PDHonline Course C548 (4 PDH)

Stormwater Control Measures-Post Construction

Instructor: John Huang, Ph.D., PE and John Poullain, PE

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5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

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SECTION 5: PERMANENT STORMWATER RUNOFF MANAGEMENT

This section of the book highlights important considerations of environmental design in the site plan and offers general guidance for permanent stormwater control measures, referred to here as SCMs. See Chapter 2 for more information about water quality impacts and hydrology considerations. See Chapter 3 for more information about interpreting stormwater features in the site development plan.

SCMs are considered permanent and are designed to control stormwater discharges for both water quantity and water quality, after the site has been completely built. These devices may be constructed and installed during the construction phase of the project, but usually are not operated until project construction is complete and the site is stabilized.

General Contractor and Site Superintendent Responsibilities

Many communities are now required to regulate post-construction practices for water quality, therefore city or county regulations may apply in addition to state and federal regulations (See Chapter 1 for information about state regulations, federal regulations and permit requirements.) In order to avoid costly corrections and project delays, it will be important for the general contractor and site superintendent to:

- Understand local water quality requirements. Many communities are upgrading stormwater ordinances and codes, because they are now required to enforce development standards to meet water quality goals. As a result, requirements may include capturing and treating small storm runoff at the site. This makes it necessary to employ green infrastructure concepts and low impact development practices, in particular environmental site designs that include:
  - Features such as stream buffers, less impervious surface (narrower streets, etc.), streetscapes, connected green spaces, parking lot controls and pocket parks.
  - Strategically placed practices such as rain gardens, bioswales, stormwater wetlands, infiltration trenches, perimeter sand filters and planter boxes.
  - Similar practices to collect and treat small storm runoff.
- To avoid costly repairs, avoid damage to designated SCM locations during construction. Become aware of all planned SCMs designed for permanent function and identify where they are to be located. Contemporary designs can include numerous on-site SCMs throughout the project site. The ultimate placement and combined functions of SCMs, as well as their connected paths, need to be protected from soil compaction and other disturbances. Such protection will eliminate the need for costly repairs and will protect against failure of the SCM.

- Coordinate long-term operations with landowners. Local regulations for permanent stormwater control measures may require a formal transfer of operation and maintenance responsibility from developer to builder or buyer.
- Notify local governments about permanent practices where regulated. The site superintendent or general contractor should inform the local governing agency about the final location of all SCMs as well as who is in charge of the operation and maintenance of each control device. Check the local ordinance for requirements.

Design Considerations When Selecting Vegetated Practices

Many contemporary SCM devices work with vegetation to increase infiltration. Vegetation will work most effectively when a diverse mix of grasses, forbs, shrubs and trees are designed together. When choosing the vegetative material, incorporate plants with diverse root structures below ground to increase the potential for water uptake by the plants. This will also help to recharge groundwater resources. Also, grasses will provide more root structure and deeper root penetration if the plants are allowed to grow and are not mowed close to the ground. Native or adapted warm season grasses provide greater root structure (up to 15 feet) when they are not mowed, whereas mowed turf grasses only provide about 1- to 2-inch deep root structures. As a general rule, trees and shrubs provide greater root structure systems than grasses do.

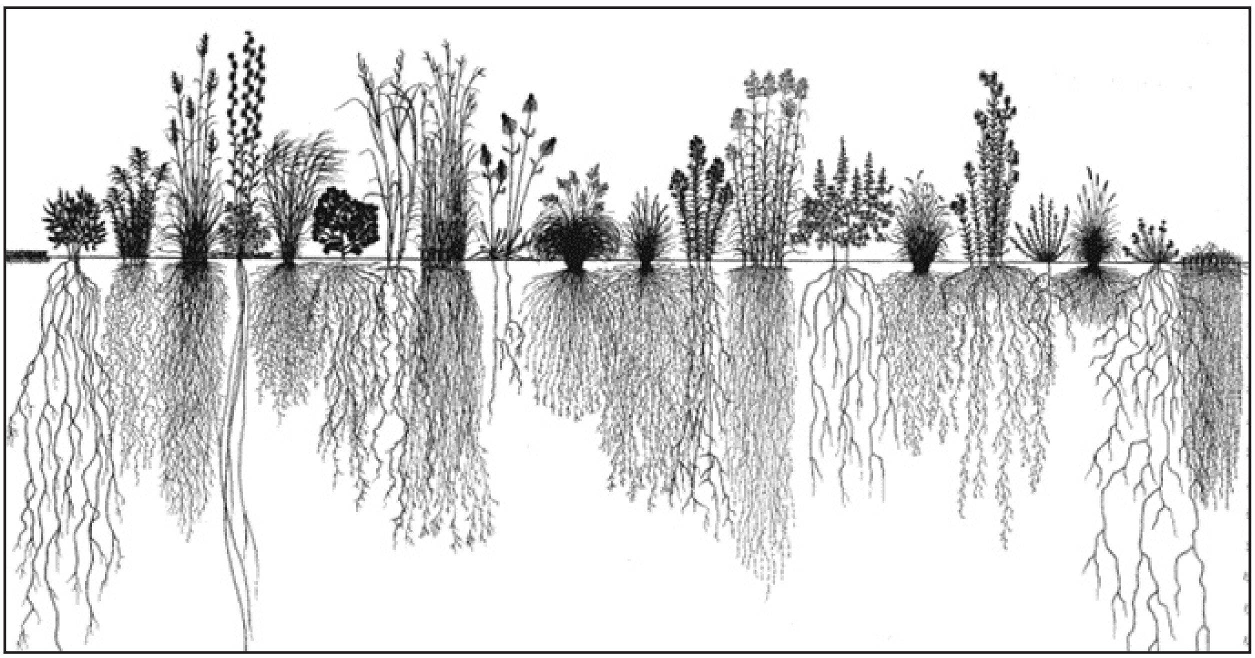

Figure 6.101 Source: *Native Plant Guide for Streams and Stormwater Facilities in Northeastern Illinois* Prepared by USDA-NRCS Chicago Metro Urban and Community Assistance Office in Cooperation with EPA Region 5, U.S. Fish and Wildlife Service, Chicago Field Office and U.S. Army Corps of Engineers, Chicago District, December 1997 (Revised May 2004).

Coordinating Long-Term Operation, Maintenance and Inspection

Long-term operation, maintenance and inspection needs, along with any safety concerns, should be communicated to the affected landowners, homeowners' association and other parties responsible for permanent oversight of the SCMs. Present and future landowners should be made aware of the potential consequences of changing vegetation types, poor maintenance practices or other actions that could cause a practice to function poorly or fail. A long-term education program should be implemented to ensure that multi-generational land owners understand the importance of maintaining practices. Without knowledge of their intended purposes, there is possibility new owners will disable functional features.

Preparing the Operation, Maintenance and Inspection Manual

Each stormwater control measure should have specific operation, maintenance and inspection information written in an operations, maintenance and inspection manual. The manual should be prepared by the design professional, and the entity responsible for operations, maintenance and inspection of each device should be identified. After construction is complete and all SCM devices are operational, the responsibility for operations, maintenance and inspection should be turned over to the proper entity, and the individuals should be provided adequate training for operations, maintenance and inspection.

Additional References and Resources

Refer to the design specifications used in your area for proper design, installation and maintenance. The *Missouri Guide to Green Infrastructure: Integrating Water Quality into Municipal Stormwater Management 2011* will provide additional information about these practices as well as non-structural strategies. See Appendix C and Appendix D for additional references and resources about environmental site design and state-of-the-practice permanent stormwater control measures.

Selecting Permanent Stormwater Control Measures

The current goal of stormwater management is to provide effective control over water quality, channel protection, recharge, overbank floods and extreme storms. Historically, the primary goal of urban stormwater management was to control the quantity peak flow rate for the purpose of flood protection.

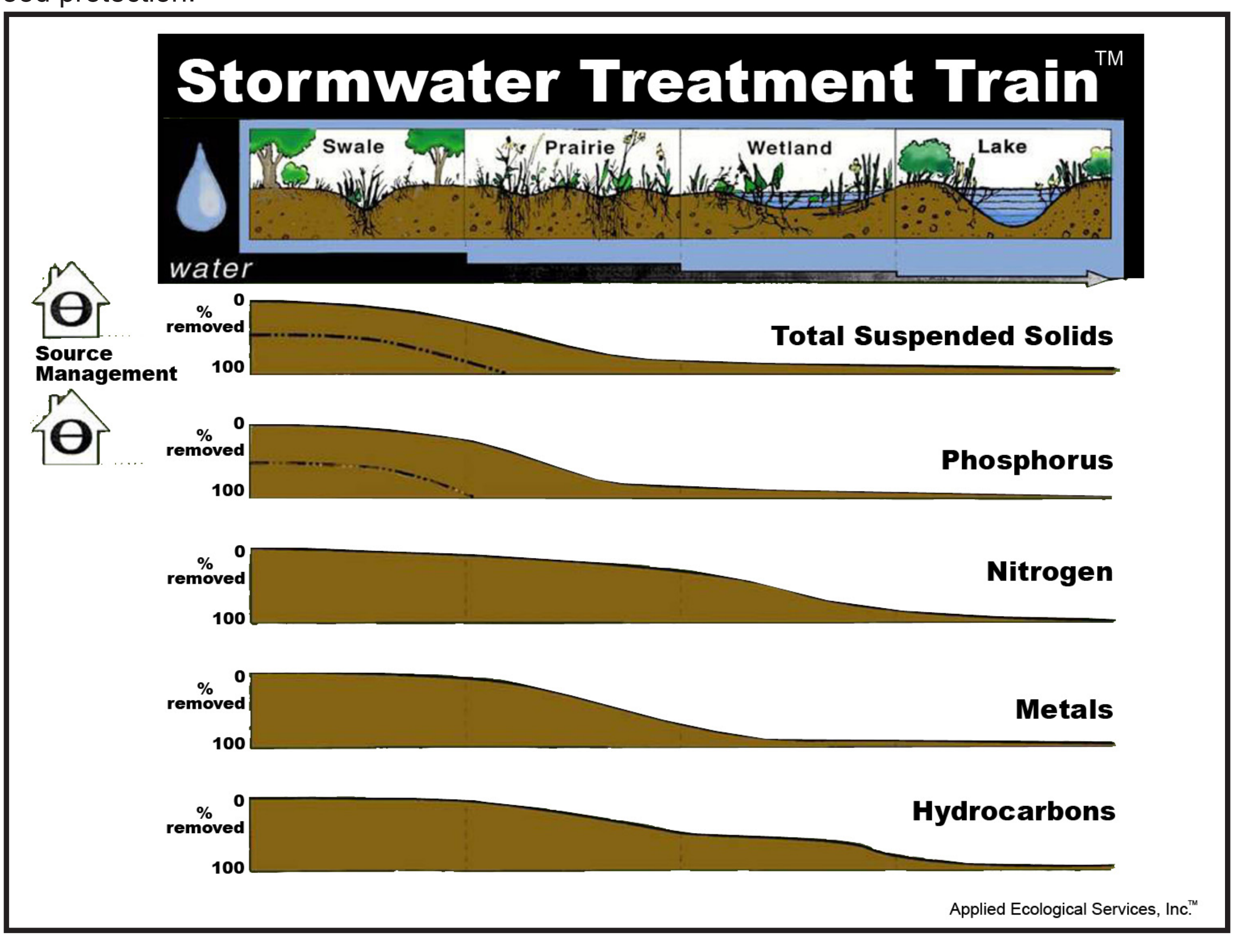

Figure 6:102 Stormwater Treatment Train printed with permission by Applied Ecological Services. See www.appliedeco.com for more STT information and project examples.

To meet current water quality goals, stormwater management practices should be selected with consideration of the overall site design. See Chapter 3 - Interpreting Stormwater Features in the Site Development Plan. Specifically, the design engineer should consider performance that combines pollution removal with water quantity control.

Pollutant Removal Mechanisms for Water Quality Control

Screening/Filtration

The capture of solid pollutants through screens or filters that use a media such as sand. Effective for removal of suspended solids.

Infiltration/Ground Water Recharge

A technique to discharge stormwater runoff to groundwater. Effective when runoff volume controls are required, pollutants can be filtered and surface water temperatures can be controlled.

Settling

Deposition of solids. Typically a minimum of 12 hours of detention is needed to effectively settle solids in stormwater ponds and stormwater wetlands.

Biological Uptake

Vegetative and microbial uptake of nutrients through biofiltration or stormwater wetlands.

Temperature Control

Techniques to reduce the heating effects when runoff flows across hot pavements.

Soil Adsorption

The physical attachment of a particle, usually nutrients and heavy metals, to the soil. See Table 6.17 for examples of practices that provide water pollution control.

Table 6.17 Primary and Secondary Pollutant Removal Mechanisms
Source: Minnesota Stormwater Control Manual

Best Management Practices Group	Pollutant Removal Mechanisms									
	Water Quality					Water Quality				
	Screening Filtration	Infiltration/ Recharge	Settling	Biological Uptake	Temperature Control	Soil Adsorption	Volume Control	Rate Control	Velocity Control	Evapotranspiration
Pollution Prevention	Not applicable - pollutants not exposed to stormwater									
Better Site Design/Low Impact Development	1	2	2	2	2	2	1	2	2	2
Runoff Volume Minimization		2			2		1	2		
Temporary Construction Sediment Control			1					1	2	
Bioretention	1	2	2	2	2	2	2	2		2
Filtration	1	2		2		2		2		2
Infiltration	2	1		2	1	2	2	2		
Stormwater Ponds		2	1	2				1	1	2
Stormwater Wetlands	2	2	1	1		2		1	1	2
Supplemental Treatment	Each supplemental and proprietary device should be carefully studied to learn the primary and secondary pollutant removal functions.									
1 = Primary Pollutant Removal 2 = Secondary Pollutant Removal Mechanism										

Water Quantity Control Mechanisms

Volume Control

Methods to limit the net increase in stormwater runoff volume caused by the creation of new impervious surfaces. Most common techniques include best site designs that offer limitation or disconnection of new surface areas, infiltration, evapotranspiration and re-use by vegetation.

Rate Control

Detention of stormwater runoff to slow the discharge of runoff to surface waters to rates comparable with pre-development conditions. Effective for peak rate control, but can significantly increase the time period of the peak flows.

Velocity Control

Similar to rate control; intentional restriction of stormwater runoff such that velocity of discharged runoff through downstream channels does not cause channel erosion.

Evapotranspiration

Specific volume control technique that uses evaporation from water surfaces or transpiration by vegetation.

See references listed in Appendix C for details about integrated stormwater management, SCM selections, specific SCM design schematics and the unified sizing approach. For example, the *Minnesota Stormwater Manual* provides detailed SCM calculations and designs, the *Low Impact Development Manual for Michigan* provides a summary of calculations and methodology, and the SUSTAIN model by EPA provides step-by-step site design and SCM selection exercises.

ROOFTOP RUNOFF CONTROLS

Rain Gardens

Figure 6.103: Maplewood, Minnesota Rain Garden. Source: University of Wisconsin-Extension and the Wisconsin Department of Natural Resources.

Practice Description

As one form of bioretention, a rain garden is designed to collect stormwater runoff from small areas. (See Bioretention System on page 6-257.) A rain garden is an attractive, landscaped area built in a natural or constructed depression and designed to capture and filter stormwater runoff as a natural system would. It is usually planted with perennial native or adaptive plants selected to tolerate periods of inundation and drought, although typically designed to drain in less than a day. Rain gardens are used to catch runoff from impervious surfaces such as rooftops, small parking lots, driveways and similar surfaces. They can be constructed in residential, commercial, parks or neighborhood areas or inside traffic roundabouts (See Figure 6.104).

Rain gardens can be constructed near the source of runoff to slow the stormwater, prevent erosion and filter pollutants before draining to local waterways. When used in combination with other rain gardens or practices, these gardens can help achieve desirable drainage rates, velocity reduction and groundwater recharge – specifically by capturing Rainfall from a small storm, or water quality storm (approximately a one-inch event) while diverting the larger storm runoff to the storm drain system. Rain gardens provide habitat and food for wildlife and enhance the aesthetics of an individual yard or a community.

Rain gardens are applicable across the Midwest, including cold climate or karst areas with minor design adjustments. They can be used individually to improve stormwater quality and reduce peak runoff rates for small areas such as rooftop drainage areas, or they can be used in multiples across a larger area. Rain gardens, as long as they are lined properly, can also be used to treat stormwater hot spots where pollution in runoff is higher than typical – gas station parking lots for example.

Figure 6:104 Rain garden in roundabout designed to capture/infiltrate stormwater, Milwaukee, WI. Source: Bob Newport, EPA Region 5

Recommended Minimum Requirements

Rain gardens should be designed by a qualified professional when they are to be built as part of a comprehensive stormwater management system. The site superintendent and field personnel should refer to plans and specifications throughout the construction process. If an individual homeowner wishes to install a rain garden, they should be able to install one by following simple guidelines. A great resource is *Rain Gardens: A How-To Manual for Homeowners* by Wisconsin Extension (see References).

Siting and Design Considerations

Consideration should be given to location of the runoff source, water quality goals, drainage volume target, slope, soil type, groundwater recharge goals, costs and performance limitations.

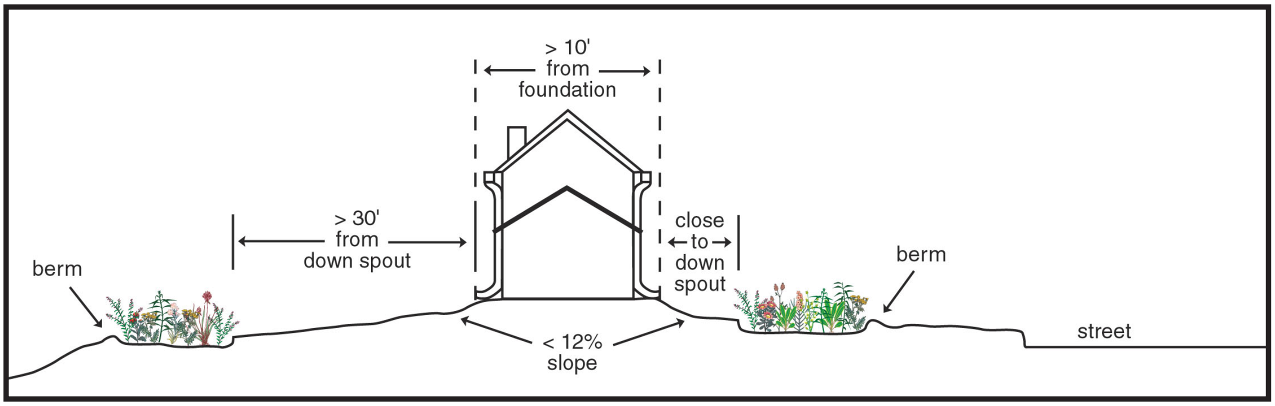

Figure 6.105 Rain Garden Schematic Diagram for Residential Applications.
Source: Wisconsin Department of Natural Resources

Site Location

Rain gardens should be placed in natural depressions or in areas where water will naturally collect. For example the lowest point of a catchment area where runoff is discharged from the rooftop. Or, stormwater can be routed to rain gardens in dryer locations, if increased groundwater recharge is the primary goal.

- Do not locate rain gardens within 10 feet of a building, because infiltration water can seep into the foundation.
- Do not locate rain gardens within 25 feet of lateral sewer lines, because they can increase the severity of inflow and infiltration into the sewer line. Sewer laterals are often located between the front of the house and the street.
- If the area naturally ponds for an extended period of time, additional engineering techniques will be needed to enhance drainage while maintaining the desired infiltration rate. Or the practice may need to be relocated.

A rain garden should have an area about 20 percent the size of the roof or driveway area draining into it. A typical rain garden for a residential home or small building is between 100 and 400 square feet. Rain gardens are often shaped longer than they are wide and positioned perpendicular to the slope of the land to maximize their function.

Pollutant Removal

Rain garden plants take up stormwater and pollutants such as:

- Heavy metals (e.g., copper, lead, zinc)
- Nutrients (e.g., nitrogen, phosphorous and potassium) and calcium.

The thin mulch layer and the engineered soil allow for quick infiltration of the stormwater. The mulch layer is exceptionally good at filtering out heavy metals from the stormwater. The soil layer filters heavy metals as well as nutrients, oil, grease and other pollutants.

Filtered stormwater percolates down to the gravel layer. The gravel stores some of the stormwater so it may continue to flow downward through the natural soil to the water table. The remaining water is re-released into the stormwater system via the underdrain if present. Rain gardens will vary in performance, based on accuracy and nature of design, installation and maintenance. More information about pollution control is available in the International Stormwater BMP Database at www.bmpdatabase.org/BMPPerformance.htm and in additional resources listed in Appendix C.

Ponding Volume and Conveyance

The ponding depth of a rain garden is typically between 4- and 6-inches. The garden should be designed to drain within two days in order to avoid nuisance insects. Exfiltration can be added where increased groundwater recharge is desired. Or, the filtered runoff can be collected in a perforated underdrain and returned to the storm drain system. The rain garden should be located relatively close to the source of runoff, but not too close to buildings or sewer laterals. The conveyance paths to and from the rain garden should be designed as part of the system, including an overflow drain if appropriate.

Rain gardens should be used to collect runoff from small areas such as:

- Rooftop runoff.
- Driveways.
- Small parking lots and similar areas.

They work best in a series of small runoff management practices if being used on larger sites. If the drainage area is too large, the rain garden will get overloaded and tend to clog.

Slope

A rain garden should be placed on a relatively shallow slope, where the slope of the surrounding watershed is limited to two percent to ensure an acceptable rate of flow into the garden area. Adequate slope is needed to ensure the water entering the rain garden can be connected with the storm drain system as necessary.

Soil

The proper design of a rain garden depends on the infiltration rate of the existing soil. If infiltration rates are less than ¼ inch per hour, the soil will need to be amended or completely replaced (engineered) to promote immediate infiltration. Engineered soil mixes are generally a homogenized mixture of equal parts of sand, topsoil and compost. Local jurisdictions may have specific requirements that should be reviewed.

Groundwater Recharge

Rain gardens are often constructed to reduce volume, rate and pollutant runoff. Design variations can be added to enhance groundwater recharge if desired or send overflow to the stormwater conveyance system if necessary. If the rain garden is designed and constructed properly to achieve infiltration, many of the small storms of concern (water quality storms) will not discharge at all. As a result, groundwater recharge will be a secondary benefit. Additional techniques and plant selection will need to be considered where groundwater levels might intersect the rain garden bed.

Plant Selection

Plant selection should include native or adaptive species tolerant of both wet and dry cycles. Deep rooted perennial plants are encouraged to increase the rate of infiltration. Larger plants have greater root capacity than smaller plants. Ponding creates conditions normally harsh to seed germination, therefore, rain gardens may need to be planted from root stock instead of from seed. Trees and shrubs may be used, but occasionally sod is used. Avoid planting evergreens if the area is to be used for snow storage, because salt can kill plants via roots that do not go dormant in the winter time.

Plants should be selected based on their native or adaptive status to the location. In Missouri, Grow Native! is an excellent resource for visual and narrative descriptions of native plants. For more information, see www.grownative.org. Many of these plants grow throughout the Midwest.

Costs

Rain garden costs will vary depending on the site preparation and plant selection. If the rain garden is excavated and new growing media installed, it will consist of one set of costs. If the rain garden is not excavated and is just amended, costs will be much lower, although the volume management will be impacted.

A general rule of thumb is that residential rain gardens average about $3 to $4 per square foot, depending on soil conditions and the density and types of plants used. Commercial, industrial and institutional site costs can range between $10 and $40 per square foot. For additional cost discussion and design tools, see LID Urban Design Tools at www.lid-stormwater.net/bio_costs.htm.

These costs should be weighed against costs for conventional stormwater management and its limitations for meeting water quality requirements. In addition, rain gardens can be incorporated into the landscaping, where operation and maintenance costs are relatively minimal. Rain gardens are designed to capture rainfall at the source of runoff, and therefore are strategically small and distributed. As landscaped features, less watering is required – especially when planted with deep-rooting native or adaptive plants. Rain gardens do not consume as much land area as a conventional detention basin. If designed, installed and maintained properly, a string of rain gardens can meet water quality requirements at a cost less than or equivalent to conventional detention basins that do not meet required water quality controls. In addition, costs to the municipality are reduced when property owners assume responsibility for the minimal operation and maintenance. However, some cost is associated with keeping property owners educated about rain garden requirements.

Additional Considerations

Rain gardens do not provide significant channel protection, unless they are used in combination with other rain gardens or practices. A single rain garden is not designed to infiltrate large volumes. It is typically designed to treat and infiltrate the first inch of runoff. However, when used in combination with other rain gardens or practices, it can provide significant volume, rate and pollution reductions, thereby protecting channels as well.

Construction

Site Preparation and Grading

It is important to protect the designated location of the rain garden throughout the construction project. Avoid compacting the soil or creating other conditions unsuitable for supporting the rain garden.

