6 Green Infrastructure Stormwater Control Measures - Strategies, Practices and Tools

This chapter provides general examples green infrastructure strategies, practices and tools, including several case studies. For more comprehensive lists and details, numerous design manuals and other resources are cited throughout this guide and in the appendices. It is essential that long-term operation and maintenance be incorporated into plans for green infrastructure. Operation and maintenance is discussed throughout the numerous design manuals available. There are also operation and maintenance resources available United States Environmental Protection Agency's, or EPA's, website at http://water.epa.gov/infrastructure/greeninfrastructure/gi_design.cfm.

Retrofitting Wet Ponds

Wet ponds are landscape features that readily remove coarser sediments (sand and some silt), and which can reduce biochemical oxygen demand, nutrients and trace metals in stormwater runoff. However, wet ponds constructed prior to water quality regulations may not have included extended detention controls or other design features needed to maximize their water quality benefit. Retrofits to these ponds may include:

1. Modifying the outlet control structure to provide extended detention.

2. Installation of deep rooted native wetland and mesic vegetation to improve infiltration on pond shelf and banks, increase public safety and help control nuisance waterfowl populations.

3. Installation of hydrophytic, high water uptake shade trees such as hybrid poplars on the south bank to decrease thermal pollution and increase evapotranspiration.

ADVANTAGES

- Extended detention outlets increase water quality detention times. The water quality benefits are achieved by creating sufficient residence time to settle out particulates, and by microbial processes that occur over time in sediments and in the water column (Minton, 2005).
- Wetland shelves can be a cost-effective method of increasing pollutant removal potential, discourage nuisance waterfowl and enhance public safety through limiting pedestrian access to the pond.

- Hybrid poplars or other flood-tolerant, but high evapotranspiration species, can evapotranspirate up to 100 gallons per day during the growing season and help shade water surfaces to minimize thermal pollution discharges and algae or phytoplankton blooms that may contribute to organic TSS discharges.

LIMITATIONS

A primary limitation of wet ponds is that they do not typically infiltrate or otherwise remove significant volume from runoff events.

- Existing hydraulic calculations must be checked in order to ensure proper function under retrofitted conditions. Changing the outlet structure to include an extended detention orifice in front of the primary outlet will increase staging depths during larger storm events.
- An adequate supply of runoff shall be available to ensure a minimum average pool depth of six to eight feet throughout the entire year.
- Wet ponds can attract undesired waterfowl populations, leading to increased potential for fecal coliform export. In contrast, wet ponds fitted with wetland shelves can help reduce fecal coliform export. Where fecal coliforms are a target pollutant due to TMDL or other site specific issue, additional stormwater control measures may be needed to filter and provide adequate treatment.
- Heavy storms may cause mixing and subsequent resuspension of solids.
- Seasonal algal blooms can export organic TSS.
- Trees should not be placed in areas where bank stability may be a concern.

Figure 6.1 Extended Wet Detention, Express Scripts Campus, Berely, MO. Source: Metropolitan St. Louis Sewer District.

Integrating Infiltration Stormwater Control Measures

Infiltration-based stormwater control measures function by requiring the water quality volume to filter through a design medium for treatment prior to discharge. Infiltration can be achieved in well-drained soils where seasonal high groundwater does not prevent adequate drainage or infiltration can be simulated in poorly drained soils through use of soil amendments and underdrains. It is important to note that infiltration drains into the subgrade beneath the stormwater control measure and that a percentage of filtration drains through a pipe.

This form of asset-based urban ecology can help drive community revitalization while helping to meet volumetric control standards.

Common names of infiltration stormwater control measures include, but are not limited to:

- Rain gardens.
- Bioretention areas.
- Infiltration trenches and basins.

Some natural subgrade soils and a variety of backfill substrates can create an environment conducive to adsorption and degradation of pollutants. For example, organic substrates provide sites for microbial attachment, which can facilitate degradation of these pollutants (e.g. oil, grease, antifreeze, herbicides). Properly designed infiltration zones can also remove excess nutrients and bacteria, and they should be considered for watersheds that discharge to streams with identified pollutants of concern (TMDL or other data).

Depth of amended soils is critical where specific infiltration volumes are assumed as part of stormwater control measure performance. One example would be where default credits are granted for infiltration practices such as bioretention.

Figure 6.2 Infiltration Basin. Source: David Dods

ADVANTAGES

- Properly constructed infiltration-based stormwater control measures can remove over 95 percent of influent TSS (Minton, 2005).
- Infiltration-based stormwater control measures that incorporate an organic layer such as compost can remove in excess of 90 percent of dissolved metals through cation exchange (EPA, 2004).

Figure 6.3 Biofiltration infiltration trench, Cumberland County, PA. Source: Pennsylvania Department of Environmental Protection

LIMITATIONS

- Where underdrains are needed to achieve adequate drainage in areas with poorly drained subgrade soils, infiltration capacity is limited to the storage volume below the underdrain.
- Class V well status may require additional permitting through state and federal agencies where infiltration systems are deeper than their widest dimension.
- Infiltration systems should consider pretreatment when constructed adjacent to potential stormwater hot spot areas. Pretreatment stormwater control measures may vary, but should be designed to mange the anticipated pollutants associated with the hot spot.
- Unless washed, crushed limestone and other aggregate containing fines should be avoided to help prevent long-term clogging.
- Depth to seasonal or average high groundwater tables may preclude the use of infiltration stormwater control measures.

Green Roofs

Green roofs and roof gardens reduce the rate of stormwater runoff from commercial, industrial and residential buildings. In contrast to traditional roofing materials, green roofs capture, store, absorb and evapotranspire stormwater. Additional non stormwater benefits include thermal insulation and energy efficiency, increased acoustic insulation, reduced heat island effect, and increased durability and lifespan of roofs. These systems are generally classified as extensive or intensive.

- Extensive green roofs are typically lightweight, have 4 inches or less of growing medium, use drought tolerant vegetation, and can structurally support limited uses such as performing necessary operation and maintenance.
- Intensive green roof designs are more elaborate and have 6 to 12 inches of growing medium. Different growth media types and depths allow for a larger selection of plants, including flowering shrubs and trees to promote pedestrian interaction.

Figure 6.4 Green Roof St. Louis Zoo, Animal Nutrition Center Source: SWT Design.

Figure 6.5 Extensive Green Roof- University of Missouri, Life Science Center- Columbia, MO. Source: www.greenroofs.org

Application

Green roofs may be used in new construction or retrofitted to existing structures. They are applicable to residential, commercial, and industrial buildings and are constructed on roofs with up to a 20 percent slope. In highly urbanized locations, green roofs would likely have the most notable effect on stormwater and heat island effect.

Benefits

- Reduces the quantity of runoff entering a storm sewer system by capture and evaporotranspiration. Significant impacts can be realized in areas with combined sewer systems.
- Improves water quality.
- Provides additional park, garden and recreation areas provided with intensive green roofs.
- Provides additional thermal insulation and energy efficiency for building.
- Provides increased durability and lifespan of building roof system.

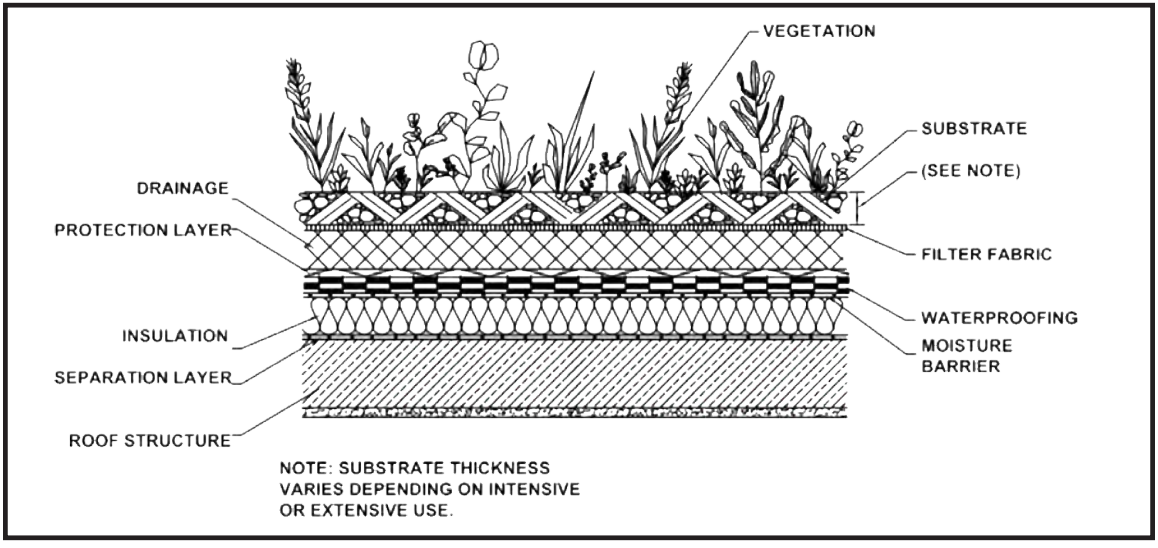

Figure 6.6 Intensive green roof profile example. Source: Center for Watershed Protection

Cost

Depending on the type of green roof, costs for green roofs are estimated to average between $14 to $40 per square foot for all use types, i.e., high density residential, commercial, industrial etc. These costs include all aspects of green roof development, from the waterproofing membrane to soil substrate creation to planting. By far the highest costs associated with green roof creation are the soil substrate/growth medium and the plant components associated with it. Green roof retrofit projects may have increased cost associated with traffic and resource scheduling concerns as well as the on-site availability of equipment and materials. The cost of planting can also increase if plants are placed individually rather than pre-grown on vegetation mats.

- Extensive green roofs range in price from $14 per square foot to $25 per square foot. Life cycle analysis should recognize the significant cost savings associated with reduced energy consumption and extended roof lifespan. www.cnt.org/repository/CNT-LID-paper.pdf
- Intensive green roofs are more costly than extensive green roofs. Estimates range from $20 to $40 per square foot, however the square foot cost may increase depending on the area and type of design. Life cycle analysis should recognize the significant cost savings associated with reducing energy consumption and extended roof lifespan. Intensive green roofs provide recreational and park space and may be justified relative to the price of land in an area.
- Municipalities may have allowances for tax credits, density credits and impervious credits for additional cost benefits. See model tax credit ordinance.

Figure 6.7 Green roof, Chicago city hall. www.cityofchicago.org

From Reduced Building Energy Use:

www.cnt.org/repository/CNT-LID-paper.pdf

Green roofs provide superior insulation compared to conventional roofs, reduce solar radiation reaching the roof surface and reduce roof surface temperatures through evaporative cooling. Estimates of reduced heat flux of a green roof as compared to a conventional roof range from 70 to 90 percent in summer to 10 to 30 percent in winter (Liu and Minor 2005; Liu and Baskaran 2003). The difference in seasonal performance is due to the fact that frozen growing media is a less effective insulator.

Note the advantages of direct shading and evaporative cooling only apply during warm weather. Models of the impact of a green roof on office building energy consumption in Chicago and Houston found a 2 percent reduction in total building electricity consumption in both cities; a 9 percent reduction in natural gas consumption for Chicago and an 11 percent reduction in natural gas consumption for Houston (Sailor 2008).

Another modeling study of an eight-story residential building in Madrid found a 1.2 percent reduction in annual building energy consumption. The bulk of the benefit comes from reduced summer cooling costs, where the authors found a 6 percent reduction compared to the conventional roof (Saiz et al., 2006).

The reduced heating and cooling loads that a green roof can provide depend on local temperatures, the portion of a building's heating and cooling load due to heat flow through the roof, the thickness of the soil layer, extent of foliage, relative humidity and wind speed and moisture content of the growing media. (Clark et al., 2008; Theodosiou 2003; Gaffin 2005)

Siting and Safety Requirements

- A structural engineer should be consulted to determine the correct loading for any proposed buildings.
- If retrofitting an existing roof, then the structural integrity of an existing roof should be inspected and verified by a professional, before proceeding with the design.
- Plants should be well-suited for local climatic conditions.

Figure 6.8 Intensive Rain Garden- Olsson Family Garden St. Louis Children's Hospital Source: www.stlouischildrens.org

- Intensive green roofs should have additional safety measures since it will likely be interactive.
- Local building codes should be referenced for roof safety requirements.

Permits

- Codes and permits for installing a green roof will vary in municipalities.

Maintenance

- Minimal to moderate.
- Should be monitored regularly during the first growing season to ensure vegetation establishment.
- Extensive and intensive green roofs should be inspected annually and lightly fertilized as needed and may need irrigation for the first growing season.
- All fertilizer applications should be prescribed by a professional in order to prevent stormwater runoff pollution.
- Intensive green roofs are maintained as landscape areas and may include gardens and irrigation systems.

Greenroof Inspections and Maintenance Checklist

Site name: _____ Owner Change since last inspection? Y N

Owner Name, Address, Phone _____

Number_____

Location: _____

Site Status: _____

Date:_____ Time: _____

Inspector: _____

Greenroof Type: Extensive Roof Cover ☐ Intensive Roof Garden ☐

Inspection Frequency Key: A=annual; M=monthly; S=after major storms; G=monthly during April-September growing season only

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Debris Removal				
Gutter inlets blocked by plant debris/trash or plant growth hindered by debris?	*M*			
Vegetation				
Any evidence of additional irrigation needs?	*G*			
Fallen leaves/debris interfering with plant health?	*M*			
Any dead plants to be replaced?	*M*			
Any need for weeding/mowing/trimming?	*G*			
Soil Substrate/Growing Medium				
Any evidence of wind or water erosion?	*A*			
Structural Components				
Any evidence of structural deterioration?	*A*			
Load-bearing walls in good condition?	*A*			
Spalling or cracking of structural parts?	*A*			
Access/maintenance routes maintained and free of debris?	*M*			
Other				
Any locations of standing water that may harbor insect infestations?	*S*			

Inspector Comments:_____

_____

_____

_____

Overall Condition of Facility: ☐ Acceptable ☐ Unacceptable

If any of the above Inspection Items are checked "Yes" for "Maintenance Needed," list Maintenance actions and their completion dates below:

Maintenance Action Needed	Due Date

The next routine inspection is scheduled for approximately: _____
(date)

Inspected by: (signature) _____

Inspected by: (printed) _____

Figure 6.9 Source: Storm Water Management Manual Volume 1, Appendix D - Memphis Shelby County Governments. (City of Memphis, 2007)

Rain Barrels

The roof of a house may receive between 600 to 1,000 gallons of water, depending on surface area, with just one inch of rainfall. A rain barrel is a small collection system that temporarily stores stormwater runoff from roof areas and is typically located under the downspout of the roof. Soaker hoses that are attached to rain barrel spigots will slowly release the stored volume which can be used for landscape irrigation. The barrel is usually constructed with a 55-gallon drum, and uses a vinyl hose, PVC couplings, and a screen grate to keep debris and insects out.

Rain barrels, given their size will be mostly useful for public education and on-site reuse, although they can provide a small level of volume control. Per stormwater expert Dr. Robert Pitt, PE, four typical rain barrels per home in the central US actually have the greatest potential irrigation use of stormwater due to having precipitation during the same seasons as evapotranspiration (about 15 inches in Kansas City per year.) This would result in only about 40 percent roof runoff reductions (compared to directly connected roofs), or about 15 percent for the whole area. If the goal is to reduce rooftop runoff by ninety percent or more to meet irrigation demands, it would likely require a storage tank about six feet by ten feet per home for example. This also assumes that effective use of the captured water occurs so that storage facilities are drawn down as soon as possible after a rain. See next section on cisterns for cisterns/storage tanks sizing and performance.

Rain barrels are relatively simple and inexpensive to construct, however there are a variety of vendors where they may be purchased as one unit. Properly maintained rain barrels should be fully sealed for vector control.

Application

Rain barrels are typically incorporated at the residential site level; however, they can be used in parks or at small office buildings. Rainwater is routed through the gutter system and diverted to the barrel where it can be stored for use in watering nearby gardens or other landscaping.

Figure 6.10 55-Gallon Rain Barrel. Source: Shockey Consulting

Benefits

- Runoff stored in rain barrels can be used at a future date for landscape watering or gray water systems.
- Reduces the cost of potable water consumption by using rainwater for irrigation.
- Reduces or minimizes stormwater runoff entering a storm sewer system.

