and the fields look good late in the season, it was decided — in consultation with the client — not to make the third fall nitrogen application. Such decisions are acceptable **but should be made with the client’s full understanding of what it is being done and why**. Otherwise, the recommendations in the plan do not match those in *Standards and Criteria*, making it appear that the planner did not completely follow the *Standards and Criteria* recommendations.

In general, the nitrogen rates are close to the nutrient needs. In some areas, the phosphorus applications may be under the recommendations. Because plans cannot exceed the nitrogen or the phosphorus nutrient needs, it was easiest to come close to the nitrogen needs while not exceeding the phosphorus needs.

Lime applications are shown on the worksheets as well. It was easy to list the lime material and show the application rate in the far-right column.

Because the recommendations for each year of the three-year plan were going to be similar, one worksheet was developed for each managed area and labeled to be good for three years — see “prepared” and “expires” dates in the first column of the header section of the worksheet. **IF** the managed areas would have had significantly different fertility for each of the three years, then the planner may choose to develop a worksheet for each management area for each year. Using the worksheets for either option is acceptable; fill them out so it is clear to the client what needs to be done and when.

The worksheet on the entrance plantings area is fairly simple. It basically shows a nitrogen application and the phosphorus and potash recommendations based on a soil test. While perhaps not necessary, this adds to the plan in that the planner is addressing possible fertilizer applications to all managed areas of the property. Again, talk with your client about what they do in these areas and how satisfied they are with their performance and/or appearance. Although you may find they do not have any formal program in place, your interest in managing such areas will improve the overall appearance of the property, which increases the value of your service to your client.

A map of the property showing the various features described in the nutrient management regulations is required to be part of the plan; however, the soils map and legend may be useful information in the plan, but the soils map and legend needs to be information contained in the client’s **office file**.

Plan Implementation

After the initial plan has been delivered, the client should begin to implement it. The degree to which it is implemented will depend on several factors. The most obvious is whether it will benefit the client either in cost savings or improved appearance of the managed area(s). Secondly, how easily can changes suggested in the plan be adapted to the client’s current methods of operation? If the recommendations in the plan are similar to what is already being done, the client is more likely to follow them. A well-written plan that addresses the specific needs of a property with a practical and realistic approach is also more likely to be successfully implemented. Finally, the client's acceptance of the plan, willingness to change, and trust in the plan writer will strongly affect the degree of plan adoption.

For those plans (or portions thereof) that are adopted, three tasks are important to its ongoing success.

1. Future Nutrient Testing

Where appropriate, the soil and tissue testing described earlier are key tools to manage the application of nutrients. Without these measures of nutrient availability balanced with plant needs, it will be difficult to accurately determine plant nutrient needs and to develop relevant, justifiable recommendations. The client should be strongly encouraged to maintain this test-critical information. Not only is it needed for developing credible nutrient management plans, it is also important in the operation management decision-making process.

2. Equipment Calibration

Equipment calibration represents another area critical to plan implementation. The plan recommendations will do little to save money and protect water quality if they cannot be followed due to inaccurate nutrient application. Calibration of all application equipment should be checked on a regular basis, especially if your client owns his own application equipment. Without the necessary adjustments indicated by calibration, the result may be to apply either too little or too much plant nutrients. The first may result in an unacceptable turf durability and turf/landscape appearance. The latter may be costly, not only because of the unnecessary expense, but also because of a negative impact on water quality. Equipment calibration is detailed in chapter 10 of this manual.

3. Application and Maintenance Records

A final area to emphasize during plan implementation is record keeping. Without good records, it is impossible to know what has been done and if any progress or improvements are being made. Examples of important information to retain are soil tests; spreader calibration settings; dates of fertilizer application and rates applied; seeding or renovation of specific areas; and any usual stresses on the areas due to disease, drought, etc., that would also impact the health and appearance of the turf. This information provides the background needed for fine-tuning future plan updates or revisions.

Plan Revision

Several factors can and will result in the need for revising the nutrient management plan. The most obvious is that the life of the plan has expired. Plans can be written for up to a three-year period. Start working with clients well ahead of the expiration date so your client will have a current plan in place at all times.

Even the best-written plan can be refined to take advantage of what has been learned in the last season. For that reason, plans will always be going through some degree of evolution. Some specific factors may result in the need for significant revisions. Changes in the predominant land use on (or adjacent to) the managed areas may require modification of the existing plan. If managed areas are dramatically changed by renovations to the landscape or construction of new buildings, roads, etc., such changes may require the plan to be revised.

Summary

The number of factors that can alter a nutrient management plan is substantial. For that reason, a sincere effort on the part of the client who manages a sizeable operation may be needed to reassess decisions made when the plan was first developed. Follow-up visits are important to the success of the planning process. Because the performance of various managed areas varies due to season conditions, it is important to continue to follow up until the client is comfortable with the plan implementation. Once the client has an understanding of the concepts and is capable of interpreting the plan, the amount of support required should significantly lessen. Having your clients increase their understanding of nutrient management and its importance creates a desire to do their best to follow the plan. More importantly, it indicates that you are delivering a good and beneficial service to your clients.

Literature Cited

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www.ext.vt.edu

PUBLICATION 430-350

Produced by Communications and Marketing, College of Agriculture and Life Sciences, Virginia Polytechnic Institute and State University, 2011

Appendix 1. Soil Investigation Procedures for Stormwater BMPs

Delaware DNREC, Sediment & Stormwater Program
(Adapted from Wisconsin Department of Natural Resources)

I. Definition

This standard defines soil investigation procedures to:

1. Perform an initial screening of a *development site*[1] to determine its suitability for potential stormwater Best Management Practices (BMPs).
2. Evaluate each area within a development site that is selected for runoff reduction.
3. Determine suitability of on-site soils to meet any structural needs.
4. Prepare a Soils Investigation Report.

II. Purpose

1. Establish methodologies to characterize the site and screen for exclusions and exemptions under the Delaware Sediment & Stormwater Regulations (DSSR).
2. Establish requirements for siting a *runoff reduction practice*[1] and the selection of design infiltration rates.
3. Establish location of on-site soils used for construction of stormwater BMPs.
4. Define requirements for a site evaluation report that insures appropriate areas are selected for infiltration and an appropriate *design infiltration rate*[1] is used, as well as whether on-site soils are adequate for the construction of proposed stormwater BMPs.

III. Conditions where Practice Applies

This standard is intended for development sites being considered for stormwater management BMPs. Additional site location requirements may be imposed by other stormwater BMP technical standards.

IV. Federal, State and Local Laws

Users of this standard shall be aware of applicable federal, state and local laws, rules, regulations or permit requirements governing infiltration devices. This standard does not contain the text of federal, state or local laws.

V. Criteria

The site evaluation consists of four steps for locating the optimal areas for infiltration, properly sizing infiltration devices, and suitability for construction of stormwater BMPs.

- Step A. Initial Screening.
- Step B. Field Verification of information collected in Step A.
- Step C. Evaluation of specific *Infiltration Area*s[1].
- Step D. Soil and Site Evaluation Reporting.

The steps shall coincide, as much as possible, for when the information is needed to determine the following: 1) the potential for infiltration on the site, 2) the optimal locations for infiltration practices, and 3) the design of the stormwater BMPs. Steps A and B shall be completed as soon as possible in the approval process.

[1] NOTE: Words in the standard that are shown in italics are described in VIII. Definitions. The words are italicized the first time they are used in the text.

Step A. Initial Screening

The initial screening identifies potential locations for infiltration practices. The purpose of the initial screening is to determine if installation is limited by soils, water table or other physical site features, and to determine where field work is needed for Step B. Optimal locations for infiltration are verified in Step B.

Information collected in Step A will be used to explore the potential for multiple infiltration areas versus relying on a regional infiltration practice. Smaller infiltration practices dispersed around a development are usually more sustainable than a single regional facility that is more likely to have maintenance and groundwater mounding problems.

The initial screening shall determine the following:

Note: Useful references for the existing resource maps and information are listed in Considerations VI.I and J.

1. Site topography and slopes greater than 20%.
2. Site soil infiltration capacity characteristics as defined in NRCS County soil surveys.
3. *Soil parent material*.
4. Regional or local depth to groundwater and bedrock. Use seasonally *high groundwater* information where available.
5. Distance to known remediation sites within 500 feet from the perimeter of the development site.
6. Presence of endangered species habitat.

7. Presence of flood plains and flood fringes.
8. Location of hydric soils based on the USDA County Soil Survey and wetlands from the DNREC State Wetland Mapping Program (SWMP).
9. Sites where the installation of stormwater infiltration practices is excluded, due to the potential for groundwater contamination.
10. Proximity of water supply wells and on-site wastewater disposal systems.
11. Potential impact to adjacent property.

Step B. Field Verification of the Initial Screening

A. Field verification is required for areas of the development site considered suitable for infiltration. This includes verification of Step A.1, 2, 3, 4, 9, 10 and 11.

B. Sites shall be tested for depth to groundwater, depth to bedrock and *percent fines* information to verify any exemption and exclusion found in Step A.10 and 11. Borings and pits shall be dug to verify soil infiltration capacity characteristics and to determine depth to groundwater and bedrock

C. Soils and geotechnical investigations must consider the following, where applicable:

1. Boreholes: Test borings for pond embankments must be located in the footprint of the embankment, spillway excavation and appurtenant structures. Boreholes must extend to sound bedrock or at least to the depth equal to the height of the dam. When the boreholes are extended to bedrock, coring of the bedrock must be performed following ASTM Standard D2113 to assess its quality and characteristics. The borehole logs must record the depths of any problems such as borehole instability (cave in, squeezing hole, flowing sands), cobbles, lost drilling fluid, lost ground, obstruction, fluid return color changes and equipment problems, and a discussion of the problem must be provided in the geotechnical report. The geotechnical report must provide details of the drilling method, drilling fluid, size of boreholes and the ground elevations at the top of the boreholes.
2. Test Pits or Trenches: Supplemental test pits or trenches must be located appropriately to provide visual inspection of soil layers, measurement of bedrock orientation and collection of bulk samples. Test pits and trenches must be logged. Collection of block samples must be performed according to ASTM Standard D7015. The geotechnical report must provide details of the method used for excavating test pits and the test pit logs must record any excavation problem observed such as instability of cut (sloughing, caving, etc.), depth of refusal, difficulty of excavating, etc.
3. Field Tests:

   a. Standard Penetration Tests (SPT): The standard penetration test must follow ASTM Standard D1586. Standard penetration resistance (SPT N or N value) is the number of blows of a 140 lbm hammer falling 30 in. required to produce 1-

foot of penetration of a specified (standard) 2-in. outside diameter, 13/8-in. inside diameter sampler into soil, after an initial 0.5 feet seating. A penetration test that does not meet these requirements is not a SPT and the penetration resistance must not be reported as a SPT N-value or N-value and care must be taken with its use for correlating soil properties. Published correlations for SPT N-value cannot be used for non-SPT blow count numbers. If SPT N-values are used for the assessment of liquefaction potential, the SPT N-values must be normalized according to ASTM Standard D6066.

b. Cone Penetration Tests (CPT): CPT tests must be performed and results provided according to ASTM Standard D5778. Electronic data must be provided on a CD along with CPT logs and interpretations. CPT tests can be used to supplement site characterization.

c. Geophysical Investigation: Geophysical survey methods may be used to supplement borehole and outcrop data and to interpret soil profile between boreholes. They can be used to plan borehole locations. ASTM Standards D6429 and D5753 provide guidance on planning and selection of geophysical methods. ASTM Standard D5777 provides guidance on test procedures and interpretation of the seismic refraction method. ASTM Standard D4428/D4428M provides test methods and interpretation of the crosshole seismic test. The geotechnical report must explain the test method and interpretation of the test results.

d. Field Permeability Test: Field permeability testing is generally required for all proposed infiltration practices and may be required for other non-infiltrating stormwater BMPs. If a field permeability test is performed, details of the test method, calculations and interpretation must be included along with the results. Testing for saturated hydraulic conductivity shall be done in accordance with ASTM-D5126 "Comparison of Field Methods for Determining Hydraulic Conductivity in the Vadose Zone". If the infiltration rate is measured with a *Double-Ring Infiltrometer* the requirements of ASTM-D3385 shall be used for the field test.

e. Measurement of Water Level in Boreholes: Water level must be measured in boreholes and test pits and shown accordingly on logs of the boreholes and test pits. The water level must be recorded during drilling and after the ground water table is stabilized. Both water levels must be provided on borehole logs along with the time of measurement. Elevation of the water table must be established based on the project datum and shown on the ground profile of the dam site.

f. Field tests with equipment such as pocket penetrometer and torvane are not acceptable for deriving design parameters. Equipment used in the geotechnical investigation must be used appropriately in accordance with ASTM standards.

4. Sample Collection for Laboratory Testing:

a. The sample collection program must be designed to meet the requirements of the laboratory tests planned for the project. Some laboratory tests require relatively undisturbed samples while others can use disturbed samples so long as the properties of the sample is preserved. Sample collection, preservation, transportation and handling must be described in the geotechnical report. ASTM Standards D4220 and D5079 must be followed to prevent samples from experiencing excessive disturbance during transportation and handling.

b. Disturbance of samples inherent to sampling techniques must be recognized. Soil samples that are obtained by driving samplers with a hammer such as the standard penetration test (ASTM Standard D1586) and penetration of samplers lined with rings (ASTM Standard D3550) are considered highly disturbed. This must be recognized when interpreting and presenting results from laboratory tests based on these samples. If the soil samples for the laboratory tests were reconstituted in the laboratory, the method of sample preparation must be explained in detail.

c. Samples collected by a Thin-Walled Tube Sampler (ASTM Standard D1587) and other samplers specifically designed to minimize disturbance during sample collection process are recognized as undisturbed samples. Description of the sampler and sample collection method must be provided.

d. For block samples, the method of collection, preservation, transportation and handling must be described in the geotechnical report. If the method complies with ASTM standard D7015, the block samples will be considered undisturbed.

e. Rock samples must be collected following the procedures outlined in ASTM Standard D2113. Rock Quality Designation (RQD) determination of rock core must follow ASTM Standard D6032.