An appropriate soil percolation rate should be established at each particular site. If the existing soils do not allow a sufficient rate of infiltration, a homogenized mixture of equal parts of sand, topsoil, and compost may be used in the rain garden to hasten infiltration. If there are concerns over long-term ponding as a result of low infiltration rates of the underlying soil, the site may need to be changed to be suitable for a rain garden. An underdrain may be used, although the relative cost of this added feature is often a concern.

Use river rocks or a filter strip to dissipate energy where water enters the garden.

- Design for rain gardens, rain barrels and cisterns should include an overflow point to accommodate severe rain events that may overload the system.

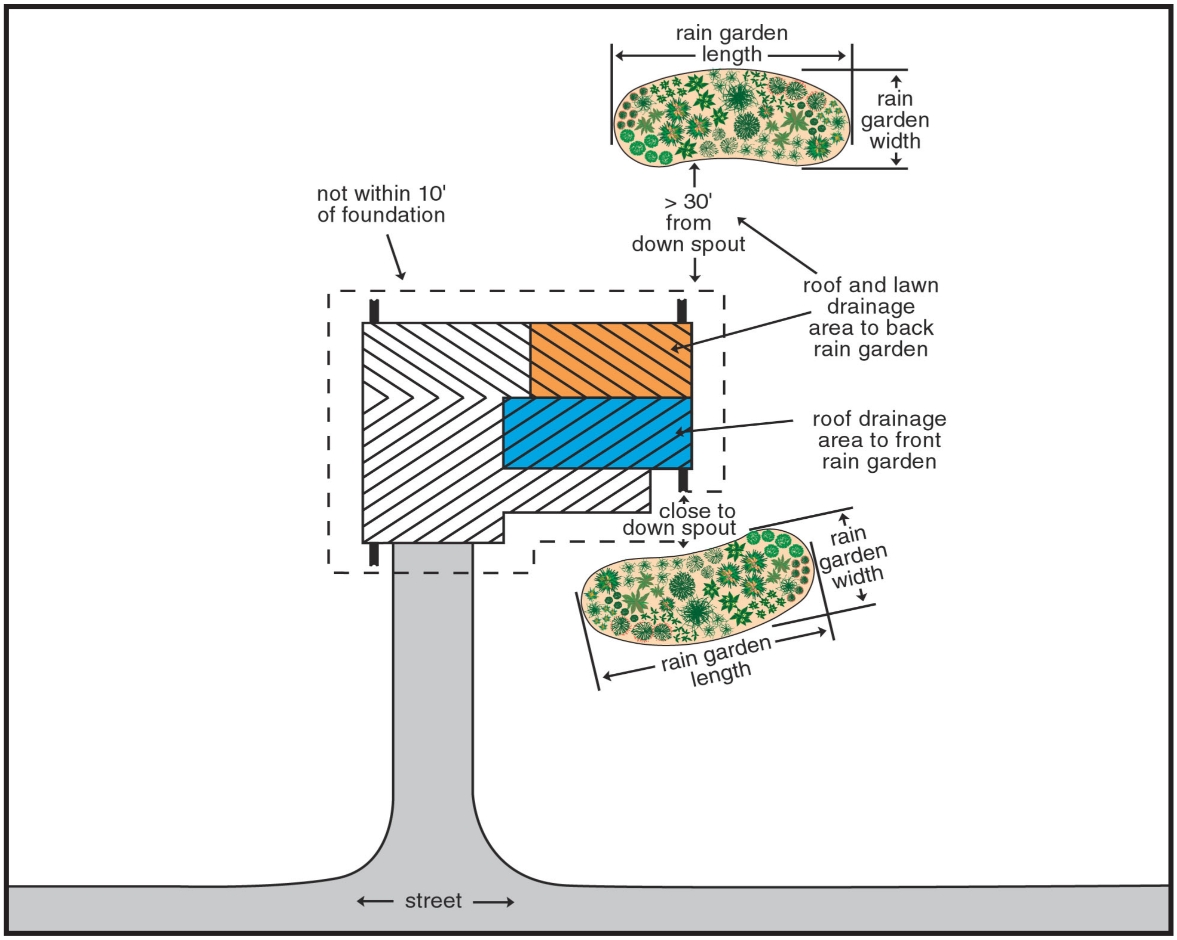

Figure 6:106 Rain garden schematic. Source: University of Wisconsin-Extension and the Wisconsin Department of Natural Resources.

Planting

- Construction and planting can be conducted year-round according to the plant type. The planting instructions for the plant should be followed.

Some engineered soil mixes may not provide sufficient strength for newly planted trees to stand in high winds. Tie straps may be needed or trees should be placed on the perimeter of the rain garden so their roots are anchored in stable soil.

Construction Verification

In the case of a professionally designed rain garden, measure the finished grades and configuration and compare them against the plans. Check elevations and dimensions of all pipes and structures.

Maintenance and Inspection

The success of a rain garden depends on careful construction and on proper follow-up care, including:

- Watering and weeding often during first growing season.
- Annual removal of dead vegetation each spring.
- Annual addition of mulch, if needed.
- Periodic inspection for soil erosion control, plant health needs and litter removal, as needed.

Common Problems and Solutions

Problem	Solution
Erosion, washout and poor plant establishment.	Check to ensure the rain garden was constructed properly. Repair eroded surface, provide fresh topsoil, reseed or re-vegetate, and apply new mulch.
Mulch is lost to wind or stormwater runoff.	Reapply mulch, use a heavier inorganic mulch (pea gravel).
Unsuccessful vegetation establishment.	Recheck soil conditions for tilth and for conditions suitable for plant growth. Choose plant species that prefer the site conditions. Reset plants during an appropriate planting season. Reapply mulch.

Disconnected Downspouts

Figure 6.107 Downspout Disconnection to a Rain Garden. Source: Courtesy of USDA-NRCS, Iowa

Practice Description

Conventional structures direct the runoff from roofs into gutters and downspouts that then flows to a hard surface (parking lot), an underground storm sewer system and in some cases a sanitary sewer system. Routing stormwater from a hard surface to a discrete channel creates a flow surge. These surges can easily overwhelm storm or sanitary sewer systems. By disconnecting downspouts and routing flow to rain gardens or other pervious areas, runoff is redirected and may prevent the collection system from overloading during heavy precipitation events. Roof runoff can be beneficially used when redirected to a yard or landscaped area, rain garden or a storage system for later use (rain barrel or cistern). See Figure 6.107 and sections on Rain Gardens on page 6-235 and Rain Barrels on page 6-245.

Recommended Minimum Requirements

Beneficial routing of downspouts may be applied to residential, commercial, industrial, or institutional properties. To ensure the designed routing of roof runoff does not result in other problems, the property owner should follow the guidance presented below:

- Discharge from pipe or downspout must not direct flow toward flood sensitive locations such as building foundations.

- Discharge point should be at least 10 feet from buildings and structures with basements or crawl spaces.

- Runoff should be discharged at least 5 feet from property boundaries, or at the furthest possible point from the adjacent property.
- Splash blocks or similar material may need to be used at the discharge point to dissipate erosive energy.
- Design for rain gardens, rain barrels and cisterns should include a designed overflow point to prevent damage to the system during severe rain events.
- Rain gardens, barrels or cisterns may need to be designed in combination across the property to attain desired reductions in volume and velocity and desired infiltration capacity.
- Discharge should be directed away from lateral sewer lines to avoid adding to inflow and infiltration problems.

Materials
Durable gutter grade materials such as aluminum, steel, copper, vinyl or plastic should be used.

Construction
Disconnecting downspouts can be simple or complex, depending on the site configuration, site requirements and goals. New projects can be readily designed to direct rooftop and similar runoff to rain gardens, barrels or cisterns. The site superintendent and field personnel should consult the site plan and specifications for direction about placement, special equipment and materials. To disconnect an existing downspout, most homeowners possess adequate skills to complete the project. See Appendix C and Appendix D for additional resources.

Installation
To disconnect an existing downspout, measure and cut approximately 9 inches above the sewer standpipe. The standpipe should be plugged or capped with an in-pipe test plug or an over the pipe cap secured with a hose clamp. An elbow and downspout extension may be secured with metal screws to the existing downspout. Downspouts must drain at least 6 feet from basement walls and at least 2 feet from crawl spaces. A splash block may be used at the end of the extension to help prevent erosion.

Maintenance and Inspection
Disconnecting a downspout typically requires minimal effort and minimal continued maintenance. Periodic maintenance activities include the following:
- Inspecting the discharge location to ensure drainage is working as intended.
- Replacing materials as needed; many materials can last 5 to10 years.
- Removing accumulated leaves or debris, 2 to 4 times per year.

Common Problems and Solutions

Problem	Solution
Foundation issues or water in the basement structure.	Downspouts must drain at least 10 feet from basement walls and at least 2 feet from crawl spaces.
Erosion where the downspout discharges.	A splash block may be used at the end of the extension to help prevent erosion.

Rain Barrels

Figure 6.108: Residential Rain Barrel. Source: *ABCs of MPs*

Practice Description

The roofs of many houses receive 600 to 1,000 gallons of water per one inch of rainfall. Rainwater falls on the roof, flows to the gutters and pours out of downspouts into the driveway or yard. Rain barrels intercept flow at the downspout, where it can be stored for use in watering nearby gardens or other landscape plantings. Usually the barrel is constructed with a 55 gallon drum, a flexible inlet pipe or hose, a spigot or closeable drain and a screen grate or closure to keep debris and insects out. Rain barrels are relatively simple and inexpensive to construct and can be placed under most residential gutter downspouts.

Recommended Minimum Requirements

Rain barrels may be applied to residential, commercial, industrial, or institutional properties. To ensure success, the property owner should follow the guidance presented below:

- Design for rain gardens, rain barrels and cisterns should include an overflow point to accommodate severe rain events that may overload the system.
- Locate the rain barrel directly under a downspout close to the structure.
- Carefully inspect screens to ensure mosquitoes cannot breed in barrels.
- Install a device to disconnect or divert water away during winter months to prevent damage from the freeze or thaw cycles.
- Provide an overflow that drains to a safe location.
- Direct overflow away from the foundation and away from lateral sewer lines.
- Secure the rain barrel to a level surface.
- Include a lid or screen that prevents the entry of mosquitoes and debris.

Construction

Installation of a rain barrel may be completed by homeowners, a property owner, or a qualified professional. Installation of a rain barrel should be in accordance with the critical elements described above. If the rain barrel is purchased from a retailer, it should be installed in accordance with the manufacturer's recommendations.

- The rain barrel should have an overflow that drains to a rain garden, bioswales or similar landscape feature.
- The rain barrel should be secured to a level surface.
- The barrel should have a lid that prevents the entry of mosquitoes and debris.

Installation

To install rain barrels on a new development, follow site plan specifications. When disconnecting an existing downspout, cut the downspout to the height necessary to accommodate the placement of the barrel. If the downspout entered a standpipe, the standpipe should be plugged or capped with an in-pipe test plug or an over-the-pipe cap secured with a hose clamp. An elbow and downspout extension may be secured with metal screws to the existing downspout and connected to the barrel. The overflow must drain at least 6 feet from basement walls and at least 2 feet from crawl spaces. A splash block may be used at the end of the extension to help prevent erosion.

Maintenance and Inspection

Installation of a rain barrel typically requires minimal effort and minimal continued maintenance. Periodic maintenance activities include the following:

- Checking the barrel and seals to ensure the system is working as designed and intended.
- Replacing materials or parts as needed.
- Removing accumulated leaves or debris a few times each year.

Common Problems and Solutions

Problem	Solution
Mosquitoes	Empty and clean the rain barrel. Ensure the screen (or spout-conformed lid) is properly in place and secured.
Foundation issues or water in the basement structure.	Route the overflow to drain further than 10 feet from basement walls and further than 2 feet from crawl spaces.
Erosion where overflows discharge.	A splash block may be used at the end of the extension to help prevent erosion

Cisterns

Figure 6.109: Residential Cistern. Source: Shockey Consulting Services

Practice Description

Practices that store rooftop runoff, such as cisterns or rain barrels can be installed as part of the overall on-site stormwater management system. A cistern collects and temporarily stores rain water runoff from an adjacent roof. Catchment capacity at many residential sites ranges between 600 to 1,000 gallons of water during a typical event. While cisterns may be applied to residential properties, their larger volume may make them especially beneficial in commercial or industrial settings where rooftops are expansive. Cisterns can be manufactured from various materials including plastic, concrete or metal. Installation costs are dependent on the material, size of application and location of the cistern (above or below ground).

Depending on local codes and available treatment methods, water collected in cisterns may be used in a variety of ways in the landscape and home. A common use is watering nearby gardens or other landscape plantings.

Recommended Minimum Requirements

Rainwater harvesting from rooftops is often considered pollutant-free, however, this runoff does contain low concentrations of pollutants such as plant debris, metals from roofing materials, nutrients from atmospheric deposition or bacteria from bird droppings. The levels of these pollutants are normally low enough to not inhibit its use for plant irrigation. Proper design and installation of the cistern will ensure problems relating to pollutants, such as system clogging, fouling, or odor, do not develop. Typically, rooftop runoff exiting the gutter system is screened to filter particles, before being routed to the cistern. Often, the design includes a method to prevent the initial flush of the roof, and its elevated amount of pollutants, from entering the cistern. Typically, collection containers should be constructed of dark materials or buried to prevent light penetration and the resulting algal growth.

Check the Uniform Plumbing Code or the International Plumbing Code; and regional and municipal building codes for criteria before initiating a rainwater harvesting project.

To ensure success, cistern construction should follow these important steps:

- For underground systems, the cistern should be a minimum distance of 100 feet from existing septic tanks and leach fields.
- Consider the depth of the water table when evaluating an underground system.
- Design of cisterns should include an overflow point to accommodate severe rain events that may overload the system.
- Choose appropriate cistern construction, drainage surfaces and filtering equipment to prevent contamination of the water supply.
- Ensure local requirements allow the construction and use of devices to catch and store rainwater.
- Review local codes for use and treatment of rainwater if its intended use is indoors.

Construction

Installation of a cistern may be completed by homeowners, a property owner, or a qualified professional. Installation of a cistern should account for four components:

- Route overflow to a safe location.
- Secure the cistern to a level surface.
- Include a conformed lid or screen to prevent entry of mosquitoes and debris.
- Install a disconnect and draining feature for use during winter months to avoid freeze or thaw damage.

Installation

Because the size, shape, materials and operation methods of marketed cisterns will vary significantly, the plans and specifications or the manufacturer's guidance should be carefully reviewed before purchase and closely followed during construction and use.

Maintenance and Inspection

Maintenance and inspection of a cistern will vary depending on the systems design and the intended use of the rainwater. Periodic maintenance activities include the following:

- Periodic checks of the system to ensure it is working as designed and intended.
- Periodic replacement of materials or parts.
- Annual removal of accumulated leaves or debris or as needed.

Additional requirements for rain water collection and use may be imposed at the local level.

Common Problems and Solutions

Problem	Solution
Mosquitoes.	Empty cistern and clean. Ensure the screen is properly fitted, or install a solid lid conformed around the drain pipe.
Foundation issues or water in the basement structure.	Route the overflow to an outlet point at least 6 feet from basement walls and at least 2 feet from crawl spaces. Increase the distance as necessary.
Erosion where overflows discharge.	Use a splash block at the end of the extension to help prevent erosion.

Green Roofs

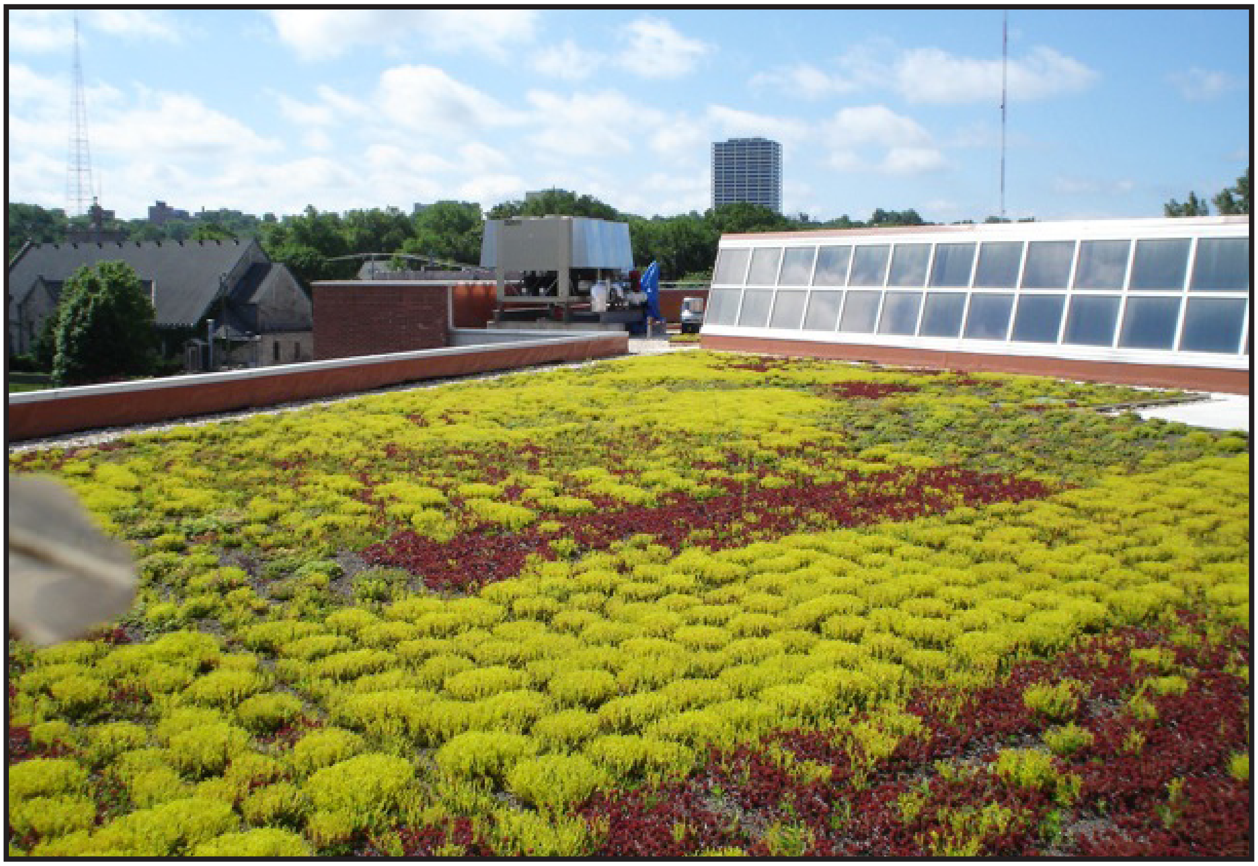

Figure 6.110: Boulevard Brewery, Kansas City, Missouri. Source: Boulevard Brewing Company

Practice Description

Green roofs are used to reduce stormwater runoff from commercial, industrial and residential buildings. In contrast to traditional roofing materials, green roofs absorb, store and evapo-transpire rainfall. Green roofs offer additional benefits including increased thermal insulation and energy efficiency, increased acoustic insulation and increased durability and lifespan.

These systems are generally classified as extensive, semi-intensive or intensive. Extensive green roofs have 6 inches or less of growing medium, whereas intensive green roofs have greater than 6 inches of substrate. Semi-intensive green roofs can be defined as a hybrid between intensive and extensive green roofs, where at least 25 percent of the roof square footage is above or below the 6 inch depth. Semi-intensive and intensive green roofs are classified as roof gardens and are typically designed to be open to foot traffic for outdoor enjoyment.

Green roofs may be used in new construction or retrofitted to existing structures. They are applicable to residential, commercial and industrial buildings and can be constructed on roofs with up to a 20 percent slope. In retrofit applications, the existing roofing should be examined for adequate structural strength.

Pollutant Removal

According to *Opportunities and Challenges for Managing Nitrogen in Urban Stormwater: a Review and Synthesis* (see Appendix C and Appendix D), mature green roof vegetation can likely take up more nutrients from rainfall and media than younger, less established green roofs. Although there is a limited body of research available nitrogen removal capabilities of green roofs, studies suggest using low to medium dosages of controlled-release fertilizers, planting species that require little or no fertilization, using less nutrient-rich organic matter amendments in green roof media and reducing irrigation to avoid creating runoff can minimize the amount of nitrogen runoff. Consequently, additional pollutants of concern such as phosphorus will also be controlled.

Additional Considerations

Structural support is critical to increased media thickness necessary to promote denificriciation and therefore green roofs are generally not an option as a retrofit practice. Opportunities are greater for incorporating adequate support into new construction, but can add to the cost of materials by an estimated six percent. However, construction costs should be weighed against reduced heating and cooling costs, increased stormwater pollution control, reduced heat island effect and increased usable space in the case of rooftop gardens designed for social activity.

Recommended Minimum Requirements

In any application, the building must be able to support the loading of green roof materials under fully saturated conditions. An extensive vegetated roof cover is typically designed with 2- to 6-inches of engineered planting media. The media should have a high mineral content and is typically 85 percent to 97 percent non-organic materials. Fertilization should be tightly controlled on vegetated roofs intended to achieve water quality benefits, because over fertilization will defeat the purpose of pollution prevention from rooftop runoff. Internal building drainage should be addressed to ensure deck drains or scuppers are protected during large rain events. Typically, vegetated roofs are grown on conventional flat roofs. Assemblies planned for roofs with pitches steeper than 2:12 should incorporate supplemental measures to provide stability and prevent sliding. Generally, the designer should consider a waterproofing layer, a soil or substrate layer that has adequate pore space and rapid infiltration capacity, and a plant layer well-suited for local climatic conditions. Plant materials range from sedums, grasses and wildflowers on extensive roofs to shrubs and small trees on intensive roofs. The designer should consult local building codes for roof safety requirements. Necessary permits and zoning laws for building a green roof in new construction or as a retrofit to existing buildings will vary between cities.

Construction

Green roofs and roof gardens have a variety of benefits. Since this SCM integrates structural components, consultation of a design engineer is necessary. Projects should closely follow plans and specifications. The following provides an example of a construction sequence. Professional guidance or contract documents may dictate a different approach depending on the project.

- Comply with all building codes and local regulations.
- Visually inspect the completed waterproofing to identify any apparent flaws, irregularities, or conditions that will interfere with the security or functionality of the green roof. The waterproofing should be tested by the roofing applicator.
- Institute a leak protection program.
- Develop measures to protect the finished waterproofing from physical damage during construction.

- Install measures to stabilize the substrate in the case of a pitched roof slope.
- Install a root barrier, if the waterproofing materials are not impenetrable to roots.
- Install and test drainage and irrigation components, including drain access chambers, internal drainage conduit, confinement border units and isolation frames.
- Install walkways and paths for projects with public access. Ensure local codes are satisfied to ensure public safety.
- Install a drainage layer, such as a geocomposite drain mat or course of drainage media and cover the layer with a separation fabric such as a geotextile.
- Install and upper growth media layer in dual media assemblies.
- Establish plants from cuttings, seed, plugs or mats and select plants based on their toleration of periods of drought and inundation. Plant material is an integral component of a green roof.
- The contractor should provide protection from wind damage as warranted by the project conditions during the plant establishment period.

Construction Verification
Measure the finished grades and configuration against the plans and specifications. Check elevations and dimensions of all pipes and structures.

Maintenance and Inspection
Green roofs need to be monitored regularly during the first growing season to ensure success. During the plant establishment period, periodic irrigation may be required. Quarterly maintenance during this period includes basic weeding and in-fill planting. Periodic inspection and roof maintenance should be performed as necessary to ensure the system is working as designed. Irrigated systems will require maintenance per manufacturer's recommendations.

Common Problems and Solutions

Problem	Solution
Insufficient vegetation.	Test irrigation and soil characteristics to ensure satisfactory growing conditions. Replace vegetation where absent. Ensure adequate inspection and maintenance.
Weeds and invasive vegetation during the establishment phase.	Remove manually. Plant adaptive and competitive species of vegetation to reduce bare areas and weed growth. Ensure adequate inspection and maintenance.