Cost

Rain barrel and associated materials usually cost under $100, however depending on the materials and type of system, may range up to $400. Standard materials should be available at a local hardware store.

Siting and Safety

- Locate rain barrel on a flat surface next to or near the downspout.
- Overflow should be directed towards landscaped area or lawn.
- Rain barrel should be fully sealed or openings should be protected with screening for vector control.

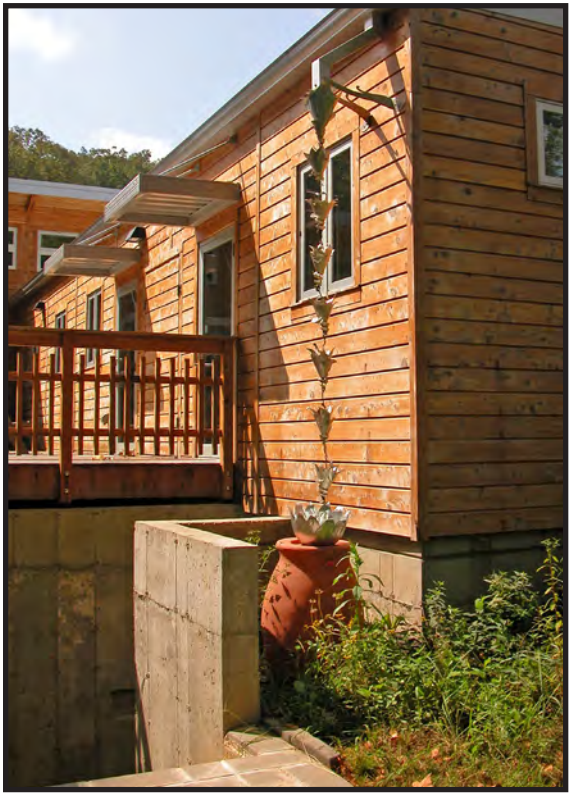

Figure 6.11Tyson Learning Center, Washington University, Eureka, MO. Source: Williams Creek Consulting

Permits

- Most municipalities do not require a permit to add a rain barrel on residential property.
- Zoning codes may prohibit a barrel in the front of the house; consult local zoning ordinances.
- Zoning codes may prohibit the disconnection of downspouts; consult local zoning ordinances.

Maintenance

- Gutters should be cleaned to minimize debris to your rain barrel.
- Periodic removal of accumulated leaves or debris in rain barrel screening.
- Periodic checks of barrel and seals to ensure system is working as designed and intended.
- The barrel interior should be cleaned and disinfected with environmentally friendly cleaner once a year.
- During cold months if freezing could be an issue, downspouts should be disconnected and barrel stored upside down to limit damage.
- To minimize debris in your rain barrel system, filters can be installed over the existing house gutter system.

Cisterns/Storage Tanks

A cistern or storage tank has the same function as a rain barrel, but stores larger volumes of rainwater. Cisterns can be located at grade or below grade. Cisterns are typically manufactured from fiberglass, plastic, concrete, or metal. In general, a 1,000-square-foot roof will produce approximately 600 gallons of rain in a one inch rain event. The cistern can be constructed a screen grate to keep debris and insects out.

Application

Cisterns may be incorporated at the residential, commercial and institutional levels. Rainwater from the roof is routed through the building's collection system and routed to the cistern where it can be stored for irrigation use. Dependent on local codes and restrictions, other uses may include reuse for toilet flushing, or installing a filtration and disinfected system to reuse as potable water. During the initial flush from the roof, the cistern should be cleaned to remove any debris that may be present during installation.

Figure 6.12 Residential Cistern.
Source: Shockey Consulting Services

Figure 6.13 Tyson Learning Center, Washington University, Eureka, MO. Source: Williams Creek Consulting

Benefits

- Reduces municipal supply water usage and associated costs during peak use.
- Can significantly reduce the quantity of runoff entering a storm sewer or receiving stream.
- Runoff stored in cisterns can be used at a future date for watering the landscape or for gray water systems.
- Can be sized to manage rooftop runoff for irrigation or other beneficial reuse.

Cost

For residential, commercial and institutional sites, cistern construction and installation costs are directly related to the volume of storage, type of material and location (above or below ground). Standard sizes are usually associated with manufacturer specifications and could be in excess of 10,000 gallons.

Cistern/Storage Tank Sizing vs. Performance				
Storage per house (ft^3 per ft^2 or roof area)	Reduction in annual roof runoff (%)	Number of 25 gallon rain barrels for 945 ft^2 roof	Tank height size required is 5 ft D (ft)	Tank height size required if 10 ft D (ft)
0.005	24	1	0.24	0.060
0.01	29	2	0.45	0.12
0.02	39	4	0.96	0.24
0.05	56	10	2.4	0.60
0.12	74	25	6.0	1.5
0.50	99	100	24	6.0

Table 6.1 Calculations for KC for using different roof runoff storage systems.
Source: Dr. Robert Pitt, PE., Ph.D., BCEE, D. WRE, Cudworth Professor of Urban Water Systems

Material	Cost - Small System	Cost - Large System
Polyethylene	$160 for 165 gallons	$1,100 for 1800 gallons
Fiberglass	$660 for 350 gallons	$10,000 for 10,000 gallons
Ferro-cement	Price variable upon location	Price variable upon location
Fiberglass/steel composite	$300 for 300 gallons	$10,000 for 5,000 gallons
Aluminum	Cost prohibitive for water use	Cost prohibitive for water use.

Table 6.2 Cistern materials cost estimate. Source: Adapted from www.lid-stormwater.net/raincist_home.htm

Siting and Safety

- Only collect roof water for reuse. Do not collect other surface water for reuse unless treated.
- Underground cisterns should have an overflow pipes. The overflow should be either daylighted to the surface down gradient in poorly drained soils or could potentially be connected to a leach field in well drained soils.
- Underground location should not be near sanitary utilities and care should be taken when proposed cistern location is near existing trees, in order to protect root systems. Maximize distance from existing trees.
- Care should be taken in selecting the type of cistern. For example, galvanized steel dramatically degrades water quality with very high zinc levels in stored water (several mg/l) and should be avoided. Some areas provide for aluminized steel. Polyethylene units are typically less expensive and do not create similar pollution concerns.

- ### Permits
  Local codes should be reviewed to determine if plumbing, electrical and/or building permits are required.
- Water treatment for reuse in the structure (as is sometimes done in commercial buildings) will likely require permits through the health department and other local entities.
- Ensure local requirements allow catchment reuse of rainwater.

Maintenance

- Periodic checks of system to ensure it is functioning as designed.
- Gutters should be cleaned frequently to minimize debris entering the cistern.
- Annual removal of accumulated sediment and debris that may have entered the cistern.
- To minimize debris in your cistern, filters can be installed to the existing house gutter system.

Rain Gardens

Figure 6.14 Theis Park Rain Garden- Kansas City, MO. Source: Shockey Consulting

A rain garden is an attractive, landscaped area built in a shallow depression (low-lying area) and is designed to capture and filter stormwater runoff from impervious surfaces such as rooftops, sidewalks, driveways and even compacted lawns. Rain gardens are typically planted with perennial native or adaptive deep-rooted plants that are selected to tolerate both periods of inundation and drought. Rain gardens function by slowing stormwater runoff, reducing runoff volume through infiltration and filtering pollutants from stormwater runoff before it enters local waterways. These gardens can help alleviate drainage issues. Rain gardens provide habitat and food for wildlife including butterflies and birds and enhance the beauty of an individual yard or a community.

Application

Rain gardens can be used to improve stormwater quality and reduce peak runoff rates for small drainage areas, typically less than one acre. They are typically constructed on residential sites but may also be incorporated into the landscaping of small commercial areas, parks and neighborhood common areas. Due to their relatively small surface area, care should be taken in providing for pretreatment and maintenance to help prevent clogging. Vegetation should also be selected to account for anticipated water quality concerns such as salt and other deciding practices.

Benefits

Rain gardens reduce the rate and quantity of stormwater runoff entering a storm sewer system. Temporary storage of initial runoff as well as interception of the storm flow both increase the time of concentration and promote infiltration.

Rain gardens can provide infiltration, filtration and removal of suspended sediments and associated pollutants, such as heavy metals. Rain gardens are designed gardens that contain aesthetically pleasing deep rooting native plants into landscape designs. Rain gardens also often provide habitat that can attract beneficial wildlife such as butterflies and hummingbirds.

Cost

The cost of a residential rain gardens can be as low as the price of necessary materials, however, they can vary considerably based on the proposed application and design. For example:

Residential Rain Garden

The following cost information is the average cost per garden installed, assuming a 100 lot subdivision. All of the facilities have an underdrain system and many of the facilities will be constructed simultaneously. Planning, designing and construction costs are all pro-rated as a portion of the overall site cost work, and sediment control, permits, fees and technical plan approval are required.

Planning phase	$95
Design phase	$340
Construction phase	$3225
Closeout phase	$130
TOTAL ESTIMATED COST:	$3,790

Source for cost: www.lid-stormwater.net/bio_costs.htm

Residential Lot in a Subdivision

This is applicable if the project is a shallow rain garden incorporating in-situ soils and no underdrain system. Homeowner, garden group, or volunteers provide the labor and no heavy construction equipment is used (most of the labor is done by hand). The disturbed area is small enough to avoid permits and fees and the rain garden is seen as a homeowner landscaping project.

Planning phase	$25
Design phase	$100
Construction phase	$950
TOTAL ESTIMATED COST:	$1,075

Source for cost: www.lid-stormwater.net/bio_costs.htm

Permits

Most municipalities do not require a permit to voluntarily construct a rain garden on residential property. Zoning codes should be consulted as many municipalities do require direct connection of downspouts. Additionally, overland flow paths need to be considered for larger storm events to prevent flooding on to neighboring properties.

Some municipalities may offer tax or fee incentives if rain gardens are committed to permanent function via deed restrictions.

Siting and Safety

- Locate at least ten feet from foundation, because moisture can damage foundation.
- Do not locate near lateral sewer lines, in order to avoid inflow and infiltration problems in lines.
- Do not divert excess water to neighbor's property where it can cause damage.

Figure 6.15 Rain garden. Source: StormwaterPA.org, a project of GreenTreks Network, Inc.

Maintenance

With the use of native vegetation and an appropriately planned design, long term maintenance in a rain garden is low relative to conventional landscaping. During the establishment period of the first three years, watering and weeding may be required on a more frequent basis. Successive years required less weeding and once established, watering should not be necessary at all except in cases of extreme drought. Annual maintenance is not necessarily different than traditional landscaping and includes removal of dead vegetation each spring, addition of mulch, unless designed with a 'green mulch' of dense ground cover vegetation and periodic inspection of soil erosion, plant health and removal of litter as needed. However, it is important to pass along information to new home/office owners on the importance of the rain garden and its continued maintenance.

Infiltration Trenches

Infiltration trenches are excavated trenches filled with granular material. Infiltration trenches are designed to intercept and capture stormwater during smaller storm events to promote groundwater recharge. Infiltration trenches remove suspended solids, bacteria, organics, soluble metals, and nutrients through mechanisms of filtration, absorption and microbial decomposition.

Green Infrastructure Application Strategy and Design Issues

Infiltration trenches are best applied in linear, well spaced patterns where possible. They are effective where soil allows an adequate infiltration rate.

Long linear applications help prevent groundwater mounding from reducing the rate of potential infiltration and they make infiltration trenches ideal for application beneath curbs, gutters, sidewalks and parking area perimeters.

Benefits

Some pollutant removal efficiency is assumed with infiltration trenches. Stormwater runoff that enters them is filtered through in-situ soils and does not directly discharge to surface waters. The runoff that enters the infiltration trench should provide groundwater recharge and eventually discharge to nearby streams.

When applied as part of a larger treatment train, infiltration trenches can help reduce the need for large, contiguous flood control stormwater control measures.

Trenches help:

- Reduce impervious surface area and associated increased volumes of runoff.
- Provide storage of initial runoff, helping to prevent thermal loading to receiving ponds or streams.

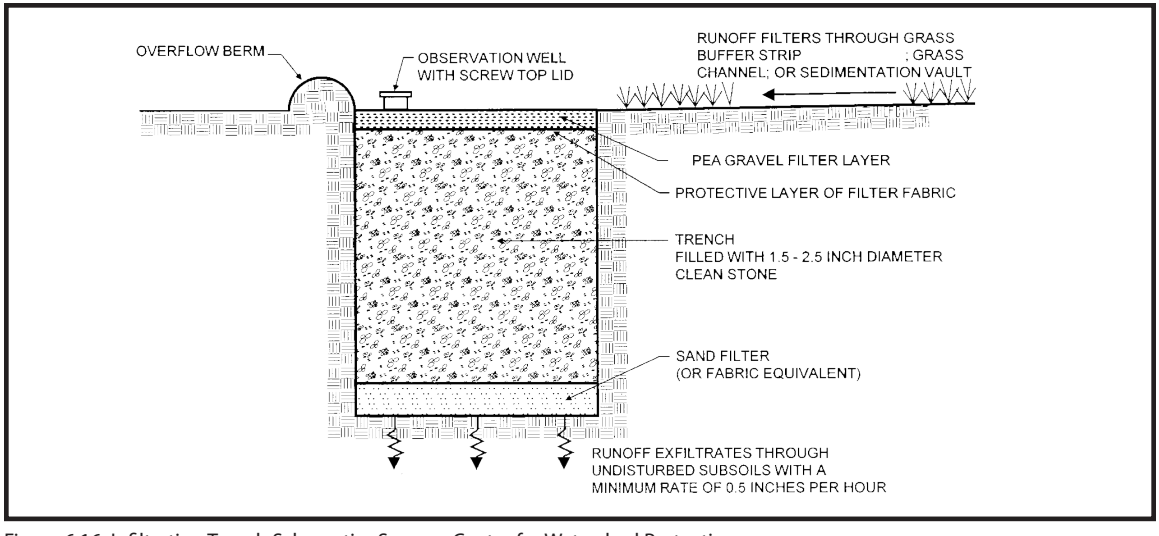

Figure 6.16 Infiltration Trench Schematic. Source: Center for Watershed Protection.

Limitations

Dry wells (or exposed infiltration trenches) basically are injection wells and can be a major contaminant source to the groundwater. Roof runoff (with no galvanized or copper roofing materials!) is probably a safe source water, but limit runoff from other source areas. Seasonal high water tables (or interfering mounding) can greatly hinder infiltration performance also. Horizontal filter fabrics also should not be used in any stormwater device as they commonly clog with the silts.

If the trench is deeper than it is wide, it may be considered an injection well that requires a stormwater discharge permit. Contact the Missouri Department of Natural Resources in your region for more information. http://dnr.mo.gov/regions/regions.htm

Relative Cost

Construction costs for infiltration trenches can vary greatly depending on site characteristics (Weiss, 2007), but can be correlated to water quality volumes. Correlations indicate that infiltration trench unit storage cost is not strongly correlated to storage volume increases. Relative to other stormwater control measures in the study, infiltration trench unit volume costs were in a similar range as bioretention but an order of magnitude higher than constructed wetlands, dry basins and wet ponds.

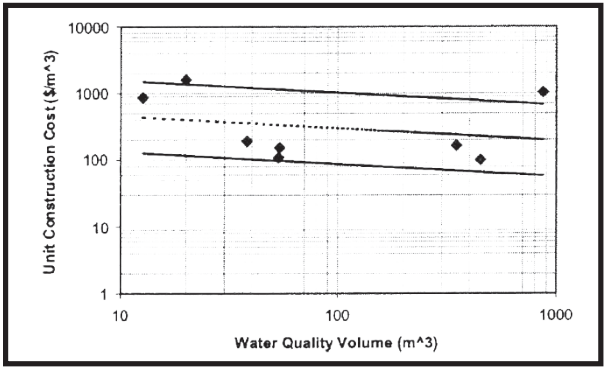

Figure 6.17 Infiltration Trench Unit Cost of Storage.
Source: Weiss et al, 2007

Figure 6.18 Infiltration Trench - Bellingham, WA.
Source: Williams Creek Consulting.