5. Soil Classification:

a. Soil classification must follow the Unified Soil Classification System as provided in ASTM Standard D2487.

b. Rock-mass classification must follow ASTM Standard D5878. A discussion must be provided on the selection of the classification system.

6. Laboratory Tests:

a. Consistency tests (Atterberg Limits) for fine-grained soil and sieve analysis for coarse-grained soil are the basic tests required for classification of soil and must be performed. Determination of density, water content and specific gravity is also required. Selection of other laboratory tests must be based on the requirements of the design project. A laboratory testing program must be developed while planning for the site investigation since it may dictate the selection of a boring method and sample collection. Limitations of the laboratory tests must be recognized in the laboratory testing program. Laboratory tests must follow appropriate ASTM standards.

b. Strength Testing:

i. Direct Shear Test (Consolidated Drained Shear Test): The direct shear test is one of the most popular shear strength tests as it provides relatively rapid determination of shear strength parameters and is less expensive to perform. However, the limitations of the test are often not recognized and/or the test method is not followed appropriately on many occasions making the test results of little value. ASTM Standard D3080 provides the test methodology and discusses specimen requirements, selection of appropriate shearing rate and presentation of the results. This standard must be followed to obtain credible shear strength parameters. **The direct shear test is not recommended on clayey soils.** Triaxial shear tests provide more accurate results for the clayey soils. The normal stress applied to the sample must represent the stress that the soil will be subjected to after construction. Soil samples must be consistent in unit weight and relative density (void ratio) since the strength of the soil varies with relative density.

ii. Unconfined Compression Test (UC Test): The unconfined compression test can be used to estimate the undrained shear strength of saturated, fine-grained foundation materials. The UC Test is applicable only for cohesive soils which will not expel or bleed water during the loading portion of the test and which will retain intrinsic strength after removal of confining pressures, such as clays or cemented soils. Dry and crumbly soils, fissured or varved soils, silts, peats, and sands cannot be tested with this method to obtain valid unconfined compression strength values. The test must follow ASTM Standard D2166. This test generally provides conservative strength parameters for the end-of-construction loading condition.

iii. Unconsolidated-Undrained Triaxial Compression Test (UU Test or Q Test): The UU Test is suitable for saturated fine-grained soils. The sample is not consolidated prior to testing and the water content of the soil is not allowed to change either prior to or during testing. This test method removes some of the limitations of the UC Test and is applicable to a wider range of fine-grained soils. ASTM Standard D2850 provides methodology for the UU Test. It is recommended that the UU Test on embankment soils be performed on samples remolded at the higher water content likely to be encountered during fill placement to represent the lowest embankment fill shear strength. Descriptions must be provided about the source and preparation of the sample. The degree of saturation of the sample must be calculated and provided with the result. The reporting guideline provided by ASTM Standard D2850 must be followed. This test provides shear strength parameters suitable for the end-of-construction loading condition (total stress analysis).

iv. Consolidated-Undrained Triaxial Compression Test with Pore Pressure Measurement (CU Test or R Test): For the consolidated undrained test, the sample is saturated and consolidated under confining pressures that approximate field conditions. Pore water pressure during the test is measured to determine effective stress parameters. The consolidated undrained test can be performed on saturated impervious or semi-impervious soils and simulates the soil conditions experienced during steady-state seepage and rapid drawdown. ASTM Standard D4767 provides the test method for consolidated undrained triaxial compression test for cohesive soils.

v. Consolidated-Drained Triaxial Compression Test (CD Test or S Test): The CD Test is similar to CU Test except the shear stress is applied slowly to allow dissipation of excess pore pressure during the shearing process. Pore pressure measurements are not required. This test is suitable for free-draining soils and provides effective stress parameters. The test can also be performed on relatively impervious soils to model strength of the embankment materials above the phreatic line.

c. One-Dimensional Consolidation Test (Oedometer Test): Oedometer tests are performed on clayey soils to obtain consolidation parameters required for the estimation of consolidation settlement. Undisturbed soil samples are required for this test. The test specimen must be fully saturated. ASTM Standards D2435 and D4186 provide the test methods, analysis and reporting of results. If the oedometer is used for evaluating collapse potential of soils, follow ASTM Standard D5333.

d. Permeability Test: The sample preparation and the test method of the permeability test must be discussed in the report. ASTM Standard D2434 provides the methodology for the constant head test on granular soils. If the falling head test is used, it must be stated as such in the report. Relative density of the granular soil specimen must be reported with the result.

e. Dispersibility Test: ASTM Standards D4647 and D4221 provide methods of evaluating dispersive properties of clay soils. A description of the sample preparation and test method must be included in the report along with the discussion of the results.

f. Collapse Potential Test: ASTM Standard D5333 provides the methodology for evaluating collapse potential of soils. This standard must be followed for the test and interpretation of the results.

g. Compaction Tests: ASTM Standards D698 and D1557 provide methods for the Standard Proctor and Modified Proctor, respectively, for the laboratory evaluation of compaction characteristics of soils containing up to 30 percent coarse materials by weight retained on the ¾-inch sieve. If the soil contains over 5 percent coarse particles retained on the ¾-inch sieve and the coarse particles are not included in the Proctor tests, it must be mentioned in the test results and a correction for the oversize curves must show all the data points along with the interpreted curve. The 100-percent saturation curve (zero air voids curve) must also be shown on the graph with the compaction curve. The sample preparation and test method must also be explained. If the soil contains more than 30 percent oversize particles retained on the ¾-inch sieve or the soil particles break during the compaction test changing gradation significantly compared to the field compaction, or the soil is gap graded, concurrence must be obtained in advance from the DNREC Sediment

& Stormwater Program on the approach and the method to be used for the compaction evaluation of such soils.

D. The following information shall be recorded for Step B:

1. The date or dates the data was collected.
2. A legible site plan/map that is presented on paper that is no less than 8 ½ X 11 inches in size and:

   a. Is drawn to scale or fully dimensional.
   b. Illustrates the entire development site.
   c. Shows all areas of planned filling and/or cutting.
   d. Includes a permanent vertical and horizontal reference point.
   e. Shows the percent and direction of land slope for the site or contour lines; highlight areas with slopes over 20%.
   f. Shows all flood plain information that is pertinent to the site.
   g. Shows the location of all pits/borings included in the report.
   h. Location of wetlands as field delineated and surveyed.
   i. Location of karst features, private wells within 100 feet of the development site, and public wells within 400 feet of the development site.

3. Soil profile descriptions must be written in accordance with the descriptive procedures, terminology and interpretations found in the Field Book for Describing and Sampling Soils, USDA, NRCS, 1998. Frozen soil material must be thawed prior to conducting evaluations for soil color, texture, structure and consistency. In addition to the data determined in Step B, soil profiles must include the following information for each soil horizon or layer:

   a. Thickness, in inches or decimal feet.
   b. Munsell soil color notation.
   c. Soil mottle or redoximorphic feature color, abundance, size and contrast.
   d. USDA soil textural class with rock fragment modifiers.
   e. Soil structure, grade size and shape.
   f. Soil consistence, root abundance and size.
   g. Soil boundary.
   h. Occurrence of saturated soil, groundwater, bedrock or disturbed soil.

4. The following additional information shall be provided for geotechnical investigations:

   a. Soil classification in accordance with the Unified Soil Classification System.
   b. Results of applicable tests conducted in accordance with Step B, Part C.
   c. Assessment of suitability of on-site soils for construction of proposed stormwater BMPs.
   d. Compaction requirements, as applicable.

Step C. Evaluation of Specific Infiltration Areas

This step is to determine if locations identified for infiltration practices are suitable for infiltration, and to provide the required information to design the practice.

A minimum number of borings or pits shall be constructed for each infiltration device (see Table 1) . The following information shall be recorded for Step C:

1. All the information under Step B.C.3.

2. A legible site plan/map that is presented on paper no less than 8 1/2 X 11 inches in size and:

   a. Is drawn to scale or fully dimensional.
   b. Illustrates the location of the infiltration devices.
   c. Shows the location of all pits and borings.
   d. Shows distance from facility to wetlands.

3. A vertical separation of two (2) feet from the seasonal high groundwater elevation is required for all infiltration practices unless an underdrain is provided. An analysis of groundwater mounding potential is required for certain classes of infiltration practices, as indicated in Table 1. The altered groundwater level, based on mounding calculations, must be considered in determining the vertical separation distance from the infiltration surface to the *highest anticipated groundwater elevation*. References include but are not limited to Finnemore 1993 and 1995, and Hantush 1967.

4. The following procedures shall be used to determine the design infiltration rate:

   a. Measured Infiltration Rate – Infiltration practices used for compliance purposes under the DSSR require field measured infiltration rates unless the use of an assumed rate is granted prior approval in accordance with Step C.4.b.. The tests shall be conducted at the least permeable soil horizon within three (3) feet of the bottom of the facility.

   b. Assumed Infiltration Rate - Table 2 contains representative infiltration rates based on soil texture. These rates may be used for designing small scale practices in lieu of field infiltration testing with prior approval from the Department and/or Delegated Agency. Select the infiltration rate from Table 2 based on the soil horizon at the bottom elevation of the proposed infiltration facility.

   c. Correction Factor - The infiltration rate shall be divided by a correction factor to determine the final rate to be used for design purposes. The correction factor adjusts the infiltration rates for the occurrence of less permeable soil horizons below the bottom of the facility and the potential variability in the subsurface soil horizons throughout the infiltration site. A less permeable soil horizon below the location of the measurement increases the level of uncertainty in the measured value. Also, the uncertainty in a measurement is increased by the variability in the subsurface soil horizons throughout the proposed infiltration site. The infiltration rate shall be divided by a correction factor in accordance with the following guidelines:

i If measured rates are used, the rate determined during field testing is divided by 2.0 to determine the final design infiltration rate. For example, if field testing results indicated a measured infiltration rate of 1.80 in/hr at the least permeable soil horizon within three (3) feet of the bottom of the facility, the final design infiltration rate would be 1.80/2.0 = 0.90 in/hr.

ii If the use of non-measured rates has been authorized, the ratio is based on the rate from Table 2 for the soil textural classification of the soil horizon at the bottom of the facility divided by the rate for the soil textural classification of the least permeable soil horizon within three (3) feet of the bottom of the facility. The final design infiltration rate is then determined from Table 3 based on this ratio. For example, a facility with a sand at the bottom of the facility (3.60 in/hr) and a least permeable layer of loamy sand (1.63 in/hr) will have a design infiltration rate ratio of about 2.2 and a correction factor of 4.0. The final design infiltration rate would therefore be 3.60/4.0 = 0.90 in/hr.

5. The minimum infiltration rate without correction factor for all runoff reduction and infiltration practices is 1.0 in/hr. To determine if infiltration is not feasible in a specific location, at least one of the following criteria must be satisfied:
   a. The area is classified as “Poor” under the Runoff Reduction Feasibility mapping, or
   b. The least permeable soil horizon three (3) feet below the bottom of infiltration system is one of the following: sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, or clay, or
   c. A field testing method conducted in accordance with this document indicates an infiltration rate less than 1.0 in/hr. The infiltration rate used to claim the exemption shall be the actual field measurement and shall be used without the correction factor applied.

Step D. Soil and Site Evaluation Report Contents

The site’s legal description and all information required in Steps B and C shall be included in the Soil and Site Evaluation Report. These reports shall be completed prior to the *construction plan* submittal. Table 1 summarizes the evaluation requirements for various types of infiltration practices.

Table 1: Evaluation Requirements Specific to Proposed Infiltration Devices

Infiltration Practice	**Tests Required**[1]	**Minimum Number of Borings/Pits Required**	**Minimum Drill/Test Depth Required Below the Bottom of the Infiltration System**
Infiltration Trenches (< 10,000 sq ft impervious drainage area)	Pits required on central systems; borings permissible for distributed systems	1 test required up to 500 linear feet and one (1) additional boring per 250 linear feet of trench, and sufficient to determine variability.	3 feet or depth to limiting layer, whichever is less.
Infiltration Trenches (> 10,000 sq ft impervious drainage area)	Pits required on central systems; borings permissible for distributed systems	1 test required up to 250 linear feet and one (1) additional boring per 250 linear feet of system, and sufficient to determine variability.	3 feet or depth to limiting layer, whichever is less.
Infiltrating Bioretention Systems	Pits required on central systems; borings permissible for distributed systems	1 test required up to 250 linear feet and one (1) additional boring per 250 linear feet of system, and sufficient to determine variability.	3 feet or depth to limiting layer, whichever is less.
Surface Infiltration Basins	• Pits required on central systems; borings permissible for distributed systems • Mounding analysis on case-by-case basis	1 test required per infiltration area with an additional boring for every 25,000 square feet of infiltration area, and sufficient to determine variability.	3 feet or depth to limiting layer, whichever is less.
Subsurface Dispersal Systems	• Pits required on central systems; borings permissible for distributed systems • Mounding analysis on case-by-case basis	1 test required per infiltration area with an additional boring for every 10,000 square feet of infiltration area, and sufficient to determine variability.	3 feet or depth to limiting layer, whichever is less.

[1]Continuous soil borings shall be taken using a bucket auger, probe, split-spoon sampler, or shelby tube. Samples shall have a minimum 2-inch diameter. Soil pits must be of adequate size, depth and construction to allow a person to enter and exit the pit and complete a morphological soil profile description.