Surface Runoff Control Practices
Bioretention System

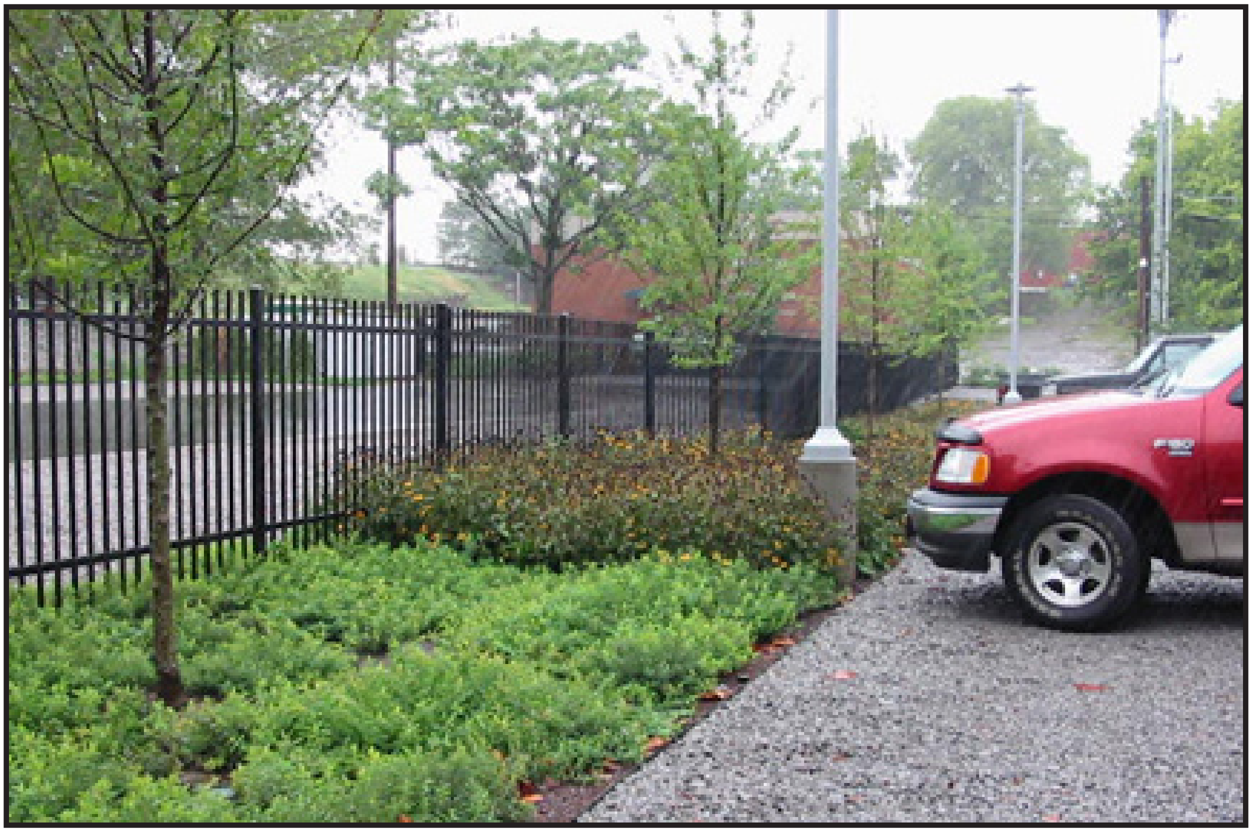

Figure 6.111: Bioretention. Source: *Green Infrastructure Digest*

Practice Description

A bioretention system is a landscaped parcel built into a natural or constructed depression; it is designed to provide on-site treatment of stormwater runoff. Bioretention systems can be located in parking lot islands or within residential areas. These systems are designed to incorporate many of the pollutant removal mechanisms that operate in natural ecosystems. During storm events, runoff water enters the bioretention system and filters through the mulch and prepared soil mix. The filtered runoff can be collected in a perforated underdrain and returned to the storm drain system. Excess runoff from larger storms is generally diverted past the facility to the storm drain system.

To achieve maximum efficiency, bioretention systems should be applied to small sites, typically less than a few acres. The drainage in larger sites should be portioned and served by more than one bioretention practice. Bioretention systems are ideal for treating runoff in urban areas and can easily be incorporated into parking lot islands or other landscaped areas. Bioretention areas may be used to treat stormwater from highly polluted areas, however, in this case, an impermeable liner may be needed below the filter bed to prevent the infiltration of pollutants into the deeper soil layers.

Recommended Minimum Requirements

Bioretention systems are adaptable to most sites and blend well with buffers, landscape berms, and environmental setback areas. The site layout of a bioretention system should be based on the contributing drainage area, underlying soils, utilities and existing vegetation. A bioretention cell should have an underdrain system, overflow, aggregate filter, planting soil bed, a mulch layer and plants that can withstand periods of inundation and drought. A bioretention cell should be designed to capture the water quality volume and to filter this water through the planting soil bed over 1 to 3 days. The cell of adequate length and width should be strategically positioned against the slope in order to maximize the capture of runoff. Inflow velocities should be reduced to less than 3 feet per second upstream of the area. Typically, a vegetated filter strip or rock diaphragm is required to reduce runoff velocities and provide a level of pretreatment. The designer should review local requirements for site grading, drainage structures, erosion and sediment control, and potential invasive vegetation.

Construction

Prior to start of construction, this SCM should be designed by a registered design professional as part of the overall site design for long-term water quality. Plans and specifications should be referred to by the site superintendent and field personnel throughout the construction process.

Site Preparation and Grading

Prior to excavation activities of any type, call 1-800-DIG-RITE (344-7483) to obtain utility locations.

The bioretention cell can be excavated before final stabilization of the surrounding watershed; however, the soil mixture and underdrain system should not be placed until the entire contributing drainage area has been stabilized. Any sediment from construction operations deposited in the bioretention cell should be completely removed from the cell after all vegetation, including landscaping within the affected watershed, has been established. Excavations performed during the construction of the cell should be limited to only that necessary to create the cell and to blend the cell with the surrounding watershed. Final graded dimensions, side slopes, and final elevations should be constructed according to design drawings and specifications. Low ground-contact pressure equipment, such as excavators and backhoes, is preferable to minimize disturbance of established areas around the perimeter of the cell. No heavy equipment should operate within the perimeter of a bioretention cell during underdrain placement, backfilling, planting or mulching of the facility.

The final steps to creating the bioretention cell should include stabilizing all surfaces and beginning a regular inspection and maintenance program.

Installation

The basic components of installing a bioretention cell include an underdrain system, overflow, aggregate, planting soil bed, a mulch layer and plant establishment.

Underdrain

An underdrain increases the ability of the soil to drain quickly and therefore ensures an adequate aerobic state that allows plants to grow. A minimum 4-inch perforated pipe with an 8- to 12-inch gravel bed should be installed as an underdrain system. At least one cleanout should be installed every 50 feet on each run. The underdrain should be connected to a up-to-date stormwater management system with adequate capacity or daylight to a suitable outfall with erosion protection. Before placing the aggregate, underdrain and bioretention soil mixture, the bottom of the excavation area should be roto-tilled to a minimum depth of 6-inches to alleviate any compaction that might impede infiltration. The soil should be in a friable condition before any roto-tilling occurs, meaning the soil can be reduced to smaller pieces with little effort, and therefore isn’t susceptible to clumping or compacting.

Overflow
Overflow components of the bioretention cell include the gravel underdrain system, an aggregate overflow curtain drain, and a high-flow overflow structure. A properly designed overflow will prevent a washout of the cell's components or a reconcentration of flow.

Aggregate Versus Sand
Aggregate provides a greater porosity and is less likely to clog when compared to a sand bed. A graded aggregate filter is preferred over soil, sand, pea gravel and course gravel. If a soil surface for planting is desired, a geotextile fabric should separate the soil from the aggregate. Alternatively, a sand bed can be used underneath the soil bed. The aggregate or sand provides additional filtration, allows aeration of the planting soil bed and therefore does not need to be separated from the soil by a geotextile fabric.

Planting Soil
A planting soil bed is a mixture of organic mulch, planting soil and sand. Typically, the mixture consists of 30 percent planting soil, 20 percent organic compost and 50 percent sand. Clay should be limited to less than 10 percent. To enhance nutrient uptake, the soil must have chemical and physical properties suitable to support a diverse microbial community. The planting soil should be placed on top of the aggregate or sand layer, and should be separated with a geotextile fabric. It should have a minimum depth of 2.5 feet to provide adequate moisture capacity and create space for the root systems of plants. If larger vegetation is used (i.e. trees or shrubs), the planting soil must be at least 4-inches deeper than the bottom of the largest root ball. This soil mix will tend to not be as firm as natural soils, so larger trees or shrubs should be supported with guy wires or similar support. The planting soil mixture, alternately called the bioretention soil mixture, should be free of stones, stumps, roots, or weedy material over 1-inch in diameter. Brush or seeds from noxious weeds should not be present in the material.

A simple bio-soil permeability test is to use a 55-gallon drum with holes in the bottom. Fill the bottom of the drum with the proposed mix until it is 1-foot from the top. Fill the barrel to the top with water and time how long it takes the water to drop 1-foot. A target rate of 2-inches per hour is common.

Plants
Trees, shrubs and other plant materials should be installed as specified in the project plans and according to applicable landscape standards with the exception that pesticides, herbicides and fertilizer should not be applied during planting under any circumstances. Pesticides, fertilizer and other soil amendments should be applied after plants are through initial shock and are growing. Plant selection should include native species tolerant of both wet and dry cycles.
Deep rooted perennials are encouraged to increase the rate of infiltration

For a list of suitable plant species, refer to Appendix C for the *Landscape Guide for Stormwater Best Management Practice Design*, St. Louis, Missouri. Also, see Grow Native! at www.grownative.org for photos and narrative description of plant species native to Missouri and the Midwest region. See additional plant information resources in Appendix C and Appendix D.

Mulch
The final layer of the bioretention cell is the mulch. The contractor should install a shredded hardwood mulch aged a minimum of six months and consists of a 50/50 combination of bark and wood from hardwood trees. The mulch should be milled and screened to a maximum 4-inch particle size and should be free from sawdust, clay, trash and any artificially introduced chemical compounds.

Construction Verification
Measure the finished grades and configuration and compare to plans and specifications. Check elevations and dimensions of all pipes and structures.

Maintenance and Inspection

For the first 1 to 3 years, bioretention systems require significant maintenance to ensure successful establishment. The primary maintenance requirement is inspection, repair and replacement of damaged or failed components. Routine inspections for standing water and corrective measures to restore proper infiltration rates are necessary. Invasive or weedy vegetation should be removed immediately upon discovery. During the first growing season, watering and weeding should be completed on a weekly basis. Over the lifetime of the facility, dead vegetation should be removed and mulch should be added each spring. Annual maintenance should include periodic inspection of soil erosion and plant health, as well as removal of litter when necessary.

Common Problems and Solutions

Problem	Solution
Erosion, washout and poor plant establishment.	Check topsoil and repair eroded surface. Reseed or re-vegetate and apply new mulch.
Mulch is lost to wind or stormwater runoff.	Reapply mulch, consider inorganic mulch in some areas.
Cells collect trash and debris.	Typical maintenance.
Standing water.	Check underdrains for clogging. Incorporate additional aggregate or sand into the soil mixture.
Unsuccessful vegetation establishment.	Examine the cell for stress factors (e.g, extended pooling, low fertility in planting medium, wildlife damage) and take corrective action.
Tall, lanky native plants.	Consider soil combinations more conducive to native plant growth in the original design. Amend the soil as necessary.

Bioswales (Vegetated Swales)

A bioswale or vegetated swale is an infiltration and filtration method typically used to pre-treat urban stormwater runoff. Bioswales can have volume and pollution reduction effects. There are generally three types of vegetated swales referred to as urban runoff management options:

- Dry swales with filter media.
- Wetland swales.
- Turf swales.

When determining whether to use a bioswale or other technology in overall site design, consideration should be given to the drainage area size, impervious area and water quality goals. Water quality swales should be used in areas where either the drainage area is small, or the impervious area is small, or both. Otherwise, larger conveyance design storms become incompatible with the features needed to provide water quality benefit (e.g., vegetative filtering, erosion).

The main difference between a bioswale and bioretention is that bioswales have a conveyance function for storms greater than the small storm (water quality storm). (See Bioretention Systems on page 6-257.) A standard bioretention system or cell does not have a conveyance function, but rather a bypass (overflow inlet) for greater storms. Wetland swales, as well as wetlands, are preferred in areas where groundwater stays charged enough to support the diverse group of wetland plants. However, wetlands are preferred over wetland swales where there is a greater need for volume reduction in addition to water quality.

All swale designs need to include a hydraulic analysis of the swale during larger storm events. The design of the larger storm events should be based on local conveyance requirements, which are typically a 10- or 15-year storm event. Many communities also have a freeboard requirement, which means the maximum water surface elevation for the design storm should be so many feet below the top of the channel, depending on the design specifications. For example, the freeboard requirement throughout St. Louis County, MO is 1-inch, but sometimes the requirement is waived for smaller “basins” depending on the risk of an overtopping event.

For a list of suitable plant species, refer to Appendix C for the *Landscape Guide for Stormwater Best Management Practice Design, St. Louis, Missouri*. Also, see Grow Native! at www.grownative.org for photos and narrative description of plant species native to Missouri and the Midwest region. See additional plant information resources in Appendix C and Appendix D.

Dry Swale

Figure 6.112 Native Parking Lot Bioswale. Anita B. Gorman Conservation Discovery Center - Kansas City, Missouri.

Practice Description

Dry swales are broad and shallow channels with vegetation covering the side slopes and channel bottom. These swales use native or adaptive plant species, and unlike the wetland swale include an engineered soil mix, a graded filter and an underdrain system for drainage to promote growth of dry swale plants. They are similar to wetland swales in that they convey stormwater runoff slowly, promoting infiltration and treatment. Their broad, shallow, vegetated channels promote infiltration, plant transpiration, adsorption, settling of suspended solids and breakdown of pollutants.

Dry swales can replace curb and gutter storm sewer systems to convey shallow concentrated flow. These swales promote infiltration and filter pollutants through creating low (slow flow) gradients, using soil and mulch to promote pollutant absorption and dense plant growth, and establishing plant species that can biologically uptake soluble pollutants. This SCM often enhances the aesthetic value of a site with minimal maintenance. It is particularly applicable in natural depressions adjacent to roads.

Recommended Minimum Requirements

The dry swale should be planted with dense, low-growing native or adaptive vegetation that can withstand periods of inundation and drought, and be salt tolerant. Longitudinal slopes should range between one and six percent and side slopes should be between 3:1 and 5:1 (horizontal distance to vertical rise referred to as H:V). Check dams may be used to provide limited detention storage and to develop a milder slope. The bottom width of the swale is typically less than 8-feet but may be sized to convey flow as required. The swale should be sized to convey the design storm event with a minimum of 6-inches of freeboard.

To determine the optimal location for a dry swale, soil conditions and compaction should be tested. Swales provide the most benefit when located adjacent to an impervious surface but can be used in combination with porous pavement. The designer should review local requirements for site grading, erosion and sediment control, and potential invasive vegetation.

For a list of suitable plant species, refer to Appendix C for the *Landscape Guide for Stormwater Best Management Practice Design, St. Louis, Missouri*. Also, see Grow Native! at www.grownative.org for photos and narrative description of plant species native to Missouri and the Midwest region. See additional plant information resources in Appendix C and Appendix D.

Construction

Prior to excavation activities of any type, call 1-800-DIG-RITE (344-7483) to obtain utility locations.

Prior to start of construction, this SCM should be designed by a registered design professional as part of the overall site design for long-term water quality. Plans and specifications should be reviewed by the site superintendent and field personnel throughout the construction process.

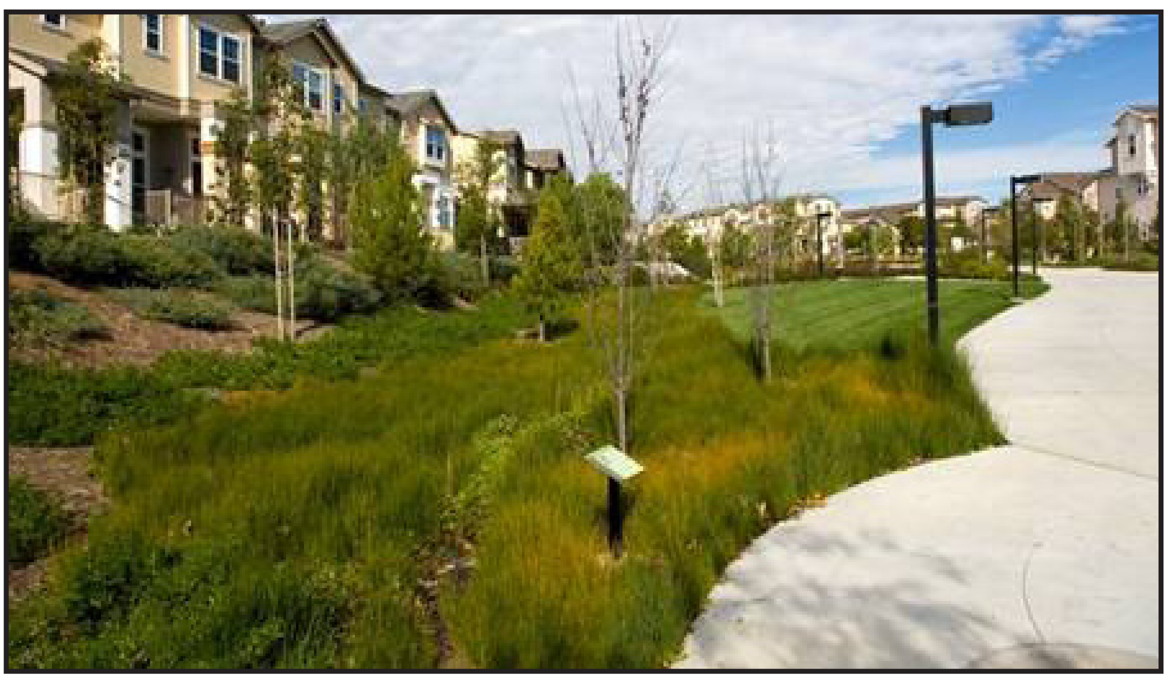

Figure 6.113: Native Vegetated Swale Source: EDAW, EACOM

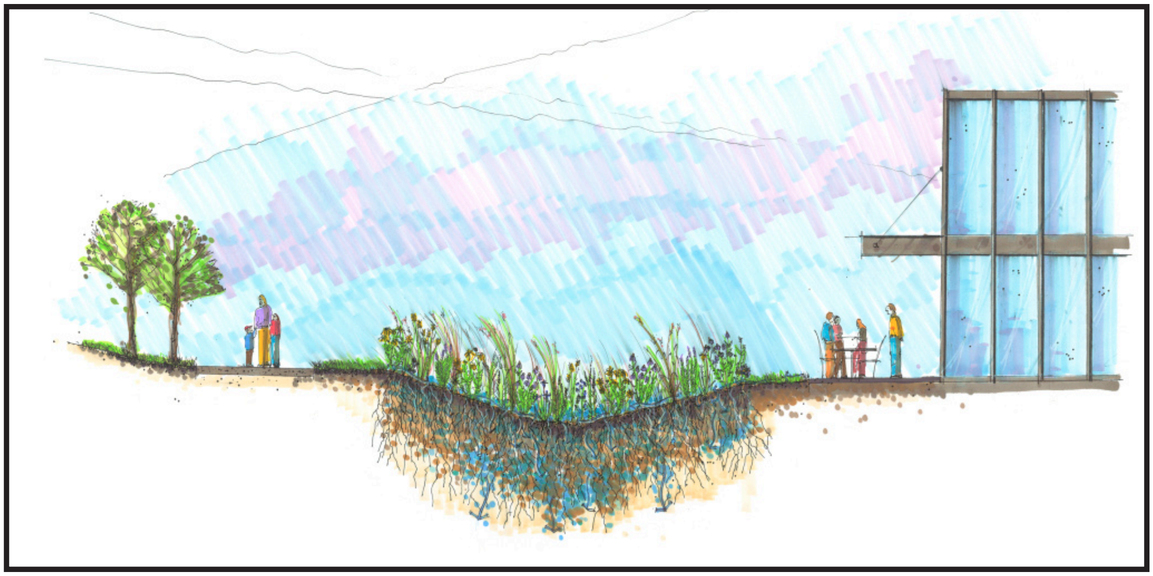

Figure 6.114 Bioswale Cross-sectional Diagram Source: NRCS, Iowa, www.ia.nrcs.usda.gov

The dry swale construction should begin only when upgradient temporary erosion and sediment control measures are in place to prevent sediment laden stormwater from depositing unwanted soil into the swale and reducing the infiltration efficiency. An example construction sequence follows:

- Rough grade the swale. It is critical excessive compaction or land disturbance be avoided when parking or using equipment, otherwise it will be necessary to amend or replace compacted soils. Excavating equipment should operate from the side of the swale and never on the bottom.

- The underdrain should be installed after the site has been rough graded. An underdrain increases the ability of the soil to drain quickly and therefore ensures an adequate aerobic state that allows plants to grow. A minimum 4-inch perforated pipe with an 8-inch gravel bed should be installed as an underdrain system. Filter fabric should be placed over the gravel bed to separate it from the planting soil bed. At least one cleanout should be installed every 50 feet. The underdrain should be connected to a conventional stormwater management system (pipes) or to an open conveyance (daylighted) to a suitable outfall with erosion protection.

- The overflow components of the bioswale include the gravel underdrain system and a high-flow overflow structure. It is critical to provide a safe discharge point for overflows.

- Install the aggregate or sand layer. Aggregate provides a greater porosity and is less likely to clog when compared to a sand bed. It is acceptable to place an 8-inch layer of aggregate underneath the planting soil bed, when it is separated by a geotextile fabric.

- Install the planting soil with careful attention to match the design grading. A planting soil bed is a mixture of organic mulch, planting soil, and sand. Typically, the mixture consists of 30 percent planting soil, 20 percent organic compost, and 50 percent sand. To enhance nutrient uptake, the soil must have a combination of chemical and physical properties that have the capacity to support a diverse microbial community. The planting soil should be placed on top of the aggregate or sand layer, separated by a geotextile fabric. The planting soil mixture, sometimes called a bioretention soil mixture, should be free of stones, stumps, roots or weedy material more than 1-inch in diameter. Brush or seeds from noxious weeds should not be present in the material.

- Seed, vegetate and install protective lining according to the plans and final planting list. Plant the swale at a time of the year when successful establishment without irrigation is most likely. Temporary irrigation, however, may be needed in periods of drought. Vegetation should be established as soon as possible to prevent erosion and scour.

  For a list of suitable plant species, refer to Appendix C for the *Landscape Guide for Stormwater Best Management Practice Design*, St. Louis, Missouri. Also, see Grow Native! at www.grownative.org for photos and narrative description of plant species native to Missouri and the Midwest region. See additional plant information resources in Appendix C and Appendix D.

- After all tributary areas are sufficiently stabilized, remove temporary erosion and sediment controls. It is important for the swale to be stabilized before receiving upland flow.

Construction Verification
Measure the finished grades and configuration and compare with the plans and specifications. Check elevations and dimensions of all pipes and structures.

Maintenance and Inspection
The required maintenance associated with bioswales is minimal. Typically, maintenance strategies for swales focus on sustaining the hydraulic and pollutant removal efficiency of the channel, as well as maintaining a diverse vegetative cover. Specific maintenance activities should occur within 48 hours after every storm event greater than a 1-inch rainfall until the plantings and vegetation are fully established. The maintenance activities should include:

- Repair erosion problems, damage to vegetation and remove sediment and debris accumulation.
- Vegetation on the side slopes should be inspected for erosion and formation of rills and gullies.
- Pools of standing water should be dewatered and discharged to an approved location and the design grade should be restored.
- Vegetation should be mowed or trimmed, as necessary to ensure safety, aesthetics, or to suppress weeds and invasive vegetation.
- The uniformity of the swale cross section and longitudinal slope should be inspected.
- The swale inlet and outlet should be inspected for signs of erosion or sediment accumulation.

Other maintenance activities should be completed as needed:

- Alternative vegetation may be planted if the existing vegetation is not thriving.
- Bare areas should be reseeded or revegetated and the appropriate erosion control measures should be installed when soil is exposed.
- During the period of establishment, the swale may need to be watered during dry periods.

Depending on the characteristics of the contributing drainage area, winter conditions may necessitate additional maintenance. The swale should be inspected at the beginning of spring for residuals of sand or salt. Moderate amounts of these materials might affect vegetative growth. Damaged vegetation should be replaced. If roadside or parking lot runoff drains to the swale, mulching or soil aeration may be required in the spring to restore the soil structure.

Common Problems and Solutions

Problem	Solution
Draw down time is greater than 72 hours.	Clean out underdrain system, ensure it is clear.
Erosion occurs on the side slope and bypasses the check dam.	Increase the length of the check dam so the lowest point is in the center of the swale.
Significant erosion between check dams.	Install additional check dam and follow recommended guideline for spacing.
Poor vegetative growth due to roadway salt accumulation.	Use nontoxic deicing agents, applied as blended magnesium chloride based liquid or as pretreated salt. Plant salt tolerant vegetation. Avoid evergreens, because roots that do not go dormant are susceptible to salt kill.
Unsuccessful vegetation establishment due to plant intolerance to conditions.	Plant selection should include native species tolerant of both wet and dry cycles and plants should be established in appropriate zones. Deep rooted perennials are encouraged to increase the rate of infiltration.

Wetland Swale

Figure 6.115: Wetland Swale. Source: Olsson Associates

Practice Description

Wetland swales are broad, shallow channels with native vegetation covering the side slopes and emergent vegetation covering the channel bottom. Unlike a dry bioswales, these swales do not include a prepared soil filter bed or underdrain system. Stormwater runoff is slowly conveyed resulting in higher rates of infiltration, plant transpiration, pollutant adsorption, settling of suspended solids and microbial breakdown of pollutants.

Wetland swales can replace curb and gutter storm sewer systems and may be used anywhere the water table is at or near the surface. These swales are well suited for roadside applications, along the property boundaries of development or in areas where stormwater tends to collect for extended periods of time.