Site Specific Cost

Where site specific plans are available, costs can be calculated using engineering quantity takeoffs. For example, excavating at $9 per cubic yard and backfilling with a washed gravel at $27 per cubic yard and a one-third porosity in the gravel, yields a cost of $4 per cubic foot of storage, or approximately $175,000 per acre foot. This cost may be cut by as much as half where the trench is part of already necessary gravel subgrade, such as a curb, gutter or sidewalk.

Siting and Safety Requirements

- Runoff from non-paved areas can increase clogging risks. Therefore, infiltration trenches are more amenable to treating directly connected impervious area.
- Infiltration trench bottom should be level, but the slope of the surface may vary.

- The length and slope of the area draining to the trench affects the volume and velocity of runoff. Designers can widen a trench to accommodate higher velocities or deepen it to increase storage volumes pending site conditions.
- Soil type affects infiltration rates. Infiltration rates, textural class and other relevant soil characteristics can be confirmed in the field by a geotechnical engineer or qualified soil scientist.
- Consideration should be given to the proximity to sensitive groundwater areas. Depending on local conditions, infiltration without pretreatment may not be appropriate when near a drinking water aquifer well head protection zone or aquifers overlain by thin or highly permeable soils or areas of shallow ground water tables.
- Infiltration trenches can sometimes be applied in the ultra-urban environment.
- Infiltration trenches should not be used in stormwater hot spots (highly contaminated areas) unless the runoff has been pre-treated by another stormwater control measure.
- In regions of karst geology, infiltration trenches might not be applied due to concerns of sinkhole formation and groundwater contamination.

Permits

Review local requirements for site grading, drainage structures, and erosion and sediment control.

Figure 6.19 Pervious Gutter, Louisville KY.
Source: Williams Creek Consulting.

Karst Prone Areas and Sinkhole Features

This stormwater control measure can promote infiltration of stormwater. Low permeability or impermeable liners may be required. Consult a geotechnical engineer or other qualified expert prior to applying this stormwater control measure in karstic geographic regions.

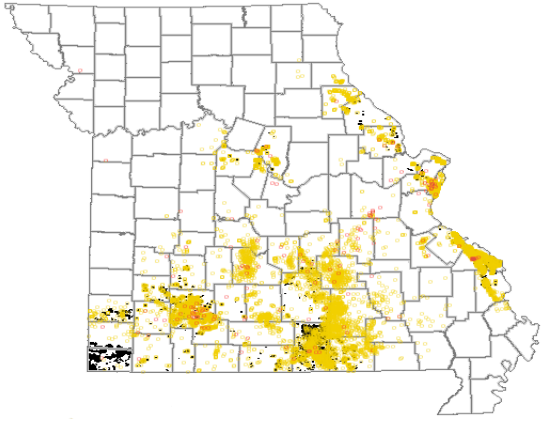

Figure 6.20 Source: Generated from Missouri CARES Website www.cares.Missouri.edu/

Maintenance

Maintenance on infiltration trenches can be moderate to high:

- Conduct semi-annual inspections of observation wells following three days of dry weather. Failure to percolate may indicate clogging.
- Pervious concrete or vegetated filter strips can be used as pre-treatment to reduce clogging. Pervious concrete can be mechanically or vacuum swept.
- Inspection of pretreatment devices and diversion structures for sediment build-up and structural damage.

INSPECTION CHECKLIST AND MAINTENANCE GUIDANCE
INFILTRATION TRENCH INSPECTION CHECKLIST

Location: _____ Owner Change since last inspection? Y N

Owner Name, Address, Phone: _____

Date: _____ Time: _____ Site conditions:_____

Inspection Items	Satisfactory (S) or Unsatisfactory (U)	Comments/Corrective Action
Inspection List		
Complete drainage of the filter in about 24 to 72 hours after a rain event?		
Clogging of trench surface?		
Clogging of inlet/outlet structures?		
Standing water in observation well when no water should be present?		
Trench clear of debris and functional?		
Evidence of leaks or seeps?		
Animal burrows in trench?		
Cracking, spalling, bulging or deterioration of concrete?		
Erosion in area draining to trench?		
Erosion around inlets, trench, or outlets?		
Pipes and other structures in good condition?		
Undesirable vegetation growth?		
Other (describe)?		
Hazards		
Have there been complaints from residents?		
Public hazards noted?		

If any of the above inspection items are **UNSATISFACTORY**, list corrective actions and the corresponding completion dates below:

Corrective Action Needed	Due Date

Inspector Signature:_____ Inspector Name (printed)_____

Figure 6.21 Source: Storm Water Management Manual Volume 1, Appendix D - Memphis Shelby County Governments. (City of Memphis, 2007)

Pervious Pavements

Pervious Pavements

Pervious pavements are any system of surface improvement that allows vehicular traffic while maintaining some degree of permeability to allow rainfall to percolate prior to running off. They can include block, turf, or gravel paver systems or can be monolithic forms of pervious concrete or asphalt.

Although pervious pavements may not provide adequate pollutant removal as a stand alone stormwater control measure, they can provide pretreatment for TSS in advance of infiltration systems. Pervious pavements can also allow for reductions in impervious surface used to calculate water quality volumes and help mimic predevelopment runoff conditions.

Pervious Pavers

Pervious pavers are blocks made of brick, stone or concrete where the joints between the blocks are filled with sand or gravel to allow stormwater to percolate downward into the sub-grade. Pervious pavers may also have an over deepened sub-grade to allow for detention and additional infiltration for groundwater recharge. Although pervious pavers can be used for high volume traffic areas, most applications are in low traffic areas, such as walks, alleys, residential neighborhood roads, driveways and parking.

Figure 6.22 River de Peres Greenway, St. Louis MO.
Source: Williams Creek Consulting

Benefits

Low = <30% Medium = 30-65% High = 65-100%

	Low	Medium	High
Suspended Solids		■	
Nitrogen		■	■
Phosphorous		■	
Metals			■
Bacteriological		■	
Hydrocarbons		■	■

Table 6.3 Source: Iowa Stormwater Manual - (Iowa State University, 2009)

Turf or Gravel Pavers

Turf or gravel pavers consists of interlocking concrete or plastic reinforced cells filled with soil and planted with turf grass or filled with gravel. Water passes through the system into a subgrade reservoir of crushed aggregate, then infiltrates into the native soil or drains into an underdrain. Turf and gravel pavers is best suited for low-vehicular traffic areas such as emergency access routes, infrequent or overflow parking areas and street shoulders. Pedestrian uses may include patios, walkways, terraces and residential driveways.

Pervious Concrete or Asphalt

Pervious pavements consist of concrete or asphalt made with cements that contain little or no fines. Water passes through the system into a subgrade reservoir of crushed aggregate, then infiltrates into the native soil or drains into an underdrain. Pervious concrete and asphalt can be designed for moderate traffic conditions.

Porous asphalt pavement consists of an open-graded coarse aggregate, bonded together by asphalt cement, with sufficient interconnected voids to allow water movement.

A typical porous asphalt pavement consists of a top porous asphalt course, a filter course, a reservoir course (designed for runoff detention and frost penetration) and existing soil or sub-base material.

Porous concrete typically consists of specially formulated mixtures of Portland cement, open-graded coarse aggregate and water.

A typical pervious concrete pavement consists of a top pervious concrete course, a filter course, a reservoir course (designed for runoff detention and frost penetration) and existing soil or sub-base material.

Green Infrastructure Application Strategy and Design Issues

Pervious pavements are a very site-adaptable stormwater control measure that can be used to replace impervious surfaces in roads, walks, drives and parking areas. In areas of special groundwater or karst concern, pervious pavements can be used above subsurface storage areas fitted with liners and underdrain systems. However, pervious pavements are not recommended near stormwater hot spots.

Figure 6.23 Porous Asphalt Alley, St. Louis, MO. Source: Metropolitan St. Louis Sewer District.

Figure 6.24 Turf pavers. Source: Williams Creek Consulting.

Benefits

- Applied in a well distributed form, pervious pavements can provide retention to help improve groundwater recharge and mimic predevelopment surface runoff volume.
- Suitable for cold-climate applications, maintains recharge capacity when frozen.
- No standing water or black ice development during winter weather conditions.
- Maintains traction while wet.
- Reduced surface temperatures; pervious concrete minimizes the urban heat island effect.
- Extended pavement life due to well drained base and reduced freeze-thaw.
- Less lighting needed due to highly reflective pavement surface (pervious concrete).
- Can minimize the need for land dedicated to stormwater control measures and increase the area available for development.
- Can help minimize the size and length of stormwater pipes and reduce the need for mass grading.

FAIRFAX, VIRGINIA
Hydrologic and Hydraulic Parameters for Pervious Concrete

For hydrologic computations using the rational method, the runoff coefficient C for pervious concrete shall be computed as follows: $C = (I - kp) / I$

Where:
I = design rainfall intensity (in/hr)
Kp = coefficient of permeability = 4.0 in/hr for pervious concrete

For hydrologic computations using the NRCS method, use a curve number of 40 for pervious concrete. For hydraulic computations, use a roughness coefficient (manning's n value) of 0.03 for pervious concrete.

SOURCE: County of Fairfax, Virginia.
Dec. 21, 2007. Letter 08-01 Pervious Concrete – Use under the innovative best management practices provisions of the Public Facilities Manual

Siting and Safety

Pervious pavements are a very large investment, occupying a large portion of the landscape relative to other stormwater control measures. Proper siting, safety, design and construction are essential to a successful application, as post-construction corrections can be problematic.

- Where recycled fly ash is used in concrete, material should be tested for leachable mercury prior to use.
- Underlying soils should not be impermeable. Michigan Division of Environmental Quality recommends a minimum infiltration rate of 0.27 in/hr. In general, the subgrade should be designed to drain or exfiltrate within 72 hours. Underdrains can be used where the subgrade infiltration rate is inadequate.
- Areas of special groundwater concern, well head protection areas, karst or other subsurface limitation may require liners or underdrains.
- Mild slopes (<5 percent) are typically necessary for proper function.
- Concerns with freezing are often expressed relevant to pervious pavement and other infiltration methods. While the subgrade drainage system should be designed to account for freeze heaving and thawing effects, the effect of freezing conditions is little to no different than the effect on normally pervious soil conditions.
- Use on sites with relatively high impervious cover in strategic locations such as parking strips or curb and gutter areas. Application to larger areas may result in unnecessarily intensive maintenance.

- Winter road treatments such as sand may require more frequent vacuuming during spring. Use of salt should be minimized to prevent excessive chlorides in groundwater. However, University of New Hampshire studies indicate that pervious concrete does not suffer from standing water or black ice conditions to the extent of traditional pavements.
- The durability and maintenance cost of alternate pavements should be evaluated against conventional surfaces.
- Construction issues include:
  - Recommends a certified pervious concrete craftsman on-site during installation (NRMCA or other).
  - Proper soil stabilization and erosion control are required to prevent clogging.
  - Quality control for material production and installation are essential for success.
  - Concrete must cure under plastic for 7-days after installation.
- Pervious pavements will require more intensive maintenance where they receive runoff from unstabilized silt or clay soils.
- To help ensure future function, signs should be placed to identify pervious pavement areas.
- High commercial traffic areas should be avoided for pervious pavement applications.

Karst Prone Areas and Sinkhole Features

This stormwater control measure can promote infiltration of stormwater. Low permeability or impermeable liners may be required. Consult a geotechnical engineer or other qualified expert prior to applying this stormwater control measure in Karstic geographic regions.

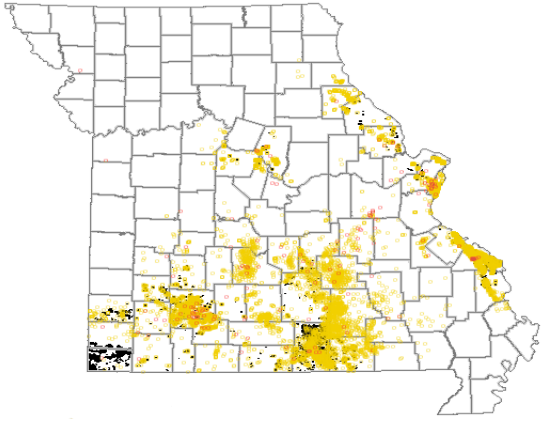

Figure 6.25 Source: Generated from Missouri CARES Website www.cares.Missouri.edu/

Special Construction Sequencing

Due to the nature of construction sites, the Missouri Protecting Water Quality field guide recommends construction sequencing criteria where pervious pavement is proposed (Missouri, 2011). Infiltration beds under pervious pavement may be used as temporary sediment basins or traps, but require excavation after the site is stabilized and sediment storage is no longer required. For 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 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 six inches. All fine grading should be done by hand and the bottom of the bed should be at a level grade to prevent localized 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 and in accordance with manufacturer's recommendations and specifications when needed, excess geotextile along bed edges can be cut back when all bare soils adjacent to beds are stabilized and vegetated.
- Clean, washed graded aggregate should be placed into the prepared bed in specified 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 relevant and applicable standards and specifications.

Cost

Cost of pervious pavements vary widely due to the wide variety of pavement types and design conditions. Each potential application should be evaluated on a site-by-site basis and compared to the cost of traditional paving systems. For comparison during design, a range of cost estimates for the basic installation of permeable paver materials is given in the table below for comparison purposes. Premiums assume that the pervious pavement is substituted for a traditional pavement.

Costs

Pervious Pavement	Traditional Pavement Cost/Ft^2	Pervious Pave-ment Cost/Ft^2	Premium Cost for Pervious /Ft^2
Asphalt	$3.50- $5	$4 -$6	$0.50 - $1
Porous Concrete	$5 - $6	$6-$8	$0 - $3
Grass/Gravel Pavers	$0.50 - $1	$1.50 - $5.75	$0.50 - $5.25
Interlocking Concrete Paving Blocks	$3.50 - $6	$8 - $12	$2 - $8.50

Table 6.4 Source: Williams Creek Consulting

Maintenance

- Ensure adjacent areas are stabilized with no soil erosion to pervious surfaces.
- Lawn debris should be removed to prevent clogging.
- Keep surfaces and overflow devices free of debris.
- Vacuum or mechanically sweep curb and gutter applications every six to 12 weeks and in larger areas with less intense sediment loads can be maintained less frequently (as needed).
- Repair failed areas as needed.
- Turf Pavers
    - Lawn clipping shall be removed.
    - Reseed as needed.
    - Water as needed.
    - Chemical and fertilizer application should be minimized.

Figure 6.26 Pervious concrete and asphalt.
Source: Williams Creek Consulting.

Figure 6.27 Pervious pavement types.
Source: Williams Creek Consulting.

Permeable Pavement Inspection and Maintenance Checklist

Site Name: _____ Owner Change since last inspection? Y N

Location: _____

Owner Name: _____

_____

Address_____Phone Number _____

Site Status: _____

Date:_____ Time: _____ Site conditions:

Inspection Frequency Key: A=annual; M=monthly; S=after major storms

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Pavement Area				
Pavement area free of debris?	*M*			
Inlets and outlets unobstructed?	*M*			
Is water standing after a storm event?	*S*			
Any evidence of clogged pores that require vacuum-sweeping?	*M*			
Access to pervious pavement (egress and ingress routes) safe and efficient?	*M*			
Vegetation				
Adjacent area fully stabilized (no evidence of eroding material into or from pervious pavement area)?	*A*			
Any noticeable irrigation needs?	*M*			
Fallen leaves/plant debris collecting in paving area?	*M*			
Grass height over 4 inches?	*M*			
Vegetation health affected by oil/grease from vehicles?	*A*			
Other	*A*			
Hazards				
Obstructions or debris affecting overflows/emergency spillways?	*M*			
Load-bearing capability of pavement intact?	*M*			

Inspector Comments:_____

_____

_____

_____

Overall Condition of Facility: ☐ Acceptable ☐ Unacceptable

Figure 6.28 Source: Storm Water Management Manual Volume 1, Appendix D - Memphis Shelby County Governments, (City of Memphis, 2007)

Tree Box and Tree Vault

A tree box or tree vault is a stormwater control measure that combines the bioretention stormwater control measure with street plantings to provide sufficient soil volume for healthy tree growth as well. A tree box is for a single tree, a vault is where several trees are planted within the same trenched area. The stormwater control measure consists of a structural box or vault with an underdrain filled with bio-engineered soils of sufficient volume to provide flow through water quality control and long term tree health. Stormwater can be accepted either through pervious pavement above the box/vault, or if placed along a street, can receive street runoff.