Table 2: Assumed Infiltration Rates for Soil Textures Receiving Stormwater

Soil Texture[1]	Infiltration Rate Without Measurement inches/hour[2]
Coarse sand or coarser	3.60
Loamy coarse sand	3.60
Sand	3.60
Loamy sand	1.63
Sandy loam	0.50
Loam	0.24
Silt loam	0.13
Sandy clay loam	0.11
Clay loam	0.03
Silty Clay loam	0.04[3]
Sandy clay	0.04
Silty clay	0.07
Clay	0.07

[1]Use sandy loam design infiltration rates for fine sand, loamy fine sand, very fine sand, and loamy fine sand soil textures.

[2] Infiltration rates represent the lowest value for each textural class presented in Table 2 of Rawls, 1998.

[3] Infiltration rate is an average based on Rawls, 1982 and Clapp & Hornberger, 1978.

Table 3: Correction Factors for Assumed Infiltration Rates

Ratio of Infiltration Rates[1]	Correction Factor
≤1	3.0
1.1 to 4.0	4.0
4.1 to 8.0	5.0
8.1 to 16.0	6.0
16.1 or greater	8.0

[1]Ratio is determined by dividing the design infiltration rate (Table 2) for the textural classification at the bottom of the infiltration facility by the design infiltration rate (Table 2) for the textural classification of the least permeable soil horizon. The least permeable soil horizon used for the ratio should be within three (3) feet of the bottom of the facility or to the depth of the limiting layer.

Required Qualifications

A. Infiltration Testing – Individuals performing infiltration testing in accordance with these procedures shall possess a Class A On-Site License issued by the DNREC Groundwater Discharges Section.

B. Site Investigations - Individuals completing site investigations shall possess a Class D (Soil Scientist) On-Site License issued by the DNREC Groundwater Discharges Section and have experience in soil investigation, interpretation and classification.

C. Site Evaluations - Individuals completing the site evaluation report shall be a licensed Soil Scientist, licensed Geotechnical Engineer or other licensed professional having the necessary knowledge, skills and training within their area of expertise to interpret the results of the site investigation and render the appropriate recommendations.

For the purposes of these procedures, individuals with higher credentials are assumed to be qualified to perform work at a level that requires lower credentials. For example, an individual that possesses a Class D license would also be authorized to perform infiltration testing.

VI. References

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VII. Definitions

Bioretention systems (Table 1): Bioretention is an infiltration device consisting of an excavated area that is back-filled with an engineered soil, covered with a mulch layer and planted with a diversity of woody and herbaceous vegetation. Storm water directed to the device percolates through the mulch and engineered soil, where it is treated by a variety of physical, chemical and biological processes before infiltrating into the native soil.

Construction Plan (V.Step D): A map and/or plan describing the built-out features of an individual lot.

Coarse sand (V.Step B.B.1): Soil material that contains 25% or more very coarse and coarse sand, and <50% any other one grade of sand.

Design infiltration rate (II.3): A velocity, based on soil structure and texture, at which precipitation or runoff enters and moves into or through soil. The design rate is used to size an infiltration device or system. Rates are selected to be minimal rates for the different types of soils. Selection of minimal rates will provide a robust design and maximize the longevity of the device.

Development site (I.1): The entire area planned for development, irrespective of how much of the site is disturbed at any one time or intended land use. It can be one lot or multiple lots.

Double-ring infiltrometer (V.Step C.4.b): A device that directly measures infiltration rates into a soil surface. The double-ring infiltrometer requires a fairly large pit excavated to depth of the proposed infiltration device and preparation of a soil surface representative of the bottom of the infiltration area.

High groundwater level (V.Step A.4): The higher of either the elevation to which the soil is saturated as observed as a free water surface in an unlined hole, or the elevation to which the soil has been seasonally or periodically saturated as indicated by soil color patterns throughout the soil profile.

Highest anticipated groundwater elevation (V.Step C.3): The sum of the calculated mounding effects of the discharge and the seasonal high groundwater level.

Infiltration areas (V): Areas within a development site that are suitable for installation of an infiltration device.

Infiltration basin (Table 1): An open impoundment created either by excavation or embankment with a flat densely vegetated floor. It is situated on permeable soils and temporarily stores and allows a designed runoff volume to infiltrate the soil.

Infiltration trench (Table 1): An excavated trench that is usually filled with coarse, granular material in which stormwater runoff is collected for temporary storage and infiltration. Other materials such as metal pipes and plastic domes are used to maintain the integrity of the trench.

Irrigation system (Table 1): A system designed to disperse stored stormwater to lawns or other pervious areas.

Limiting layer (Table 1): A limiting layer can be bedrock, an aquatard, aquaclude or the seasonal high groundwater table.

Percent fines (V. Step B.B): the percentage of a given sample of soil, which passes through a # 200 sieve.

Regional device (V.Step A): An infiltration system that receives and stores stormwater runoff from a large area. Infiltration basins are the most commonly used regional infiltration devices.

Redevelopment (V.Step A.6): Areas where new development is replacing older development.

Runoff reduction practice (II.2): Sometimes used synonymously with infiltration practice. A structure or mechanism engineered to facilitate the entry and movement of precipitation or runoff into or through the soil. Examples of runoff reduction practices include infiltration trenches, infiltrating bioretention systems, infiltration basins, and subsurface dispersal systems..

Soil parent material (V.Step A.3): The unconsolidated material, mineral or organic, from which the solum develops.

Subsurface dispersal systems (Table 1): An exfiltration system that is designed to discharge stormwater through piping below the ground surface, but above the seasonal high groundwater table.

Appendix 2. Stormwater BMP Landscaping Guidelines

Landscaping is critical to the performance and function of many stormwater management facilities. Therefore, a landscaping plan shall be provided for any practice that relies on vegetation as a key component.

Minimum plan elements should include the proposed template to be used, delineation of planting areas, the planting plan, including the size, the list of planting stock, sources of plant species, and the planting sequence, including post-nursery care and initial maintenance requirements. It is highly recommended that the planting plan be prepared by a landscape architect, wetland scientist, or horticulturalist in order to tailor the planting plan to the site-specific conditions; however, the plan must be overseen and signed by a qualified, licensed professional registered in the State of Delaware.

Native plant species are preferred over non-native species, but some ornamental species may be used for landscaping effect if they are not aggressive or invasive, and do not exceed 25% of the total landscaping plan. Under no circumstances can aggressive, invasive species be utilized. Native species suitable for stormwater management BMP's are listed below. **Table 1** provides native herbaceous plants, and **Table 2** lists native trees and shrubs. Additional information on Delaware native plants can be found at the following internet links:

- **US Department of Agriculture:** http://plants.usda.gov
- **University of Delaware College of Agriculture and Natural Resources Cooperative Extension Native Plants:** http://ag.udel.edu/extension/horticulture/pdf/NativePlants.pdf
- **University of Delaware Water Resources Agency Flora of Delaware Online Database:** http://www.wra.udel.edu/de-flora
- **Delaware Native Plant Society:** http://www.delawarenativeplants.org
- **Delaware Nature Society Native Plants Resource Links:** http://www.delawarenaturesociety.org/links.html#np

BMPs requiring a Landscape Plan:

Bioretention Facilities

The degree of landscape maintenance that can be provided will determine some of the planting choices for urban bioretention areas. Plant selection differs if the area will be frequently mowed, pruned, and weeded, in contrast to a site which will receive minimum annual maintenance. Typically the bioretention areas are covered with hardwood mulch and planted with a mixture of shrubs, herbaceous flowering plants, ferns, and other perennial species.

Constructed Wetlands

The landscape plan for a constructed wetland should outline a realistic, long-term planting strategy to establish and maintain desired wetland vegetation. The plan should indicate how wetland plants will be established within each inundation zone (e.g., wetland plants, seed-mixes, volunteer colonization, and tree and shrub stock) and whether soil amendments are needed to get plants started. The plan should outline a detailed schedule for the care, maintenance and possible reinforcement of vegetation in the wetland and its buffer, particularly for the first 10 years of establishment.

Other Stormwater BMPs
Additional stormwater facilities besides bioretention and constructed wetland can and should be vegetated; these include wet ponds, vegetated filter strips and vegetated roofs. The landscape plan for each shall select appropriate plants, planting requirements, and maintenance requirements. Wet ponds, vegetated filter strips and other BMPs can use the recommended native plants listed in the tables below. Vegetated roofs, particularly extensive roofs, require a more drought and wind resistant plant, and shall refer to the specific landscaping requirements mentioned in the Vegetated Roof specification.

Planting Requirements:

1. The Plan view(s) of the Landscape Plan must have topography at a contour interval of no more than 1 foot and spot elevations throughout the cell showing the wetland configuration. The different planting zones (e.g., high marsh, deep pool, upland floodplain), must be noted with the plant species to be planted.
2. The Landscape Plan shall include a plant schedule corresponding to the planting plan, specifying emergent, perennial, shrub and tree species, quantity of each species, stock size, type of root stock to be installed, and spacing.
3. The Landscape Plan shall include notes and details regarding the site preparation, soil amendments, construction sequence, soil stabilization, planting specifications, and maintenance criteria.
4. The maintenance criteria must indicate how and when to remove and replace dead plants, eradicate invasive species, and restabilize eroded areas.
5. The planting plan should specify native plant species over non-native plant species. A minimum of 75% of the planting used must be a native species to Delaware, and in no instance can any aggressive invasive species be planted, such as cattails, Phragmites and purple loosestrife.
6. Planting and seeding of the facility to establish a vegetative cover must be completed as quickly as possible after completion of earthwork (following requirements of the Construction Site Stormwater Management Plan). Establishing a groundcover of herbaceous species or 2 to 4 inches of triple shredded hardwood mulch is important for erosion control and site stabilization. The planting of the remainder of the species, i.e., trees, shrubs and flowering herbaceous plants, can be delayed until the appropriate planting season, however, the project will not be closed out until all of the species on the Landscape Plan have been planted and 70% of the species on the Landscape Plan have been established for more than 1 growing season.
7. Trees and shrubs shall not be planted above or immediately adjacent to structural components of the facility such as underdrains, inflow or outflow pipes, structural

embankments, or water control structures.

8. Trees must be planted in areas where the soil depth is a minimum of four feet to allow for the root structure of mature trees.
9. If the stormwater management facility is to accept snow-melt runoff, salt tolerant species should be incorporated into the planting of those portions of the facility subject to prolonged inundation. A bioretention facility shall never to be used for prolonged snow storage.
10. For Constructed Wetlands, trees and shrubs must be incorporated into the design to provide both bank stabilization, shade and a diverse wetland community. By surface area, a minimum of 25% of the Constructed Wetland area must be planted with trees and shrubs. They can be planted in tree islands, peninsulas, high marsh, floodplain, and buffer areas depending on the inundation tolerance of the species. Willow or other live stakes may be planted to help stabilize stream and wetland banks.

Planting Recommendations:

1. Plant species should be located within the facility based on their wetland indicator status and tolerance to inundation and/or soil saturation. Generally, plants with an indicator status of “obligate” or “OBL” will be suitable for planting Zones 3 and 4; plants with an indicator status of “facultative wet” or “FACW” will be suitable for planting in Zones 4 and 5; and plants with an indicator status of “facultative” or “FAC” or “facultative upland” or “FACU” will be suitable for planting in Zone 5. Upland plant species not identified in this document may also be suitable for planting in Zone 5. Relatively few species are suitable for planting in Zones 1 and 2. Consult the inundation tolerance category in the tables within this document for guidance on plant species selection.
2. To increase the success of plant establishment, most plant species should be planted in the drier portion of their inundation tolerance range. Many plants can tolerate flooding or soil saturation only seasonally and do not establish successfully in flooded conditions. This is especially true of trees and shrubs.
3. A good planting strategy includes varying the size and age of the plant stock to promote a diverse structure. Using locally grown container and bare root stock is usually the most successful approach. It is recommended that buffer planting areas be over-planted with a small stock of fast growing successional species to achieve quick canopy closure and to shade out invasive plant species.
4. If trees and shrubs are incorporated in the plan, the recommended spacing between trees is 15 feet on center, and the recommended spacing between shrubs is 5 to 10 feet on center. Trees may be planted in clusters to share rooting space on compacted wetland side-slopes.
5. The recommended spacing for herbaceous plants should be approximately 1.5 feet on center.
6. In cases where herbaceous plants will be planted within the drip-line of trees, shade tolerant species should be considered.

7. Plants should be kept in containers of water or moist coverings to protect their root systems and keep them moist when transporting them to the planting location.
8. Plants should be ordered well in advance of the installation as several months of lead time may be needed to fill orders for native upland and wetland plant stock.
9. Planting holes should be amended with compost (a 2:1 ratio of loose soil to compost) prior to planting.
10. For Constructed Wetlands, to add diversity to the wetland and increase survivability, 5 to 7 species of emergent wetland plants should be planted, using at least four emergent species designated as aggressive colonizers. If the appropriate planting is achieved, the entire wetland should be colonized within three years. Individual plants should be planted 18 inches on center within each grouping of plants.