Recommended Minimum Requirements

The wetland swale should be planted with dense, low-growing native vegetation that can withstand periods of inundation, drought and soils with high electrical conductivity (high salt content). Longitudinal slopes should range between one and six percent and side slopes should be between 3:1 and 5:1 (H:V). Check dams may be used to provide limited detention storage and to develop a slower flow rate. The bottom width of the swale should be between 2- and 8-feet. The swale should be sized to convey the largest/average 24-hour, 10- to 15-year storm event with a minimum of 6-inches of freeboard (based on local conveyance requirements).

To determine the optimal location for a wetland swale, soil conditions and compaction should be tested. Swales provide the most benefit when located adjacent to an impervious surface but can be used in combination with porous pavement. The designer should review local requirements for site grading, erosion and sediment control, and potential invasive vegetation.

For a list of suitable plant species, refer to Appendix C for the *Landscape Guide for Stormwater Best Management Practice Design*, St. Louis, Missouri. Also, see Grow Native! at www.grownative.org for photos and narrative description of plant species native to Missouri and the Midwest region. See additional plant information resources in Appendix C and Appendix D.

Pollutant Removal

The wetland swale has water quality treatment mechanisms similar to stormwater wetlands, which rely primarily on settling of suspended solids, adsorption and uptake of pollutants by vegetative root systems. Chloride contamination of shallow groundwater tables should always be of concern in the design and application of wetland swales.

Construction

Prior to excavation activities of any type, call 1-800-DIG-RITE (344-7483) to obtain utility locations.

Prior to start of construction, this SCM should be designed by a registered design professional as part of the overall site design for long-term water quality. Plans and specifications should be reviewed by the site superintendent and field personnel throughout the construction process.

The wetland swale is constructed directly within existing soils and may or may not intercept the water table. Like the dry swale, the water quality volume within the wet swale should be stored for approximately 24 hours. The wetland swale has water quality treatment mechanisms similar to stormwater wetlands, which rely primarily on settling of suspended solids, adsorption, and uptake of pollutants by vegetative root systems. These systems are often called wetland channel systems since they are basically a linear shallow wetland system.

The wetland swale construction should begin only when the upgradient temporary erosion and sediment control measures are in place. An example construction sequence follows:

- Rough grade the swale. Equipment should avoid excessive compaction or land disturbance. Excavating equipment should operate from the side of the swale and never on the bottom. If excavation leads to compaction of the subgrade, 18-inches should be removed and replaced with a blend of topsoil and sand to promote infiltration and the establishment of plants and microbes. Topsoil shall be thoroughly deep plowed into the subgrade in order to penetrate the compacted zone and promote aeration and the formation of macropores. Following this, the area should be disked prior to final grading of topsoil.

- Construct check dams, if required.

- Fine grade the swale. Accurate grading is critical for swales because even the smallest nonconformities may compromise flow conditions.

- Seed, vegetate and install protective lining as per approved plans and according to final planting list. Plant the swale at a time of the year when successful establishment without irrigation is most likely. Temporary irrigation, however, may be needed in periods of drought.

- Vegetation should be established as soon as possible to prevent erosion and scour, however it make take a few years for plants to become fully established.

After all tributary areas are sufficiently stabilized, temporary erosion and sediment controls may be removed. It is important for the swale to be stabilized before receiving upland flow.

Maintenance and Inspection

The required maintenance associated with wetland swales is minimal. Typically, maintenance strategies for swales focus on sustaining the preferred hydraulic flow and pollutant removal efficiency of the channel, as well as maintaining a higher biological richness through promoting microbial growth and a diverse vegetative cover. The following maintenance activities should occur within 48 hours after every storm event greater than 1-inch rainfall.

- Repair erosion problems, damage to vegetation and remove sediment and debris accumulation.
- Vegetation on the side slopes should be inspected for erosion and formation of rills and gullies.
- Pools of standing water should be dewatered and discharged to an approved location and the design grade should be restored.
- Vegetation should be mowed or trimmed, on an annual basis, as necessary to ensure safety and aesthetics, or to suppress weeds and invasive vegetation. Mowing equipment should avoid wet areas where compaction of the swale and erosion would be potential issues.
- Use wet tolerant plants in the bottom of the swales so the area will not be bare or begin to collect sediment. See available plant resources in Appendix C and Appendix D.
- The uniformity of the swale cross section and longitudinal slope should be inspected.
- The swale inlet and outlet should be inspected for signs of erosion or sediment accumulation.

Other maintenance activities should be completed as needed:

- Alternative plant species may be planted if the existing vegetation is not thriving.
- Bare areas should be replanted and the appropriate erosion control measures should be installed when soil is exposed.
- If the drawdown time is greater than 48 hours, the swale should be roto-tilled and replanted.
- Check dams should be repaired if channelization and erosion are identified.
- During the period of establishment, the swale may need to be watered during dry periods.

Depending on the characteristics of the contributing drainage area, winter conditions may necessitate additional maintenance. The swale should be inspected at the beginning of spring for residuals of sand or road salt. Moderate amounts of these materials may affect the plant and microbial growth. Damaged vegetation and contaminated soils should be replaced. If roadside or parking lot runoff drains to the swale, mulching or soil aeration may be required in spring to restore the soil structure.

Common Problems and Solutions

Problem	Solution
Erosion occurs on the side slope and bypasses the check dam.	Increase the length of the check dam so the lowest point is in the center of the swale.
Significant erosion between check dams.	Install additional check dam and follow recommended guideline for spacing.
Poor vegetative growth due to roadway salt accumulation.	Use nontoxic deicing agents, applied as blended magnesium chloride based liquid or as pretreated salt. Plant salt tolerant vegetation. Avoid evergreens, because roots that go dormant in the winter time can take up salt and kill the plants.
Unsuccessful vegetation establishment due to plant intolerance to conditions.	Plant selection should include native or adaptive species tolerant of both wet and dry cycles. Plants should be established in appropriate climate zones. Deep rooted perennials are encouraged to increase the rate of infiltration.

Turf Swale

Figure 6.116 Turf Swale. Source: N. Klopfenstein, NRCS, Cole County

Practice Description

A turf swale is also referred to as grass-lined channel, grass waterway or grass swale, and it differs from dry or wet bioswales in that no special provisions or materials are included to maximize infiltration or pollution reduction.

Typically, an objective for constructing a turf swale is for the purpose of handling concentrated surface runoff in such a way as to prevent damage from erosion and the resulting sedimentation downgradient. However, turf swales offer the least amount of water quality and volume control when compared to other bioswales or bioretention options.

This practice has historically been used for sites where:

- Concentrated runoff is expected to cause erosion damage.
- Sufficient stability for the channel can be achieved through a vegetative lining.
- Channel grades are generally less than 5 percent.
- Significant space is available to allow for a sufficient channel width for gentle side slopes.

However, this practice is basically a conveyance ditch, which does not serve as a stormwater control measure adequate to control peak flow for water quality or design storms. If used at all, this practice should be limited to linear projects.

Typical uses include roadside ditches, channels at property boundaries, outlets for diversions and stabilizing concentrated flow areas. The grass-lined channel will provide better infiltration and greater root structure if the vegetation is allowed to grow to its full height and not mowed short, serving more as a vegetated dry swale described previously in this section. Selective native or adaptive grasses can provide a functional root depth up to 15 feet, whereas mowed turf grasses provide 1- to 2- inches of root structure. Colored photos and specifications of Missouri native plants are available at www.grownative.org.

Recommended Minimum Requirements

Prior to start of construction, grass-lined channels should be designed by a registered design professional as part of the overall site design for stormwater management. Plans and specifications should be reviewed by the site superintendent and field personnel throughout the construction process. The channel should be built according to planned alignment, grade and cross section. Some of the typical features are:

Cross Section

Trapezoidal or parabolic.

Side Slopes

3:1 or flatter for trapezoidal channels.

Channel Stabilization

Use erosion control blankets, turf reinforcement mats or other appropriate practices as specified in the design plan.

Outlet

Channels should empty into sediment traps, detention/ retention basins or stable outlets.

Subsurface Drain

Use in areas with seasonally high water tables or seepage problems.

Construction

Site Preparation

Prior to excavation activities of any type, call 1-800-DIG-RITE (344-7483) to obtain utility locations.

Install sediment traps or drains if needed. Remove brush, trees and other debris from the construction area and dispose of properly.

Grading

Excavate and shape the channel to dimensions shown on the design specification, removing and properly disposing of excess soil so surface water can enter the channel freely.

If a subsurface drain is needed, install it as designated in the plans.

Provide topsoil as needed to enhance the growth of grass within the channel.

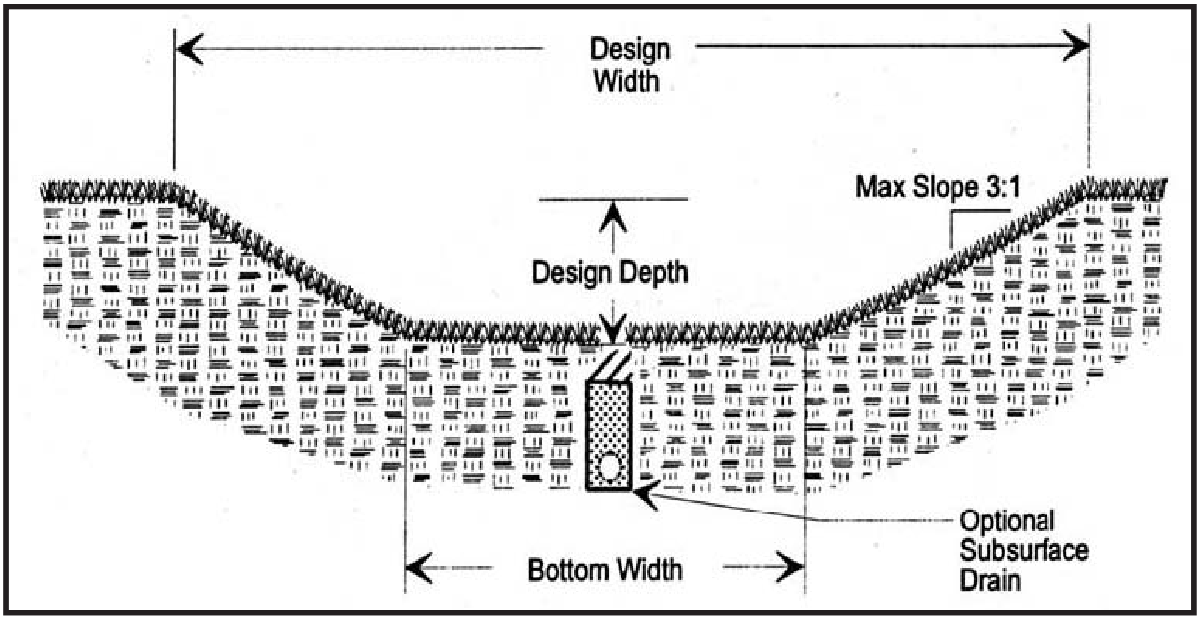

Figure 6.117 Typical Trapezoidal Turf Swale. Source: St. Charles County Soil and Water Conservation District, Missouri

Erosion Control

Protect all concentrated inflow points along the channel with erosion-resistant linings, sod or other appropriate measures.

Fertilize and seed or sod the channel immediately after grading and protect with erosion control blankets, turf reinforcement mats or mulch according to the design plan.

Channel should outlet at a stable location.

Construction Verification

Check finished grade and cross section of the channel throughout the length of the watercourse. Verify the evenness of channel cross sections at several locations to ensure sheet flow.

Maintenance and Inspection

- Inspect the channel following storm events both during and after grass cover is established; make needed repairs immediately.
- Check the channel outlet and road crossings for blockage, sediment, bank instability, breaks and eroded areas. Remove any blockage and make repairs immediately.
- Remove significant sediment and debris from the channel to maintain design cross section and grade, and to prevent spot erosion.
- A specific operations and maintenance plan should be provided by the design professional and transferred to the person responsible for long-term operations and maintenance. Adequate training should be provided as well.

Common Problems and Solutions

Problem	Solution
Variations in topography on-site indicate the channel will not function as intended. Changes in plan may be needed.	Consult with the registered design professional.
Erosion occurs in the channel before vegetation is fully established, due to lack of adequate controls above the channel.	Establish controls above the channel. Repair, reseed and install erosion control blankets or turf reinforcement mats.
Gullying, head cutting or settling in the channel due to overly steep grade or improperly placed drain.	Refer to design specifications or design professional to ensure proper design or re-design of the channel, use erosion-resistant lining and ensure drain is properly placed (typically on the side for post-construction versus at the bottom during construction.)
Overbank erosion, spot erosion, channel meander or flooding occurs due to instability.	Remove accumulated debris and sediment, stabilize and revegetate trouble spots.
Side slope caves in as a result of unstable, high-water-table soil, steep banks or high-flow velocity. Most likely to occur on the outside of channel curves.	An alternate practice may be more appropriate, such as a wetland or wetland swale. Consult with the design professional.
Ponding along the channel due to improperly graded approach or blocked surface inlets.	Improve the channel grade or remove blockage.
Erosion at the channel outlet due to instability.	Install an outlet stabilization structure.
Sediment deposited at the channel outlet due to unidentified channel or watershed erosion.	Find and repair the source of any channel erosion and stabilize the drainage area with permanent practices professionally designed to protect water quality.
Design specifications for seed variety, seeding dates or erosion control materials cannot be met.	Substitution may be required. Unapproved substitutions could result in channel erosion.

Dry Pond (Detention)

Figure 6.118 Dry Pond. Source: ABC's of BMP's, LLC

Practice Description

A dry pond is a surface storage basin or facility designed to provide water quantity control and limited water quality benefits through stormwater detention or extended detention. Dry ponds, also known as dry detention basins or dry detention ponds, are ponds designed to store and then release stormwater runoff from a specified design rainfall event. Unlike wet ponds, dry ponds do not have a permanent pool.

The historical purpose of a dry pond is to reduce the peak flow rate of stormwater runoff – essentially providing flood control.   These types of dry ponds seldom meet the overall quantity and quality objectives as a stand alone practice.   Flood detention ponds were not designed to detain stormwater from small flow events.

Variations of dry ponds include:

- Dry pond for peak flow rate (flood) control only (Figure 6:118).
- Extended detention dry pond for limited water quality control and for channel protection .
- Combination dry pond – combining flood control with extended detention.

Sometimes a dry pond is an acceptable option for achieving flood detention. However, volume reducing (i.e., retention) practices are preferred over flood detention practices as a method of flood control in the lower portion of a major watershed or drainage basin. A dry pond should also be a last resort option in the upper portion of the watershed, because many alternative practices are available to simultaneously reduce volume, protect against flooding and achieve water quality. As an example, Figure 6:119 illustrates a similar 100-year flood detention benefit is achieved by retaining 1.1-inches of rainfall retention in multiple mircoscale practices across a residential development.

Given adequate space in the urban environment, dry ponds can be used to retrofit a drainage area to provide flood control, channel protection and in some cases temperature control. As noted above, it is also important to note where in the major watershed the detention basin is located. As a rule of thumb, detention basins are most effective when placed in the upper 1/3 of a major watershed. Otherwise, detention basins provided in the lower portion of the watershed will likely release water at the same time flow from the upper portion of the watershed reaches the same point. This can make downstream flooding and erosion problems worse by forcing even larger volumes of water into the downstream channel.

Dry ponds are sometimes converted from construction site sediment basins through the removal of sediment, addition of vegetation and modification of the basin outlet structure. Dry ponds are permanent “post construction” ponds as opposed to a sediment basin, and therefore should not be designed or used to store construction site sediment.

Dry ponds should not be put into use until after all construction is complete and the site is completely stabilized. These ponds detain the stormwater flow from rain events but do not hold it for long periods of time. These are designed to be fully vegetated on bottom and side slopes. The outlet structure is designed and built at the lowest point in the basin, allowing the basin to fully drain. Dry ponds should be constructed so all stormwater is detained, not retained as in a retention or “wet” pond.

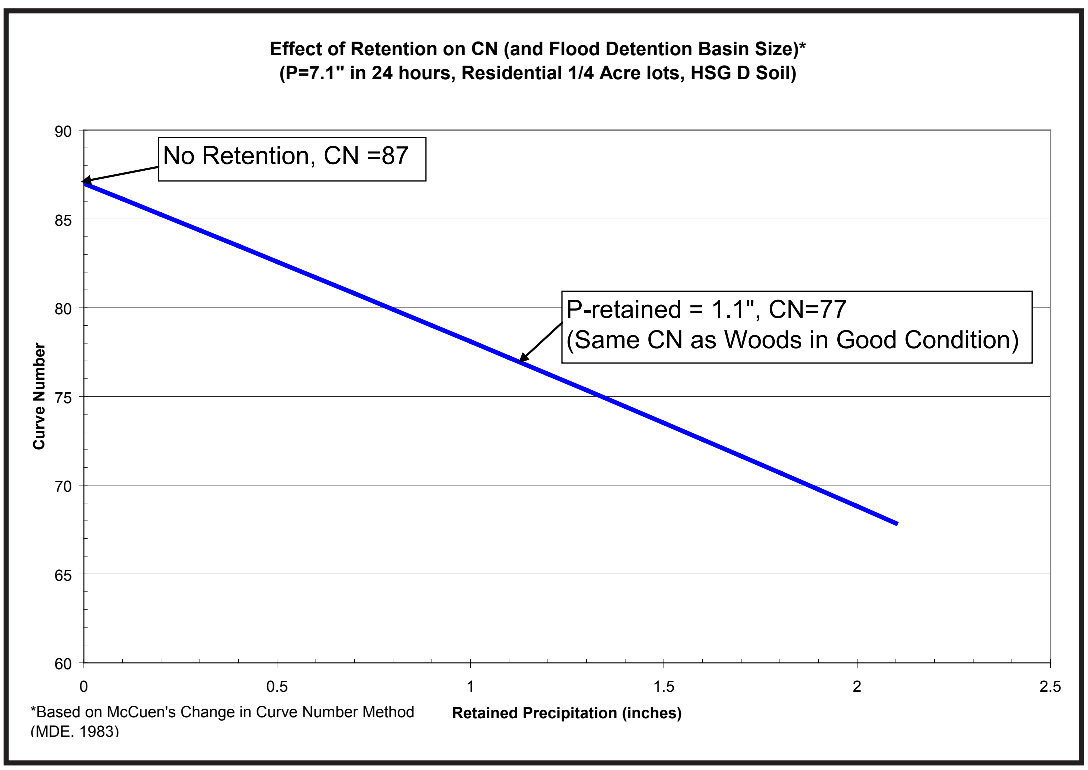

Figure 6.119 Effect of retention on curve number (and flood detention basin size). Source: Metropolitan St. Louis Sewer District

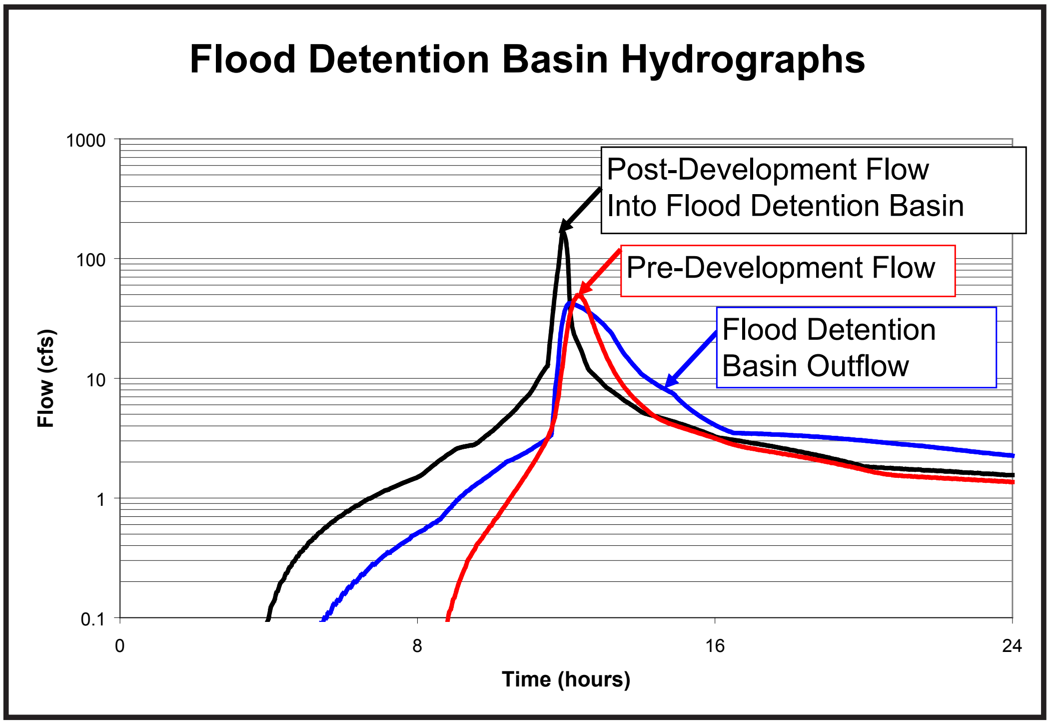

Figure 6:120 Dry pond for peak flow rate control only. Source: Metropolitan St. Louis Sewer District

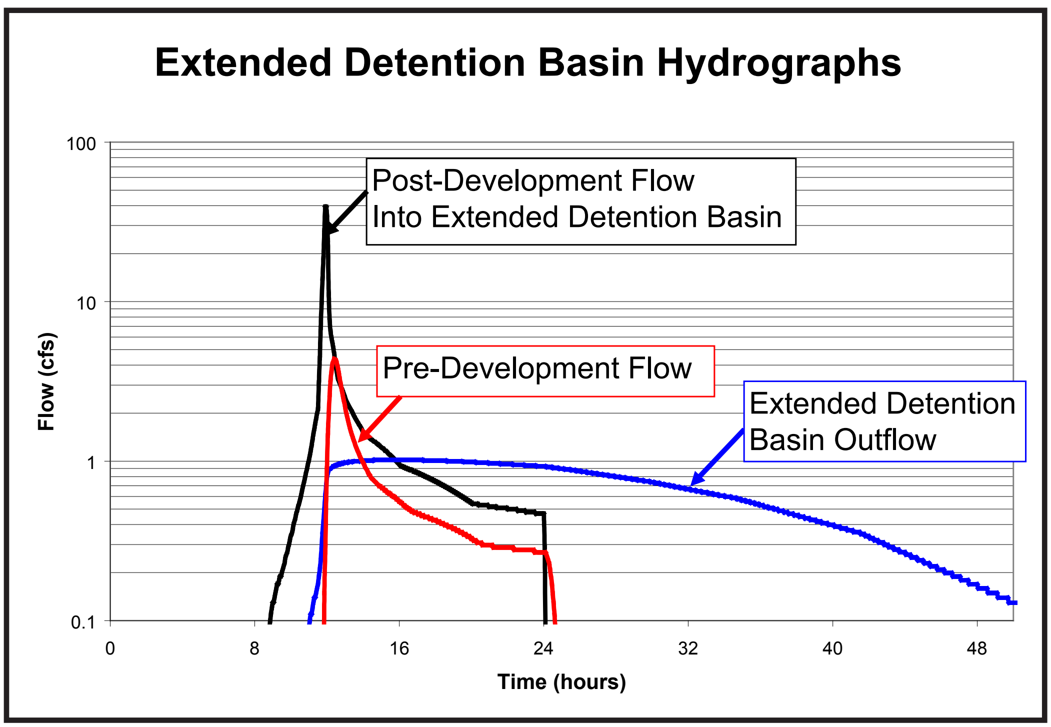

Figure 6.121 Extended detention dry pond for limited water quality control and for channel protection.
Source: Metropolitan St. Louis Sewer District

Pollutant Removal

As noted previously, the historical purpose of a dry pond is to reduce the peak flow rate of stormwater runoff – essentially providing flood control. The dry pond is often used to reduce the peak flow rate from stormwater events and may temporarily minimize flooding downstream. Dry ponds designed to provide extended detention can benefit downstream water quality by protecting downstream channels from the frequent storm events that cause streambank erosion. However, when used to remove settleable pollutants, studies show some of the sediment and other pollutants are re-suspended and then discharged in recurring storm events

See Appendix C for the reference publication *Stormwater BMPs: Selection, Maintenance and Monitoring.* Additionally, dry ponds are not effective removers of soluble pollutants. As such, this practice seldom meets the overall quantity and quality objectives as a standalone practice.

If water quality treatment is a goal of dry detention basin design and construction, a wet or extended stormwater pond design should be incorporated. Dry ponds should be used in conjunction with other practices, as part of an overall treatment series; they should include enhancements such as a sediment forebay, extended storage, a micropool at the outlet, a long shape to minimize short-circuiting or a combination of these features. Effectiveness of dry ponds varies significantly depending on design, incorporation of companion water quality practices and maintenance.

Dry ponds with concrete conveyance channels or pilot swales should not be used, because they convey polluted stormwater directly to stream resources. See Figure 6:122.