Figure 6.29 Post-Construction Image - Tree Box.
Source: Urban Design Tools. Low Impact Development
www.lid.stormwater.net/

Benefits

Low = <30% Medium = 30-65% High = 65-100%

	Low	Medium	High
Suspended Solids			
Nitrogen			
Phosphorous			
Metals			
Bacteriological			
Hydrocarbons			

Table 6.5 Source: Iowa Stormwater Manual - (Iowa State University, 2009)

Green Infrastructure Application

Strategy and Design Issues

Healthy mature street trees can provide significant amenities to a community such as reduced heat island effect; reduced stormwater volume through interception on leaves, branches and bark; increased time of concentration of stormwater flows; and increased property value. For a tree to remain healthy and reach the growth potential necessary to provide these amenities, it must have sufficient soil volume, which may or may not be provided in traditional urban tree plantings.

Substituting stormwater tree boxes for traditional street tree planters is an effective way of improving runoff control. Tree boxes/vaults are a site-adaptable stormwater control measure, particularly in dense urban areas, that can be cost comparable to traditional tree planters. Systems are generally applied to small drainage areas and can be applied both along roads under sidewalks and in public plazas where large trees would be favorable.

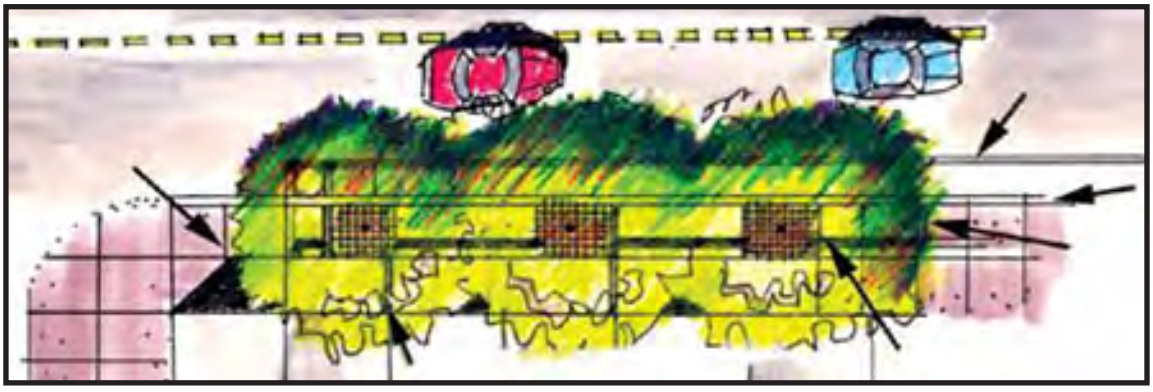

Figure 6.30 A linear storm water tree pit, Source: Urban Watershed Forestry Manual. Part 2: Conserving and Planting Trees at Development Sites.

Benefits

- Tree box/vaults use bioretention- type soils and have similar high nutrient and pollutant removal efficiencies.
- Tree box/vaults can be used in street ROWs particularly in heavy traffic areas with no on-street parking where few other stormwater control measures can.
- Tree box/vaults can be incorporated into a treatment train approach, including those preferring pretreatment such as dry detention/ retention basins.
- Mature trees provide aesthetic enhancement to property, lower air temperature in paved urban areas and clean the air.
- Properly designed systems can reduce the size of piped stormwater collection systems.

Siting Issues

- 625 square feet of soil area are typically recommended per tree for long term viability.
- Overhead lines and buried utilities should be avoided or considered when selecting plant material.

Cost

Tree boxes/vault costs can range considerably depending on size of the box/vault and whether proprietary systems are used. Costs can start at the low end at $2,500 per tree box and escalate up to $10,000 per tree box. Consideration should be given to the life-cycle cost-benefit over time due to the increase in stormwater control and property value as the trees grow in size and value each year.

Permits

Tree boxes/vaults typically do not require any specific permitting but it often requires review and approval by municipal authorities if it is to be incorporated into the regulated stormwater collection system. Review local requirements for site grading, drainage structures, erosion and sediment control and potential invasive vegetation.

Landscaping

Selecting plant material for tree box/vault areas are a critical design element to improve both the function and aesthetics. Native trees, are well adapted to or have evolved under local climate conditions.

Because native species exhibit a broad spectrum of tolerances to flooding, specifying trees suitable for the anticipated duration of inundation or saturation is critical for a successful design. The U.S. Fish and Wildlife Service has developed an indicator status list for most vascular plants throughout the U.S. The indicators include:

- Obligate wetland, or OBL: Plants which nearly always (more than 99 percent of the time) occur in wetlands under natural conditions.
- Facultative wetland, or FACW: Plants which usually occur in wetlands (from 67 to 99 percent of the time), but are occasionally found in non wetlands.
- Facultative, or FAC: Plants which are equally likely to occur in wetlands and non wetlands and are found in wetlands from 34 to 66 percent of the time.
- Facultative upland, or FACU: Plants which usually occur in non wetlands (from 67 to 99 percent of the time), but occasionally found in wetlands.
- Upland, or UPL: Plants which almost always (more than 99 percent of the time) under natural conditions occur in non wetlands.

Note: A given indicator status shown with a "+" or a "-" means that the species is more or less often found in wetlands than other plants with the same indicator status without the "+" or "-" designation.

Indicator Status Website: www.plants.usda.gov

Indicator status of particular plants can assist the designer in specifying plants that will tolerate the depth, duration and frequency of saturation within each hydrologic zone of the wetland design. Furthermore, blooming period may be used as a selection criterion to improve the aesthetics of a design throughout the growing season.

Maintenance

Maintenance is low. Watering during establishment is often necessary. Maintenance decreases in successive years. Semi-annual inspection of sediment build up, plant health, and removal of litter will maintain bioretention soil functions and services. Tree box/vaults may actually lower utility costs by requiring less watering than similarly landscaped areas.

Figure 6.31 Tree vault, Arlington, VA.
Source: www.arlingtonva.us/departments/EnvironmentalServices

Bioretention

Bioretention is a landscape feature built in a natural or constructed depression that filters stormwater runoff using the pollutant removal mechanisms that operate in natural ecosystems. During water quality and other small storm events, stormwater filters through the engineered or native soil media. Runoff from larger storms generally ponds and overflows to a structure that drains to the storm system. Filtered runoff can be collected in a perforated underdrain and returned to the storm system or allowed to infiltrate into the subsoil. Larger storm events will likely overflow into a catch basin and enter the stormwater conveyance system.

Green Infrastructure Application Strategy and Design Issues

Bioretention is a very site-adaptable stormwater control measure that can be used to replace other landscape options such as parking lot islands, streetscapes, or on-lot landscapes. Bioretention can also be used to treat stormwater hot spots with design modifications specific to the pollutant of concern.

Figure 6.32 Bioretention - Delaware Health Village, Delaware, OH. Source: Williams Creek Consulting

Benefits

Low = <30% Medium = 30-65% High = 65-100%

	Low	Medium	High
Suspended Solids		■	■
Nitrogen		■	
Phosphorous		■	
Metals		■	
Bacteriological			■
Hydrocarbons		■	

Table 6.6 Source: Iowa Stormwater Manual - (Iowa State University, 2009)

If applied at a great enough level of frequency and intensity, bioretention can also minimize the need for large, contiguous flood and stormwater control measures. Bioretention soil mixes vary widely. When developing local standards for "biosoil," consideration should be given to:

- Local availability of material.
- Biosoil depth, pH and nutrient content relative to water quality goals, not necessarily a universal growing medium.
- Minimum and maximum infiltration capacity.

Many design manuals prescribe design criteria for different types of bioretention areas. Pending site characteristics and anticipated target pollutants, these design criteria may be excessive and unnecessarily increase construction costs.

(*Rethinking Bioretention Design Concepts*, M. Clar, E. Laramore, H. Ryan, Department of Land Use, New Castle County, DE). However, depth of amended soils is critical where specific infiltration volumes are assumed as part of stormwater control measure performance. One example would be where default credits are granted for infiltration practices such as bioretention.

Where no default infiltration credit is assumed, the 2008 Clar research indicates:

- Maximum allowable ponding depths should be a function of vegetation type, adjacent land use, allowable drawdown times, or other defined condition. Increasing allowable stage depth from six inches to depths of 12 or 18 inches could increase the cost effectiveness of bioretention areas by two to three times and make them more effective at mimicking pre-construction runoff conditions.
- Underdrains may be needed where subgrade soils are poorly drained. In areas where the subgrade is capable of infiltrating design volumes within 72 hours, consideration should be given to not requiring underdrains. Removing the underdrains can help increase the infiltration capacity of a bioretention area.

Benefits

- Significant water quality improvement, including reduction or removal of dissolved nutrients, metals and hydrocarbons. Pollutants are removed through uptake by vegetation, soil absorption and biogeochemical activity in the soil column. Vegetation in the bioretention area also filters and helps prevent resuspension of sediment.

Figure 6.33 Bioretention System - medical facility in Ohio.
Source: Williams Creek Consulting

- Similar to any constructed landscape, bioretention can be low to high maintenance, pending the aesthetic requirements of the landscape. Relevant to upland ornamental landscapes, a mature bioretention area is generally more resistant to colonization by upland nuisance weeds, better adapted to thrive in saturated and flooded conditions and more tolerant to droughts.
- Can provide retention to help improve groundwater recharge and mimic pre-construction surface runoff volumes.
- Can be applied in large areas such as boulevards or parking area buffers, bioretention can decrease downstream channel erosion and reduce peak runoff rates.
- Can provide increased aesthetic value.
- Provides public outreach opportunities along greenways.

Siting and Safety

- Bioretention areas should be placed at least ten feet from building foundations and designed not to stage to a depth that may flood the structure. Where bioretention is designed nearer foundations, the architect or structural engineer should be consulted regarding underdrains and other drainage improvements to help ensure building safety and flood protection.
- As needed, river rocks or a grass filter strip may be used to dissipate energy where water enters the treatment cell.

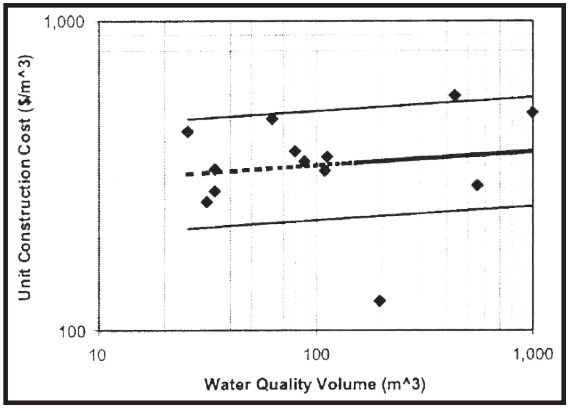

Figure 6.34 Bioretention Unit Cost of Storage.
Source: Weiss et al, 2007.

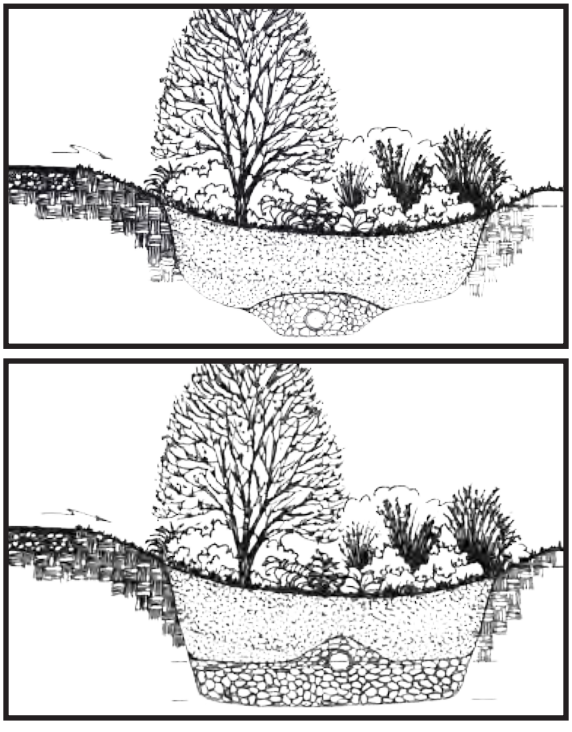

Figure 6.35 Infiltration/filtration/recharge.
Source: Bioretention manual - Environmental Services Division Department of Environmental Resources - the Prince George's County, Maryland.

Relative Cost

Construction costs can vary greatly depending on site characteristics. However, an equation was developed to estimate the cost of bioretention prior to design (Brown and Schueler, 1997).

C = 7.3V0.99 where:

C = Construction, design and permitting cost
V = Treatment volume (ft3)

Costs developed with this equation can be inflated to the present value and can be used for conceptual comparisons among alternate stormwater control measures early in a planning process. The above formula yields a value of approximately $6.50 per cubic foot of treatment volume.

Case Study Cost

National databases or local case studies can be used to estimate costs. An EPA case study (EPA, Office of Water, Bioretention Applications, 2000, EPA-841-B-00-005A) done in Inglewood, Maryland, constructed a 38 feet by 12 feet bioretention to manage approximately one-half acre of impervious surface. This bioretention cell represents only two percent of a watershed area that is nearly 100 percent impervious. The cost was reported to be $4,500, or approximately $10 per square foot.

Permits

Bioretention typically does not require any specific permitting but it often requires review and approval by municipal authorities if it is to be incorporated into the regulated stormwater collection system or is to be constructed in public owned right-of-way.

Primary Cost Components for Bioretention			
Implementation Stage	**Primary Cost Components**	**Basic Cost Estimated**	**Other Considerations**
Site Preparation	Tree and plant protection	Protection cost ($/acre) x Affected area (acre)	Removal of existing structures, topsoil removal and stockpiling.
	Topsoil salvage	Salvage cost ($/acre) x Affected area (acre)	
	Clearing and grubbing	Clearing cost ($/acre) Affected area (acre)	
Site Formation	Excavation/ grading	4-ft depth Excavation cost ($/acre) x Area (acre)	Soil and rock fill material, tunneling.
	Hauling material off-site	Excavation cost x (% of material to be hauled away)	
Structural Components	Inlet structure	$/Structure	Pipes, catch basins, manholes, valves.
	Outlet structure	$/Structure	
Site Restoration	Soil preparation	Soil cost ($/acre) x Seeding/planting area (1-ft average depth per acre	Tree protection, soil amendments, seed bed preparation, trails.
	Seeding or sodding	Seeding cost ($/acre) x Seeded area (acre)	
	Planting/ transplanting	Planting cost ($/acre) x Planted area (acre)	
Annual Operation, Maintenance and Inspection	Debris removal	Removal cost ($/acre) x Area (acre) x Frequency (2/1 yr)	Vegetation maintenance, cleaning of structures.
	Invasive plant removal	Labor cost ($/hr) x Time x Frequency	
	Sediment removal	Removal cost ($/acre) x Area (acre) x Frequency (1/5 yr)	
	Erosion repair	Repair cost ($/acre) x Affected area	
	Gate/Valve operation	Operation cost ($) x Operation Frequency (2/1 yr)	
	Inspection	Inspection cost ($) x Inspection Frequency (2/1 yr)	
	Mowing	Mowing cost ($) x Mowing frequency (4/1 yr)	

Table 6.7 Source: Minnesota Stormwater Manual Version 2, 2008.

Landscaping

Landscaping of bioretention areas are a critical design element to improve both the function and aesthetics of bioretention areas. Native plants are well adapted to or have evolved under local climate conditions. Native plant species are typically characterized by deep rooting systems which assist with infiltration.