Inundation Zones:

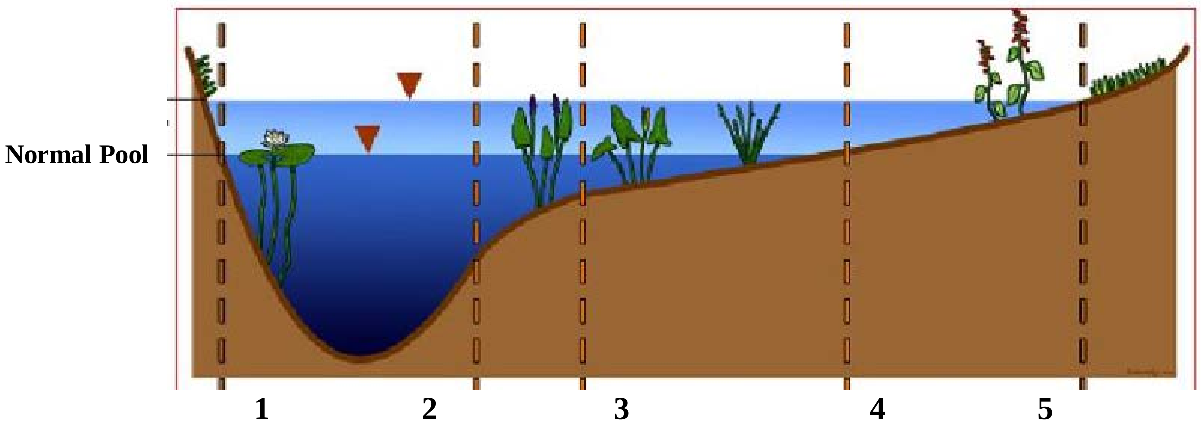

Figure 1. Inundation Zones: (1) Deep Pool (depth -36 to -18 inches), (2) Transition Zone (depth -18 to -6 inches), (3) Low Marsh Zone (depth -6 inches to normal pool), (4) High Marsh Zone (normal pool to +12 inches), and (5) Floodplain (+12 to +30 inches) (adapted from Hunt et al,. 2007). Bioretention Areas, and other facilities without a permanent pool, will only have Zones 4 and 5.

Native Species:

Table 1 and **Table 2** below show native plants appropriate for use in stormwater BMPs. Only those species indicated for Zones 4 and 5 are appropriate for bioretention facilities and other BMPs that do not have a permanently saturated zone. Plants indicated for Zones 2 and 3 may be used in Constructed Wetlands and Wet Ponds in addition to the plants indicated for Zones 4 and 5. The plants inundation tolerance should be noted and located appropriately within the facility.

Table 1. Herbaceous Plants for Delaware Stormwater BMP's

Plant	Wetland Indicator[1]	Zone[2]	Plant Form	Light	Notes
Arrow Arum (*Peltandra virginica*)	OBL	3, 4	Perennial	Full Sun-Part Shade	Berries are eaten by wood ducks; Inundation up to 1 ft
Arrowhead, Broad-Leaf (Duck Potato) (*Sagittaria latifolia*)	OBL	3, 4	Perennial	Full Sun	Aggressive colonizer; Inundation up to 1 ft
Arrowhead, Bulltongue (*Sagittaria lancifolia*)	OBL	3, 4	Perennial	Full Sun-Part Shade	Aggressive colonizer; Inundation up to 2 ft
Aster, New England *(Aster novae-angliae)*	FACW	4, 5	Perennial	Full Sun-Part Shade	Attractive flowers
Aster, New York *(Aster novi-belgii)*	FACW+	4, 5	Perennial	Full Sun-Part Shade	Attractive flowers; tolerates poor soils
Aster, October Skies *(Aster oblongifolius 'October Skies')*	UPL	5	Perennial	Full Sun	Masses of blue flowers in Sept/Oct
Aster, Perennial Saltmarsh *(Aster tenuifolius)*	OBL	4	Perennial	Full Sun-Part Shade	Salt tolerant
Aster, Raydons Favorite *(Aster oblongifolius 'Raydon's Favorite')*	UPL	5	Perennial	Full Sun	Masses of blue flowers in Sept/Oct
Aster, showy *(Eurybia spectabilis) (Aster spectabilis)*	FAC	4, 5	Perennial	Full Sun - Part Shade	Masses of blue flowers in Sept/Oct
Aster, smooth blue *(Symphyotrichum laeve) (Aster laevis)*	FAC	4, 5	Perennial	Full Sun - Part Shade	Blue cone-shaped clusters with yellow centers
Aster, white heath *(Symphyotrichum ericoides)* *(Aster ericoides)*	FAC	4, 5	Perennial	Full Sun - Part Shade	Drought tolerant
Beardtongue (*Penstemon digitalis)*	FAC	4, 5	Perennial	Full Sun	Tolerates poor drainage
Beebalm *(Monarda didyma)*	FAC+	4, 5	Perennial	Full Sun-Part Shade	Herbal uses; attractive flower
Black-Eyed Susan *(Rudbeckia hirta)*	FACU	5	Perennial	Full Sun-Part Shade	
Blue star, Blue Ice *(Amsonia 'Blue Ice')*	FACU	5	Perennial	Full Sun-Part Shade	Clusters of steely blue flowers in May
Blue star, Willow leaf *(Amsonia tabernaemontana)*	FACU	5	Perennial	Full Sun-Part Shade	

Blue vervain *(Verbena hastata)*	FACW	4, 5	Perennial	Full Sun	Tall thin spikes of violet blue
Bluebells, Virginia *(Mertensia virginica)*	FACW	4, 5	Perennial	Part Shade-Full Shade	Attractive flower; dormant in summer
Blueflag Iris (*Iris versicolor*)	OBL	3, 4	Perennial	Full Sun-Part Shade	Inundation up to 6 in.
Blueflag, Virginia *(Iris virginica)*	OBL	3, 4	Perennial	Full Sun-Part Shade	Tolerates standing water
Bluestem, Big *(Andropogon gerardii)*	FAC	5	Grass	Full Sun	Attractive in winter; forms clumps
Bluestem, Little *(Schizachyrium scoparium)*	FACU	5	Grass	Full Sun	Tolerates poor soil conditions
Broomsedge (*Andropogon virginicus*)	FACU+	5	Grass	Part Sun-Part Shade	Inundation up to 3 in., can be fluctuating; winter food and cover
Burreed (*Sparganium americanum*)	OBL	3, 4	Perennial	Full Sun-Part Shade	Inundation 0-6 in.
Cardinal Flower *(Lobelia cardinalis)*	FACW+	4, 5	Perennial	Full Sun-Part Shade	Long bloom time
Common Rush (*Juncus effusus*)	OBL	3, 4	Grass	Full Sun-Part Shade	Aggressive colonizer; Inundation up to 12 in.
Common Three Square (*Schoenoplectus pungens)*	OBL	3, 4	Grass	Full Sun	Aggressive colonizer; Inundation up to 6 in.
Coneflower, Orange *(Rudbeckia fulgida)*	FAC	5	Perennial	Full Sun-Part Shade	Bright gold with brown cone July to October
Coneflower, Purple *(Echinacea purpurea)*	FACU	5	Perennial	Full Sun - Part Shade	Purple flowers with large gold centers July and August
Coreopsis, Lanceleaf *(Coreopsis lanceolata)*	FACU	5	Perennial	Full Sun	Bright yellow 2.5" flowers May-August
Coreopsis, Threadleaf *(Coreopsis verticillata)*	FAC	5	Perennial	Full Sun-Part Shade	Drought tolerant
Fern, New York *(Thelypteris noveboracensis)*	FAC	5	Fern	Part Shade-Full Shade	Drought tolerant
Fern, Royal *(Osmunda regalis)*	OBL	4	Fern	Full Sun-Full Shade	Tolerates short term flooding; drought tolerant

Fescue, Red *(Festuca rubra)*	FACU	5	Grass	Full Sun- Full Shade	Moderate growth; good for erosion control
Goldenrod, Grassleaf *(Euthamia graminifolia)*	FAC	4, 5	Perennial	Full Sun - Part Shade	Yellow flowers
Goldenrod, Rough-leaf *(Solidago rugosa)*	FAC	4, 5	Perennial	Full Sun	Yellow flowers
Goldenrod, Seaside *(Solidago sempervirens)*	FACW	4, 5	Perennial	Full Sun	Salt tolerant yellow flowers
Hyssop-leaved thoroughwort *(Eupatorium hyssopifolium)*	FACU	5	Perennial	Full Sun - Part Shade	Flat-topped clusters of white fringed flowers in fall
Ironweed, New York *(Vernonia noveboracensis)*	FACW	4, 5	Perennial	Full Sun	Deep purple
Joe Pye Weed *(Eupatorium dubium)*	FACW	4, 5	Perennial	Full Sun - Part Shade	Purple rounded heads
Joe Pye Weed *(Eupatorium fistulosum)*	FACW	4, 5	Perennial	Full Sun - Part Shade	Pink lavender huge rounded heads
Joe Pye Weed *(Eupatorium purpureum)*	FACW	4,5	Perennial	Full Sun - Part Shade	Flat-topped clusters of white fringed flowers in fall; Periodic inundation
Lizard's Tail (*Saururus cernus*)	OBL	3, 4	Perennial	Shade Tolerant	Aggressive colonizer; Inundation up to 3 in.
Lobelia, Great Blue *(Lobelia siphilitica)*	FACW+	4, 5	Perennial	Part Shade- Full Shade	Blooms in late summer; bright blue flowers
Marsh Hibiscus (*Hibiscus moscheutos*)	OBL	3, 4	Perennial	Full Sun	Inundation up to 3 in.; can tolerate periodic dryness
Milkweed , Swamp *(Asclepias incarnata)*	OBL	4	Perennial	Full Sun- Part Shade	Drought tolerant
Milkweed, Butterfly *(Asclepias tuberosa)*	UPL	5	Perennial	Full Sun- Part Shade	Drought tolerant
Pickerelweed (*Pontederia cordata*)	OBL	3, 4	Perennial	Full Sun- Part Shade	Aggressive colonizer; Inundation up to 1 ft.
Phlox, Garden *(Phlox paniculata)*	FACU	5	Perennial	Full Sun- Part Shade	Large panicles of pink to purple flowers
Phlox, Meadow *(Phlox maculata)*	FACW	4, 5	Perennial	Full Sun	Aromatic; spreads

Pond Weed (*Potamogeton pectinatus*)		2			Full inundation; high wildlife value
Purple-top *(Tridens flavus)*	FACU	5	Grass	Full Sun - Part Shade	
Rice Cutgrass (*Leersia oryzoides*)	OBL	3, 4	Grass	Full Sun	Inundation up to 3 in.; shoreline stabilization
Sea-Oats (*Uniola paniculata)*	FACU-	5	Grass	Full Sun	Salt tolerant; attractive seed heads
Sedge, Broom *(Andropogon virginicus)*	FACU	3, 4	Grass	Full Sun	Drought tolerant; attractive fall color
Sedge, Muskingum *(Carex muskingumensis)*	OBL	3, 4	Grass	Full Sun - Part Shade	
Sedge, Pennsylvania *(Carex pennsylvanica)*	FAC	3, 4	Grass	Full Sun - Shade	
Sedge, Tussock *(Carex stricta)*	FACW	3, 4	Grass	Full Sun - part shade	
Smooth Saltmarsh Cordgrass *(Spartina alternifolia)*	OBL	4	Grass	Full Sun	Salt tolerant
Softstem Bulrush (*Scipus validus*)	OBL	3, 4	Grass	Full Sun	Aggressive colonizer; Inundation up to 2 ft.
Sunflower, Swamp *(Helianthus angustifolius)*	FACW	4, 5	Perennial	Full Sun	Bright yellow flowers late summer to fall covering the plant
Sunflower, Thin-leaved *(Helianthus decapetalus)*	FACU	5	Perennial	Full Sun - Part Shade	Single light yellow flowers in late summer
Swamp rosemallow *(Hibiscus moscheutos)*	OBL	4	Perennial	Full Sun - Part Shade	3-4" rose pink flowers Aug-Sept
Switchgrass (*Panicum virgatum*)	FAC	4, 5	Grass	Full Sun	Inundation up to 3 in.; Tolerates wet/dry conditions
Switchgrass, Coastal *(Panicum amarum)*	FAC	4, 5	Grass	Full Sun	Adaptable; great erosion control
Turtlehead, White *(Chelone glabra)*	OBL	4	Perennial	Full Sun- Part Shade	Excellent growth
Violet, Common Blue *(Viola papilionacea)*	FAC	5	Perennial	Full Sun- Full Shade	Stemless; spreads

Virginia mountain-mint (*Pycnanthemum virginianum)*	FACW	4, 5	Perennial	Full Sun-Part Shade	Showy silver bracts surround small clusters of pale lavender flowers
Water Lily *(Nymphaea odorata)*	OBL	2, 3	Perennial		
Waterweed (*Elodea canadensis*)	OBL	2	Perennial	Full Sun	High inundation
Wild celery (*Valisneria americana*)		2			High inundation
Wild Rice (*Zizania aquatica*)	OBL	3, 4	Annual	Full Sun	Inundation up to 1 ft.
Wild Rye, Canada *(Elymus canadensis)*	FACW-	4, 5	Grass	Full Shade	Adaptable
Wild Rye, Virginia *(Elymus virginicus)*	FACW-	4, 5	Grass	Part Shade-Full Shade	Adaptable
Woolgrass (*Scirpus cyperinus*)	OBL	3, 4	Grass	Full Sun	Aggressive colonizer; Inundation up to 3 in.

[1] Wetland Indicator:

FAC = Facultative, equally likely to occur in wetlands or non-wetlands (estimated probability 34%-66%).

FACU = Facultative Upland, usually occurs in non-wetlands (estimated probability 67%-99%); occasionally found on wetlands (estimated probability 1%-33%).

FACW = Facultative Wetland, usually occurs in wetlands (estimated probability 67%-99%), but occasionally found in non-wetlands.

OBL = Obligate Wetland, occurs almost always (estimated probability 99%) under natural conditions in wetlands.

[2] Zone:

Zone 1: -48 to -18 inches below the normal pool elevation. Not planted due to poor survival rate.