Sediment clean-out should be tested for toxicants in compliance with current disposal requirements if commercial or industrial land uses contribute to the catchment, or if visual or olfactory indications of pollution are noticed

Figure 6.122 Detention basin with concrete conveyance channel. Source: Metropolitan St. Louis Sewer District

Costs Considerations

According to the Stormwater Manager's Resource Center, construction costs vary considerably, but the estimated costs of a typical extended dry detention basin may range from $41,600 per one acre-foot pond to $1,380,000 for a 100 acre-foot pond.

Costs associated with required space should be considered, especially when other practices such as bioswales and rain gardens can be worked into the natural landscape and meet water quality requirements.

Consideration should be given also to the economic impacts to neighboring properties. According to Emmerling-Dinovo, a 1995 study found that dry ponds can actually detract from the perceived value of homes adjacent to a dry pond by between three and 10 percent.
See the Appendix C reference for *Stormwater Detention Basins and Residential Locational Decisions* (1995.)

The estimated cost of maintenance is typically estimated at about three to five percent of the construction cost.

Recommended Minimum Requirements

Key considerations for constructing a dry pond is how big the pond should be, how the land should be graded, the location and size of the outlet structure and the elevation of drainage outlets. Typically, detention basins are designed through modeling to demonstrate specific design storm requirements that will be met. Deviation from the design can result in basin inefficiency at best, and intesifying of downstream flooding and erosion problems at worst.

Design should be in accordance with state-of-the-practice specifications aimed at achieving water quality criteria. When designed in conjunction with other appropriate runoff volume-reducing SCMs, detention basins may be reduced in size. Forebays may be provided at all major inflow points to capture coarse sediment, prevent excessive sediment accumulation in the main basin and minimize erosion by inflow. The basin may also be planted with dense, low-growing native or adaptive vegetation that can withstand periods of inundation and drought, require no mowing and provide aesthetic and wildlife benefits.

For a list of suitable plant species, refer to Appendix C for the *Landscape Guide for Stormwater Best Management Practice Design*, St. Louis, Missouri. Also, see Grow Native! at www.grownative.org for photos and narrative description of plant species native to Missouri and the Midwest region. See additional plant information resources in Appendix C and Appendix D.

Construction

Prior to excavation activities of any type, call 1-800-DIG-RITE (344-7483) to obtain utility locations.

Follow all federal, state and local requirements for impoundment sites. See Chapter 1 for information about regulations and permit requirements.

Prior to start of construction, detention basins should be designed by a registered design engineer. Plans and specifications should be reviewed by the site superintendent and field personnel throughout the construction process. The detention basin should be built according to the planned grades and dimensions.

An example construction sequence follows:

- Construction should begin only when the erosion and sediment control measures are in place.

- The site should be prepared for excavation or construction of the embankment. Site preparation includes the removal of existing vegetation within the construction limits, as necessary for construction. Tree roots, rocks or boulders should be removed from the excavated area and disposed of in designated disposal areas.

- Embankments should be constructed. Inlet and outlet structures should be installed, per the construction plans.

- The final grading should include placement of planting soil.

- Seeding, planting and mulching should be completed as specified in the plans. The contractor should install geo-textiles and erosion control measures specified in the plans.

- After all tributary areas are sufficiently stabilized, remove temporary erosion and sediment controls. It is important for the swale to be stabilized before receiving upland flow.

Consult with the registered design engineer if any of the following occur:

- Seepage is encountered during construction.

- Variations in topography on-site indicate detention pond will not capture the drainage area intended.

- Design specifications for fill, pipe, seed/plant variety or seeding/planting dates cannot be met.

- Depression holds water long after the rain event, which does not allow vegetation to survive.

- Substitutions are required. Unapproved substitutions could lead to failure.

Construction Verification

Check the finished grades and configuration for all elements. Check elevations and dimensions of all pipes and structures. If at final grade the basin storage volume is less than indicated on the plan (e.g., 10 percent less), orifice invert elevations vary more than 0.1’ from plan, or if orifice size if different from plan, then the engineer should be consulted to determine if basin performance has been negatively impacted and if adjustments are needed.

Maintenance and Inspection

A specific operations and maintenance plan should be provided by the design engineer and transferred to the person responsible for long-term operations and maintenance. Adequate training should be provided as well. Typical maintenance requirements include the following:

- Inspect the detention basin after each storm event greater than 1-inch in 24 hours. Remove trash and other debris from the basin. Collected sediment should be removed when 10 percent of the basin design volume has been filled, or 50 percent of the sediment forebay is filled.

- Periodically (e.g., annually) check the embankment, emergency spillway and outlet for erosion damage, piping, settling, seepage or slumping along the toe or around the barrel and repair upon discovery.

- Remove nuisance vegetation on the embankment as needed during the growing season (e.g., April to October).

- Remove rodents that burrow into the dam.

Common Problems and Solutions

Problem	Solution
Piping failure along conduit; caused by improper compaction, omission of anti-seep collar, leaking pipe joints or use of unsuitable soil.	Repair damage, check pipe joints and seal leak if necessary. Use suitable soil for backfill. Consider installing anti-seep collar or pressure-injecting grout around the pipe.
Erosion of spillway or embankment slopes; caused by inadequate vegetation or improper grading and sloping.	Repair damage and establish suitable grade or vegetation. Perform a soil test and amend the embankment as needed to establish vegetation.
Slumping or settling of embankment; caused by inadequate compaction or use of unsuitable soil.	Excavate failed material and replace with properly compacted suitable soil.
Slumping; caused by steep slopes.	Excavate dislocated material and replace with properly compacted suitable soil. Consider flattening slope.
Erosion and caving below principal spillway; caused by inadequate outlet protection.	Repair damaged area and install proper outlet protection.
Basin not located properly for access; results in difficult and costly maintenance.	Improve access to site.
Ponding stormwater for long periods of time and dead vegetation caused by principal discharge area not at lowest elevation.	Check with the engineer to determine if the discharge can be lowered or if the basin can be filled. Re-vegetate damaged areas.
Frequent operation of emergency spillway, long-term ponding and increased erosion potential caused by principal discharge point too small.	Consider increasing capacity of principal discharge, install supplemental discharge or install suitable erosion protection in emergency spillway.
Stormwater released from pond or basin too rapidly; caused by discharge.	Consider resizing discharge and add additional energy dissipation at discharge location.
Unsuccessful vegetation establishment.	Consider selecting plants that are native species tolerant of both wet and dry cycles and appropriate for the plant zone. Deep rooted perennials are encouraged to increase the rate of infiltration. Inspect plans to ensure they are properly planted and have correct soil conditions. Properly water them through establishment. Maintain plantings to make sure they are not taken over by noxious plants or weeds.

Wet Pond ("Retention")

Figure 6.123: Extended Wet Detention, Express Scripts Campus, Berkeley, MO.
Source: Metropolitan St. Louis Sewer District

Practice Description

Wet ponds are often referred to as stormwater ponds, retention ponds or wet detention ponds. A wet pond is designed to collect stormwater runoff in a permanent pool during storm events. The water stored in the pond is later displaced by new runoff. A wet pond can provide pollutant removal primarily through settling and microbial, plant and algal biological uptake. While wet ponds can provide water quality improvement, their role in runoff volume reduction is limited. Wet ponds are best used in combination with other stormwater control measures in an overall stormwater treatment train to achieve the desired affects of pollution control, storage and flow rate reduction. Many of the hydrograph principles that apply to dry ponds also apply to wet ponds. (See Dry Ponds on page 6-277.)

Variations of wet ponds include:

- Flow-Through (Wet) Pond (no extended detention, this pond has an essentially unrestricted spillway as its primary outlet, with its crest at the elevation of the permanent pool).
- Extended wet detention (extended detention storage is provided above the permanent pool).
- Water reuse pond (used primarily for irrigation.)

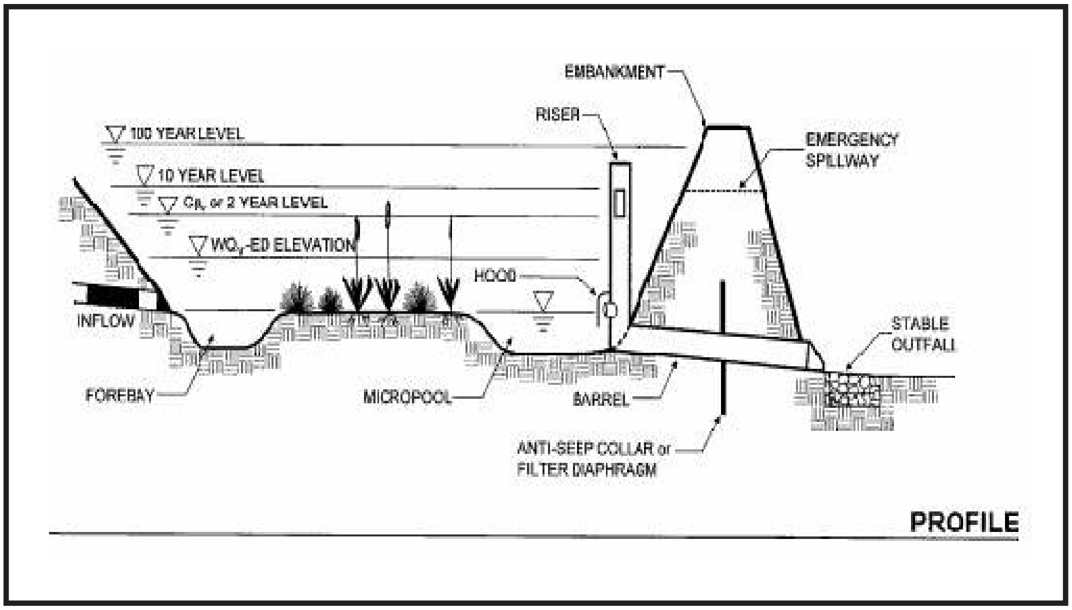

Figure 6:124 Wet Pond Cross Section Source: U.S. Environmental Protection Agency

The extended wet detention pond is a wet pond that works in tandem with a dry detention pond located above the permanent pool. During storm events, water is collected in the detention storage pond above and released over a period of 12 to 48 hours into the wet pond below.

Wet ponds can be used as a retrofit option in existing communities as modifications to existing detention facilities to enhance water quality treatment and downstream channel protection. If water quality, storage and reduced flow rate are the goals, wet ponds should be used in conjunction with other SCMs in an overall stormwater treatment train to achieve the best results. See Figure 6:102. At the very least, sediment and pollutant removal, as well as maintenance needs, can be enhanced through the use of multiple cells in succession.

Geese can often be attracted to wet ponds if the edges are mowed. However, unmowed native or adaptive vegetation around the edges will discourage geese and help to filter pollutants from stormwater runoff.

Additional Considerations

- Fluctuating water elevations make it difficult to establish plants.
- Use wet detention basins to treat runoff from stormwater hot spots, only if significantly separated from the groundwater table.
- Use of wet ponds is limited in dense urban areas due to the amount of space and drainage area required.
- Not appropriate for discharge to cold water resources, due to the potential for thermal pollution.
- Not appropriate for karst areas without significant consideration to leakage or sinkhole prevention.
- Safety is always a concern where permanent pools of water exist.

Cost Considerations

According to the Center for Watershed Protection, typical costs for wet detention ponds range from $17.50 to $35 per cubic meter ($0.50 to $1 per cubic foot) of storage area (CWP, 1998). The total cost for a pond includes permitting, design and construction and maintenance costs. Permitting costs may vary depending on state and local regulations. Typically, wet detention ponds are less costly to construct in undeveloped areas than to retrofit into developed areas. This is due to the cost of land and the difficulty in finding suitable sites in developed areas. The cost of relocating pre-existing utilities or structures is also a major concern in developed areas. Several studies have shown the construction cost of retrofitting a wet detention pond into a developed area may be 5 to 10 times the cost of constructing the same size pond in an undeveloped area. Annual inspection and maintenance costs can generally be estimated at three to five percent of the construction costs.

Recommended Minimum Requirements

The design should reflect the design criteria that could include the following key elements:

- An adequate contributing drainage area, typically more than 10 acres. A water balance assessment should be provided for smaller drainage areas.
- Natural high groundwater table.
- Maintenance of a permanent water surface.
- A length to width ratio of 2:1, or irregular shapes that maximize flow path between inlet and outlet points.
- An aquatic bench with diverse vegetation around the perimeter.
- Relatively impermeable soils, or lining of the pond bottom.
- A forebay for coarse sediment and trash collection.
- Outfall protection to prevent erosion.
- Access for maintenance.

The designer should review local requirements for site grading, drainage structures, erosion and sediment control, and potential invasive vegetation. In Missouri, dams with a height of 35 feet or greater require approval from the Missouri Department of Natural Resources' Dam Safety Program. (See Chapter 1 for information about permits and regulations.)

For a list of suitable plant species, refer to Appendix C for the *Landscape Guide for Stormwater Best Management Practice Design*, St. Louis, Missouri. Also, see Grow Native! at www.grownative.org for photos and narrative description of plant species native to Missouri and the Midwest region. See additional plant information resources in Appendix C and Appendix D.

Construction

Prior to excavation activities of any type, call 1-800-DIG-RITE (344-7483) to obtain utility locations.

Follow all federal, state and local requirements for impoundment sites. See Chapter 1 for information about regulations and permit requirements.

Prior to start of construction, the wet pond should be designed by a registered design engineer. Typically, this SCM is comprised of a forebay, an embankment to create the basin(s), an outlet structure, a spillway for overflows and safe access.

Plans and specifications should be reviewed by the site superintendent and field personnel and followed closely throughout the construction process. The basin should be built according to the planned grades and dimensions. An example construction sequence follows:

- Construction should begin only when the erosion and sediment control measures are in place.
- The site should be prepared for excavation or construction of the embankment. Site preparation includes the removal of existing vegetation within the construction limits, as necessary for construction. All tree roots, rocks, or boulders should be removed from the excavated area.
- Rough grading of the basin should be completed carefully to ensure compaction of the bottom of the basin.
- Embankments should be constructed. Inlet and outlet structures should be installed, per the construction plans.
- The final grading should include placement of planting soil.
- Seeding, planting and mulching should be completed as specified in the plans. The contractor should install geo-textiles and erosion control measures specified in the plans.
- After all tributary areas are sufficiently stabilized, remove temporary erosion and sediment controls.

Construction Verification

Construction verification needs for dry and wet ponds are similar. Check the finished grades and configuration for all elements. Check elevations and dimensions of all pipes and structures.

Maintenance and Inspection

A specific operations and maintenance plan should be provided by the design professional. After construction is complete and the detention basin is operational, operations and maintenance of each device is performed by the personnel identified in the operations and maintenance manual. Typical maintenance requirements include the following:

- Periodically check the embankment, emergency spillway and outlet for erosion damage, piping, settling, seepage or slumping along the toe or around the barrel and repair immediately.
- Clean and remove trash and vegetative debris from inlet and outlet structures, mow side slopes as needed.
- Semi-annual inspection for invasive vegetation.
- Annual inspection to monitor damage, hydrocarbon build-up, sediment accumulation and debris in inlet and outlet devices.
- Repair erosion and remove excess sediment from forebay as needed.
- Manage and harvest wetland plants annually.
- Renovate the facility when pool volume has been reduced significantly or when the pond becomes eutrophic (excessive in nutrients, resulting in algal blooms and poor water quality.)

Common Problems and Solutions

Problem	Solution
Piping failure along conduit; caused by improper compaction, omission of anti-seep collar, leaking pipe joints or use of unsuitable soil.	Repair damage, check pipe joints and seal leak if necessary. Use suitable soil for backfill. Consider installing anti-seep collar.
Erosion of spillway or embankment slopes; caused by inadequate vegetation or improper grading and sloping.	Repair damage and establish suitable grade or vegetation.
Slumping or settling of embankment; caused by inadequate compaction or use of unsuitable soil.	Excavate dislocated material and replace with properly compacted suitable soil.
Slumping; caused by steep slopes.	Excavate dislocated material and replace with properly compacted suitable soil. Consider flattening slope.
Erosion and caving below principal spillway; caused by inadequate outlet protection.	Repair damaged area and install proper outlet protection.
Basin not located properly for access; results in difficult and costly maintenance.	Relocate basin to more accessible area or improve access to site.
Ponding stormwater for long periods of time and dead vegetation caused by principal discharge area not at lowest elevation.	Lower the discharge to release storm flows and re-vegetate damaged areas.
Frequent operation of emergency spillway, long-term ponding and increased erosion potential caused by principal discharge point too small.	Consider increasing capacity of principal discharge, install supplemental discharge or install suitable erosion protection in emergency spillway.
Stormwater released from pond or basin too rapidly; caused by discharge.	Consider resizing discharge and add additional energy dissipation at discharge location.
Unsuccessful vegetation establishment.	Consider selecting plants that are native species tolerant of both wet and dry cycles and appropriate for the plant zone. Deep rooted perennials are encouraged to increase the rate of infiltration. Inspect plans to ensure they are properly planted and have correct soil conditions. Properly water them through establishment. Maintain plantings to make sure they are not taken over by noxious plants or weeds.

Stormwater Wetlands (Constructed Wetlands)
Practice Description
Stormwater wetlands are constructed wetland systems that temporarily store stormwater runoff in shallow pools supportive of wetland plants. They are constructed primarily for the purposes of water quality treatment and flood control; primarily flow attenuation and some runoff volume reduction. Stormwater wetlands are constructed for maximum removal of stormwater pollutants through microbial breakdown of pollutants, pollutant uptake by plants, settling and absorption. Stormwater wetlands typically have less biodiversity than natural wetlands in terms of plant and animal life. Natural wetlands are to be protected and should never be used for stormwater management, because their function is critical to watershed health. See Chapter 1 for regulations and permit requirements.

Constructed wetlands are a widely applicable stormwater management practice in areas where sufficient land is available. There should be significant separation from groundwater if constructed wetlands accept runoff from stormwater hot spots. If the areas are designed to encourage wildlife use, the design must ensure pollutants in stormwater runoff do not affect organisms living in or near the wetland. When retrofitting a watershed with SCMs, stormwater wetlands can provide both educational and habitat value.

For a list of suitable plant species, refer to Appendix C for the *Landscape Guide for Stormwater Best Management Practice Design*, St. Louis, Missouri. Also, see Grow Native! at www.grownative.org for photos and narrative descriptions of plant species native to Missouri and the Midwest region.

Stormwater wetland designs vary in the relative amount of shallow water, deep water and dry storage above the wetland. The five general design variations include:

- Shallow marsh system.
- Pond/wetland system.
- Extended detention wetland.
- Submerged gravel wetland.
- Pocket Wetland.

Of the wetland types, the extended detention wetland or pond/wetland system may be most common in urban areas with adequate land. Where space is more limited or retrofits are needed, a submerged gravel wetland might be considered. Pocket ponds are only an option where groundwater is available to help charge the pond; not a typical setting in urban environments. The shallow marsh system requires the largest area of all wetland types.

Shallow Marsh System

A shallow marsh system includes a combination of pools (low marsh) and vegetated hummocks (high marsh), plus a micropool at the outlet. Pools wind through the high marsh in meandering pathways to extend the amount of time stormwater is held and treated in the system and to increase contact between stormwater and vegetation. These systems are generally shallow and therefore receive no groundwater inputs, so they typically require large drainage areas (e.g., >25 acres) to contribute the necessary water volume to the system.

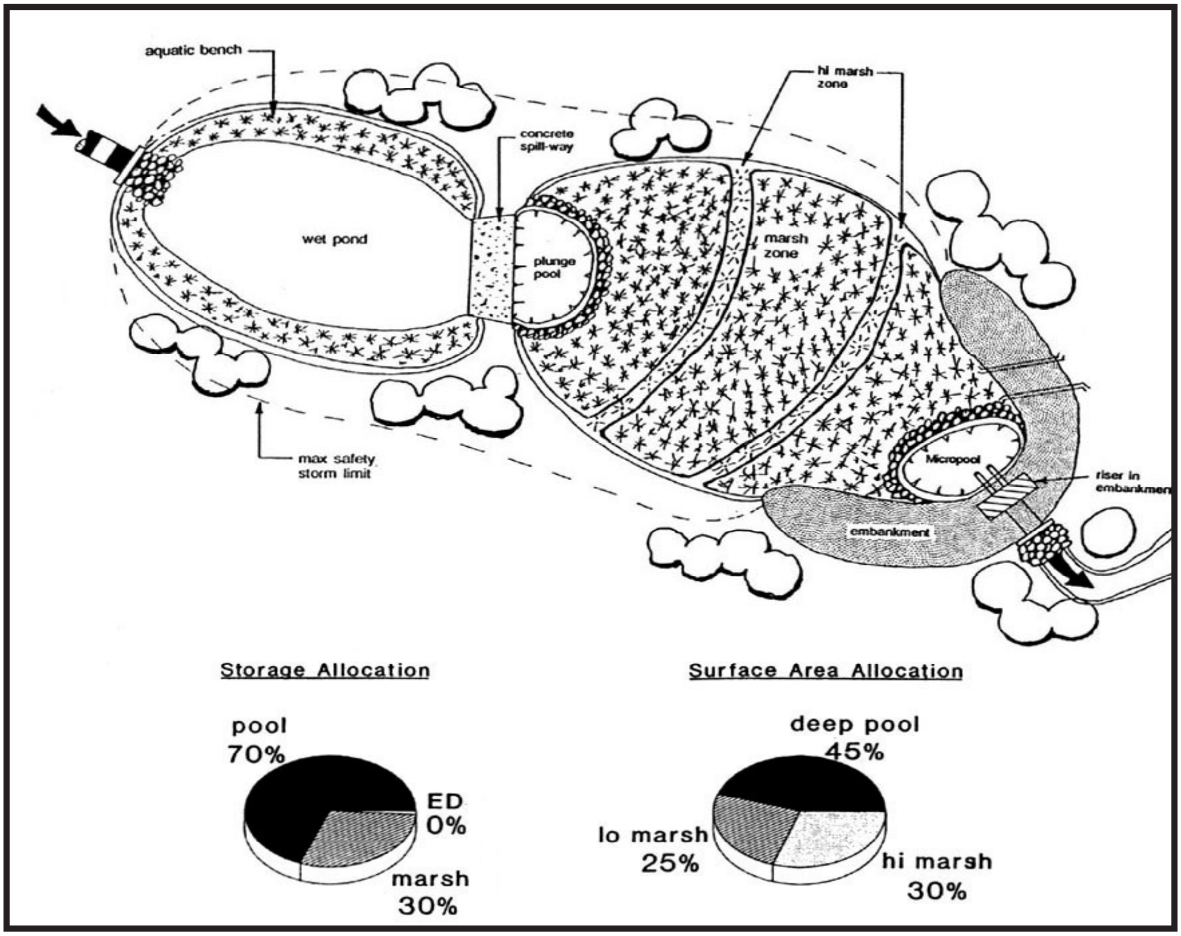

Figure 6.125 Pond/Wetland System Source: Center for Watershed Protection

Extended Detention Wetland

An extended detention wetland is much like a shallow marsh system, but it includes the addition of a forebay and safety bench.

An extended detention wetland includes features to enhance storage, downstream channel protection and pollution reduction. It has sufficient volume to temporarily detain runoff during storm events and hold a permanent pool of fairly shallow depth. Biological and chemical activity in the pond plays an important role in pollutant uptake, particularly of nutrients. Flow through the root systems allows vegetation to remove nutrients and dissolved pollutants from stormwater. When an extended detention wetland is sized, designers need to consider the storage volumes provided. Typically, a significant portion (e.g., 50 percent) of the water quality volume (the volume of rainfall produced by the 90th to 95th percentile storm that occurs in 24 hours) is provided in the micropool(s). The detention volume above the pool is designed to provided extended detention of the remaining portion of the water quality volume, channel protection volume and flood protection volume.

Because the ponding depths are typically shallow to be effective, extended detention wetlands require a large amount of surface area to obtain sufficient volume. Because they function best in larger drainge areas, they may be a good choice to treat runoff from large industrial and commercial project sites that have sufficient space for their construction. These constructed wetlands can also provide aesthetic/recreational value and wildlife habitat.