Because deep-rooted native and adaptive species exhibit a broad spectrum of tolerances to flooding, specifying plant material suitable for the anticipated duration of inundation or saturation is critical for a successful design. The U.S. Fish and Wildlife Service has developed an indicator status list for most vascular plants throughout the U.S. The indicators include:

- Obligate wetland: Plants nearly always (more than 99 percent of the time) found in wetlands under natural conditions.
- Facultative wetland: Plants which usually occur in wetlands (from 67 to 99 percent of the time), but occasionally found in non wetlands.
- Facultative: Plants which are equally likely to occur in wetlands and non wetlands and are found in wetlands from 34 to 66 percent of the time.
- Facultative upland: Plants which usually occur in non wetlands (from 67 to 99 percent of the time), but occasionally found in wetlands.
- Upland: Plants which almost always (more than 99 percent of the time) under natural conditions occur in non wetlands.

Indicator status of particular plants can assist the designer in specifying plants that will tolerate the depth, duration and frequency of saturation within each hydrologic zone of the wetland design. Furthermore, blooming period may be used as a selection criterion to improve the aesthetics of a design throughout the growing season.

Indicator status can be reviewed at www.plants.usda.gov.

While selection of individual species will vary based on the intended function of a project or preferences of a designer, some particularly aggressive and opportunistic species should be avoided in wetland plantings. Furthermore, if volunteers of these species are identified, a management plan is recommended for their control and prevention. These species, commonly referred to as invasive include the following:

Common Name	Latin Name
Broad-leaved cattail	*Typha latifolia*
Narrow-leaved cattail	*Typha angustifolia*
Hybrid cattail	*Typha x glauca*
Common Reed	*Phragmites australis*
Purple loosestrife	*Lythrum salicaria*
Johnson Grass	*Sorghum halepense*

Maintenance

- Similar to traditional landscaping.
- Irrigate as necessary while plants are establishing.
- Cut and remove dead vegetation in the spring.
- Annual addition of mulch may be required unless designed with dense groundcover.
- Semi annual inspection should be conducted for erosion, plant health and litter removal.

Bioretention and Organic Filters Plants

Latin Name	Common Name	Submerged & Emergent (water depth in feet)	Pond Edge & Permanent Water	Over sand	Lower slopes & bioretention base	Upper slopes	Height (feet)	Spacing (feet)	Seasonal Interest - Color and Months	J	F	M	A	M	J	J	A	S	O	N	D	Sun	Pt Sun	Pt Shade	Shade	Dry	Medium	Wet	Birds	Butterflies	Fall Color	Winter Interest	Flood frequency tolerance	Flood height tolerance	Flood duration tolerance (days)	Salt tolerance	Aggressiveness	Silt tolerance
Grasses/Sedges																																						
Andropogon gerardii	Big bluestem			x	x	x	4-6	2	plum	x	x							x	x	x	x	x				x	x		x		x	x	M	12	2		M	
Bouteloua curtipendula	Sideoats grama			x		x	1-2	1	tan							x	x	x	x	x		x	x			x	x		x			x	L				L	
Carex praegracilis*	Tollway sedge		x		x	x	1-2	1.5	tan				x	x	x							x	x			x	x	x	x				H	12	2	H	H	H
Carex grayi	Bur sedge		x		x		1-2	1.5	tan				x	x	x							x	x	x	x		x	x	x				H	24	3		L	
Carex shortiana	Short's sedge		x		x	x	2	1.5	bluish				x	x	x							x	x	x		x	x	x	x			x	M	24	3		L	
Carex vulpinoidea	Fox sedge		x		x		2-3	1.5	tan					x	x	x						x	x	x			x	x				x	H	24	3	L	L	
Chasmanthium latifolium	River oats			x	x	x	2-4	1.5	green						x	x	x	x	x	x			x	x	x	x	x		x		x	x	M	12	1		H	
Schizachyrium scoparium	Little bluestem			x		x	2-3	1.5	bronze	x	x						x	x	x	x	x	x				x	x		x		x	x	L			M	L	L
Sporobolus heterolepis	Prairie dropseed				x	x	2-3	1.5	tan								x	x	x	x	x	x				x	x		x			x	L				L	
Forbs																																						
Amsonia illustris	Shining bluestar		x	x	x		2-3	2.5	lt. blue				x	x								x	x	x		x	x	x		x	x		H	36	5		L	H
Aster novae-angliae	New England aster		x		x		3-4	2	violet								x	x				x	x				x	x		x	x		M	24	3	L	H	
Chelone obliqua	Rose turtlehead		x		x		3-4	2	ose/purple								x	x	x			x	x	x	x		x	x					M	12	1		M	
Coreopsis lanceolata	Lanceleaf coreopsis			x		x	1-2	1.5	yellow			x	x	x								x	x			x				x			L		1		L	
Echinacea pallida	Pale purple coneflower					x	2-3	1.5	violet						x	x						x	x			x	x		x				L				L	
Echinacea purpurea	Purple coneflower					x	2-3	1.5	lt. purple						x	x	x						x	x	x	x	x		x	x			L				L	
Eryngium yuccifolium	Rattlesnake master				x	x	4-5	1.5	green						x	x	x	x				x				x	x			x		x	M	12	2	M	L	
Eupatorium coelestinum	Mist flower; wild ageratum		x	x	x		1-2	1.5	avender							x	x	x	x			x	x				x	x		x			H	12	3		M	H
Hibiscus lasiocarpos	Rose mallow		x	x	x		3-7	2.5	white/pink							x	x	x	x			x	x	x		x	x		x	x			H	36	5		M	M
Iris virginica	Southern blueflag iris		x		x		2-3	2	blue							x	x					x	x					x	x		x	H	36	4		M	M
Pycnanthemum tenuifolium	Slender Mountain Mint			x	x	x	2-3	1.5	white							x	x	x				x	x	x		x	x						L		1		M	
Ratibida pinnata	Yellow/Grey coneflower			x	x	x	3-5	1.5	yellow						x	x	x					x	x			x	x		x	x			M	12	1	M	H	L
Rudbeckia fulgida	Orange coneflower				x		2	2	yellow						x	x	x	x				x	x			x	x			x		x	L				M	
Rudbeckia hirta	Black-eyed Susan						2-3	1.5	yellow						x	x	x	x				x				x	x			x			L				M	
Solidago rugosa	Rough-leaved goldenrod				x	x	2-3	1.5	yellow								x	x				x	x	x	x	x	x			x		x	L			M	H	L
Solidago speciosa	Showy goldenrod				x	x	2-3	1.5	yellow								x	x				x	x	x		x	x			x		x	L			M	H	L
Verbesina helianthoides	Yellow wingstem						2-3	1.5	yellow							x						x	x	x		x	x		x	x			L				M	
Zizia aurea	Golden alexander					x	1-3	1.5	yellow					x	x							x	x	x		x	x			x			L			M	H	
Trees/Shrubs																																						
Carpinus caroliniana	Musclewood				x	x	15-20	20	yellow	x	x	x							x	x	x	x	x	x		x	x				x	x	M	6	1		L	
Cercis canadensis	Redbud			x	x	x	10-20	15	pink				x	x								x	x	x		x	x						L			L	M	L
Hamamelus virginiana	Eastern witchazel		x		x	x	10-15	15	yellow										x	x	x		x	x	x	x	x				x	x	L			L	L	
Quercus alba	White oak				x	x	40-60	30	green				x	x					x	x		x	x	x	x	x	x		x	x	x	x	L			H	L	

Requirements

Local Ecotype Rule: Plants of Missouri or Southern Illinois ecotype are required.

Must use a minimum of 5 grass/sedge species and 8 forb species for each BMP. It is recommended that this list be provided to landscape contractors/buyers in case substitutions are required.

Each species must consist of between 5% - 15% of the total plant count for each BMP.

Refer to Planting, Water, and Mulch Requirements for Stormwater BMP's for plant sizes and irrigation requirements

Biodegradable erosion blanket must be used on slopes greater than 10%.

Erosion blankets must be coarse to allow varying leaf sizes (examples include Geojute, Curlex #1 and NorthAmerican Green S75 single net straw blanket, or equivalent)

*Experimental for practice and/or limited availability in commercial trade

Figure 6.36 Source: Landscape Guide for Stormwater Best Management Practice Design - St. Louis, MO.
Note: This table is not an all inclusive list for species that may tolerate proposed growing conditions.

Bioretention Inspections and Maintenance Checklist

Site Name: _____ Owner Change since last inspection? Y N

Location: _____

Owner Name: _____

_____

Address_____Phone Number _____

Site Status: _____

Date:_____ Time: _____ Site conditions:

Inspection Frequency Key: A=annual; M=monthly; S=after major storms

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Treatment Area				
Treatment area free of debris?	*M*			
Inlets and outlets unobstructed?	*M*			
Is there standing water longer than 24 hours after a storm event?	*S*			
Evidence or erosion?	*M/S*			
Vegetation				
Adjacent area fully stabilized (no evidence of eroding material into Bioretention area)?	*A*			
Plant height not less than design ponding depth?	*A*			
Plant composition according to approved plan?	*A*			
Grass height not more than 6 inches?	*M*			
Vegetation overgrown?	*A*			
Other	*A*			
Hazards				
Have there been complaints from residents?	*M*			
Public hazards noted?	*M*			

Inspector Comments:_____

_____

_____

_____

Overall Condition of Facility: ☐ Acceptable ☐ Unacceptable

Figure 6.37 Source: Storm Water Management Manual Volume 1, Appendix D - Memphis Shelby County Governments. (City of Memphis, 2007)

Bioswales

Bioswales (Vegetative Swales)

Wetland swales, dry swales with filter media and filter strips can be flow-through channels or have characteristics that allow them to retain and infiltrate runoff. The vegetation in the filters can range from turf to native grasses and may include woody plants. Pending their design, they are sometimes only suitable as pre-treatment practices as part of a larger treatment train.

1. Dry swales with filter media are broad and shallow channels with native vegetation covering the side slopes and channel bottom. As opposed to wetland swales, these swales, natural or constructed, include an engineered soil matrix and underdrain system for improved drainage and filtration. Specified vegetation should be able to tolerate drought and saturated soil conditions. They convey stormwater runoff slowly, promoting infiltration and water quality treatment.

2. Wetland swales are flat or shallow sloped channels with hydrophytic vegetation in the channel base. Stormwater runoff is slowly conveyed resulting in higher rates of infiltration, increased plant transpiration, adsorption of pollutants, settling of suspended solids, and microbial breakdown of nutrients and hydrocarbons. They can also be designed with check dams to increase their stormwater retention capabilities.

Benefits

Low = <30% Medium = 30-65% High = 65-100%

	Low	Medium	High
Suspended Solids			■
Nitrogen		■	
Phosphorous	■	■	
Metals		■	■
Bacteriological		■	■
Hydrocarbons			■

Table 6.8 Source: Iowa Stormwater Manual - (Iowa State University, 2009)

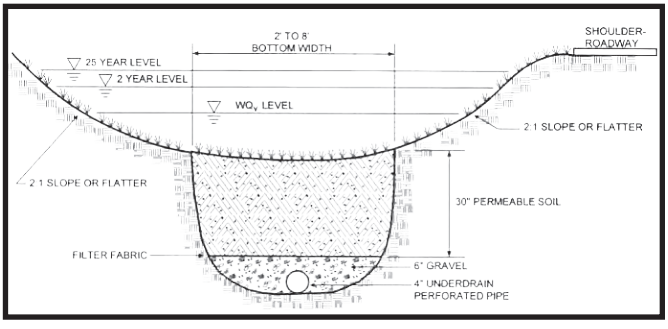

Figure 6.38 Dry swale. Source: Center for Watershed Protection

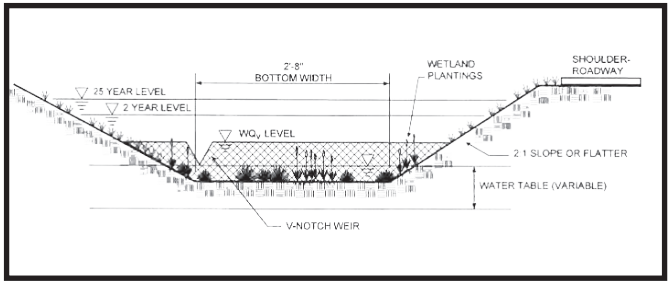

Figure 6.39 Wetland swale. Source: Center for Watershed Protection

3. Turf swales and vegetated filter strips are primarily a pre-treatment stormwater control measure designed to treat sheet flow from adjacent impervious surfaces. They function by reducing runoff velocity and filtering sediment and other pollutants. Filter strips are often adjacent to parking areas, incorporated as the outer zone of a stream buffer, or located upstream of other stormwater control measures and are not typically a stand alone practice. Depending on the condition of underlying soils, filter strips can provide limited infiltration.

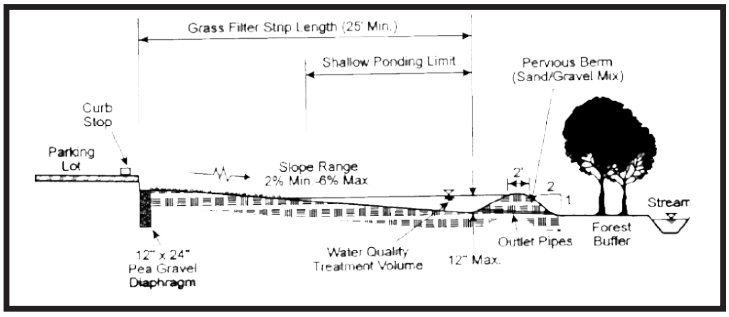

Figure 6.40 Turf Swale. Source: Center for Watershed Protection, 1996

Vegetative filters, designed as grass channels or swales, may be used as the primary conveyance between or out of best management practices, as well as providing some treatment for stormwater runoff. Native plant swales perform better than turf due to deeper root systems.

Figure 6.41 Bioswale - Clifty Creek, Ind. Source: Williams Creek Consulting.

Green Infrastructure Application Strategies

Many codes and ordinances require that swales have a minimum slope in order to maintain well drained conditions. In context of green infrastructure, swales do not necessarily need to have slope and can sometimes produce greater benefits where they have zero slope.

The conveyance potential inherent to all vegetated filters makes their application well suited to sustainable infrastructure.
Example applications include:

- Parking lots - Turf swales and filter strips can be installed at the perimeter of the parking area and vegetated to serve as landscape buffers from adjacent developments.
- Streetscapes – Filter strips and swales can follow street topography. They can be used in combination with rain gardens or other bioretention to create a network of vegetated conveyance and distributed storage systems similar to natural drainage patterns.
- Green space – swales can be used as low flow channels in dry detention basins to keep the balance of the basin available for passive recreation.

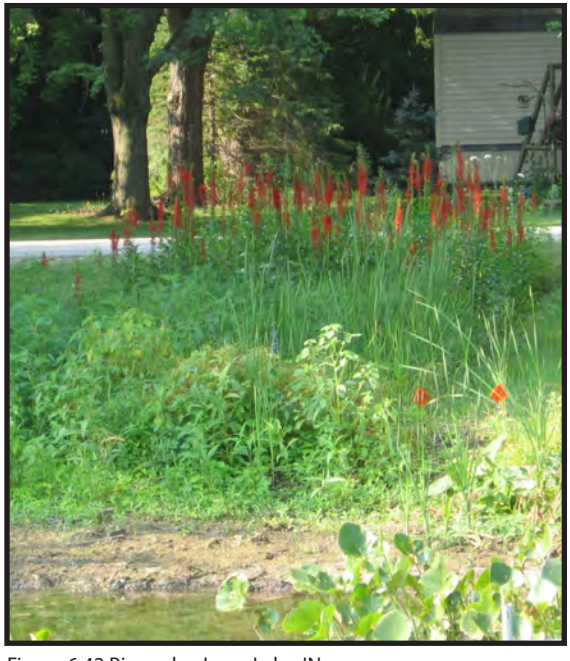

Figure 6.42 Bioswale - Loon Lake, IN.
Source: Williams Creek Consulting

Benefits

- Significant water quality improvement, including reduction or removal of dissolved nutrients, metals and hydrocarbons. Pollutants are removed through uptake by vegetation and microbiological processes. Vegetation physically filters out sediments and helps prevent resuspension.
- Can provide limited retention and detention.
- Increases the time of concentration relative to conventional pipe collection systems, which can help reduce peak runoff rates and mimic the predevelopment hydrograph.
- Can increase biodiversity relative to other centralized stormwater control measures such as dry detention or wet ponds.
- Does not suffer seasonal maintenance issues such as wet pond spring or fall algae blooms or dry basin mowing.
- Creates opportunities for a linear network of common area that can be used for pedestrian trails, maintenance access and emergency vehicle access.
- Can help minimize mass earthwork requirements where used to maintain predevelopment drainage patterns.