Zone 2: -18 to -6 inches to the normal pool elevation (plants should not be planted lower than -12 inches).

Zone 3: -6 inches to the normal pool elevation.

Zone 4: Normal pool elevation to +12 inches.

Zone 5: +12 to +30 inches above the normal pool elevation.

Only species that are indicated for Zones 4 and 5 should be planted in bioretention facilities, raingardens, filter strips, and other stormwater facilities that lack a permanent water surface elevation.

Table 2. Trees and Shrubs for Delaware Stormwater BMP's					
Plant	**Wetland Indicator[1]**	**Zone[2]**	**Plant Form**	**Light**	**Notes**
Arrow-wood *(Viburnum dentatum)*	FAC	4, 5	Shrub	Full Sun-Part Shade	Pollution Tolerant
Green Ash *(Fraxinus pennsylvanica)*	FACW	4, 5	Tree	Full Sun-Part Shade	
Azalea , Dwarf *(Rhododendron atlanticum)*	FAC		Shrub	Part Shade	High wildlife value
Azalea, Hoary *(Rhododendron canescens)*	FACW		Shrub	Part Shade	
Azalea, Pinxterbloom *(Rhododendron periclymenoides)*	FAC		Shrub	Part Shade	
Azalea, Swamp *(Rhododendron viscosum)*	OBL	3, 4	Shrub	Part Shade	
Bayberry, Northern *(Myrica pennsylvanica)*	FAC		Shrub	Full Sun-Part Shade	Tolerates some salt; can be maintained as hedge
Birch, River *(Betula nigra)*	FACW	4, 5	Tree	Full Sun-Part Shade	Very adaptable; early spring flowers
Black-Haw *(Viburnum prunifolium)*	FACU		Shrub	Full Sun-Part Shade	Forms thickets; edible nut
Blueberry, Highbush *(Vaccinium corymbosum)*	FACW-		Shrub	Full Sun-Part Shade	
Blueberry, Lowbush *(Vaccinium angustifolium)*	FACU-		Shrub	Full Sun-Part Shade	
Box Elder *(Acer Negundo)*	FACW-	5	Tree	Full Sun-Part Shade	
Button Bush (*Cephalanthus occidentalis*)	OBL	3, 4	Shrub	Full Sun-Part Shade	
Cedar, Atlantic White *(Charnaecyparis thyoides)*	OBL	3, 4	Tree	Full Sun	
Cedar, Eastern Red *(Juniperus virginiana)*	FACU		Tree	Full Sun	Pollution Tolerant
Choke Cherry *(Prunus virginiana)*	FACU		Shrub	Full Sun	Pollutant tolerant; salt tolerant

Chokeberry *(Aronia arbutifolia)*	FACW		Shrub	Part Shade-Full Shade	
Chokeberry, Black *(Aronia melanocarpa)*	FACW		Shrub	Part Shade-Full Shade	
Cotton-wood, Eastern *(Populus deltoides)*	FAC		Tree	Full Sun	Winter food source for birds
Cypress, Bald *(Taxodium distichum)*	OBL	3, 4	Tree	Full Sun - Part Shade	Drought tolerant; deciduous conifer
Dogwood, Grey *(Cornus racemosa)*	UPL		Shrub	Full Sun-Part Shade	
Dogwood, Red Twig *(Cornus sericea)*	FACW+		Shrub	Full Sun-Part Shade	
Dogwood, Silky *(Cornus amomum)*	FACW		Shrub	Full Sun-Part Shade	Salt tolerant
Elderberry (*Sambucus canadensis*)	FACW	4, 5	Shrub	Full Sun	
Fringetree, White *(Chionanthus virginicus)*	FAC+		Tree	Full Sun - Part Shade	
Gum, Black *(Nyssa sylvatica)*	FAC	4, 5	Tree	Full Sun-Part Shade	Salt tolerant
Gum, Sweet *(Liquidambar styraciflua)*	FAC	5	Tree	Full Sun - Part Shade	
Hackberry, Common *(Celtis occidentalis)*	FACU		Tree	Full Sun-Full Shade	Drought tolerant; attractive bark
Hazelnut, American *(Corylus americana)*	FACU		Shrub	Part Shade	Attractive bark
Holly, American *(Ilex opaca)*	FACU-		Shrub-Tree	Full Sun-Full Shade	Winter food source for birds
Holly, Inkberry *(Ilex glabra)*	FACW-		Shrub	Full Sun-Part Shade	
Holly, Winterberry *(Ilex laevigata)*	OBL		Shrub	Full Sun-Part Shade	Long lived
Holly, Winterberry Common *(Ilex verticillata)*	FACW+		Shrub	Full Sun-Full Shade	Edible Fruit

Inkberry *(Ilex glabra)*	FACW	5	Shrub	Full Sun	
Magnolia, Sweetbay *(Magnolia virginiana)*	FACW+	4, 5	Tree	Full Sun - Part Shade	
Maple, Red *(Acer rubrum)*	FAC	4, 5	Tree	Full Sun-Part Shade	Pollution Tolerant
Ninebark, Eastern *(Physocarpus opulifolius)*	FACW-		Shrub	Full Sun-Part Shade	Pollution tolerant
Oak, Pin *(Quercus palustris)*	FACW	4, 5	Tree	Full Sun	Pollution tolerant
Oak, Shingle *(Quercus imbricaria)*	FAC		Tree	Full Sun	
Oak, Swamp White *(Quercus bicolor)*	FACW+		Tree	Full Sun - Part Shade	
Oak, Willow *(Quercus phellos)*	FAC+	4, 5	Tree	Full Sun	
Pepperbush, Sweet *(Clethra alnifolia)*	FAC+	5	Shrub	Part Shade-Full Shade	Salt tolerant
Persimmon *(Diospyros virginiana)*	FAC-		Tree	Full Sun - Part Shade	
Shadblow *(Amelanchier canadensis)*	FAC		Tree	Full Sun-Part Shade	
Smooth Alder *(Alnus serrulata)*	OBL	3, 4	Shrub	Part Shade-Full Shade	
Spicebush *(Lindera benzoin)*	FACW-	3, 4	Shrub	Full Sun-Part Shade	
Swamp Rose *(Rosa palustris)*	OBL	3, 4	Shrub	Full Sun-Part Shade	
Sweetbells leucothoe *(Leucothoe racemosa)*	FACW		Shrub	Full Sun-Full Shade	
Sycamore, American *(Platanus occidentalis)*	FAC+	4, 5	Tree	Full Sun	
Viburnum, Nannyberry *(Viburnum lentago)*	FAC		Shrub	Full Sun-Full Shade	

Viburnum, Swamphaw *(Viburnum nudum)*	OBL		Shrub	Full Sun-Part Shade	
Virginia Sweetspire *(Itea virginica)*	OBL		Shrub	Full Sun-Part Shade	
Black Willow *(Salix nigra)*	UPL	4, 5		Full Sun	
Winterberry (*Ilex verticillatta*)	OBL	4, 5	Shrub	Full Sun	
Witch-Hazel, American *(Hamamelis virginiana)*	FAC-		Shrub	Part Shade-Full Shade	Excellent fall color

[1] Wetland Indicator:

FAC = Facultative, equally likely to occur in wetlands or non-wetlands (estimated probability 34%-66%).

FACU = Facultative Upland, usually occurs in non-wetlands (estimated probability 67%-99%); occasionally found on wetlands (estimated probability 1%-33%).

FACW = Facultative Wetland, usually occurs in wetlands (estimated probability 67%-99%), but occasionally found in non-wetlands.

OBL = Obligate Wetland, occurs almost always (estimated probability 99%) under natural conditions in wetlands.

[2] Zone:

Zone 1: -48 to -18 inches below the normal pool elevation. Not planted due to poor survival rate.

Zone 2: -18 to -6 inches to the normal pool elevation (plants should not be planted lower than -12 inches).

Zone 3: -6 inches to the normal pool elevation.

Zone 4: Normal pool elevation to +12 inches.

Zone 5: +12 to +30 inches above the normal pool elevation.

Only species that are indicated for Zones 4 and 5 should be planted in bioretention facilities, raingardens, filter strips, and other stormwater facilities that lack a permanent water surface elevation. If a Zone is not listed, professional judgment shall be utilized.

Appendix 3. Compost Material Properties

This specification shall apply for all applications where compost is used as or within a construction or post-construction stormwater best management practice. Particle size specifications vary depending on use, as noted in Table 3.1.

Table 3.1: Compost Material Properties

Parameter	Range	Testing Method
Particle Size	For Amendments: 100% pass through a ½" screen For Compost Logs: 99% pass through a 2" screen; max. 40% pass through a 3/8" screen	TMECC 2.02-B
pH	6.0-8.0	TMECC 4.11
Manufactured Inert Material	<1% dry weight basis	TMECC 3.08-A
Organic Matter	35-95% dry weight basis	TMECC 5.07-A
Soluble Salt Concentration	≤ 6.0 mmhos/cm	TMECC 4.10-A
Carbon to Nitrogen Ratio (C:N)	≤ 25:1	
Stability (Carbon Dioxide evolution rate)	≤ 4 C / unit VS / day	TMECC 5.08-B
Maturity (seed emergence and seedling vigor)	>80% relative to positive control	TMECC 5.05-A
Trace Metals	Arsenic < 11 mg/kg[2] Cadmium < 4 mg/kg Chromium < 35 mg/kg[3] Copper < 310 mg/kg Lead < 400 mg/kg Mercury < 10 mg/kg Molybdenum < 2 mg/kg Nickel < 160 mg/kg Selenium < 26 mg/kg Zinc < 2.300 mg/kg	EPA SW-846
Dry Bulk Density	30-45 lb/cu.ft.	
Moisture content	35-55%	

Compost Specifications

Compost used to fulfill regulatory requirements shall meet the criteria set forth in this specification. In addition, it must be provided by an active member of the U.S. Composting Seal of Testing Assurance (STA) program.

The compost shall be the result of the biological degradation and transformation of plant-derived materials under conditions that promote anaerobic decomposition. No manure or biosolids shall be included. The material shall be well composted, free of viable weed seeds, and stable with regard to oxygen consumption and carbon dioxide generation. The compost shall have a moisture content that has no visible free water or dust produced when handling the material. It shall meet the following criteria, as reported by the U.S. Composting Council STA Program Compost Technical Data Sheet (See Table 14.3).

Soluble salt refers to the amount of soluble ions in a solution of compost and water. The concentration of soluble ions is typically estimated by determining the solution's ability to carry an electrical current, i.e., electrical conductivity. The units of measure for soluble salts are either mmhos/cm or dS/m (they are 1:1 equivalent). Plant essential nutrients are actually supplied to plants in a salt form. While some specific soluble salts, (e.g., sodium, chloride), may be more detrimental to plants, most composts do not contain sufficient levels of these salts to be a concern in landscape applications. Plant species have a salinity tolerance rating and maximum tolerable quantities are known. Excess soluble salts can cause phytotoxicity to plants. Compost may contribute to, or dilute, the cumulative soluble salts content of a growing media or soil. Reduction in soluble salts content can be achieved through thorough watering at the time of planting. Most composts have a soluble salt conductivity of 1.0 to 10.0 mmhos/cm, whereas typical conductivity values in soil range from 0 to 1.5 in most areas of the country. 6 mmhos/cm is moderately saline and will inhibit the growth of some plants. The final selection of plants should be made after a soil test identifies the limiting characteristics of the soil mix.

The ***Carbon to Nitrogen Ratio*** is the first step in evaluating the maturity and stability of a compost sample. A Carbon to Nitrogen (C:N) ratio of less than or equal to 25 is acceptable prior to the additional tests of maturity and stability. Currently there are a number of tests available to determine compost stability and maturity. Some have been published in Test Methods for the Examination of Composting and Compost (TMECC) by the U.S. Composting Council (USCC), while commercial laboratories have developed others.

Stability refers to a specific stage or state of organic matter decomposition during composting, which is related to the type of organic compounds remaining and the resultant biological activity in the material. The stability of a given compost is important in determining the potential impact of the material on nitrogen availability, volume, and porosity in soil or growth media. Compost as a soil amendment requires a stable to very stable product that will prevent nutrient tie up and maintain or enhance oxygen availability in soil or growth media.

Maturity is the degree or level of completeness of composting. Maturity is not described by a single property and therefore maturity is best assessed by measuring two or more compost characteristics. Some immature composts may contain high amounts of free ammonia, certain organic acids or other water-soluble compounds which can limit seed germination and root development, or cause odor. All uses of compost require a mature product free of these potentially phytotoxic components. The bioassay used in the STA Program uses a seed germination and growth test to measure the percent of seed emergence and relative seedling vigor.

Trace metals are elements whose concentrations are regulated due to the potential for toxicity to humans, animals, or plants. Regulations governing the heavy metal content of composts, fertilizers, and certain other horticultural and agricultural products have been promulgated on both the State and Federal levels. Specific trace elements, often referred to as heavy metals include arsenic, cadmium, chromium, copper, lead, mercury, molybdenum nickel, selenium, and zinc. The quantity of these elements are measured on a dry weight basis and expressed as mg/kg (milligram per kilogram) or ppm (parts per million). Many of these elements are actually needed by plants for normal growth, although in limited quantities. Therefore, measuring the concentration of these elements, as well as other plant nutrients, can provide valuable management data relevant to the fertilizer requirements of plants and subsequent fertilizer application rates. All composts that contain regulated feedstocks must meet national and/or state safety standards for metals in order to be marketed.

Moisture content (percent) is the measure of the quantity of water present in a compost product; expressed as a percentage of total weight. The moisture content of compost affects its ***bulk density*** (weight per unit volume) and, therefore, affects handling and transportation. Overly dry compost (35% moisture, or below) can be dusty and irritating to work with, while very wet compost (55 to 60%) can become heavy and clumpy, making its application more difficult and delivery more expensive. A preferred moisture percent for finished compost is 35-55%.