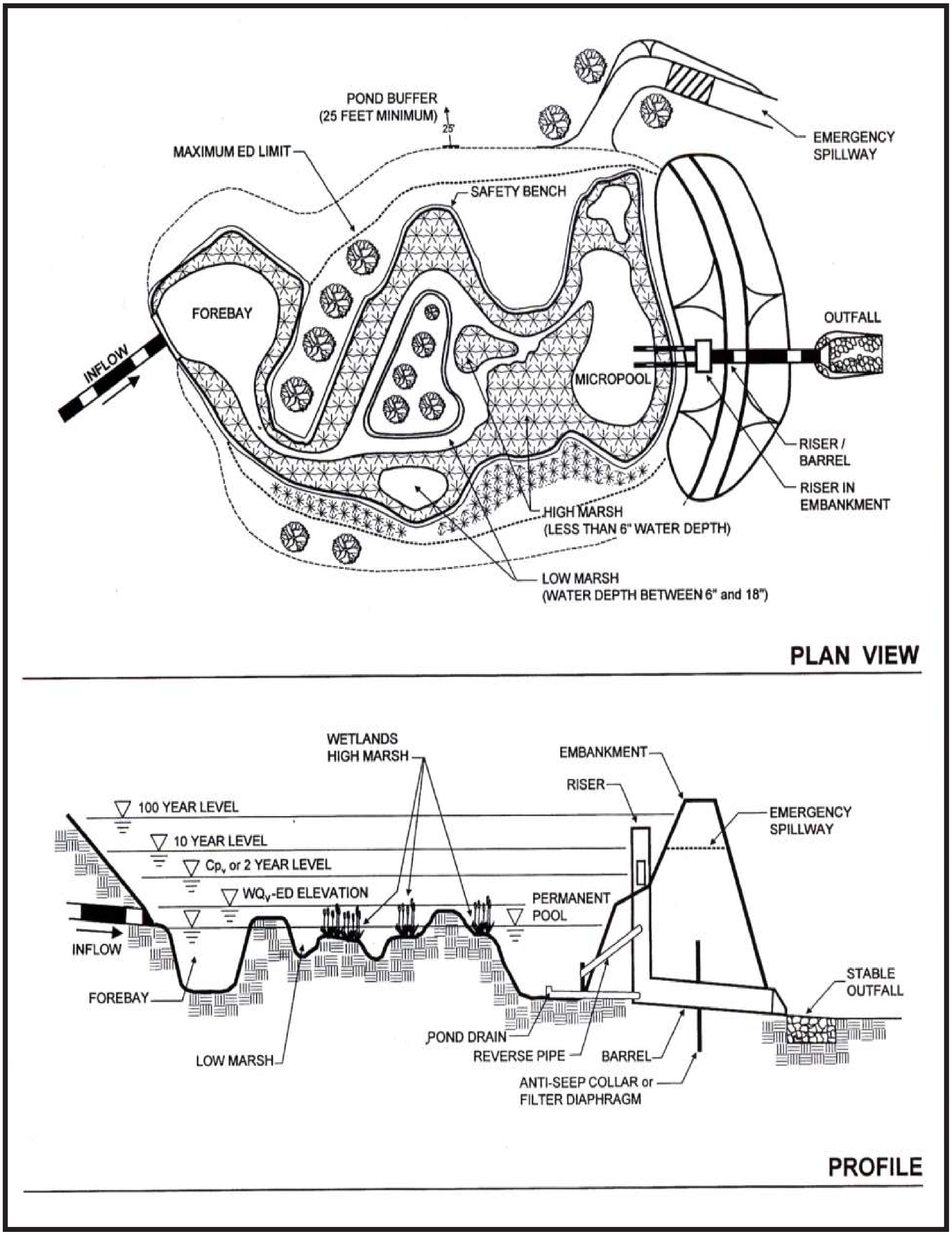

Figure 6.126: Constructed Extended Detention Wetland. Source: Center for Watershed Protection

Figure 6.127: Extended Detention Wetland in a Residential Development. Dover, Delaware. Source: Kevin Magerr, PE, CPESC, CPSWQ.

The successful design, installation and function of constructed wetlands depends on the hydrology, underlying soils, planting soil, size and volume, vegetation, configuration, and maintenance access. Large areas are necessary for application of this SCM; the contributing drainage area should be at least 10 acres. The area for a wetland is generally 3 to 5 percent of its drainage area but it should be sized to treat the water quality volume and if necessary, mitigate the peaks of larger runoff events. A wetland must be able to receive and retain enough rain, runoff and groundwater to maintain vegetation. Even with a large drainage area, a constant source of inflow can improve the biological health of a wetland.

Submerged Gravel Wetland

A submerged gravel wetland is a practice that can be used in retrofit situations draining less than five acres. In the submerged gravel wetland, the system is designed for runoff to flow through a rock filter with wetland plants at the surface. Pollutants are removed through biological activity on the surface of the media (e.g., gravel) and pollutant uptake by the plants. This practice is fundamentally different from other wetland designs because, while most wetland designs behave

Figure 6.128: Submerged Gravel Wetland. Source: Center for Watershed Protection, Copyright 2000.

much like wet ponds (with differences in grading and landscaping), gravel-based wetlands are more similar to filtering systems. Design considerations should be given to potential clogging and odor problems. Submerged gravel wetlands are commonly associated with wastewater treatment applications, but have been adapted to stormwater treatment application.

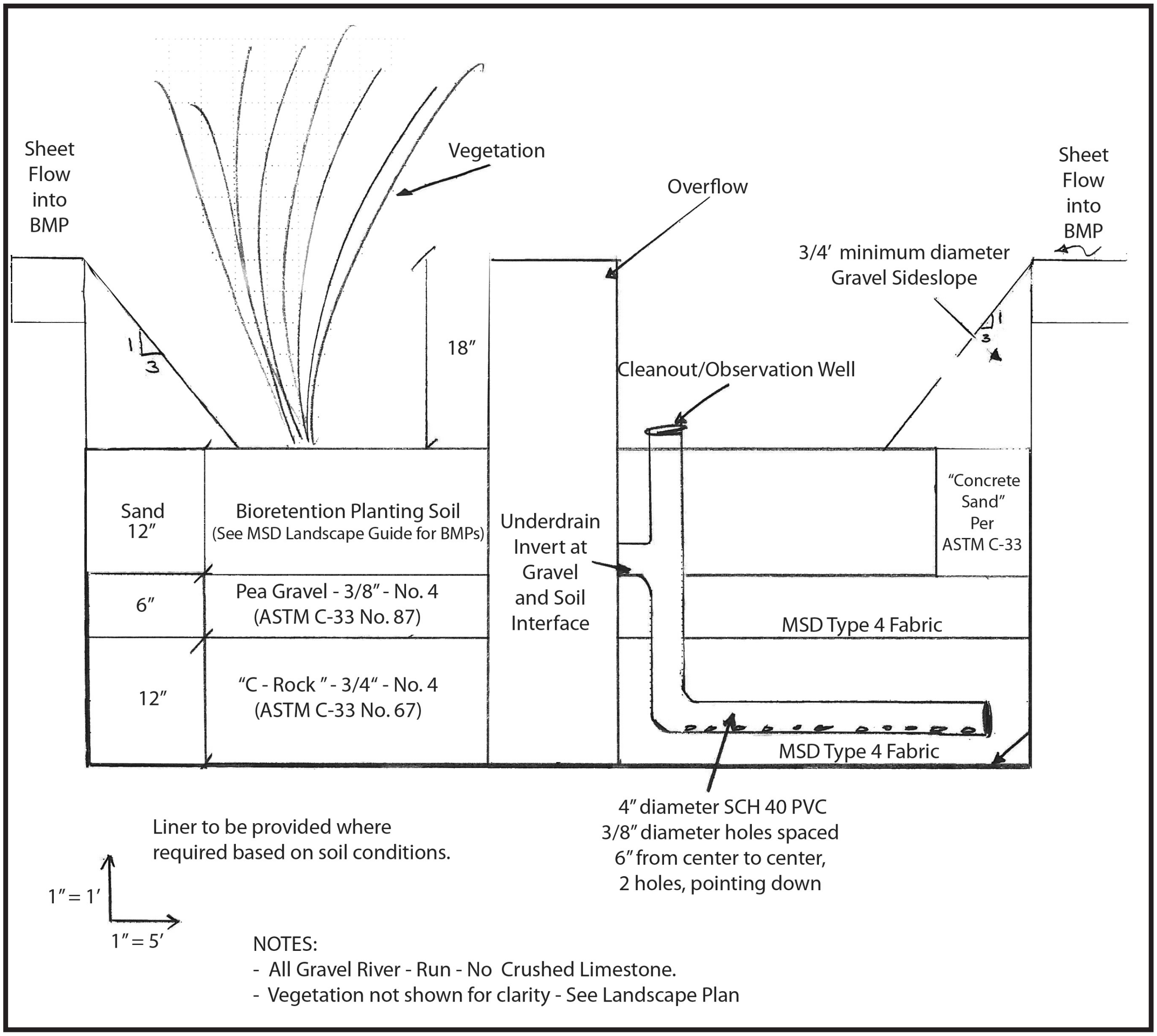

Figure 6.129. Submerged Gravel Wetland. Source: Metropolitan St. Louis Sewer District

Pond/Wetland System
A pond/wetland system consists of multiple cells with at least one wet pond followed by at least one shallow marsh and draining areas less than 25 acres. This practice can save space when compared to a shallow marsh system which requires a greater area of land to address storage.

Pollutant Removal
Wetlands can be designed to primarily remove total suspended solids, oils and greases, fecal coliform and biochemical oxygen demand. They can also be designed to remove some levels of Total phosphorus, nitrogen, heavy metals and floatables.

The following in formation on pollutant removal comes from EPA's *Stormwater Wetland* fact sheet. (See reference in Appendix C.) Wetlands are among the most effective stormwater management practices at removing stormwater pollutants. A wide range of research is available to estimate the effectiveness of wetlands. Wetlands have high pollutant removal rates, and are particularly effective at removing nitrate and bacteria. Table 6.18 provides pollutant removal data derived from the Center for Watershed Protections's National Pollutant Removal Database for Stormwater Treatment Practices (Winer, 2000).

Table 6.18. Typical Pollutant Removal Rates of Wetlands (%) (Winer, 2000.)

Pollutant	Stormwater Treatment Practice Design Variation			
	Shallow Marsh	ED Wetland1	Pond/Wetland System	Submerged Gravel Wetland1
Suspended Solids	83±51	69	71±35	83
Total Phosphorus	43±40	39	56±35	64
Total Nitrogen	26±49	56	19±29	19
Nitrogen Oxide	73±49	35	40±68	81
Metals	36-85	(80)-63	0-57	21-83
Bacteria	761	NA	NA	78

[1] Data based on fewer than five data points

The effectiveness of wetlands varies considerably, but many believe proper design and maintenance help to improve their performance. The siting and design criteria presented in the EPA's *Stormwater Wetland* fact sheet reflect the best current information and experience to improve the performance of wetlands. A joint project of the American Society of Civil Engineers and the EPA Office of Water may help to isolate specific design features that can improve performance. The National Stormwater Best Management Practice database is a compilation of stormwater practices that includes both design information and performance data for various practices. As the database expands, inferences about the extent to which specific design criteria influence pollutant removal may be made. [More information is available at the International BMP Database located at www.bmpdatabase.org.]

Additional Considerations
The following information about wetland limitations is adapted from EPA's *Stormwater Wetland* fact sheet. See reference in Appendix C. Some features of stormwater wetlands that might make a design challenging include the following:

- Each wetland consumes a relatively large amount of space, making it an impractical option on some sites.
- Improperly designed wetlands might become a breeding area for mosquitoes.

- Wetlands require careful design and planning to ensure wetland plants are sustained after the practice is in place.
- It is possible stormwater wetlands may release nutrients during the non-growing season.
- Designers need to ensure wetlands do not negatively impact natural wetlands, forest or groundwater quality.

Cost Considerations

The following information comes from EPA's *Stormwater Wetland* fact sheet from their menu of stormwater BMPs. See Appendix C. Wetlands are relatively inexpensive stormwater practices to construct, not counting the cost of land. Construction cost data for wetlands are rare, but one simplifying assumption is that they are typically about 25 percent more expensive than stormwater ponds of an equivalent volume. Using this assumption, an equation developed by Brown and Schueler (1997) to estimate the cost of wet ponds can be modified to estimate the cost of stormwater wetlands using the equation:

C = 30.6V0.705 where: C = Construction, design and permitting cost.
V = Wetland volume needed to control the 10-year storm (ft3).

Using this equation, typical construction costs are the following:

- $57,100 for a 1 acre-foot facility.
- $289,000 for a 10 acre-foot facility.
- $1,470,000 for a 100 acre-foot facility.

Wetlands consume about 3 to 5 percent of the land that drains to them, which is relatively high compared with other stormwater management practices.

For wetlands, the annual cost of routine maintenance is typically estimated at about 3 percent to 5 percent of the construction cost. Alternatively, a community can estimate the cost of the maintenance activities outlined in the maintenance section. Wetlands are long-lived facilities (typically longer than 20 years). Thus, the initial investment into these systems may be spread over a relatively long time period.

Recommended Minimum Requirements

Underlying soils should be identified and tested. Hydrologic soil groups 'C' and 'D' are suitable without modification but 'A' and 'B' soils may require the addition of clay or other impermeable material to line the facility. Soil permeability should be tested and calculations should demonstrate the wetland will not dry out. Organic soils should be used to establish vegetation. Vegetation is an integral part of a wetland and plays a role in reducing flow velocities, promoting settling, providing growth surfaces for beneficial microbes, and taking up pollutants. Vegetation types such as emergent, low marsh, high marsh, and buffer plants should be installed in appropriate zones for the various areas in a wetland. To allow maintenance activities, a stable and permanent access should be provided to the forebay, outlet and embankment areas. Also, an understanding of seasonal groundwater levels is critical.

Medium-fine textured soils (such as loams and silt loams) are best to establish vegetation, retain surface water while permitting groundwater recharge and capture pollutants. For a list of suitable plant species, refer to Appendix C for the *Landscape Guide for Stormwater Best Management Practice Design*, St. Louis, Missouri. Also, see Grow Native! at www.grownative.org for photos and narrative description of plant species native to Missouri and the Midwest region.

In karst (e.g., limestone) topography, wetlands should be designed with an impermeable liner to prevent groundwater contamination or sinkhole formation, and to help maintain the permanent pool. The designer should review local requirements for site grading, drainage structures, erosion and sediment control, and potential invasive vegetation.

The wetland should be designed by a registered design engineer as part of the overall site design for long-term water quality. Design considerations include:

- Water quality goals, flood management goals and performance needs (including appropriate variation for new growth, redevelopment or restoration).
- Proximity to karst and groundwater and other limitations.
- Wetland to watershed ratio and other sizing criteria.
- Topography, soils, sediment forebays.
- Buffers to separate wetland from the surrounding area.
- Above ground berms or high marsh wedges placed perpendicular to the flow path to increase dry weather flow paths within the wetland.
- Placement of the outlet with clog-prevention micropool.
- Maintenance access.
- Long-term operation, Inspection and maintenance.
- Construction sequencing.

Construction

Prior to excavation activities of any type, call 1-800-DIG-RITE (344-7483) to obtain utility locations.

Follow all federal, state and local requirements on impoundment sites. See Chapter 1 for information about regulations and permit requirements.

Plans and specifications should be referred to by the site superintendent and field personnel throughout the construction process. The construction sequence may include:

- Separating the wetland area from the contributing drainage area and initiating an appropriate erosion and sediment control plan.
- Clearing the area to be excavated of all existing vegetation. Removing tree roots, rocks and boulders. Filling all stump holes and crevices with impermeable materials.
- Excavating the bottom of the constructed wetland to the desired elevation, as indicated in the plans.
- Grading the embankments.
- Installing inlet and outlet control structures.
- Final grading and compacting of subsoil.
- Applying and grading the planting soils. It is critical the final grading match the design

because aquatic plants are sensitive to the depth of water.

- Installing geotextiles and other permanent erosion control measures.
- Seeding, planting and mulching according to the plans.

Maintenance and Inspection

Routine harvesting of vegetation has been documented to increase nutrient removal capacity of a constructed wetland and prevent the export of these constituents. Typical maintenance includes:

- Inspect the facility semiannually for burrows, sediment accumulation, structural integrity of the outlet and litter accumulation. The banks of the wetland should be inspected and areas of erosion repaired upon discovery. Sediments should be removed if they are within 18 inches of an outlet structure.
- Maintain emergent and perimeter shoreline vegetation. Site and road access are important to facilitate monitoring and maintenance.
- Remove nuisance vegetation or animals, if present.
- Harvest vegetation as prescribed in the specifications. Frequencies will vary. Vegetation is typically not collected during the growing season.
- The side slopes should be maintained at a slope that does not exceed 4:1 (H:V). Slopes showing excessive erosion may require erosion control and safety measures.

Sediments that accumulate in constructed wetlands may require special disposal. If there is any uncertainty about the sediment characteristics, the Missouri Department of Natural Resources should be consulted and department disposal recommendations should be followed.

Construction Verification

Check the finished grades and configuration for all earthwork. Check elevations and dimensions of all pipes and structures.

Common Problems and Solutions

Problem	Solution
Erosion of slopes; caused by inadequate vegetation or improper grading and sloping	Repair damage and establish suitable grade or vegetation.
Slumping or settling of embankment; caused by inadequate compaction or use of unsuitable soil	Excavate failed material and replace with properly compacted suitable soil.
Insufficient vegetation due to improper zones or depths of ponding.	Lower the discharge to release storm flows and re-vegetate damaged areas.
Stormwater released from pond or basin too rapidly; caused by discharge	Consider resizing discharge and add additional energy dissipation at discharge location.
Unsuccessful vegetation establishment.	Plant selection should include native species tolerant of both wet and dry cycles. Deep rooted perennials increase the rate of infiltration.

Infiltration Basin

Figure 6.130: Infiltration Basin. Source: University of Wisconsin Extension

Practice Description

Infiltration basins are earthen structures that capture stormwater in a shallow pool and infiltrate runoff into the ground over a period of 72 hours. Infiltration basins differ from detention basins in that they do not have an outlet. Typically, an infiltration basin includes an inlet, sediment forebay, level spreader, spillway, backup underdrain, an emergency spillway and a stilling basin. Vegetation is used within the basin to improve the permeability of soils and reduce the potential for erosion. Some communities have observed it is difficult to maintain desired turf grass. Alternative plant materials should be considered.

An infiltration basin should be designed by a registered design engineer as part of the overall site design for long-term water quality. Design considerations include:

- Infiltration basins should be restricted to areas where groundwater contamination, site feasibility, soil permeability and clogging at the site are not concerns.
- The contributing drainage area to a basin should not produce high concentrations of sediments and should be less than 2 acres.
- This SCM works well toward the end of a treatment train when there are sufficient pretreatment steps to reduce the sediment loads.
- Because these basins are designed for maximum infiltration, they should not be constructed in regions of karst topography, due to concerns of sinkhole formation and groundwater contamination.
- These basins should never be constructed in stormwater hot spots. Stormwater hotspots are areas that produce higher concentrations of pollutants than what is normally found in urban runoff.

Recommended Minimum Requirements

Infiltration basins may be incorporated into new development or used to retrofit existing lawns and open spaces. Site selection for an infiltration basin should be based on soil infiltration, depth to water table, setbacks, loading rates and existing vegetation. Soil investigation and infiltration testing provides essential information for a proper design. Basins should be located 150 feet away from drinking water wells to prevent possible contamination and these basins should not be located adjacent to building foundations; they should be placed at least 10 feet down-gradient and 100 feet up-gradient from foundations. Infiltration basins should not be used in areas where groundwater is close to the surface.

After locating the infiltration basin, the designer should prepare plans sufficient for the structure to retain 1-foot freeboard during the average 100-year peak runoff. Use of a backup underdrain (capped or closed with a valve during normal operation) may be considered if there is concern the basin may not drain. The underdrain may need to be used later when surface soils become clogged and need to be amended or replaced. Inlets to the basin should have erosion protection. The slope of the infiltration basin base should be less than 1 percent to ensure even water distribution and infiltration. The berms surrounding the basin should be constructed of compacted earth with a minimum top width of 2-feet and side slopes not steeper than 3:1 (H:V). The length to width ratio of the basin should be 3:1 or greater. The designer should review local requirements for site grading, drainage structures, erosion and sediment control and planting.

Construction

Prior to excavation activities of any type, call 1-800-DIG-RITE (344-7483) to obtain utility locations.

Follow all federal, state and local requirements for impoundment sites. See Chapter 1 for information about regulations and permit requirements.

Prior to the start of construction, plans and specifications should be reviewed by the site superintendent and field personnel throughout the construction process. The wetland should be built according to the planned grades and dimensions.

Site Preparation

The infiltration basin area should be protected from compaction prior to installation. Proper erosion and sediment control measures should be installed and maintained during construction to prevent site runoff from entering the infiltration basin.

Grading and Installation
It is preferable to locate infiltration basins with consideration of existing topography to minimize excavation. If necessary, excavate the basin bottom to an uncompacted sub-grade free from rocks and debris. It is important to avoid compaction of the sub-grade. After the bottom and side slopes have been established, the outlet control structures should be installed. Finally, the topsoil should be vegetated and stabilized. Erosion and sediment control measures must remain in place and maintained until the site is stabilized.

Vegetation
The selection should include native and adaptive species tolerant of both wet and dry cycles. Deep rooted perennials are encouraged to increase the rate of infiltration.

For a list of suitable plant species, refer to Appendix C for the *Landscape Guide for Stormwater Best Management Practice Design*, St. Louis, Missouri. Also, see Grow Native! at www.grownative.org for photos and narrative description of plant species native to Missouri and the Midwest region.

Construction Verification
Measure the finished grades and configuration and compare against the plans and specifications. Check elevations and dimensions of all pipes and structures.

Maintenance and Inspection
Twice each year, the basin and inlets should be inspected for accumulation of trash, sediment and erosion. They should also be checked for stabilization and vegetation quality. Inspections should also occur after significant runoff events and drainage times should be observed to match the design intention. The vegetation along the surface should be maintained and any bare spots identified during inspections should be revegetated. Depending on the vegetative cover species, an infiltration basin may be carefully mowed as needed but care should be taken to avoid excessive compaction by mowers (i.e. mowing should not occur when the ground is saturated).

Common Problems and Solutions

Problem	Solution
Potential failure due to improper siting, design and lack of maintenance.	Incorporate pretreatment if contributing drainage area is providing too much sediment.
Compaction during mowing.	Rototill existing soil when in friable condition and reseed.
Drawdown time is longer than 72 hours.	Rototill existing soil when in friable condition and reseed.
Unsuccessful vegetation establishment.	Recheck soil conditions for tilth and for conditions suitable for plant growth. Choose plant species that prefer the site conditions and are appropriate for the plant zone. Reset plants during an appropriate planting season. Reapply mulch.
Unsuccessful vegetation establishment.	Plant selection should include native species tolerant of both wet and dry cycles. Deep rooted perennials increase the rate of infiltration.

Infiltration Trench

Practice Description

Infiltration trenches are excavated trenches filled with granular material. These trenches are primarily used to slow stormwater runoff rates and promote infiltration of runoff into the ground. The most effective period of an infiltration trench is during the first flush of a runoff event when most of the runoff and pollutants are captured. Infiltration trenches remove suspended solids, bacteria, organics, soluble metals and nutrients through mechanisms of filtration, absorption and microbial decomposition. This SCM may be used in combination with another SCM such as a detention basin to increase the control of peak flows, or in combination with other SCMs as part of an overall treatment train.

Figure 6.131: Infiltration trench with geotextile. Source: Southeast Michigan Council of Governments/Michigan Department of Natural Resources

Infiltration trenches have select applications and their use is restricted by concerns due to common site factors, such as potential groundwater contamination, soils and clogging. In regions of karst (i.e., limestone) topography, infiltration trenches may not be appropriate due to concerns of sinkhole formation and groundwater contamination. Infiltration trenches can sometimes be applied in the ultra-urban environment but should not be located adjacent to stormwater hot spots. Two features that can restrict their use are the potential of infiltrated water to interfere with existing infrastructure and poor infiltration capacity of soils.

Figure 6.132: Biolfiltration Infiltration Trench, Cumberland County, PA.
Source: Pennsylvania Department of Environmental Protection

Recommended Minimum Requirements

This SCM should be designed by a registered design engineer as part of the overall site design for long-term water quality. Site selection for an infiltration trench should be based on soil infiltration, depth to water table, setbacks, loading rates and existing vegetation. Soil investigation and infiltration testing is a minimum requirement to inform design. Trenches should be located 150 feet away from drinking water wells to prevent possible contamination and should not be located adjacent to building foundations; they should be placed at least 10 feet down-gradient and 100 feet up-gradient from foundations. Infiltration trenches should not be used in areas where groundwater is close to the surface. This SCM may have either a grassed or gravel surface and may be located adjacent to roadways or impervious paved areas.

The width and depth of an infiltration trench may vary. The depth of stone, however, should be limited to six feet. The designer should review local requirements for site grading, drainage structures, erosion and sediment control and invasive or nuisance vegetation.

Construction

Prior to excavation activities of any type, call 1-800-DIG-RITE (344-7483) to obtain utility locations.

Follow all federal, state and local requirements on impoundment sites. See Chapter 1 for information about regulations and permit requirements.

Plans and specifications should be reviewed by the site superintendent and field personnel throughout the construction process.

Site Preparation and Installation

Protecting the infiltration trench area from compaction prior to installation is critical. If possible, the infiltration trench should be constructed during the later phases of site construction to prevent sedimentation or damage from construction activity. Erosion and sediment control measures need to be installed prior to construction and maintained during the course of construction.
A construction sequence might include:

- Install and maintain erosion and sediment control measures.
- Excavate the infiltration trench bottom to develop a uniform, level, uncompacted subgrade free from rocks and debris. It is critical to not compact the subgrade.
- Place nonwoven geotextile fabrics along the bottom and sides of the trench. (Clogging tendencies of the fabric should be taken into consideration during design.) Nonwoven geotextile fabric should be rolled out to overlap by a minimum of 16-inches within the trench. Excess geotextile should be folded and secured during stone placement.
- Install upstream and downstream cleanouts and control structures.
- Install continuously perforated pipe as indicated on plans. Backfill with uniformly graded, clean-washed aggregate in 8-inch lifts, lightly compacting between lifts.
- If topsoil is to be placed on top of the trench, a geotextile should be folded and secured over the infiltration trench and the area shall be seeded and stabilized.
- Within 24 hours, remove any sediment that enters inlets during construction.