Primary Cost Components for Bioswales			
Implementation Stage	**Primary Cost Components**	**Basic Cost Estimated**	**Other Considerations**
Site Preparation	Tree and plant protection	Protection cost ($/acre) x Affected area (acre)	Removal of existing structures, topsoil removal and stockpiling.
	Topsoil salvage	Salvage cost ($/acre) x Affected area (acre)	
	Clearing and grubbing	Clearing cost ($/acre) Affected area (acre)	
Site Formation	Excavation/grading	4-ft depth Excavation cost ($/acre) x Area (acre)	Soil and rock fill material, tunneling.
	Hauling material off-site	Excavation cost x (% of material to be hauled away)	
Structural Components	Under-drains	Under-drain cost ($/lineal ft.) x length of device	Pipes, catch basins, manholes, valves.
	Vault structure (for media filters)	$/Structure	
	Media (for media filters)	Media cost ($/cubic yard) x filter volume (cubic yard)	
	Inlet structure (for vegetative filters)	$/Structure	Tree protection, soil amendments, seed bed preparation, trails.
	Outlet structure (for vegetative filters)	$/Structure	
Site Restoration	Filter Strip	Sod cost ($/sq. ft.) x Filter strip area	Vegetation maintenance, cleaning of structures.
	Soil preparation	Soil cost ($/acre) x Seeding/planting area (1-ft average depth per acre	
	Seeding	Seeding cost ($/acre) x Seeded area (acre)	
	Planting/transplanting	Planting cost ($/acre) x Planted area (acre)	
Annual Operation, Maintenance and Inspection	Debris removal	Removal cost ($/acre) x Area (acre) x Frequency (2x/1 yr)	Vegetation maintenance, cleaning of structures.
	Sediment removal	Removal cost ($/acre) x Area (acre) x Frequency (5x/1 yr)	
	Gate/Valve operation	Operation cost ($) x Operation Frequency (2x/1 yr)	
	Inspection	Inspection cost ($) x Inspection Frequency (6x/1 yr)	
	Mowing (for vegetative filters)	Mowing cost ($) x Mowing frequency (4x/1 yr)	

Table 6.9 Source: Minnesota Stormwater Manual Version 2, 2008.

Siting Considerations

- Swales are well suited for roadside applications or along the property boundaries of development.
- Side slopes should not be steeper than 3:1 for maintenance and safety considerations.
- Concrete maintenance surfaces can be used at inlets for ease of maintenance
- To help maintain slow velocities and increase opportunities for infiltration during conveyance, swales should be designed with minimal or no slope. In steeper topographic areas, check dams can be used to help slow small storm runoff velocities and protect the swale against erosion.

Cost

Cost is dependent upon the size of the swale, use of seeds or plugs, presence of a pretreatment forebay and the extent of necessary excavation during construction. Capital cost varies between $10 to $50 dollars per linear foot depending on these factors (Storm, 1999). For similar sized applications, wet swales can be less expensive than bioswales due to no requirement for special backfill or underdrains.

Permits

Review local requirements for site grading, drainage structures, erosion and sediment control and potential invasive vegetation.

Landscaping

Landscaping of vegetated filters is a critical design element to improve both the function and aesthetics. Native plants are well adapted to or have evolved under local climate conditions. Native plant species are typically characterized by deep rooting systems which assist with infiltration.

Because native species exhibit a broad spectrum of tolerances to flooding, specifying plant material suitable for the anticipated duration of inundation or saturation is critical for a successful design. The U.S. Fish and Wildlife Service has developed an indicator status list for most vascular plants throughout the U.S. The indicators include:

- Obligate wetland, or OBL: Plants which nearly always (more than 99 percent of the time) occur in wetlands under natural conditions.
- Facultative Wetland, or FACW: Plants which usually occur in wetlands (from 67 to 99 percent of the time), but occasionally found in non wetlands.
- Facultative, or FAC: Plants which are equally likely to occur in wetlands and non wetlands and are found in wetlands from 34 to 66 percent of the time.
- Facultative Upland, or FACU: Plants which usually occur in non wetlands (from 67 to 99 percent of the time), but occasionally found in wetlands.
- Upland, or UPL: Plants which almost always (more than 99 percent of the time) under natural conditions occur in non wetlands.

Indicator status of particular plants can assist the designer in specifying plants that will tolerate the depth, duration and frequency of saturation within each hydrologic zone of the wetland design. Furthermore, blooming period may be used as a selection criterion to improve the aesthetics of a design throughout the growing season.

Indicator status can be reviewed at www. plants.usda.gov.

While selection of individual species will vary based on the intended function of a project or preferences of a designer, some particularly aggressive and opportunistic species should be avoided in wetland plantings. Furthermore, if volunteers of these species are identified, a management plan is recommended for their control and prevention. These species, commonly referred to as invasive include the following:

Invasive Plants to Avoid

Common Name	Latin Name
Broad-leaved cattail	Typha *latifolia*
Narrow-leaved cattail	Typha *angustifolia*
Hybrid cattail	Typha *x glauca*
Common Reed	Phragmites *australis*
Purple loosestrife	Lythrum *salicaria*
Johnson Grass	Sorghum *halepense*

Maintenance

- Relatively low to medium, depending on the type of vegetation and mowing frequency.
- Sediment should be removed as needed near inlets to prevent blocking or clogging.
- Remove trash as needed.
- Invasive and exotic species should be removed.
- Mowing of turf swales will be necessary.
- Semiannual inspection for:
    - Sediment accumulation.
- Invasive and exotic species vegetation.
    - Integrity of the slopes and center line.
    - Corrective actions in areas of erosion.

Bioretention and Organic Filters Plants

Latin Name	Common Name	Submerged & Emergent (water depth in feet)	Pond Edge & Permanent Water	Over sand	Lower slopes & bioretention base	Upper slopes	Height (feet)	Spacing (feet)	Seasonal Interest - Color and Months	Sun	Pt Sun	Pt Shade	Shade	Dry	Medium	Wet	Birds	Butterflies	Fall Color	Winter Interest	Flood frequency tolerance	Flood height tolerance	Flood duration tolerance (days)	Salt tolerance	Aggressiveness	Silt tolerance
Grasses/Sedges	Grasses/Sedges																									
Andropogon virginicus	Broomsedge			x		x	1-2	1.5	orange	x				x		x		x	x	L		1		M	L
Bouteloua curtipendula	Sideoats grama			x		x	1-2	1	tan	x				x	x		x			x	L		1		L	L
Carex muskingumensis	Palm sedge		x	x	x		1-2	1.5	tan	x	x	x	x	x	x	x	x			H	24	3+		M	H
Carex praegracilis*	Tollway sedge		x		x	x	1-2	2	tan	x	x			x	x	x	x			H	12	2	H	H	H
Carex vulpinoidea	Fox sedge		x		x		2-3	1.5	tan	x	x	x			x	x				H	24	3+	L	L	H
Panicum virgatum	Switchgrass			x	x	x	3-6	2.5	pink	x	x	x			x	x	x		x	M	12	2	M	M	M
Schizachyrium scoparium	Little bluestem			x		x	2-4	1.5	bronze	x				x	x		x		x	x	L	12	1	M	L	L
Sporobolus heterolepis	Prairie dropseed				x	x	2-3	1.5	tan	x				x	x		x			x	L				L	
Forbs																										
Asclepias tuberosa	Butterfly milkweed			x		x	1-2	1.5	orange	x				x	x			x			L			V	M	
Baptisia australis	Blue wild indigo						3-4	3-4	blue	x	x	x		x	x			x			L				M	
Blephilia ciliata	Ohio horsemint					x	1-2	1.5	pink		x	x	x	x	x			x		x	L					
Coreopsis lanceolata	Lanceleaf coreopsis			x		x	1-2	1.5	yellow	x	x			x	x			x			L		1		L	
Echinacea purpurea	Purple coneflower					x	2-3	1.5	t. purple		x	x	x	x	x		x	x			L				L	
Eryngium yuccifolium	Rattlesnake master				x	x	4-5	1.5	green	x				x	x			x		x	M	12	2	M	L	
Pycnanthemum tenuifolium	Slender Mountain Mint			x	x	x	2-3	1.5	white	x	x	x		x	x						L		1		M	
Ratibida pinnata	Yellow/Grey coneflower			x	x	x	3-5	1.5	yellow	x	x			x	x		x	x			M	12	1	M	H	L
Rudbeckia subtomentosa	Sweet coneflower				x	x	3-4	2	yellow	x	x				x	x		x		x	H	12	2		M	
Scutellaria incana	Hoary skullcap				x		2-3	2	blue			x	x	x	x			x			L					L
Solidago rigida	Stiff goldenrod				x	x	3-5	1.5	yellow	x					x					x	L	12	2	M	H	L
Verbesina helianthoides	Yellow wingstem			x	x	x	2-3	1.5	yellow	x	x	x		x	x		x	x							M	
Zizia aurea	Golden alexander					x	1-3	1.5	yellow	x	x	x			x			x			H	12	1	M	H	U
Trees/Shrubs																										
Cornus florida	Flowering dogwood			x	x	x	10-20	15	white		x	x	x	x	x		x		x	x	L			L	L	L
Diospyos virginiana	Persimmon			x	x	x	30-40	20	orange	x	x	x		x	x		x		x	x	M	12	1		M	M
Ostrya virginiana	Hophornbeam				x	x	20-30	20	green		x	x	x	x	x						L				L	L
Quercus muhlenbergii	Chinquapin oak				x	x	40-50	35	green		x	x	x	x	x					x	L			H	L	L

Requirements

Local Ecotype Rule: Plants of Missouri or Southern Illinois ecotype are required.
Must use a minimum of 5 grass/sedge species and 8 forb species for each BMP. It is recommended that this list be provided to landscape contractors/buyers in case substitutions are required.
Each species must consist of between 5% - 15% of the total plant count for each BMP.
Refer to Planting, Water, and Mulch Requirements for Stormwater BMP's for plant sizes and irrigation requirements
Biodegradable erosion blanket must be used on slopes greater than 10%.
Erosion blankets must be coarse to allow varying leaf sizes (examples include Geojute, Curlex #1 and NorthAmerican Green S75 single net straw blanket, or equivalent)

*Experimental for practice and/or limited availability in commercial trade

Figure 6.43 Source: Landscape Guide for Stormwater Best Management Practice Design - St. Louis, MO.
Note: This table is not an all inclusive list for species that may tolerate proposed growing conditions.

Enhanced Swales/ Grass Channels/ Filter Strips Inspections and Maintenance Checklist

Site name: _____ Owner Change since last inspection? Y N

Owner Name, Address, Phone _____

Number_____

Location: _____

Site Status: _____

Date:_____ Time: _____

Inspector: _____

Inspection Frequency Key: A=annual; M=monthly; S=after major storms

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Debris Removal				
Facility and adjacent area free of debris?	*M*			
Inlets and outlets free of debris?	*M*			
Any dumping of yard wastes into facility?				
Litter (branches) removed?	*M*			
Vegetation				
Surrounding area fully stabilized? (no evidence of eroding material into swale, channel or filter strip)	*M*			
Grass mowed?	*M*			
Plant height not less than design water depth?	*M*			
Fertilized per specifications?	*M*			
Plan composition according to approved plan?	*M*			
Unauthorized or inappropriate plantings?	*A*			
Plants healthy? (no diseased or dying vegetation)	*M*			
Evidence of plants stressed from inadequate watering?	*M*			
Filtration Capacity				
Clogging from oil or grease?	*M*			
Facility dewaters between storms?	*M*			
Check dams and energy dissipators/sumps				
Any evidence of sedimentation build up	*A,S*			
Are sumps greater than 50% full of sediment?	*A,S*			
Any evidence of erosion and down stream toe of drop structures?	*A,S*			
Sediment Deposition				
Swale clean of sediments	*A*			
Sediment not > 20% of swale design depth	*A*			

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Outlet/Overflow Spillway				
In good condition?	*A*			
Any evidence of erosion?				
Any evidence of blockages?	*A*			
Has facility been filled or blocked inappropriately?	*A*			

Inspector Comments:_____

Overall Condition of Facility: ☐ Acceptable ☐ Unacceptable

If any of the above Inspection Items are checked "Yes" for "Maintenance Needed," list Maintenance actions and their completion dates below:

Maintenance Action Needed	Due Date

The next routine inspection is scheduled for approximately: _____
(date)

Inspected by: (signature) _____
Inspected by: (printed) _____

Figure 6.44 Source: Storm Water Management Manual Volume 1, Appendix D - Memphis Shelby County Governments. (City of Memphis, 2007)

Wet Retention and Detention Basins

Wet Ponds

Wet ponds are a type of detention basin typically designed for large storm management and can be designed with extended detention controls to improve small storm management. Ponds rely on physical, biological and chemical processes to remove pollutants from incoming stormwater runoff. The primary treatment mechanism is gravitational settling of particulates and their associated pollutants. Algae and aquatic vegetation can help manage nutrients, however many nutrients in ponds are released when these organisms die. Volatilization and chemical activity can also occur, breaking down and assimilating a number of other stormwater contaminants such as hydrocarbons, however lighter hydrocarbons such as gasoline will float and may pass through ponds untreated.

Wet and dry ponds perform very differently (see the International BMP Database) dry ponds are not very effective pollutant control devices (low to medium), while wet ponds are usually highly effective for particulate bound pollutants. Both can be the most effective control for energy reductions though (needed for habitat protection), to balance the flow-duration distribution for a site (after upland infiltration).

Benefits Low = <30% Medium = 30-65% High = 65-100%			
	Low	Medium	High
Suspended Solids			
Nitrogen			
Phosphorous			
Metals			
Bacteriological			
Hydrocarbons			

Table 6.10 Source: Iowa Stormwater Manual - (Iowa State University, 2009)

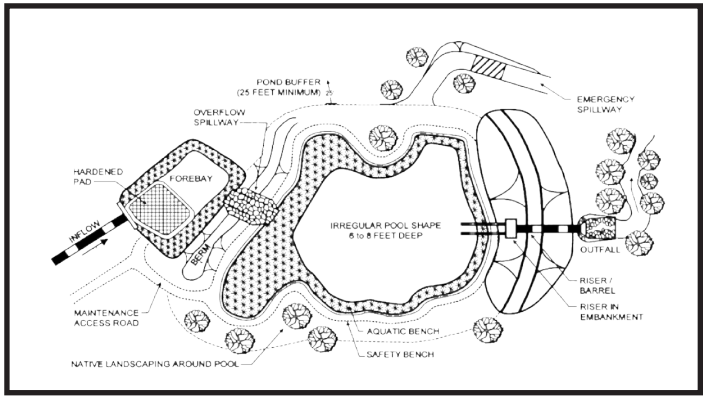

Figure 6.45 Flow-through wet detention pond. Source: Center for Watershed Protection, 1996

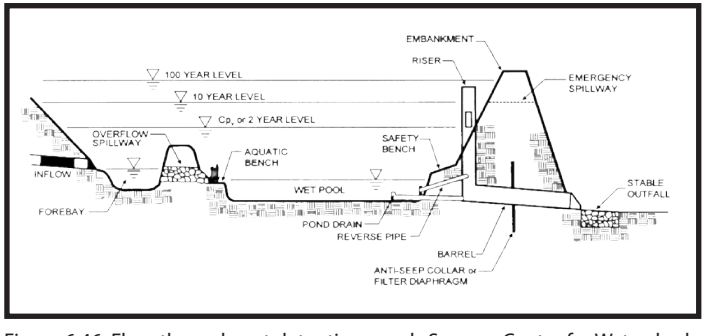

Figure 6.46 Flow-through wet detention pond. Source: Center for Watershed Protection, 1996

Variants in wet pond design include:

1. Flow-through Wet Detention Ponds typically have a weir or single orifice outlet control to slow the release of runoff from large, infrequent storms such as 10-year or 100-year storms. Designers need to consider drawdown times when designing slopes above normal pool. Rapid drawdown times can contribute to slope instability and bank failure.