Pathogens, such as bacteria and other infectious microorganisms, should be limited in compost derived from plant-based material, versus bio-solids, but may be present due to animal feces and other sources. Pathogen removal of the compost shall be in compliance with Title 40 of the Code of Federal Regulations Part 503 (or 40 CFR 503),

Appendix 4. Stormwater Hotspots Guidelines

Stormwater hotspots are defined as commercial, industrial, institutional, municipal, or transport-related operations that produce higher levels of stormwater pollutants, and/or present a higher potential risk for spills, leaks or illicit discharges. Hotspot sources can be separated into two main categories: vehicles and outdoor storage. Additional information for each of the listed operations is included following the plan requirements in the profile sheets. The following post construction operations may be classified as storm water hotspots operations:

- **Vehicle Maintenance and Repair**
- **Vehicle Fueling**
- **Vehicle Washing**
- **Vehicle Storage**
- **Loading and Unloading**
- **Outdoor or Bulk Material Storage**

If any of the above operations occur on a site during construction, management of these operations will be handled through pollution prevention details on the approved Sediment and Stormwater Management Plan.

However, if any of the above operations are expected to occur as part of post construction operations on a planned development site, NPDES general permit coverage to discharge stormwater from an industrial use may be required. DNREC Division of Water's Surface Water Discharges Section should be contacted regarding the need for an Industrial Stormwater Discharge permit.

Projects that will have any of the above as part of post construction operations on the project site, regardless of whether the project has an industrial stormwater discharge permit, should consider the following hotspot operation pollution prevention BMPs in design of the project site.

Vehicle Maintenance and Repair Operations

- Provide locations for recycling collection of used antifreeze, oil, grease, oil filters, cleaning solutions, solvents, batteries, hydraulic and transmission fluids.
- Cover all vehicle and equipment repair areas with a permanent roof of canopy.
- Connect outdoor vehicle storage areas to a separate storm water collection system with an oil/grit separator or sand filter.
- Designate a specific location for outdoor maintenance activities that is designed to prevent storm water pollution (paved, away from storm drains, and with storm water containment measures)
- Stencil or mark storm drain inlets with "No Dumping, Drains to ______" message.

Vehicle Fueling

- Cover fueling stations with a canopy or roof to prevent direct contact with rainfall.
- Design fueling pads to prevent the run-on of storm water and pretreat any runoff with an oil/grit separator or a sand filter.
- Locate storm drain inlets away from the immediate vicinity of the fueling area.
- Stencil or mark storm drain inlets with "No Dumping, Drains to ______" message.

- Pave fueling stations with concrete rather than asphalt.

Vehicle Washing
- Include flow-restricted hose nozzles that automatically turn off when left unattended.
- Provide a containment system for washing vehicles such that wash water does not flow into storm drain system.
- Label storm drain inlets with "No Dumping, Drains to ______" signs to deter disposal of wash water in the storm drain system.
- Design facilities with designated areas for indoor vehicle washing where no other activities are performed (e.g. fluid changes or repair services).

Vehicle Storage
- Label storm drain inlets with "No Dumping, Drains to ______" message.
- All stormwater runoff from the fleet storage area must receive pretreatment via an oil/grit separator or sand filter.
- Untreated stormwater from the fleet storage area may not be discharged off site.
- Connect outdoor vehicle storage areas to a separate storm water collection system with an oil/grit separator or sand filter.

Loading and Unloading
- Design liquid storage areas with impervious surfaces and secondary containment.
- Minimize storm water run-on by covering storage areas with a permanent canopy or roof.
- Slope containment areas to a drain with a positive control (lock, valve, or plug) that leads to the sanitary sewer (if permitted) or to a holding tank.
- Provide permanent cover for building materials stored outside.
- Direct runoff away from building material storage areas.
- Install a high-level alarm on storage tanks to prevent overfilling.

Outdoor or Bulk Material Storage
- Grade the designated loading/unloading to prevent run-on or pooling of storm water.
- Cover the loading/unloading areas with a permanent canopy or roof.
- Install an automatic shutoff valve to interrupt flow in the event of a liquid spill.
- Install a high-level alarm on storage tanks to prevent overfilling.
- Pave the loading/unloading area with concrete rather than asphalt.
- Position roof downspouts to direct storm water away from loading/unloading areas.

Profile Sheet

Hotspot Source Area: Vehicles

VEHICLE MAINTENANCE AND REPAIR

Description

Vehicle maintenance and repair operations can exert a significant impact on water quality by generating toxins such as solvents, waste oil, antifreeze, and other fluids. Often, vehicles that are wrecked or awaiting repair can be a storm water hotspot if leaking fluids are exposed to storm water runoff (Figure 1). Vehicle maintenance and repair can generate oil and grease, trace metals, hydrocarbons, and other toxic organic compounds. Table 1 summarizes a series of simple pollution prevention techniques for vehicle maintenance and repair operations that can prevent storm water contamination. You are encouraged to consult the Resources section of this sheet to get a more comprehensive review of pollution prevention practices for vehicle maintenance and repair operations.

Figure 1: Junkyard and Potential Source of Storm Water Pollution

Application

Pollution prevention practices should be applied to any facility that maintains or repairs vehicles in a subwatershed. Examples include car dealerships, body shops, service stations, quick lubes, school bus depots, trucking companies, and fleet maintenance operations at larger industrial, institutional, municipal or transport-related operations. Repair facilities are often clustered together, and are a major priority for subwatershed pollution prevention.

Table 1: Pollution Prevention Practices for Vehicle Maintenance and Repair Activities
• Avoid hosing down work or fueling areas
• Clean all spills immediately using dry cleaning techniques
• Collect used antifreeze, oil, grease, oil filters, cleaning solutions, solvents, batteries, hydraulic and transmission fluids and recycle with appropriate agencies
• Conduct all vehicle and equipment repairs indoors or under a cover (if done outdoors)
• Connect outdoor vehicle storage areas to a separate storm water collection system with an oil/grit separator that discharges to a dead holding tank, the sanitary sewer or a storm water treatment practice
• Designate a specific location for outdoor maintenance activities that is designed to prevent storm water pollution (paved, away from storm drains, and with storm water containment measures)
• Inspect the condition of all vehicles and equipment stored outdoors frequently
• Use a tarp, ground cloth, or drip pans beneath vehicles or equipment being repaired outdoors to capture all spills and drips
• Seal service bay concrete floors with an impervious material so cleanup can be done without using solvents. Do not wash service bays to outdoor storm drains
• Store cracked batteries in a covered secondary containment area until they can be disposed of properly
• Wash parts in a self-contained solvent sink rather than outdoors

Primary Training Targets

Owners, fleet operation managers, service managers, maintenance supervisors, mechanics and other employees are key targets for training.

Feasibility

Pollution prevention techniques for vehicle repair facilities broadly apply to all regions and climates. These techniques generally rely on changes to basic operating procedures, after an initial inspection of facility operations. The inspection relies on a standard operations checklist that can be completed in a few hours.

Implementation Considerations

Employee training is essential to successfully implement vehicle repair pollution prevention practices. The connection between the storm drain system and local streams should be emphasized so that employees understand why any fluids need to be properly disposed of. It is also important to understand the demographics of the work force; in some communities, it may require a multilingual education program.

Cost - Employee training is generally inexpensive, since training can be done using posters, pamphlets, or videos. Structural practices can vary based on what equipment is required. For instance, solvent sinks to clean parts can cost from $1,500 to $15,000, while spray cabinets may cost more than $50,000. In addition, proper recycling/disposal of used or spilled fluids usually requires outside contractors that may increase costs.

Resources

Stormwater Management Manual for Western Washington: Volume IV -- Source Control BMPs.
http://www.ecy.wa.gov/biblio/9914.html

California Stormwater Quality Association. 2003 California Stormwater BMP Handbook: Industrial and Commercial.
http://www.cabmphandbooks.com/

Coordinating Committee For Automotive Repair (CCAR) Source: US EPA CCAR-*Green*Link®, the National Automotive Environmental Compliance Assistance Center CCAR-*Green*Link® Virtual Shop
http://www.ccar-greenlink.org/

Auto Body Shops Pollution Prevention Guide. Peaks to Prairies Pollution Prevention Information Center.
http://peakstoprairies.org/p2bande/autobody/abguide/index.cfm

Massachusetts Office of Technical Assistance for Toxics Use Reduction (OTA). Crash Course for Compliance and Pollution Prevention Toolbox
http://www.state.ma.us/ota/pubs/toolfull.pdf

Model Urban Runoff Program: A How-To Guide for Developing Urban Runoff Programs for Small Municipalities.
http://www.swrcb.ca.gov/stormwtr/murp.html

US EPA. Virtual Facility Regulatory Tour: Vehicle Maintenance. FedSite Federal Facilities Compliance Assistance Center.
http://permanent.access.gpo.gov/websites/epagov/www.epa.gov/fedsite/virtual.html

City of Santa Cruz. Best Management Practices for Vehicle Service Facilities (in English and Spanish).
http://www.ci.santa-cruz.ca.us/pw/pdf/vehiclebmp.pdf

City of Los Angeles Bilingual Poster of BMPs for Auto Repair Industry
http://www.lastormwater.org/downloads/PDFs/autopstr.pdf

Profile Sheet	**Hotspot Source Area: Vehicles**	
	VEHICLE FUELING	

Description

Spills at vehicle fueling operations have the potential to directly contribute oil, grease, and gasoline to storm water, and can be a significant source of lead, copper and zinc, and petroleum hydrocarbons. Delivery of pollutants to the storm drain can be sharply reduced by well-designed fueling areas and improved operational procedures. The risk of spills depends on whether the fueling area is covered and has secondary containment. The type, condition, and exposure of the fueling surface can also be important. Table 1 describes common pollution prevention practices for fueling operations.

Application

These practices can be applied to any facility that dispenses fuel. Examples include retail gas stations, bus depots, marinas, and fleet maintenance operations (Figure 1). In addition, these practices also apply to temporary above-ground fueling areas for construction and earthmoving equipment. Many fueling areas are usually present in urban subwatersheds, and they tend to be clustered along commercial and

Figure 1: Covered Retail Gas Operation Without Containment for Potential Spills

Table 1: Pollution Prevention Practices For Fueling Operation Areas
• Maintain an updated spill prevention and response plan on premises of all fueling facilities (see Profile Sheet H-7)
• Cover fueling stations with a canopy or roof to prevent direct contact with rainfall
• Design fueling pads for large mobile equipment to prevent the run-on of storm water and collect any runoff in a dead-end sump
• Retrofit underground storage tanks with spill containment and overfill prevention systems
• Keep suitable cleanup materials on the premises to promptly clean up spills
• Install slotted inlets along the perimeter of the “downhill” side of fueling stations to collect fluids and connect the drain to a waste tank or storm water treatment practice. The collection system should have a shutoff valve to contain a large fuel spill event
• Locate storm drain inlets away from the immediate vicinity of the fueling area
• Clean fuel-dispensing areas with dry cleanup methods. Never wash down areas before dry clean up has been done. Ensure that wash water is collected and disposed of in the sanitary sewer system or approved storm water treatment practice
• Pave fueling stations with concrete rather than asphalt
• Protect above ground fuel tanks using a containment berm with an impervious floor of Portland cement. The containment berm should have enough capacity to contain 110% of the total tank volume
• Use fuel-dispensing nozzles with automatic shutoffs, if allowed
• Consider installing a perimeter sand filter to capture and treat any runoff produced by the station

highway corridors. These hotspots are often a priority for subwatershed source control.

Primary Training Targets

Training efforts should be targeted to owners, operators, attendants, and petroleum wholesalers.

Feasibility

Vehicle fueling pollution prevention practices apply to all geographic and climatic regions. The practices are relatively low-cost, except for structural measures that are installed during new construction or station remodeling.

Implementation Considerations

Fueling Area Covers - Fueling areas can be covered by installing an overhanging roof or canopy. Covers prevent exposure to rainfall and are a desirable amenity for retail fueling station customers. The area of the fueling cover should exceed the area where fuel is dispensed. All downspouts draining the cover or roof should be routed to prevent discharge across the fueling area. If large equipment makes it difficult to install covers or roofs, fueling islands should be designed to prevent storm water run-on through grading, and any runoff from the fueling area should be directed to a dead-end sump.

Surfaces - Fuel dispensing areas should be paved with concrete; the use of asphalt should be avoided, unless the surface is sealed with an impervious sealant. Concrete pads used in fuel dispensing areas should extend to the full length that the hose and nozzle assembly can be pulled, plus an additional foot.

Grading - Fuel dispensing areas should be graded with a slope that prevents ponding, and separated from the rest of the site by berms, dikes or other grade breaks that prevent run-on of urban runoff. The recommended grade for fuel dispensing areas is 2 - 4% (CSWQTF, 1997).

Cost - Costs to implement pollution prevention practices at fueling stations will vary, with many of the costs coming upfront during the design of a new fueling facility. Once a facility has implemented the recommended source control measures, ongoing maintenance costs should be low.