Construction Verification

Check the finished grades and configuration of all elements. Check elevations and dimensions of all pipes and structures.

Maintenance and Inspection

Pretreatment devices, catch basins and inlets should be inspected for sediment buildup and cleaned at least twice each year. Observation wells should be inspected following three days of dry weather because failure to percolate will indicate clogging. If vegetation is planted on the surface of the infiltration trench, it should be maintained in good condition, and any bare spots should be revegetated as soon as possible. A vehicle should not be parked or driven over the surface of an infiltration trench. Care should be taken to avoid compaction by mowers if the trench has surface vegetation. Upon failure, the trench should be rehabilitated and trench walls should be excavated to expose clean soil.

Common Problems and Solutions

Problem	Solution
Potential failure due to improper siting, design and lack of maintenance.	Incorporate pretreatment if the contributing drainage area is providing too much sediment.
Sediment accumulation at catch basins or inlets.	Remove accumulated sediment through standard maintenance procedures.
Practice not functioning well.	Infiltration trenches do not work well in clay soils. Practice should be initially designed with amended soils, or a different practice should be chosen.

Porous Pavement and Pervious Pavers

Figure 6.133: Porous Asphalt Alley, St. Louis, MO. Source: Metropolitan St. Louis Sewer District

Practice Description

Porous pavement and a variety of pervious pavers provide a permeable surface that can be used to replace traditional pavement areas. Several systems may be used including pervious concrete and porous asphalt, precast concrete grids, modular unit pavers, geowebs and other manufactured pavement systems.

Porous pavement is usually built with an underlying stone reservoir that temporarily stores surface runoff before it infiltrates into the subsoil. Porous asphalt and pervious concrete looks very similar to traditional pavement, however, porous pavement contains little or no “fine” materials. Instead, it contains voids that allow infiltration through the pavement. Porous asphalt consists of an open-graded coarse aggregate, bonded together by asphalt cement, with sufficient interconnected voids to allow water movement. Pervious concrete typically consists of specially formulated mixtures of Portland cement, open-graded coarse aggregate and water. Pervious concrete has enough void space to allow rapid percolation of stormwater through the pavement. Moderate traffic zones are ideal locations for the application of porous pavement options.

See Appendix D for reference to EPA Menu of BMPs, specifically post-construction fact sheets named *Permeable Interlocking Concrete Pavement, Pervious Concrete Pavement and Porous Asphalt Pavement*.

Additional Considerations

- In some areas, such as truck loading docks and areas of high commercial traffic, porous pavement is inappropriate and presents maintenance issues.
- Since porous pavement is an infiltration practice, it should not be applied at stormwater hot spots (areas of unusually high pollution runoff) due to the potential for groundwater contamination.
- Porous pavement is not an option for drinking water recharge areas, due to contamination potential.

Pervious pavers and turf blocks can be used as a porous pavement option. Options include pre-cast concrete grids with void areas for grass, modular unit pavers installed with pervious material in the gaps, and geowebs designed for soil reinforcement. Alternative pavers can be used to replace historical pavement options in parking lots, driveways and walkways. The traffic volume, weight and frequency limit application. Pervious pavement and turf blocks are often applied to overflow parking areas and in residential settings. They can be used in combination with other stormwater SCMs.

Recommended Minimum Requirements

This SCM should be designed by a registered design engineer as part of the overall site design for long-term water quality.

Porous pavement should be used for low to medium traffic areas, for parking lanes and parking lots. Porous pavements should be placed on flat ground, but the slopes of the site draining to the practice should not be steeper than 15 percent. Soils need to have a permeability of at least 0.5 inches per hour. An alternative design for soils with low porosity would be the installation of a discharge pipe from a storage area beneath the pervious pavement that drains to the traditional storm sewer system. To reduce the risk of contamination, design should provide significant separation of 2- to 5-feet from the bottom of the porous pavement stone reservoir and the seasonally high groundwater table. Additionally, porous pavement installations should not be installed within the vicinity of drinking water wells. The bottom of the stone reservoir should be flat, so that runoff can infiltrate through the entire surface.

Pervious pavers and turf blocks should be situated to accept smaller contributing drainage areas, usually less than 5 acres, with relatively high impervious cover. The designer should evaluate the durability and maintenance cost of alternate pavement options. Soil types will affect infiltration rates and clay soils will substantially limit infiltration on a site. If groundwater pollution is a concern, permeable pavers should not be used.

The designer should always review local requirements for site grading, drainage structures and erosion and sediment control.

Construction

Prior to excavation activities of any type, call 1-800-DIG-RITE (344-7483) to obtain utility locations.

Follow all federal, state and local requirements on impoundment sites. See Chapter 1 for information on regulations and permit requirements.

Plans and specifications should be reviewed by the site superintendent and field personnel throughout the construction process.

Due to the nature of construction sites, pervious pavement and other infiltration measures should be installed toward the end of the construction period. Infiltration beds under pervious pavement may be used as temporary sediment basins or traps. After the site is stabilized and sediment storage is no longer required, the bed may be excavated to its final grade and the pervious pavement system can be reinstalled as directed in the contract documents. The following sequence of construction steps provides an example:

- The existing subgrade under the bed areas should not be compacted or subject to excessive construction equipment prior to geotextile and stone bed placement.
- Where the erosion of the subgrade has caused accumulation of fine materials or surface ponding, this material shall be removed with light equipment and the underlying soils should be scarified to a minimum depth of 6-inches. All fine grading should be done by hand and the bottom of the bed should be at a level grade to prevent ponding.
- Earthen berms between infiltration beds should be left in place during excavation. These berms do not require compaction if proven stable during construction.
- If an underdrain system is designed, it should be installed before the subgrade for the infiltration bed is prepared.
- Geotextile and bed aggregate should be placed immediately after approval of subgrade preparation. Geotextile should be placed in accordance with manufacturer's recommendations and specifications. Geotextile fabric should overlap a minimum of 16-inches and should be secured at least 4-feet outside of the bed in order to prevent any runoff or sediment from entering the storage bed. This edge strip should remain in place until all bare soils adjacent to beds are stabilized and vegetated. As the site is fully stabilized, excess geotextile along bed edges can be cut back.
- Clean, uniformly washed graded aggregate should be placed into the prepared bed in 8-inch lifts. Each layer should be lightly compacted, with the construction equipment kept off the bed bottom as much as possible. After bed aggregate is installed to the desired grade, a 1- inch layer of base course such as AASHTO M-43 #57 aggregate could be installed uniformly over the surface in order to provide an even surface for paving.
- The pervious pavement materials (pervious concrete or asphalt) or pavers should be installed in accordance with current standards.

Construction Verification

The full permeability of the pavement surface should be tested by applying clean water at a rate of at least 5 gallons per minute over the surface. All applied water should infiltrate directly without puddle formation or surface runoff.

Maintenance and Inspection

Pervious Pavement

The primary goal of pervious pavement maintenance is to prevent the pavement surface and underlying infiltration bed from clogging. Pores can become clogged when fine particles deposit on the surface from vehicles, the atmosphere and runoff from adjacent land surfaces. Clogging increases with age and use. Permeability can be maintained through vacuum sweeping using equipment, frequency schedules and precautions defined in the operation and maintenance plan. In areas where extreme clogging has occurred, half inch holes can be drilled through the pavement surface every few feet or so to allow stormwater to drain to the aggregate base. All inlet structures draining to the infiltration area should be cleaned out at least annually. Additionally, the surface should be inspected for deterioration annually. If not easily noticed, pervious pavement areas should be identified with signage to aid inspection.

Planted areas adjacent to a pervious pavement area should be well maintained to prevent soil washout onto the pavement. Any bare spots or eroded areas should be revegetated upon discovery. Planted areas should be inspected on a semiannual basis.

Trucks and other heavy vehicles should be prevented from tracking or spilling dirt on the pavement. All construction or hazardous materials carriers should be prohibited from driving on pervious pavement.

Winter maintenance for a pervious parking lot is typically less intensive because pervious pavement has superior snow melting characteristics. The underlying stone beds absorb and retain heat so freezing rain and snow melt faster on pervious pavement. Abrasives such as sand should not be applied on or adjacent to the pervious pavement. Snow plowing is acceptable, provided it is completed carefully, with the blade set slightly higher than usual (about 1-inch). Salt is acceptable though nontoxic, organic deicers, applied as blended magnesium chloride-based liquid products or as pretreated salt, are preferable.

Potholes are unlikely although settling may occur. For damaged areas less than 50 square feet, a pothole or failure should be patched by any means suitable with standard pavement or a pervious mix. If the repair area is greater than 50 square feet, the design engineer should be consulted. The pavement surface should never be seal coated.

Pavers

Maintenance of paver systems will vary greatly. The owner and engineer should refer to the manufacturer's recommendations. The turf installed in the pervious voids should be maintained with minimal fertilizer. The application of deicing chemicals should be limited.

Common Problems and Solutions

Problem	Solution
Decreased infiltration capacity.	Porous pavements are best maintained by vacuuming.
Pothole damage in an areas less than 50 square feet.	A pothole or failure should be patched by any means suitable with standard pavement or a pervious mix.
Sediment accumulation from adjacent landscaped areas.	Planted areas should be well maintained to prevent soil washout onto the pavement. Any bare spots or eroded areas should be revegetated upon discovery.

Sand Filters

Figure 6.134: Perimeter Sand Filter. Source: Center for Watershed Protection

Practice Description

Sand filter systems may be constructed on the surface or underground in vaults for large sites. Perimeter filters with a two-chamber concrete vault can be applied along the perimeter of a parking lot. Pocket sand filters are used at small sites and combine a sediment basin or filter strip preceding a vegetated depression full of sand. Sand filters are associated with high removal rates for filterable pollutants such as sediment, organic solids (i.e., biological oxygen demand), and fecal coliform bacteria. These filters are not efficient in removing soluble pollutants such as metals and nutrients.

Because sand filters provide treatment (pollutant capture), they are preferred to infiltration practices when contamination of groundwater is a concern, such as in areas where underlying soils cannot treat runoff or where groundwater tables are high. Because flow-through is fairly rapid, sand filters are not significant volume reducing SCMs.

A typical sand filter system consists of two or three chambers: a sedimentation basin to remove floatable materials and heavy sediments, a filtration basin where runoff is filtered by a self contained bed of sand and a discharge chamber. Runoff is diverted to the bed, collected by underground pipes and then discharged into a stream or channel.

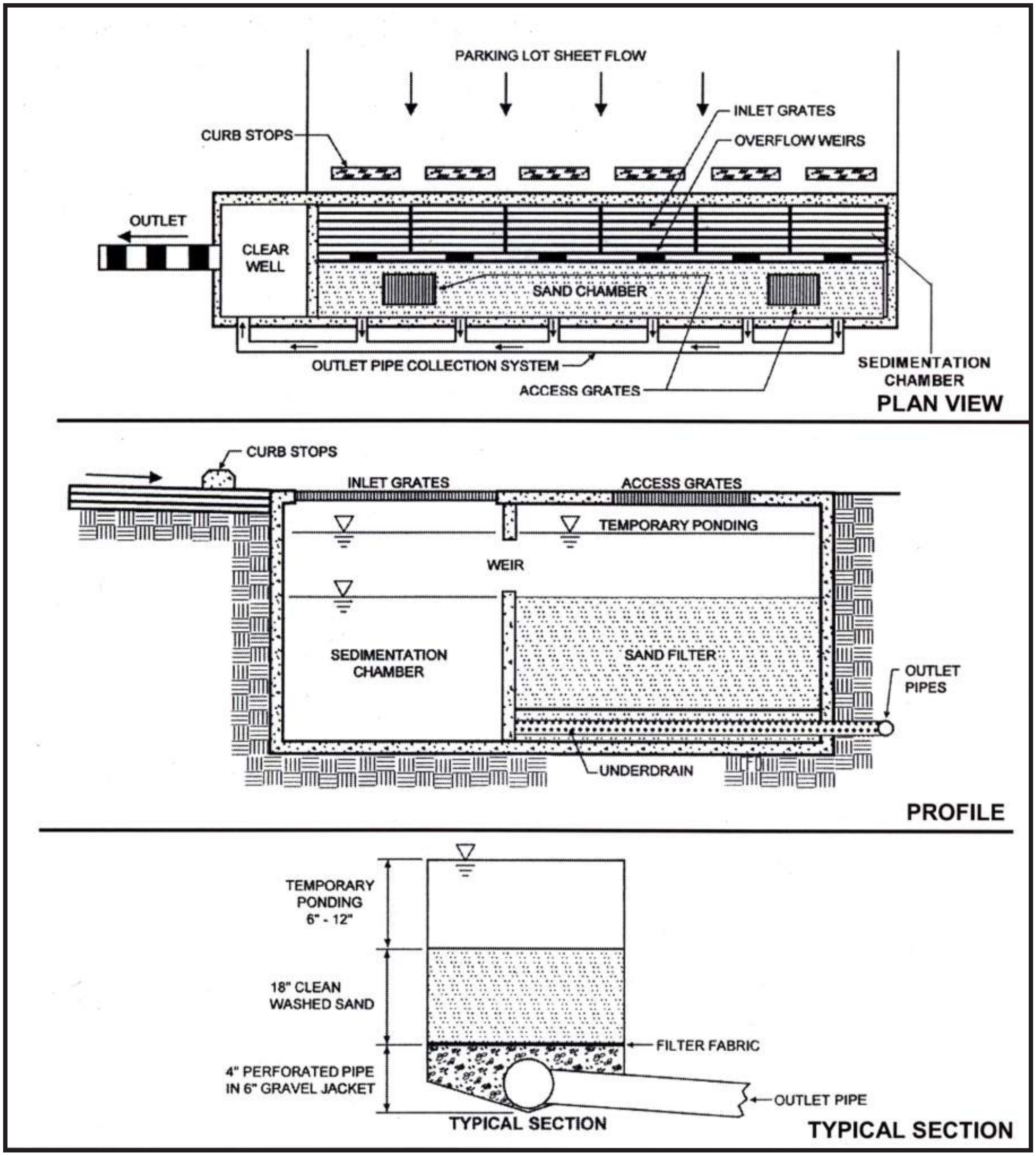

Figure 6.135: Perimeter Sand Filter. Source: Center for Watershed Protection (©2000)

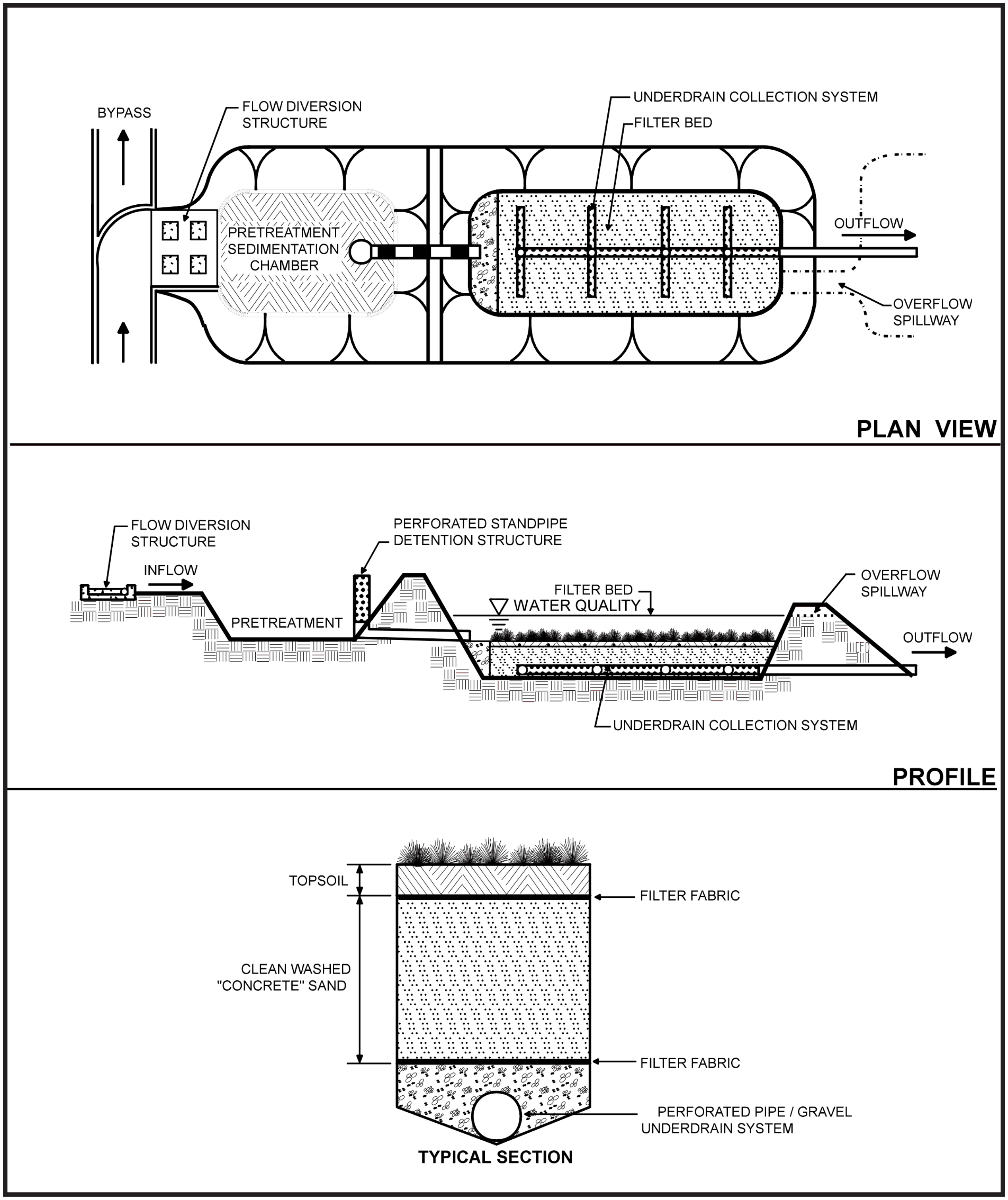

Figure 6.136: Surface Sand Filter. Source: Center for Watershed Protection (©2000)

Recommended Minimum Requirements

To avoid hydraulically overloading the device, the contributing drainage area to any sand filter should be limited to 5 acres. Sand filters should be designed as off-line practices to capture and treat only the water quality storm and to bypass the larger flows. When used in combination with sedimentation basins, sand filters should be installed as an initial pretreatment step.

Construction

Prior to start of construction, this SCM should be designed by a registered design professional as part of the overall site design for long-term water quality. Plans and specifications should be reviewed by the site superintendent and field personnel throughout the construction process. Elevations of pipe inverts, weirs and filter beds are critical to sand filter performance and should be checked during construction.

Construction Verification

Measure the finished grades and configuration and compare against the plans and specifications. Check elevations and dimensions of all pipes and structures.

Maintenance and Inspection

Maintenance and inspection of a sand filter will vary depending on the design. Periodic maintenance activities should include the following:

- Frequent inspection of overflow, removal of organic material, and removal of sediment from the sediment basin or chamber.
- Quarterly monitoring of water levels in underground filters.
- Biannual inspection for erosion of pretreatment surface and pocket sand filters.

Common Problems and Solutions

Problem	Solution
Erosion or washout.	Install a device for energy dissipation at the eroded or washed out location.
Clogging due to high sediment loading.	Stabilize adjacent contributing drainage areas or perform frequent clean-outs.
Cells collect trash and debris.	Conduct regular trash and debris removal.
Standing water.	Use corrective measures to ensure proper infiltration.

Hydrodynamic Separation

Figure 6.137: Hydrodynamic Separator. Source: MSD

Practice Description

Hydrodynamic separators, also called swirl concentrators or vortex separators, are available in a wide variety of proprietary devices. These systems target coarse solids and large oil droplets using vortex-enhanced sedimentation or cylindrical sedimentation.

These proprietary systems can provide pretreatment to other technologies in urban areas where surface SCMs are not feasible. Stormwater runoff is not detained, rather it flows through these separation systems at a designed rate controlled by the inflow pipe. They often provide pretreatment for other systems (like filters). It is noted that these devices provide no volume reduction benefits and are generally used only in a retrofit role. They are also used for stormwater hotspots where space is limited for other SCMs.

Recommended Minimum Requirements

Hydrodynamic separators may work if designed off-line with an upstream diversion structure to address larger flows. Head losses across the system should be considered. The design of the system is specific to the manufacturer. The designer should review local requirements for site grading, drainage structures, and erosion and sediment control.

Construction

The design of the system is specific to the manufacturer. Plans and specifications should be referred to by field personnel throughout the construction process. The contributing drainage area should be fully stabilized prior to the operation of the device.

Construction Verification

Check the finished elevations and configuration for all elements. Check elevations and dimensions of all pipes and structures to verify installation.

Maintenance and Inspection

Maintenance requirements and procedures are specified by the manufacturer.

- Regular maintenance is required to prevent the re-suspension of trapped pollutants. Maintenance frequency is a function of the site specific runoff characteristics.
- Maintenance is usually performed with a vacuum truck.
- Maintenance requirements and procedures are specific to each system and specified by the manufacturer.

Common Problems and Solutions

The manufacturer should be consulted if there are problems with this SCM. Maintenance requirements and procedures are specified by the manufacturer. This device is maintenance intensive due to the small capacity. If this device is not cleaned out routinely, the trapped materials may result in highly polluted discharges during the next storm event.

Catch Basin Inserts

Figure 6.138: Catch Basin Inserts. Source: Shockey Consulting Services

Practice Description

Catch basin inserts are manufactured filters designed to remove trash, debris, coarse sediments, and sometimes oils from stormwater runoff. They are located at the storm drain inlet structure, often installed beneath a catch basin inlet grate.

This device alone does not address all water quality needs. Catch basin inserts are installed to provide pretreatment of runoff from roads, parking lots, commercial and industrial sites. These inserts present an inexpensive option for pretreatment retrofit and are often used in conjunction with other downstream SCMs such as media filtration and infiltration. Manufacturer specifications should be compared to site specific targeted constituents. It is noted these devices provide no volume reduction benefits and are generally used only in a retrofit role. They are also used for stormwater hotspots where runoff pollution is unusually high and where space is limited for other SCMs. However, filters are a more effective way of treating hotspots where space permits.

Recommended Minimum Requirements

Catch basin inserts may be easily installed at most existing storm drain inlets. The design of the system is specific to the manufacturer. The design professional should ensure the capacity of the inlet remains sufficient and does not result in localized flooding. The designer should review local requirements for drainage structures and erosion and sediment control.

Construction
The design of the system is specific to the manufacturer. Plans and specifications should be referred to by field personnel throughout the construction process. The contributing drainage area should be fully stabilized prior to the operation of the device.

Construction Verification
Check the finished elevations and configuration for all elements. Check elevations and dimensions of all pipes and structures to verify installation.

Maintenance and Inspection
Frequent maintenance is critical to ensure functionality of the storm drainage system. Maintenance requirements and procedures are specified by the manufacturer. Maintenance frequency is a function of the site specific runoff characteristics.

Common Problems and Solutions
The manufacturer should be consulted if there are problems with this SCM. Maintenance requirements and procedures are specified by the manufacturer. This device is maintenance intensive due to the small capacity. If this device is not cleaned out routinely, the trapped materials may result in highly polluted discharges during the next storm event.

Baffle Boxes and Oil/Grit Separators

Figure 6.139: Wetland Swale. Source: Olsson Associates

Practice Description

There is a wide range of configurations and designs of proprietary baffle box or oil/grit separators. Most of these systems are installed offline, bypassing the larger flows. These systems typically have a sediment chamber sized based on Stoke's Law principles, and a chamber to trap floatables such as oils and trash.

There are proprietary and non-proprietary systems. This device is used for limited water quality enhancement in urban areas when land is not available for surface SCMs. They often provide pretreatment for other systems (like filters). Baffle boxes may be incorporated with pre-treatment filters for surface SCMs. These devices allow water to flow through and the rate is regulated by the bypass structure. It is noted these devices provide no volume reduction benefits. Baffle boxes are generally used only in a retrofit role. As a companion practice with filters, they can be used where space is limited for other SCMs or for stormwater hot spots that produce higher concentrations of pollutants than what is normally found in urban runoff.

Recommended Minimum Requirements

Baffle boxes and oil/grit separators are underground and can be adapted to almost any site as an offline treatment. There must be sufficient grade change across the bypass line to ensure that treated water returns to the main line. Specific design and performance expectations are based on the manufacturer. The designer should review local requirements for site grading, drainage structures and erosion and sediment control.

Construction

The design of the system is specific to the manufacturer. Plans and specifications should be referred to by field personnel throughout the construction process. The contributing drainage area should be fully stabilized prior to the operation of the device.

Construction Verification

Check the finished elevations and configuration for all elements. Check elevations and dimensions of all pipes and structures to verify installation.