2. Extended Detention Wet Ponds use a multiple orifice outlet to provide extended detention of small storms. Designers need to consider drawdown times when designing vegetation on slopes near the normal water surface, as these areas may be inundated for extended periods unsuitable for turf grasses.

3. Pond/Wetland Systems are combinations of deep open water areas and wetland shelves. This combination can share the advantages of both systems.

3. Water reuse ponds used primarily for irrigation.

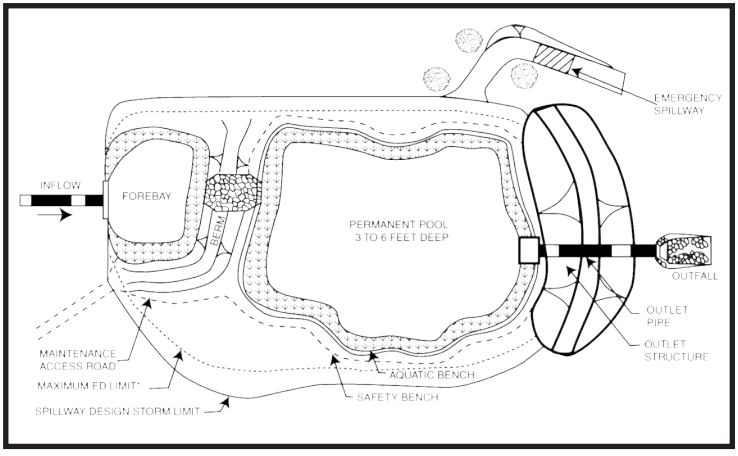

Figure 6.47 Extended wet detention. Source: Center for Watershed Protection, 1996

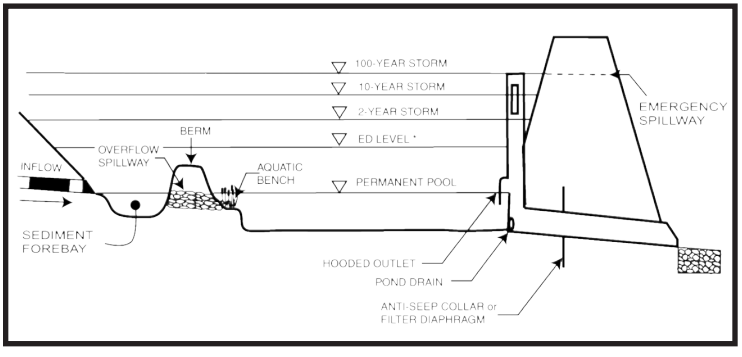

Figure 6.48 Extended wet detention. Source: Center for Watershed Protection, 1996

Green Infrastructure Application Strategy

Wet ponds are well suited to regional stormwater management applications. The large footprint of regional basins create opportunities for trails, fishing areas and other amenities.

Wet ponds can also be retrofitted with extended detention controls and/or wetland shelves. Extended detention controls can be designed to improve an existing wet pond's management of multiple design storms. Wetland shelves can help provide a safety barrier between open water and the shoreline, and help control waterfowl populations and associated fecal coliform issues, although coliform removal rates vary widely and do not necessarily meet pollutant removal requirements alone.

Figure 6.49 IntelliPlex - Shelbyville, IN. Source: Williams Creek Consulting

Water balance calculators are recommended where wet ponds are at the end of a green infrastructure treatment train. The infiltration capacity of many green infrastructure stormwater control measures and the reduced runoff from non-structural stormwater control measure practices may not provide adequate volumes of water to maintain wet pond design pool elevations and result in stagnant or otherwise reduced pond health.

Benefits

- Efficient control of peak discharge rates to help decrease downstream channel erosion and reduce peak runoff rates.
- Long term sequestering of sediments.
- When designed with wetland shelves, wet ponds can increase biodiversity and aquatic habitat.
- Less construction cost than similarly sized constructed wetland systems.

Potential Drawbacks

- Can have seasonal algae blooms.
- Can become clogged with invasive and exotic vegetation such as milfoil.
- Pose a drowning safety risk.
- Can create a net export of suspended solids where nutrients cause phytoplankton and algae blooms.
- Can attract nuisance waterfowl populations.
- Have difficulty settling fine grained particles.

Minimal infiltration is typically provided by wet ponds. However, exceptions may occur where a wet pond normal pool elevation is equal to the seasonal high groundwater table. This is a difficult condition to achieve and attempting but failing to execute properly can result in:

- Normal pool set above the seasonal high water table. This condition can result in exposed pond shelves, making the safety ledge ineffective at preventing pedestrian access to steep, submerged slopes.

Figure 6.50 Corporate headquarters - Plainfield, IN. Source: Williams Creek Consulting

- Normal pool set below the seasonal high water table. This condition can result in dewatering of the shallow aquifer through continuous discharge. Lowering of the water table results in a long-term increase in discharge volumes to receiving streams and can damage or kill trees and other vegetation unable to reach the depressed water table elevation.

Safety

Due to drowning risk, public safety is important in wet pond design. Issues to address include:

- The principal outlet or spillway should not permit access by small children.
- Endwalls above pipe outfalls greater than 48 inches in diameter should be fenced to prevent a hazard Access to open water should be limited using fencing or vegetation.
- Prohibited use signs should be posted.
- Setbacks from roads should be set to minimize risks to vehicular accidents.
- Shallow shelves should extend into the pond prior to dropping off to deep depths.
- Dam safety regulations should be strictly followed where relevant and applicable.

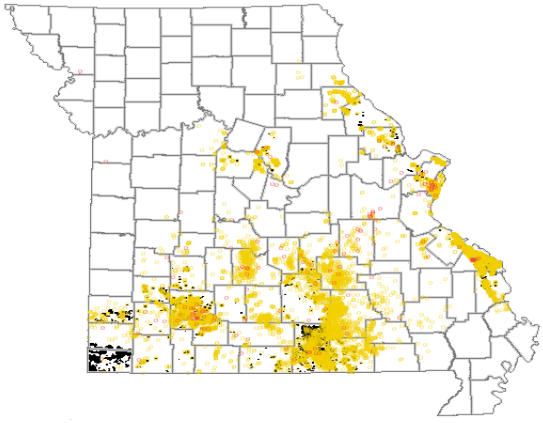

Figure 6.51 Source: Generated from Missouri CARES Website www.cares.Missouri.edu/

Karst Prone Areas and Sinkhole Features

This stormwater control measure can promote infiltration of stormwater. Low permeability or impermeable liners may be required. Consult a geotechnical engineer or other qualified expert prior to applying this stormwater control measure in karstic geographic regions.

Siting Considerations

- Minimum average depths of 6 to 8 feet help provide long term storage capacity for sediment.
- Ponds may require liners to prevent leaking.

Relative Cost

Construction costs for surface wet ponds can vary greatly pending site characteristics (Weiss, 2007), but can be correlated to water quality volumes. Correlations indicate that wetland unit storage cost decreases as storage volume increases (see figure). Relative to other stormwater control measures in the study, constructed wet pond unit volume costs are similar in magnitude to dry basins and wetlands, but an order of magnitude lower than bioretention. However, these costs do not consider the expense of setting aside land, which can be significant.

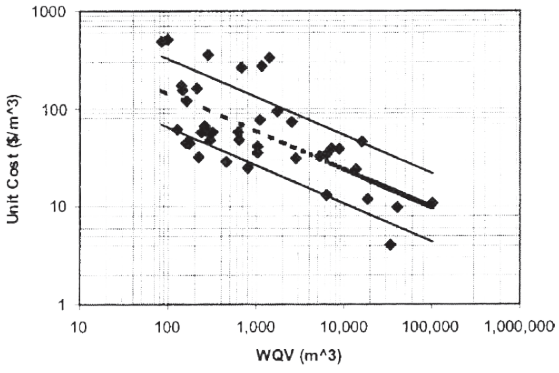

Figure 6.52 Bioretention Unit Cost of Storage.
Source: Weiss et al, 2007.

Construction costs can vary greatly pending site characteristics. However, an equation was developed to estimate the cost of extended detention wetlands prior to design (Brown and Schueler, 1997).

C = 24.5 V(0.705) Where:

C = Construction, design and permitting cost.
V = Volume needed to control the 10-year storm (ft3).

Costs developed with this equation can be inflated to the present value and can be used for conceptual comparisons among alternate stormwater control measures early in a planning process. For example, the same study that provides a formula for wetlands indicates wet ponds cost approximately 20 percent less than a similarly sized wetland.

Case Study Cost

National databases or local case studies can be used to estimate costs. The 2008 Minnesota Stormwater Manual estimates that wet ponds cost from $30,000 to $60,000 per acre-foot of storage. This study projects the annual cost of routine maintenance to be approximately five percent of the construction cost and that the typical design life is longer than 20 years.

Site Specific Cost

Where site specific plans are available, costs can be calculated using engineering quantity takeoffs. For example, excavating 12 feet below existing grade at $9 per cubic yard yields a cost of $0.44 per square foot of wet pond area. Assuming this wet pond stages approximately three to four feet, the cost of storage is approximately $4,800 to $6,400 per acre foot, much less than the Minnesota manual indicates. However, these costs do not include dewatering, inlet and outlet controls, or other considerations that may have affected the Minnesota manual study.

Primary Cost Components for Wet Ponds			
Implementation Stage	**Primary Cost Components**	**Basic Cost Estimated**	**Other Considerations**
Site Preparation	Tree and plant protection	Protection cost ($/acre) x Affected area (acre)	Removal of existing structures, topsoil removal and stockpiling.
	Topsoil salvage	Salvage cost ($/acre) x Affected area (acre)	
	Clearing and grubbing	Clearing cost ($/acre) Affected area (acre)	
Site Formation	Excavation/grading	4-ft depth Excavation cost ($/acre) x Area (acre)	Soil and rock fill material, tunneling.
	Hauling material off-site	Excavation cost x (% of material to be hauled away)	
	Inlet structure	$/Structure	Pipes, catch basins, manholes, valves.
	Outlet structure	$/Structure	
Site Restoration	Seeding	Seeding cost ($/acre) x Seeded area (acre)	Tree protection, soil amendments, seed bed preparation, trails.
	Planting/ transplanting	Planting cost ($/acre) x Planted area (acre)	
Annual Operation, Maintenance and Inspection	Debris removal	Removal cost ($/acre) x Area (acre) x Frequency (2x/1 yr)	Vegetation maintenance, cleaning of structures.
	Invasive plant removal	Labor Cost ($/) x Time x Frequency	
	Sediment removal	Removal cost ($/acre) x Area (acre) x Frequency (1x/5 yrs)	
	Gate/Valve operation	Operation cost ($) x Operation frequency (2x/1 yr)	
	Inspection	Inspection cost ($) x Inspection frequency (2x/1 yr)	
	Mowing	Mowing cost ($) x Mowing frequency (4x/1 yr)	

Table 6.11 Source: Minnesota Stormwater Manual Version 2, 2008.

Landscaping

Landscaping of ponds is a design element to improve both the function and aesthetics of stormwater ponds. Native plants are well adapted to or have evolved under local climate conditions. Native plant species are typically characterized by deep rooting systems which assist with infiltration.

Because native species exhibit a broad spectrum of tolerances to flooding, specifying plant material suitable for the anticipated duration of inundation or saturation is critical for a successful design. The U.S. Fish and Wildlife Service has developed an indicator status list for most vascular plants throughout the U.S. The indicators include:

- Obligate wetland: Plants which nearly always (more than 99 percent of the time) occur in wetlands under natural conditions.
- Facultative Wetland: Plants which usually occur in wetlands (from 67 to 99 percent of the time), but occasionally found in non wetlands.
- Facultative: Plants which are equally likely to occur in wetlands and non wetlands and are found in wetlands from 34 to 66 percent of the time.
- Facultative Upland: Plants which usually occur in non wetlands (from 67 to 99 percent of the time), but occasionally found in wetlands.
- Upland: Plants which almost always (more than 99 percent of the time) under natural conditions occur in non wetlands.

Indicator status of particular plants can assist the designer in specifying plants that will tolerate the depth, duration and frequency of saturation within each hydrologic zone of the wetland design. Furthermore, blooming period may be used as a selection criterion to improve the aesthetics of a design throughout the growing season.

Indicator status can be reviewed at www.plants.usda.gov.

While selection of individual species will vary based on the intended function of a project or preferences of a designer, some particularly aggressive and opportunistic species should be avoided in wetland plantings. Furthermore, if volunteers of these species are identified, a management plan is recommended for their control and prevention. These species, commonly referred to as invasive include the following:

Invasive Plants to Avoid

Common Name	Latin Name
Broad-leaved cattail	Typha *latifolia*
Narrow-leaved cattail	Typha *angustifolia*
Hybrid cattail	Typha *x glauca*
Common reed	Phragmites *australis*
Purple loosestrife	Lythrum *salicaria*
Eurasian water-milfoil	Myriophyllum *spicatum*
Johnson grass	Sorghum *halepense*

Maintenance

- Inlets and outlets should be kept clear of debris to prevent blocking or clogging.
- Remove trash as needed.
- Invasive and exotic species should be removed from pond banks and shelves.
- Semiannual inspection for sediment accumulation.
- Invasive and exotic species vegetation management.
- Integrity of the outfall structures.
- Inspect berms for nuisance wildlife damage.

Wet Retention and Detention Basins Plants

Latin Name	Common Name	Submerged & Emergent (water depth in feet)	Pond Edge & Permanent Water	Over sand	Lower slopes & bioretention base	Upper slopes	Height (feet)	Spacing (feet)	Seasonal Interest - Color and Months	J	F	M	A	M	J	J	A	S	O	N	D	Sun	Pt Sun	Pt Shade	Shade	Dry	Medium	Wet	Birds	Butterflies	Fall Color	Winter interest	Flood frequency tolerance	Flood height tolerance	Flood duration tolerance (days)	Salt tolerance	Aggressiveness	Silt tolerance
Grasses/Sedges	Grasses/Sedges																																					
Carex annectans	Yellow fruited sedge		x		x		2-3	1.5	tan				x	x	x							x	x	x		x	x	x			x	H	12	3		L	
Carex grayi	Bur sedge		x		x		1-2	1.5	tan				x	x	x								x	x	x	x	x	x				M	12	2		L	M
Carex crinita	Fringed sedge		x		x		2-3	1.5	brown					x	x							x	x	x		x	x	x				H	12	3	U	L	
Carex muskingumensis	Palm sedge		x	x	x		2-3	1.5	tan				x	x	x	x	x					x	x	x	x	x	x	x			x	H	24	3		M	M
Carex vulpinoidea	Fox sedge		x		x		2-3	1.5	tan					x	x	x						x	x	x		x	x				x	H	24	3	L	L	
Juncus effusus	Soft rush	0-1	x				2-3	1.5	green									x	x	x	x	x	x			x	x	x			x	H	24	4	L	M	M
Scirpus atrovirens	Great green bullrush		x	x	x		2-3	1.5	green				x	x	x							x	x			x	x	x			x	M	12	3		L	
Scirpus cyperinus*	Wool grass		x				3-4	1.5	orange					x	x	x	x	x	x	x	x	x	x				x	x		x	x	H	24	3		M	
Forbs																																						
Asclepias incarnata	Marsh milkweed		x	x	x		2-4	2	pink							x	x	x	x			x	x				x	x		x		M	18	3	M	M	
Chelone obliqua	Rose turtlehead		x		x		3-4	2	rose/purple								x	x	x			x	x	x	x		x	x				M	12	1		M	
Equisetum hyemale	Horsetail		x	x	x		2-4	2.5	green				x	x						x	x	x	x	x			x	x			x	H	36	5		H	H
Helenium autumnale	Sneezeweed		x		x		3-4	2	yellow							x	x	x	x			x	x	x			x	x	x	x		M	18	3	M	M	
Hibiscus lasiocarpos	Rose mallow		x	x	x		3-7	2.5	white/pink							x	x	x	x			x	x	x			x	x		x	x	H	36	5		M	M
Iris fulva	Copper iris		x	x	x		2-3	1.5	copper					x	x							x	x				x	x	x			M	12	1		M	
Iris virginica	Southern blueflag iris		x		x		2-3	2	blue							x	x					x	x					x	x		x	H	36	4		M	M
Lobelia cardinalis	Cardinal flower		x	x	x		2-3	1.5	red							x	x	x				x	x	x	x		x	x	x	x		H	18	5	L	M	U
Mimulus ringens*	Allegehny monkey flower		x	x	x		1-2	1.5	lavender							x	x	x				x	x				x	x				M	24	1		M	
Nymphaea odorata	Fragrant water lily	1-5					1	10	white							x	x	x				x						x				H	36			H	
Pontedaria cordata	Pickeral weed	0-1	x				1-2	2.5	blue						x	x	x	x	x			x	x	x				x				M	12	4	L	L	U
Sagittaria latifolia	Arrowleaf	0-1	x				1-4	2.5	white							x	x	x				x						x	x			M	18	3	M	M	L
Saururus cernuus	Lizard tail	0-1	x				1-2	2.5	white						x	x	x	x				x	x	x	x			x				H	24			H	
Thalia dealbata	Wild canna	0-2	x				4-7	5	purple							x	x	x				x						x				H	24			M	H
Trees/Shrubs																																						
Aesculus pavia	Red buckeye		x		x		10-20	15	red			x	x									x	x	x			x	x	x			H	18	2		L	M
Cephalanthus occidentalis	Buttonbush	x	x		x		5-10	7.5	white						x	x	x					x	x	x			x	x		x		H	36	7		M	H
Quercus macrocarpa	Bur oak		x		x	x	40-60	35	green										x	x		x	x	x			x	x			x	H	36	5	H	L	H
Taxodium disticum	Bald cypress	x	x	x	x		40-60	20	orange										x	x		x	x	x			x	x			x	H	36	7		L	H

Figure 6.53 Source: Landscape Guide for Stormwater Best Management Practice Design - St. Louis, MO.
Note: This table is not an all inclusive list for species that may tolerate proposed growing conditions.