Resources

Best Management Practice Guide – Retail Gasoline Outlets. Prepared by Retail Gasoline Outlet Work Group. http://www.swrcb.ca.gov/rwqcb4/html/programs/stormwater/la_ms4_tentative/RGO BMP Guide_03-97_.pdf

Stormwater Management Manual for Western Washington: Volume IV -- Source Control BMPs. http://www.ecy.wa.gov/biblio/9914.html

California Stormwater Quality Association. 2003 California Stormwater BMP Handbook: New Development and Redevelopment. http://www.cabmphandbooks.com/

City of Los Angeles, CA Best Management Practices for Gas Stations http://www.lacity.org/SAN/wpd/downloads/PDFs/gasstation.pdf

City of Dana Point Stormwater Best Management Practices (BMPs) For Automotive Maintenance And Car Care http://www.danapoint.org/water/WC-AUTOMOTIVE.pdf

Alachua County, FL Best Management Practices for Controlling Runoff from Gas Stations http://environment.alachua-county.org/Natural_Resources/Water_Quality/Documents/Gas%20Stations.pdf

California Stormwater Regional Control Board Retail Gasoline Outlets: New

Development Design Standards For Mitigation Of Storm Water Impacts
http://www.swrcb.ca.gov/rwqcb4/html/programs/stormwater/la_ms4_tentative/RGOpaper.pdf
http://www.swrcb.ca.gov/rwqcb4/html/programs/stormwater/la_ms4_tentative/RGOPaperSupplement_12-01_.pdf

Canadian Petroleum Products Institute Best Management Practices Stormwater Runoff from Petroleum Facilities
http://www.cppi.ca/tech/BMPstormwater.pdf

City of Monterey (CA). Posters of Gas Station BMPs.
http://www.monterey.org/publicworks/stormeduc.html

Pinole County, CA Typical Stormwater Violations Observed in Auto Facilities and Recommended Best Management Practices (BMPs)
http://www.ci.pinole.ca.us/publicworks/downloads/AutoStormwater.pdf

Profile Sheet	Hotspot Source Area: Vehicles **VEHICLE WASHING**	

Description

Vehicle washing pollution prevention practices apply to many commercial, industrial, institutional, municipal and transport-related operations. Vehicle wash water may contain sediments, phosphorus, metals, oil and grease, and other pollutants that can degrade water quality. When vehicles are washed on impervious surfaces such as parking lots or industrial areas, dirty wash water can contaminate storm water that ends up in streams.

Application

Improved washing practices can be used at any facility that routinely washes vehicles. Examples include commercial car washes, bus depots, car dealerships, rental car companies, trucking companies, and fleet operations. In addition, washing dump trucks and other construction equipment can be a problem. Washing operations tend to be unevenly distributed within urban subwatersheds. Vehicle washing also occurs in neighborhoods, and techniques to keep wash water out of the storm drain system are discussed in the car washing profile sheet (N-11). Table 1 reviews some of the pollution prevention techniques available for hotspot vehicle washing operations.

Primary Training Targets

Owners, fleet managers, and employees of operations that include car washes are the primary training target.

Feasibility

Vehicle washing practices can be applied to all regions and climates. Vehicle washing tends to occur more frequently in summer months and in drier regions of the country. Sound vehicle washing practices are not always used at many sites because operators are reluctant to change traditional cleaning methods. In addition, the cost of specialized equipment to manage high volumes of wash water can be too expensive for small businesses.

Improved vehicle washing practices are relatively simple to implement and are very effective at preventing storm water contamination. Training is essential to get owners and employees to adopt these practices, and should be designed to overcome cultural and social barriers to improved washing practices.

Table 1: Pollution Prevention Practices for Vehicle Washing
• Wash vehicles at indoor car washes that recycle, treat or convey wash water to the sanitary sewer system • Use biodegradable, phosphate-free, water-based soaps • Use flow-restricted hose nozzles that automatically turn off when left unattended • Wash vehicles on a permeable surface or a washpad that has a containment system • Prohibit discharge of wash water into the storm drain system or ground by using temporary berms, storm drain covers, drain plugs or other containment system • Label storm drains with “No Dumping” signs to deter disposal of wash water in the storm drain system • Pressure and steam clean off-site to avoid runoff with high pollutant concentrations • Obtain permission from sewage treatment facilities to discharge to the sanitary sewer

Implementation Considerations

The ideal practice is to wash all vehicles at commercial car washes or indoor facilities that are specially designed for washing operations. Table 2 offers some tips for indoor car wash sites. When washing operations are conducted outside, a designated wash area should have the following characteristics:

- Paved with an impervious surface, such as Portland cement concrete
- Bermed to contain wash water
- Sloped so that wash water is collected and discharged to the sanitary sewer system, holding tank or dead-end sump
- Operated by trained workers to confine washing operations to the designated wash area

Outdoor vehicle washing facilities should use pressurized hoses without detergents to remove most dirt and grime. If detergents are used, they should be phosphate-free to reduce nutrient loading. If acids, bases, metal brighteners, or degreasing agents are used, wash water should be discharged to a treatment facility, sanitary sewer, or a sump. In addition, waters from the pressure washing of engines and vehicle undercarriages must be disposed of using the same options.

Discharge to pervious areas may be an option for washing operations that generate small amounts of relatively clean wash water (water only - no soaps, no steam cleaning). The clean wash water should be directed as sheet flow across a vegetated area to infiltrate or evaporate before it enters the storm drain system. This option should be exercised with caution, especially in environmentally sensitive areas or protected groundwater recharge areas.

The best way to avoid stormwater contamination during washing operations is to drain the wash water to the sanitary sewer system. Operations that produce high volumes of wash water should consider installing systems that connect to the sewer. Other options for large and small operations include containment units to capture the wash water prior to transport away for proper disposal (Figure 1). If vehicles must be washed on an impervious surface, a storm drain filter should be used to capture solid contaminants.

Table 2: Tips for Indoor Car Wash Sites *(Adapted from U.S. EPA, 2003)*
▪ Facilities should have designated areas for indoor vehicle washing where no other activities are performed (e.g. fluid changes or repair services)
▪ Indoor vehicle wash areas should have floor drains that receive only vehicle washing wastewater (not floor washdown or spill removal wash waters) and be connected to a holding tank with a gravity discharge pipe, to a sump that pumps to a holding tank, or to an oil/grit separator that discharges to a municipal sanitary sewer
▪ The floor of indoor vehicle wash bays should be completely bermed to collect wash water
▪ Aromatic and chlorinated hydrocarbon solvents should be eliminated from vehicle-washing operations
▪ Vehicle-washing operations should use vehicle rinsewater to create new wash water through the use of recycling systems that filter and remove grit.

Figure 1: Containment System Preventing Wash Water from Entering the Storm Drain

EPA's National Compliance Assistance Centers (http://www.assistancecenters.net/). Temporary, portable containment systems can be shared by several companies that cannot afford specialized equipment independently.

Table 3: Sample Equipment Costs for Vehicle Washing Practices	
Item	**Cost**
Bubble Buster	$2,000 –2,500*
Catch basin insert	$65*
Containment mat	$480-5,840**
Storm drain cover (24" drain)	$120.00 **
Water dike/ berm (20 ft)	$100.00 **
Pump	$75-3,000**
Wastewater storage container	$50-1,000+**
*Source: *U.S. EPA, 1992 **Robinson, 2003*	

Resources

EPA FedSite Virtual Facility Regulatory Tour, Vehicle Maintenance Facility Tour. Vehicle Washing - P2 Opportunities http://permanent.access.gpo.gov/websites/epagov/www.epa.gov/fedsite/virtual.html

Alachua County Pollution Prevention Fact Sheet: Best Management Practices for Controlling Runoff from Commercial Outdoor Car Washing. http://environment.alachua-county.org/Natural_Resources/Water_Quality/Documents/Commercial Outdoor Car Wash.pdf.

Kitsap County Sound Car Wash Program. http://www.kitsapgov.com/sswm/carwash.htm.

Washington Department of Ecology. 1995. Vehicle and Equipment Wash Water Discharges: Best Management Practices Manual. Olympia, Washington. http://www.ecy.wa.gov/pubs/95056.pdf

U.S. Environmental Protection Agency. Pollution Prevention/Good Housekeeping for Municipal Operations. http://cfpub2.epa.gov/npdes/stormwater/menuofbmps/poll_18.cfm

California Stormwater Quality Association. 2003 California Stormwater BMP Handbook: Industrial and Commercial. http://www.cabmphandbooks.com/

Profile Sheet

Hotspot Source Area: Vehicles

VEHICLE STORAGE

Description

Parking lots and vehicle storage areas can introduce sediment, metals, oil and grease, and trash into storm water runoff. Simple pavement sweeping, litter control, and storm water treatment practices can minimize pollutant export from these hotspots. Table 1 provides a list of simple pollution prevention practices intended to prevent or reduce the discharge of pollutants from parking and vehicle storage areas.

Application

Pollution prevention practices can be used at larger parking lots located within a subwatershed. Examples include regional malls, stadium lots, big box retail, airport parking, car dealerships, rental car companies, trucking companies, and fleet operations (Figure 1). The largest, most heavily used parking lots with vehicles in the poorest condition (e.g., older cars or wrecked vehicles) should be targeted first. This practice is also closely related to parking lot maintenance source controls, which are discussed in greater detail in profile sheet H-11.

Primary Training Targets

Owners, fleet operation managers, and property managers that maintain parking lots are key training targets.

Figure 1: Retail Parking Lot

Table 1: Pollution Prevention Practices for Parking Lot and Vehicle Storage Areas
Parking Lots • Post signs to control litter and prevent patrons from changing automobile fluids in the parking lot (e.g., changing oil, adding transmission fluid, etc.) • Pick up litter daily and provide trash receptacles to discourage littering • Stencil or mark storm drain inlets with "No Dumping, Drains to ______" message • Direct runoff to bioretention areas, vegetated swales, or sand filters • Design landscape islands in parking areas to function as bioretention areas • Disconnect rooftop drains that discharge to paved surfaces • Use permeable pavement options for spillover parking (Profile sheet OS-11 in Manual 3) • Inspect catch basins twice a year and remove accumulated sediments, as needed • Vacuum or sweep large parking lots on a monthly basis, or more frequently • Install parking lot retrofits such as bioretention, swales, infiltration trenches, and storm water filters (Profile sheets OS-7 through OS-10 in Manual 3) *Vehicle Storage Areas* • Do not store wrecked vehicles on lots unless runoff containment and treatment are provided • Use drip pans or other spill containment measures for vehicles that will be parked for extended periods of time • Use absorbent material to clean up automotive fluids from parking lots

Feasibility

Sweeping can be employed for parking lots that empty out on a regular basis. Mechanical sweepers can be used to remove small quantities of solids. Vacuum sweepers should be used on larger parking lot storage areas, since they are superior in picking up deposited pollutants (See Manual 9). Constraints for sweeping large parking lots include high annual costs, difficulty in controlling parking, and the inability of current sweeper technology to remove oil and grease. Proper disposal of swept materials might also represent a limitation.

Implementation Considerations

The design of parking lots and vehicle storage areas can greatly influence the ability to treat storm water runoff. Many parking areas are landscaped with small vegetative areas between parking rows for aesthetic reasons or to create a visual pattern for traffic flow. These landscaped areas can be modified to provide storm water treatment in the form of bioretention (Figure 2).

Figure 2: Parking Lot Island Turned Bioretention Area

Catch basin cleanouts are also an important practice in parking areas. Catch basins within the parking lot should be inspected at least twice a year and cleaned as necessary. Cleanouts can be done manually or by vacuum truck. The cleanout method selected depends on the number and size of the inlets present (see Manual 9).

Most communities have contractors that can be hired to clean out catch basins and vacuum sweep lots. Mechanical sweeping services are available, although the cost to purchase a new sweeper can exceed $200,000. Employee training regarding spill prevention for parking areas is generally low-cost and requires limited staff time.

Resources

California Stormwater Quality Association. 2003 California Stormwater BMP Handbook: Industrial and Commercial
http://www.cabmphandbooks.com/

Stormwater Management Manual for Western Washington: Volume IV -- Source Control BMPs. WA Dept. of Ecology
http://www.ecy.wa.gov/biblio/9914.html

Profile Sheet	**Hotspot Source Area: Outdoor Materials** **LOADING AND UNLOADING**	

Description

Outdoor loading and unloading normally takes place on docks or terminals at many commercial, industrial, institutional, and municipal operations. Materials spilled or leaked during this process can either be carried away in storm water runoff or washed off when the area is cleaned. As a result, many different pollutants can be introduced into the storm drain system, including sediment, nutrients, trash, organic material, trace metals, and an assortment of other pollutants. A number of simple and effective pollution prevention practices can be used at loading/unloading areas to prevent runoff contamination, as shown in Table 1.

Application

While nearly every commercial, industrial, institutional, municipal and transport-related site has a location where materials or products are shipped or received, the risk of storm water pollution is greatest for operations that transfer high volumes of material or liquids, or unload potentially hazardous materials. Some notable examples to look for in a subwatershed include distribution centers, grocery stores, building supply outlets, lawn and garden centers, petroleum wholesalers, warehouses, landfills, ports, solid waste facilities, and maintenance depots (Figure 1). Attention should also be paid to industrial operations that process bulk materials, and any operations regulated under industrial storm water NPDES permits.

Primary Training Targets

Owners, site managers, facility engineers, supervisors, and employees of operations with loading/unloading facilities are the primary training target.