Maintenance and Inspection

Maintenance requirements and procedures are specified by the manufacturer. Regular maintenance is required to prevent the re-suspension of trapped pollutants. Maintenance frequency is a function of the site specific runoff characteristics. Removal of trapped material is performed with a vacuum truck as needed, usually annually.

Common Problems and Solutions

The manufacturer should be consulted if there are problems with this SCM. Maintenance requirements and procedures are specified by the manufacturer. Limitations include limited pollutant removal, no volume control, frequent maintenance, proper disposal of trapped sediment, oil and grease, expensive to install and maintain when compared to other practices, and cannot be used for the removal of dissolved or emulsified oils such as coolants, soluble lubricants, glycols and alcohols. Also, the contributing area should be limited to one acre or less of impervious cover.

Streambank Protection: Preservation, Enhancement and Restoration

Figure 6.140: Streambank Erosion. Source: Shockey Consulting LLC, Burr Oak Woods, Jackson County, MO

Practice Description

Restoration of the streambanks becomes necessary when permanent stormwater control measures have been insufficient or nonexistent to control runoff from the disturbed areas. Streams that receive increased flow volume and velocity will likely suffer bank erosion if not protected. Streambank protection can be vegetative, structural or a combined method where live plant material is incorporated into a structure (bioengineering). Vegetative protection is frequently the least costly and the most compatible with natural stream characteristics. Because each reach of channel is unique, a professional team should be consulted to ensure the specific site characteristics and sensitivities are considered in the design and installation of protective or restorative measures. The professional team will need to focus on streambank and channel stability, upstream contributions to increased flow and volume, and specific stream characteristics that will determine stabilization design (e.g. stream grade and soil type).

Streambanks tend to erode in watersheds where surface runoff rates have increased, causing higher peak flows in the stream. As a result, the stream reforms to carry its new load. Negative impacts to the stream result from changes in the watershed, such as removal of vegetation along a streambank, removal of open space, pavement of large-scale surfaces, removal of healthy vegetation upland and installation of piped stormwater systems.

Considerations in determining which type of streambank protection to use include:

- Current and future watershed conditions.
- Discharge velocity.
- Sediment load.
- Channel slope.
- Dynamics of bottom scour.
- Soil conditions.
- Present and anticipated channel roughness.
- Compatibility with other improvements.
- Changes in channel alignment.
- Fish and wildlife habitat.

Bioengineered Streambank and Channel Protection

Bioengineering involves the use of living vegetation in combination with soil reinforcing agents such as reinforcing mats to provide bank stabilization by increasing soil shear resistance, dewatering saturated soils, and by reducing local shear stresses through increased hydraulic roughness.

Bioengineering is advantageous where there is minimal access for equipment and workers and in environmentally sensitive areas where minimal site disturbance is required. Most techniques can also be used for stream channel or bank protection. Once established, woody vegetation becomes self-repairing and needs little maintenance.

Combinations of vegetative and structural protection provide some of the advantages of both. The structures provide immediate erosion, sliding and washout protection. Vegetation provides greater infiltration than some structural methods, increases channel roughness, and filters and slows surface runoff entering the stream. Vegetation also helps maintain fish and wildlife habitat, and a natural appearance along the stream. It is important that the designer target the cause, not the symptom, of the problem in order to design an effective repair.

Combined methods can be used in areas where velocities exceed 6 feet per second, along bends, in highly erodible soils and on steep channel slopes. Common materials include cellular matrix confinement systems, grid pavers and bioengineering techniques. The upstream and downstream ends of the protection should begin and end along stable reaches of the stream. This practice should be designed for capacity at mature and self-sustaining growth and for stability at low or dormant growth.

See Appendix C and Appendix D for design manual references and other resources. More information about bioengineering practices is available from your local Natural Resources Conservation Service/Soil and Water Conservation District, the Missouri Department of Conservation, University Extension or local design professionals. See Soil Bioengineering for Slope Protection and Erosion Control Transition Mats

Vegetative Streambank Protection

Effective vegetative protection depends on locating plants where their natural characteristics provide the greatest benefit and their growth is assured. General planting information is listed below; however vegetation should be planted in accordance to the design plan with consideration to the vegetative zones. As above, vegetative protection should be designed for capacity at mature and self-sustaining growth and for stability at low or dormant growth. The location of each zone depends on the elevations of the mean high water level, the mean water level and the mean low water level as shown in Figure 6.141.

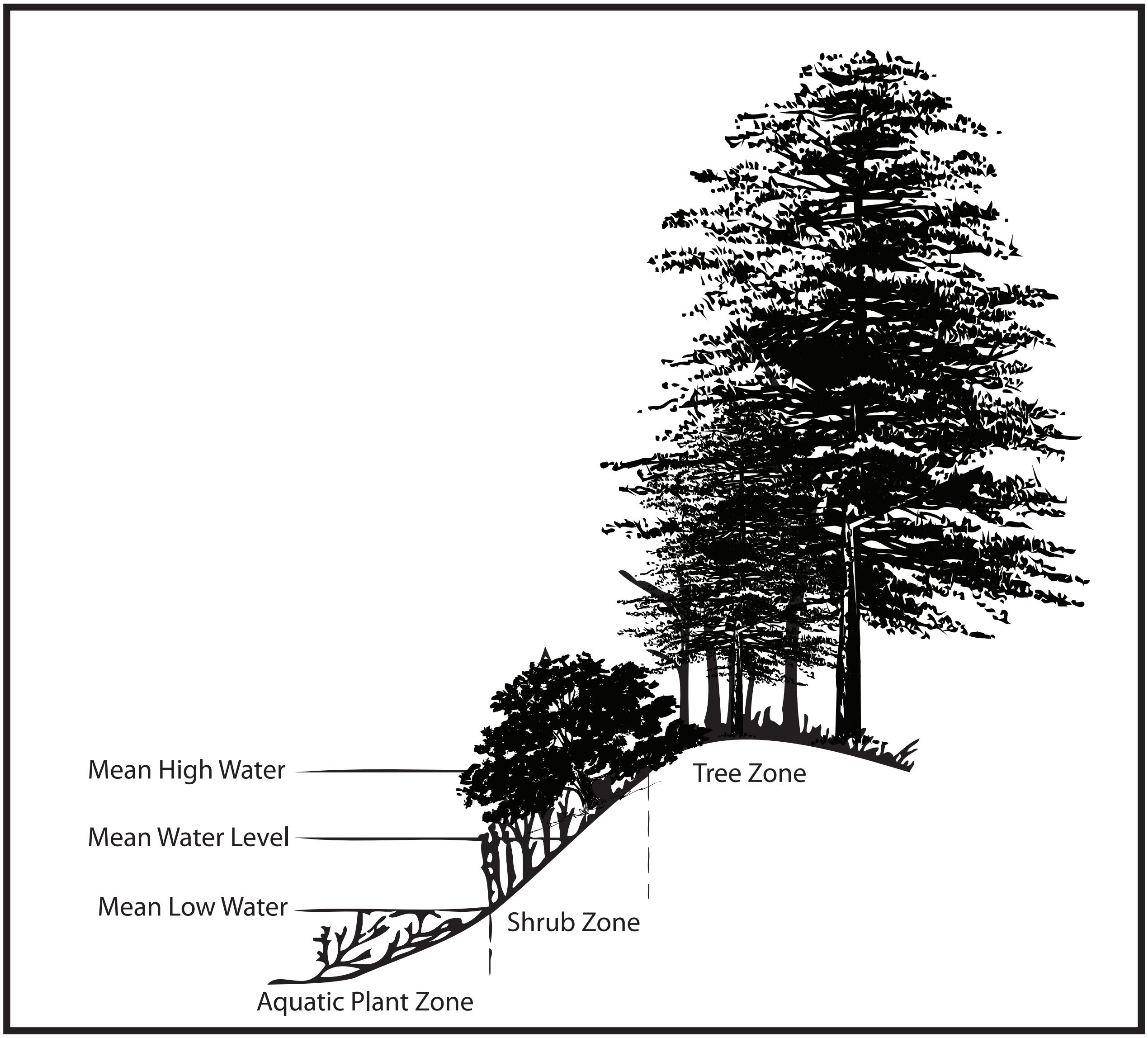

Figure 6.141: Vegetative Zones for Streambank Protection. Source: Missouri Department of Natural Resources

Aquatic Plant Zone

The aquatic plant zone includes the stream bed and is normally submerged at all times. Most often this area is not planted, yet sometimes aquatic plants are added here to achieve greater diversification in the restored stream bank community.

Shrub Zone

The shrub zone lies on the bank slopes just below the mean high water level and is normally dry, except during floods. Willows, silver maple, poplar and dog wood trees can be planted (staked) from top-of-bank to mean water line. They are preferred because they have high root densities and root depth, root shear and tensile strength is higher than that of most grasses or forbs, and they can transpire water at high rates.

- Upland trees should not be planted in the shrub zone. Refer to Appendix C and Appendix D for plant resource information, including the Grow Native! website for photos and narratives about Missouri native plants or consult the Missouri Department of Conservation, Kansas Wildlife and Parks or a professional forester for appropriate wetland shrub and tree species. Some grasses, sedges and bushes should be planted in the shrub zone if shear is not too high and plants are not submersed frequently or for long periods of time.
- Plant grasses in the spring or the fall. To seed grasses, roughen the seedbed, lime and fertilize according to soil test results. Check with the local Natural Resources Conservation Service, Missouri Department of Conservation, University Extension office or a local design professional for an appropriate seed mixture.

Tree Zone

Plant upland trees along the banks of the stream and not on the slopes. If trees provide shade to the streambank, grasses should be planted that will thrive in shady conditions.

Structural protection with engineered structures alone or bioengineered with plants should be provided in locations where velocities exceed 6-feet per second, along bends, in highly erodible soils and in steep channel slopes. Common materials include rock and revetments. Grouted riprap is not recommended, because grouted rock does not move with freeze/thaw and wetting/drying cycles. This lifting action results in voids quickly forming under grouted rock, allowing erosive forces to penetrate the structure and create potential failure of the grout and rock movement. The upstream and downstream ends of the structural protection should begin and end along stable reaches of the stream.

Streambank restoration efforts that involve structural practices or combination methods should be considered temporary if overall watershed factors are not considered in the design. Contributing erosion factors need to be corrected, because erosion will otherwise render the structural practice ineffective.

Structural Streambank Protection

Grid Pavers

Grid pavers are modular concrete units with interspaced void areas that can be used to armor a streambank while also establishing vegetation. Grid pavers are typically tied together with cables and come in a variety of shapes and sizes.

Figure 6.142: Interlocking concrete blocks along Two Mile Creek, St. Louis County.
Source: K. Grimes, SWCD, St. Louis County

Cellular Confinement Matrices

Cellular confinement matrices are commercial products usually made of heavy-duty polyethylene formed into a honeycomb-type matrix. The cellular confinement matrices are flexible to conform to surface irregularities. The combs may be filled with soil, sand, gravel or cement. If soil is used to fill the combs, vegetation must also be established.

Gabions

Gabions are rock-filled wire baskets stacked to form a wall against the streambank. Gabions are not the preferred alternative for streambank protection when bioengineering practices are available to provide adequate protection. Efforts should be made to identify the sources of erosion and streambank destabilization such as upstream devegetation, increased imperviousness, extensive curb and guttering. Efforts should be made to restore upland vegetation, slow the flow of stormwater entering the stream system and reroute to alternative practices. It is better to correct the problems, otherwise gabions and similar practices such as filter fabric revetments are only temporary fixes.

Gabions are typically designed to slow the flow of stormwater. They are sometimes used on steep slopes for temporary stabilization where there is not enough room to accommodate a “softer”, vegetated solution. Gabions are very labor intensive to construct, but are semi-flexible, permeable and can be used to line channel bottoms and streambanks. They can be placed (and vegetated when possible) in a manner to provide good drainage.

Additional Considerations

Gabions are more expensive than either vegetated slopes or riprap.

The wire baskets used for gabions may be subject to heavy wear and tear due to wire abrasion by bedload movement in streams with high velocity flow. Gabions are difficult to install, requiring large equipment. Gabions are not the preferred alternative for streambank protection when bioengineering practices are available to provide adequate protection. Gabions are considered temporary. Permanent stabilization is dependant upon locating and correcting the problems contributing to erosion and destabilization. When gabions break down, the stream should already be in the process of stabilizing if erosive factors have been addressed upstream.

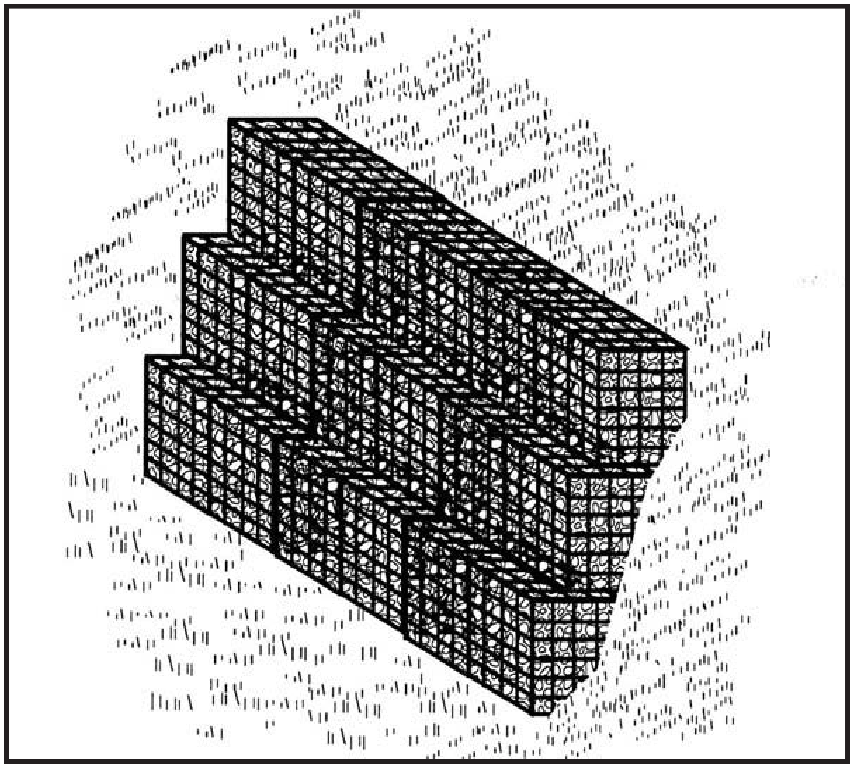

Figure 6.143 Typical gabion installation. Source: Shockey Consulting Services

Recommended Minimum Requirements

Streambank protection projects should be designed by a registered Professional Engineer as part of the overall site design for long-term water quality, with significant attention given to upstream and downstream hydrologic factors and overall watershed health. Streambank and wetland work within jurisdictional waters require federal, state and possibly local permits. See Chapter 1 for regulation information.

Figure 6.144 Example of stable and unstable streambank. Source: MDC

Streambank protection should be considered in the initial design phases of any development project. An interdisciplinary team may provide the needed variety of expertise. Protection methods should focus on preserving, enhancing or restoring the stream hydraulics such that streambanks no longer erode.

Protection measures should begin and end at stable locations along the bank. Stable locations are typically where the streambed is armored with stable rocks occurring naturally at riffles, or man-made armored sections such as culvert crossings. By working between these stable locations, the impacts of the streambank protection are limited to the channel between stable locations so the erosive forces are not transferred to another location.

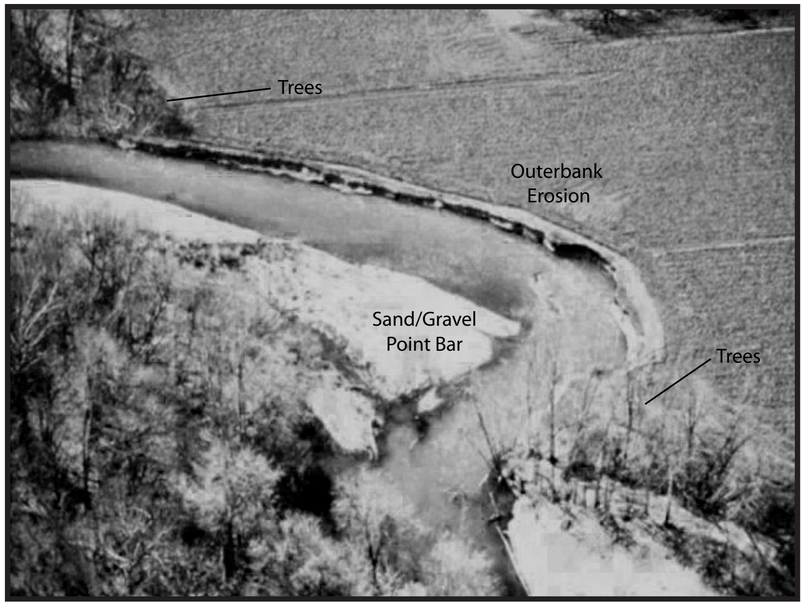

Figure 6.145 Example of stable and unstable streambank. Source: MDC

Before work is done within the channel, it should be determined if a Section 404 permit is required from the Corps of Engineers, as well as a Section 401 permit from the Department of Natural Resources. A local floodplain study may also be required. The site superintendent, job foreman and field personnel should refer to the plans and specifications throughout the construction process. The site superintendent should discuss any potential need for such permits with the site owner.

Several important considerations when designing streambank or channel protection include:

- **Velocities:** Vegetation alone may provide effective protection when stream velocities are 6-feet per second or less. Consider structural protection for velocities greater than 6-feet per second. Use the highest velocity expected, which is determined by evaluating the velocities through the full range of storms from the very frequent small events through large storm events. Allowable velocities vary depending on the soil and plant types. Refer to applicable design standards and manuals for more details.

- **Channel Bottom:** Downcutting must be stabilized before installing bank protection. An engineered grade control may be needed where downcutting is severe.

- **Streambank Plantings:** Consider the natural growth needs, patterns and preferences of selected planting stock when reestablishing the streambank community.

- **Plant Selection:** Use native or adaptive plant materials for establishment and long term success, because adapted plants are easier to establish and require less maintenance. See Appendix C and Appendix D for references about guiding plant selections.

- **Structural Methods:** Constructed “hard surfaced” features may be needed in especially challenging spots such as bends in the channel or changes in channel slope or where changes in hydrology, sediment load and channel alignment are occurring.

- **Combined Methods:** Many bioengineering practices (i.e. use of “living” structures) are useful to protect streambanks and channels. (See Bioengineered Streambank and Channel Protection on page 6-324.)

- **Permits Requirements:** See Chapter 1 for regulation and permit requirements.

Construction

Initial Site Considerations

- Before starting construction, ensure all plans follow local, state and federal government regulations for any stream modification within jurisdictional waters. See Chapter 1 for regulation and permit requirements.

- Prior to excavation activities of any type, call 800-DIG-RITE (344-7483) to obtain utility locations.

- Examine the channel bottom before streambank protection measures are installed. Determine the need for grade control.

- Locate stable points along the channel to serve as anchor points for stream protection structures.

Follow design specifications for clearing, grubbing and grading. Grid pavers, cellular confinement matrices, gabions or other proprietary products should be designed and constructed into the project in accordance with manufacturer's guidelines and as specified in the design plan.

When filling products with rock, only durable crushed limestone, dolomite or granitic rock should be used. Shale, siltstone and weathered limestone should not be used because of their solubility or tendency to crumble. Depending on soil type, a filter fabric or a granular filter may need to be placed between streambank material and gabions. Use attractive facing stone toward the front of the wall.

Establish desirable vegetation where possible in between rocks and materials within the pavers, matrices or gabions. Otherwise, invasive and poorly rooting plants will take over the practice, reducing its effectiveness. Desirable vegetation will also increase habitat value.

Erosion Control

Minimize the size of all disturbed areas and stabilize as soon as each phase of construction is complete. Use temporary diversions to prevent surface water from running onto the streambank protection area. Route overland flow so it maintains the least possible velocity and exits the project site at a protected location. This information should be outlined in the community's stormwater pollution prevention plan associated with state, local or federal permits. See Chapter 1 for regulation and permit information.

Plant vegetation immediately after construction to promptly stabilize all disturbed areas.

Safety

Store all construction materials well away from the stream to avoid transport of polluted runoff or materials to the stream.

Clear, grub and grade the streambank surface to prepare for installing the matrices. Install systems according to engineered design plans and manufacturer's recommendations.

At the completion of each workday, move all construction equipment to a safe storage area out of and away from the stream to prevent damage from flooding. While working in streams, whether flowing or not, the following precautions should be taken:

- Avoid working above steep slopes on the streambank where cave-ins are possible.

- Fence area and post warning signs if trespassing is likely.

- Provide a means for draining the construction site if it becomes flooded.

Construction Verification
For vegetative protection, check to see planting and seeding was done in compliance with the design specifications. For structural protection, check cross section of the channel, thickness of protection and confirm the presence of filter cloth between the protection and the streambank.

Maintenance and Inspection
Bank stability and vegetation should be assessed during routine inspections and after each storm event during the initial 2 years following construction. If any minor bank instabilities are documented, the repair should include back-filling with soil, installing erosion control blanket or bonded fiber matrix, planting seed blends and vegetative cover recommended in the plans.

Significant bank instabilities should be addressed by a professional design engineer. The extent of the project areas should be monitored with great frequency at project completion and less often as the project establishes, as presented below.

Table 6.18: Monitoring Frequency Following Plant Establishment

Growing Seasons	Frequency of Monitoring
1 - 2 years	Bi - Weekly
3 - 5 years	Bi-Monthly
Project Life	Two Inspections Annually

Maintenance activities should be in response to any new bank instabilities or vegetation issues detected. Maintenance activities may consist of weed control, bank stabilization and replanting vegetation that has died or eroded. It is important to identify what caused any issues so their reoccurrence can be prevented.

Bare areas of soil greater than 1 ft^2 shall be reseeded immediately upon discovery and protected from soil erosion. For any new plantings, adequate soil moisture is critical to plant establishment, and adequate soil moisture must be maintained immediately after each plant is sowed or set.

The project should require the contractor or property owner to maintain the plants throughout the first full growing season until they become established. Plants are more susceptible to mortality during the first two weeks of their growth and often require supplemental watering.

It is also important that other environmental and man-made stresses be monitored and timely adjustments be made to take these stresses into account. Some anticipated stresses include:
- Herbivory or Grazing (insects, deer, livestock).
- Vandalism.
- Wildlife Damage (rabbits, deer, beaver, muskrat).
- Insect infestations (grasshoppers, army cutworm, spider mites).
- Disease (not a frequent problem with non-horticultural varieties).
- Water stress (drought early on, typically the design is flood tolerant).
- Weather Damage (wind, hail).
- Weed Infestation.

Streambank maintenance after construction is the responsibility of the land owner, municipality or sewer district. The landowner needs to understand their responsibility and the state and local requirements in their area. Larger issues can be addressed through cooperative watershed planning and partnerships with regional planning groups.

Common Problems and Solutions

Problem	Solution
Variations in topography on-site indicate protection will not function as intended.	Consult with a registered Professional Engineer, changes in plan may be needed.
Design specifications for vegetative or structural protection cannot be met.	Consult with registered Professional Engineer, substitution may be required. Unapproved substitutions could result in erosion damage to the streambank and cause project failure.
Erosion of streambank; caused by inadequate vegetation, improper structural protection or an increase in stream velocity due to upstream development.	Repair erosion, establish adequate vegetation or structural protection and reduce stream velocities.
Slumping failure or slides in streambank; caused by steep slopes.	Repair a slide by excavating failed material and replacing with properly compacted fill. Consider flattening the slope and consult the Professional Engineer.

Rock Lined Channels

Highway drainage designers are ultimately left with the task of capturing runoff that does not infiltrate and then routing it via storm sewer to an outlet at some location. In the distant past, it was common to let this runoff discharge directly to a receiving water body, often resulting in an actively erosive area. Later, it became common to line the channel area with various sized rocks (riprap) in order to solve the problem.

Riprap is still used, however it is not always the most structurally sound nor is it the most aesthetic approach. Natural and synthetic geotextile reinforcements may be a suitable alternative and are available to fit a variety of needs. Choosing between these options depends a great extent on the nature of the problem. Product specifications for strength and applications should be examined to choose the proper material. Another option is compost-grouted riprap, in which compost is sprayed into voids and serves as a root medium for native plants.

As with grade controls, these reinforcement methods can be part of an initial installation or easily retrofit if a problem is identified and in need of a solution. However, erosive factors need to be addressed elsewhere in the watershed to avoid further failure.

- Rock lined channels require properly sized, graded, bedded and placed rock that rises and settles with soil movement.
- Stream banks should be sloped at 2:1 or flatter.
- In some cases, it might by beneficial to place filter fabric or a granular filter between the rock and the natural soil.
- Construct the riprap layer with sound, durable rock. Refer to plan for gradation and layering.
- Large and small rocks are required to lock in pieces and should not be flat or elongated.
- Place the toe of the rock at least 2-foot below the stream channel bottom or below the anticipated scour depth. Install toe walls as specified in plan.
- Extend the top of the riprap layer at least up to the two year water surface elevation. Vegetate the interface and remainder of bank.