Table 1: Pollution Prevention Practices for Loading and Unloading Areas
• Avoid loading/unloading materials in the rain • Close adjacent storm drains during loading/unloading operations • Surround the loading/unloading area with berms or grading to prevent run-on or pooling of storm water. If possible, cover the area with a canopy or roof • Ensure that a trained employee is always present to handle and cleanup spills • Inspect the integrity of all containers before loading/unloading • Inspect equipment such as valves, pumps, flanges, and connections regularly for leaks, and repair as needed • Install an automatic shutoff valve to interrupt flow in the event of a catastrophic liquid spill • Install a high-level alarm on storage tanks to prevent overfilling • Pave the loading/unloading area with concrete rather than asphalt • Place drip pans or other temporary containment devices at locations where leaks or spills may occur, and always use pans when making and breaking connections • Position roof downspouts to direct storm water away from loading/unloading areas and into bioretention areas • Prepare and implement an Emergency Spill Cleanup Plan for the facility (see Profile Sheet H-7) • Sweep loading/unloading area surfaces frequently to remove material that could otherwise be washed off by storm water • Train all employees, especially fork lift operators, on basic pollution prevention practices and post signs • Use seals, overhangs, or door skirts on docks and terminals to prevent contact with rainwater

Feasibility

Loading/unloading pollution prevention practices can be applied in all geographic and climatic regions, and work most effectively at preventing sediment, nutrients, toxic materials, and oil from coming into contact with storm water runoff or runon. Few impediments exist to using this practice, except for the cost to retrofit existing loading and unloading areas with covers or secondary containment.

Implementation Considerations

Loading/unloading pollution prevention practices should be integrated into the overall storm water pollution prevention plan for a facility. Employee training should focus on proper techniques to transfer materials, using informational signs at loading docks and material handling sites and during routine safety meetings.

Cost - Costs to implement loading/unloading pollution prevention practices consist of one-time construction costs to retrofit new or existing loading areas, but annual maintenance costs are relatively low thereafter. Exceptions include industries that elect to use expensive air pressure or vacuum systems for loading/unloading facilities, which can also be expensive to maintain (U.S. EPA, 1992). Ongoing costs include employee training and periodic monitoring of loading/unloading activities.

Figure 1: Loading/Unloading Area of Warehouse

Resources

California Stormwater Quality Association. 2003 California Stormwater BMP Handbook: Industrial and Commercial. http://www.cabmphandbooks.com/

Stormwater Management Manual for Western Washington: Volume IV -- Source Control BMPs. WA Dept. of Ecology 99-14 http://www.ecy.wa.gov/biblio/9914.html

Ventura County Flood Control District Clean Business Program Fact Sheet http://www.vcstormwater.org/sheet-materials.htm

Business Best Management Practices Stormwater Bmp #3 - Shipping/Receiving/Loading Docks http://www.cleancharles.org/stormwater_bmp3.shtml

City of Los Angeles, CA Reference Guide For Stormwater Best Management Practices http://www.lastormwater.org/downloads/PDFs/bmp_refguide.pdf

Profile Sheet	Hotspot Source Area: Outdoor Materials	
	OUTDOOR STORAGE	

Description

Protecting outdoor storage areas is a simple and effective pollution prevention practice for many commercial, industrial, institutional, municipal, and transport-related operations. The underlying concept is to prevent runoff contamination by avoiding contact between outdoor materials and rainfall (or runoff). Unprotected outdoor storage areas can generate a wide range of storm water pollutants, such as sediment, nutrients, toxic materials, and oil and grease (Figure 1).

Materials can be protected by installing covers, secondary containment, and other structures to prevent accidental release. Outdoor storage areas can be protected on a temporary basis (tarps or plastic sheeting) or permanently through structural containment measures (such as roofs, buildings, or concrete berms). Table 1 summarizes pollution prevention practices available for outdoor storage areas.

Application

Many businesses store materials or products outdoors. The risk of storm water pollution is greatest for operations that store large quantities of liquids or bulk materials at sites that are connected to the storm drain system. Several notable operations include nurseries and garden centers, boat building/repair, auto recyclers/body shops, building supply outlets, landfills, ports, recycling centers, solid waste and composting facilities, highway maintenance depots, and power plants. Attention should also be paid to industrial operations that process bulk materials, which are often regulated under industrial storm water NPDES permits.

Figure 1: Mulch Stored Outdoors at a Garden Center

Primary Training Targets

Owners, site managers, facility engineers, supervisors, and employees of operations with loading/unloading facilities are the primary training target.

Feasibility

Outdoor storage protection can be widely applied in all regions and climate zones, and requires routine monitoring by employees. Most operations have used covering as the major practice to handle outdoor storage protection (U.S. EPA, 1999). The strategy is to design and maintain outdoor material storage areas so that they:

- Reduce exposure to storm water and prevent runon
- Use secondary containment to capture spills
- Can be regularly inspected
- Have an adequate spill response plan and cleanup equipment

Table 1: Pollution Prevention Practices for Protecting Outdoor Storage Areas
• Emphasize employee education regarding storage area maintenance • Keep an up-to-date inventory of materials stored outdoors, and try to minimize them • Store liquids in designated areas on an impervious surface with secondary containment • Inspect outdoor storage containers regularly to ensure that they are in good condition • Minimize storm water run-on by enclosing storage areas or building a berm around them • Slope containment areas to a drain with a positive control (lock, valve, or plug) that leads to the sanitary sewer (if permitted) or to a holding tank • Schedule regular pumping of holding tanks containing storm water collected from secondary containment areas

Implementation Considerations

Covers - The use of impermeable covers is an effective pollution prevention practice for non-hazardous materials. Covers can be as simple as plastic sheeting or tarps, or more elaborate roofs and canopies. Site layout, available space, affordability, and compatibility with the covered material all dictate the type of cover needed for a site. In addition, the cover should be compatible with local fire and building codes and OSHA workplace safety standards. Care should be taken to ensure that the cover fully protects the storage site and is firmly anchored into place.

Secondary Containment - Secondary containment is designed to contain possible spills of liquids and prevent storm water run-on from entering outdoor storage areas. Secondary containment structures vary in design, ranging from berms and drum holding areas to specially-designed solvent storage rooms (Figure 2).

Secondary containment can be constructed from a variety of materials, such as concrete curbs, earthen berms, plastic tubs, or fiberglass or metal containers. The type of material used depends on the substance contained and its resistance to weathering. In general, secondary containment areas should be sized to hold 110% of the volume of the storage tank or container unless other containment sizing regulations apply (e.g., fire codes).

If secondary containment areas are

Figure 2: Secondary Containment of Storage Drums Behind a Car Repair Shop

uncovered, any water that accumulates must be collected in a sanitary sewer, a storm water treatment system, or a licensed disposal facility. Water quality monitoring may be needed to determine whether the water is contaminated and dictate the method of disposal. If the storm water is clean, or an on-site storm water treatment practice is used, a valve should be installed in the containment dike so that excess storm water can be drained out of the storage area and directed either to the storm drain (if clean) or into the storm water treatment system (if contaminated). The valve should always be kept closed except when storm water is drained, so that any spills that occur can be effectively contained. Local sewer authorities may not allow discharges from a large containment area into the sewer system, and permission must be obtained prior to discharge. If

discharges to the sanitary sewer system are prohibited, containment should be provided, such as a holding tank that is regularly pumped out.

Employee training on outdoor storage pollution prevention should focus on the activities and site areas with the potential to pollute storm water and the proper techniques to manage material storage areas to prevent runoff contamination. Training can be conducted through safety meetings and the posting of on-site informational signs. Employees should also know the on-site person who is trained in spill response.

Cost - Many storage protection practices are relatively inexpensive to install (Table 2). Actual costs depend on the size of the storage area and the nature of the pollution prevention practices. Other factors are whether practices are temporary or permanent and the type of materials used for covers and containment. Employee training can be done in connection with other safety training to reduce program costs. Training costs can also be reduced by using existing educational materials from local governments, professional associations or from EPA's National Compliance Assistance Centers (http://www.assistancecenters.net).

Table 2: Sample Equipment Costs for Outdoor Storage Protection

Storage Protection Device	Cost
Concrete Slab (6")	\$3.50 to \$5.00 per ft^2
Containment Pallets	\$50 to \$350 based on size and # of barrels to be stored
Storage buildings	\$6 to \$11 per ft^2
Tarps & Canopies	\$25 to \$500 depending on size of area to cover
Sources: Costs were derived from a review of Ferguson et al.*, 1997 and numerous websites that handle proprietary spill control or hazardous material control products*	

Resources

California Stormwater Quality Association. 2003 California Stormwater BMP Handbook: Industrial and Commercial. http://www.cabmphandbooks.com/

Rouge River National Wet Weather Demonstration Project. Wayne County, MI. http://www.rougeriver.com/geninfo/rougeproj.html

Storm Water Management Fact Sheet: Coverings. USEPA, Office of Water, http://www.epa.gov/owm/mtb/covs.pdf.

EPA Office of Wastewater Management Storm Water Management Fact Sheet: Coverings http://www.epa.gov/owm/mtb/covs.pdf

California Stormwater Quality Association Factsheet: Outdoor Storage of Raw Materials http://www.cabmphandbooks.com/Documents/Municipal/SC-33.pdf

Alameda Countywide Clean Water Program Outdoor Storage of Liquid Materials http://www.cleanwaterprogram.com/outdoor_stor_liquid_fact_sht.pdf

Washtenaw County, MI Community Partners for Clean Streams Fact Sheet Series #1: Housekeeping Practices http://www.ewashtenaw.org/content/dc_drnbmp1.pdf

Appendix 5. Design of Stormwater Conveyance Systems

The Chezy-Manning formula is to be used to compute the system's transport capacities:

$$Q = \frac{1.486}{n} \times A \times R^{2/3} \times S^{1/2}$$

Where:

Q = channel flow (cfs)
n = Manning’s roughness coefficient (Table A.1)
A = cross-sectional area of flow (ft^2)
R = hydraulic radius (ft)
S = channel slope (ft/ft)

Table A-5.1 Manning’s Roughness Coefficient (n) Values for Various Channel Materials

Channel Materials	**Roughness Coefficient**
Concrete pipe and precast culverts	0.013
Monolithic concrete in boxes, channels	0.015
PVC pipes 24" to 36" 42" and larger	0.011 0.019 0.021
Sodded channel with water depth < 1.5'	0.050
Sodded channel with water depth >1.5'	0.035
Smooth earth channel or bottom of wide channels with sodded slopes	0.025
Rip-rap channels	0.035

Note: Where drainage systems are composed of more than one of the above channel materials, a composite roughness coefficient must be computed in proportion to the wetted perimeter of the different materials.

Also, the computation for the flow velocity of the channel shall use the continuity equation as follows:

$$Q = A \times V$$

Where:

V = velocity (ft/sec)
A = cross-sectional area of the flow (ft^2)

Appendix 6. Design of Flow Control Structures

Flow control devices are orifices and weirs. The following formulas shall be used in computing maximum release rates from the designed stormwater management facility

1) Circular Orifices:

$$Q = CA(2gh)^{0.5}$$

Where: Q = orifice discharge (cfs)
C = discharge coefficient = 0.6
A = orifice cross-sectional area = 3.1416(D^2/4) (ft^2)
g = 32.2ft/sec^2 (gravitational acceleration)
h = hydraulic head above the center of the orifice (ft)

When h < D, the orifice shall be treated as a weir:

$$Q = CLH^{3/2}$$

Where: Q = flow through the weir (cfs)
C = 3
L = diameter of orifice (ft)
H = hydraulic head above bottom of weir opening (ft)

2) Flow Under Gates:

Flow under a vertical gate can be treated as a square orifice. For submerged conditions:

When outflow is not influenced by downstream water level:

$$Q = b \times a \times C \times \left[2g \times \left(\frac{H_0}{H_0 + H_i} \right) \right]^{0.5}$$

Where: Q = flow through the gate (cfs)
b = width of gate (ft)
a = gate opening height (ft)
C = discharge coefficient
g = 32.2 ft/sec^2 (gravitational acceleration)

When outflow is influenced by downstream water level:

$Q' = KQ$

Where K = coefficient found in Figure B.1

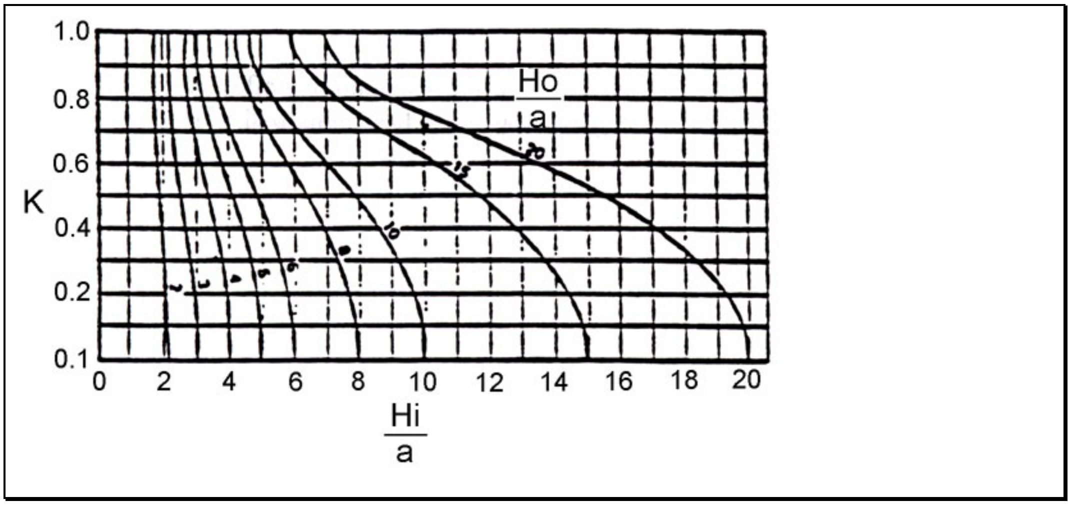

Figure B.1 Absolute Downstream Control of Flow Under Gate

3) Weirs:

Rectangular: $Q = 3.33H^{1.5}(L - 0.2H)$

60° V-notch: $Q = 1.43H^{2.5}$

90° V-notch $Q = 2.49H^{2.48}$

Where: Q = flow through the weir (cfs)
H = hydraulic head above the bottom of the weir (ft)
L = length of the weir crest (ft)