Storm Water Pond Inspections and Maintenance Checklist

Site Name: _____ Owner Change since last inspection? Y N

Location: _____

Owner Name:

Address_____Phone Number

Site Status: _____

Date:_____ Time: _____ Site conditions:

Storm Water Pond Type: Wet Pond ☐ Wet ED Pond ☐ Micropool Pond ☐ Multiple Pond System ☐ Dry Pond ☐

Inspection Frequency Key: A=annual; M=monthly; S=after major storms

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Embankment and Emergency Spillway				
Vegetation healthy?	*A/S*			
Erosion on embankment?	*A/S*			
Animal burrows in embankment?	*A/S*			
Cracking, sliding, bulging of dam?	*A/S*			
Drains blocked or not functioning?	*A/S*			
Leaks or seeps on embankment?	*A/S*			
Slope protection failure functional?	*A/S*			
Emergency spillway obstructed?	*A/S*			
Erosion in/around emergency spillway?	*A/S*			
Other (describe)	*A/S*			
Riser and Principal Spillway				(describe type: concrete pipe, slotted weir, channel, etc.)
Low-flow orifice functional?	*A/S*			
Trash rack (Debris removal needed? Corrosion noted?)	*A/S*			
Sediment buildup in riser?	*A*			
Concrete/masonry condition (Cracks or displacement? Spalling?)	*A*			
Metal pipe in good condition?	*A*			
Control valve operation?	*A*			
Pond drain valve operation?	*A*			
Outfall channels functioning, not eroding?	*A*			
Other (describe)	*A*			
Sediment Forebays				
Sedimentation description				
Sediment cleanout needed (over 50% full)?	*A/S*			

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Permanent Pool Areas (if applicable)				
Undesirable vegetation growth?	*M*			
Visible pollution?	*M*			
Shoreline erosion?	*M*			
Erosion at outfalls into pond?	*M*			
Headwalls and endwalls in good condition?	*M*			
Encroachment into pond or easement area by other activities?	*M*			
Evidence of sediment accumulation?	*A*			
Dry Pond Areas (if applicable)				
Vegetation adequate?	*M*			
Undesirable vegetation or woody plant growth?	*M*			
Excessive sedimentation?	*A*			
Hazards				
Have there been complaints from residents?	*M*			
Public hazards noted?	*M*			

Inspector Comments:_____

_____

_____

_____

Overall Condition of Facility: ☐ Acceptable ☐ Unacceptable

If any of the above Inspection Items are checked "Yes" for "Maintenance Needed," list Maintenance actions and their completion dates below:

Maintenance Action Needed	Due Date

The next routine inspection is scheduled for approximately: _____
(date)

Inspected by: (signature) _____
Inspected by: (printed) _____

Figure 6.54 Source: Storm Water Management Manual Volume 1, Appendix D - Memphis Shelby County Governments. (City of Memphis, 2007)

Dry Ponds and Extended Dry Detention Basins

Dry Ponds and Extended Dry Detention Basins

Traditional dry ponds were historically used for large storm management and located at the end of a piped collection system with little or no pretreatment. These types of basins were normally turfed, dry, fitted with a low flow concrete channel and viewed as providing little water quality benefit relative to other stormwater control measures. If pollutant removal efficiency is an important consideration, then dry detention ponds may not be the most appropriate choice. If water quality treatment is a goal of dry detention basin design and construction, a wet or extended stormwater pond design should be incorporated. If dry ponds are used, they 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.

Figure 6.55 Detention basin with concrete conveyance channel.
Source: Metropolitan St. Louis Sewer District

Wet and dry ponds perform very differently (see the International BMP Database; dry ponds are not very effective pollutant control devices (low to medium), while wet ponds are usually highly effective for particulate bound pollutants. Both can be the most effective control for energy reductions though (needed for habitat protection), to balance the flow-duration distribution for a site (after upland infiltration).

Green Infrastructure Application Strategy and Design Issues

Green infrastructure application strategies may include:

- Stormwater control measures constructed upstream to filter sediment and other pollutants so that the dry retention basin need only serve to manage peak rates of discharge.
- Installing "micro-stormwater control measures" such as constructed wetlands or wet pond micropools near inlets and outlets within dry basins to sequester sediment and improve pollutant removal.
- Constructing vegetated micro-stormwater control measures such as swales, rain gardens or filter strips to manage smaller storms around the perimeter of the dry basin. Larger, infrequent storms may stage into the remainder of the dry basin, making it available for recreational use in all but severe storm events. This practice is similar to many municipal parks located within the 100-year floodplain or other intermittently flooded area.

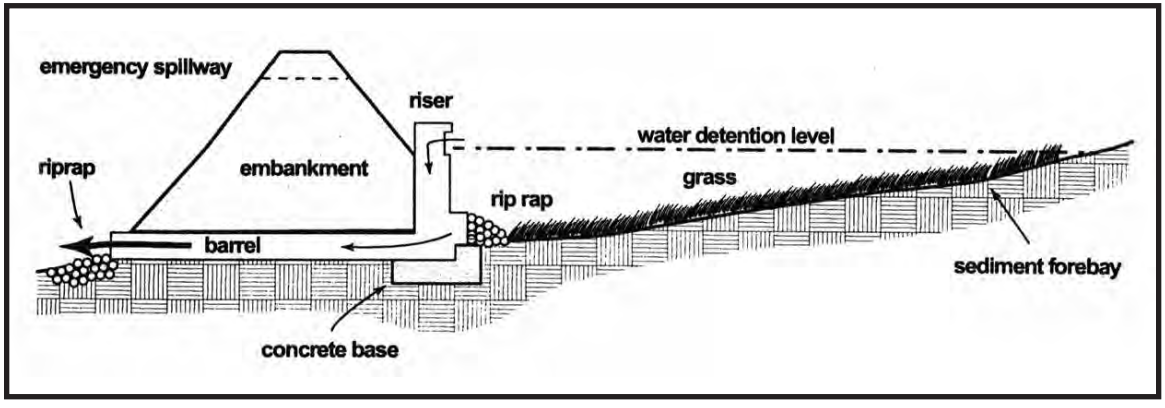

Figure 6.56 Example profile view of a dry pond design. Source: EPA Dry Detention Pond fact sheet.
http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=67&minmeasure=5

- Installing soil amendments and underdrains to incorporate many of the biofiltration benefits of bioretention areas into a dry basin design.
- Dry detention basins can be constructed as long linear features that can store, treat and convey runoff. Linear stormwater control measure practices can greatly reduce grading and stormwater pipe requirements while improving pedestrian greenway connectivity.

Benefits

- Potential for significant water quality improvement, including reduction or removal of dissolved nutrients, metals and hydrocarbons. Pollutants are removed through uptake by vegetation, soil absorption and biogeochemical activity in the soil column. Vegetation in the micro-stormwater control measures within the basin can filter and help prevent resuspension of sediment.
- Dry basins can be low to high maintenance, depending on the aesthetic requirements of the landscape or the overloading of sediments from neighboring construction projects. Relevant to upland ornamental landscapes, a mature dry basin area is generally more resistant to colonization by upland nuisance weeds, better adapted to thrive in saturated and flooded conditions and more tolerant to droughts.
- In some cases, where soil conditions allow, it can provide retention to help improve groundwater recharge and mimic predevelopment surface runoff volumes.

Figure 6.57 Dry detention basin. Source: ABC's of BMP's, LLC

- Can decrease downstream channel erosion and reduce peak runoff rates from large storm events.
- Can provide passive or active recreation open space opportunities.
- Can be among the most cost effective approaches to runoff management.

Limitations

(Minnesota, 2008)

- Limited monitoring data are available and field longevity is not well documented.
- Failure can occur due to improper siting, design, construction and maintenance.
- Systems are susceptible to clogging by sediment and organic debris.
- There is a risk of groundwater contamination depending on subsurface conditions, land use and aquifer susceptibility.
- They are not ideal for stormwater runoff from land uses or activities with the potential for high sediment or pollutant loads.
- They are not recommended for areas with steep slopes.

Even though there are potential pollution and physical clogging problems with infiltration, it is one of the most important elements in the stormwater runoff treatment train. Fear of the limitations should not prevent well designed systems from being used.

Karst Prone Areas and Sinkhole Features

This stormwater control measure can promote infiltration of stormwater. Low permeability or impermeable liners may be required. Consult a geotechnical engineer or other qualified expert prior to applying this stormwater control measure in karstic geographic regions.

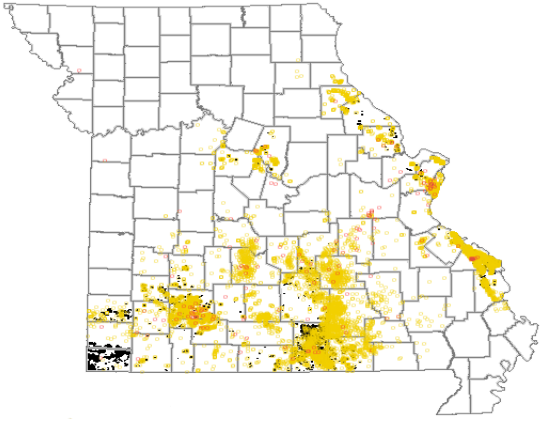

Figure 6.58 Source: Generated from Missouri CARES Website www.cares.Missouri.edu/

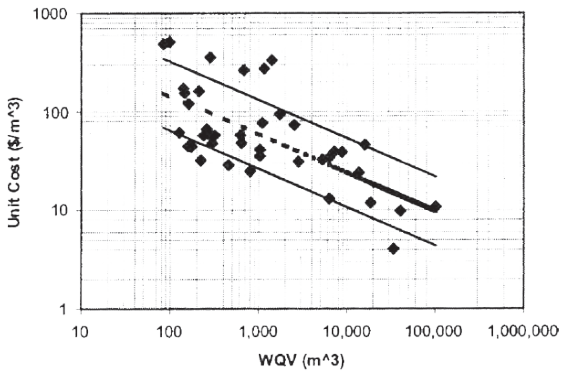

Figure 6.59 Dry detention unit cost of storage.
Source: Weiss et al. 2007

Relative Cost

Construction costs for dry basins can vary greatly pending site characteristics (Weiss, 2007), but can be correlated to water quality volumes. Correlations indicate that dry basin unit storage cost decreases as storage volume increases (see Figure 6.59). Relative to other stormwater control measures in the study, dry basin unit volume costs were similar to constructed wetlands and wet ponds, but an order of magnitude lower than bioretention or infiltration trenches. However, these costs do not include the cost to set aside the larger area of land required to construct a pond.

Another study developed an equation to estimate the cost of dry detention prior to design (Brown and Schueler, 1997):

C = 12.4V(0.76) where:

C = Construction, design and permitting cost.
V = Volume needed to control the 10-year storm (ft^3).

Costs developed with this equation can be inflated to the present value and can be used for conceptual comparisons among alternate stormwater control measures early in a planning process. The above formula yields a value of approximately $42,000 per acre-foot of volume.

In a comparative study shown in Table 6.13, results indicate that dry detention basins are among the most inexpensive stormwater control measures to maintain; however, dry basins designed for infiltration may require slightly more maintenance. This assumes the basin is not inundated with neighboring construction runoff.

Annual O&M as a Percent of Construction Cost

Stormwater Control Measure	EPA, 1999	Weiss, 2007
Retention basins and constructed wetlands.	3-6%	Not reported.
Detention basins	<1%	1.8-2.7%
Constructed wetlands	2%	4-14.1%
Infiltration trench	5-20%	5.1-126%
Sand filters	11-13%	0.9-9.5%
Swales	5-7%	4.0-178%
Bioretention	5-7%	0.7-10.9%
Filter strips	$320/acre (maintained)	Not reported
Wet Ponds	Not reported	1.9-10.2%

Table 6.12 Source: Weiss et al. 2007

Site Specific Cost

Where site specific plans are available, costs can be calculated using engineering quantity takeoffs. For example, mass excavating five feet below existing grade at $6,000 per acre foot, and installing turf or native seed at $4,000 per acre, yields a cost of $34,000 per acre. Assuming this dry basin area stages approximately three to four feet, a simplified cost of storage is approximately $9,000 to $11,000 per acre foot.

Infiltration Practices Cost Components			
Implementation Stage	**Primary Cost Components**	**Basic Cost Estimated**	**Other Considerations**
Site Preparation	Tree and plant protection	Protection cost ($/acre) x Affected area (acre)	Removal of existing structures, topsoil removal and stockpiling.
	Infiltration area protection	Silt fence cost ($/ft.) x Perimeter of infiltration area	
	Clearing and grubbing	Clearing cost ($/acre) Affected area (acre)	
	Topsoil salvage	Salvage cost ($/acre) x Affected area (acre)	
Site Formation	Excavation/ grading	4-ft depth Excavation cost ($/acre) x Area (acre)	Soil and rock fill material, tunneling.
	Hauling material off-site	Excavation cost x (% of material to be hauled away)	
Structural Components	Vault structure (for underground infiltration)	$/Structure	Pipes, catch basins, manholes, valves.
	Media (for infiltration trenches)	Media cost ($/cubic yd.) x filter volume (cubic yd.)	
	Geotextile	Geotextile cost ($/cubic yd.) x area of trench, including walls	
	Inlet structure	$/Structure	
	Overflow structure	$/Structure	
	Observation well	$/Structure	
Site Restoration	Soil preparation	Topsoil or amendment cost ($/acre) x Area (acre)	Tree protection, soil amendments, seed bed preparation, trails.
	Seeding	Seeding cost ($/acre) x Seeded area (acre)	
	Filter strip	Sod cost ($/sq. ft) x filter strip	
	Planting/ transplanting	Planting cost ($/acre) x Planted area (acre)	
Annual Operation, Maintenance and Inspection	Sediment removal	Removal cost ($/acre) x Area (acre) x Frequency (1x/5 yrs)	Vegetation maintenance, cleaning of structures.
	Debris removal	Removal cost ($/acre) x Area (acre) x Frequency (1x/2 yr)	
	Inspection	Inspection cost ($) x Inspection frequency (6x/1 yr)	
	Mowing	Mowing cost ($) x Mowing frequency (6x/1 yr)	

Table 6.13 Source: Minnesota Stormwater Manual Version 2, 2008.

Figure 6.60 Dry Detention- Shelbyville, IN.
Source: William Creek Consulting.

Landscaping

Landscaping of dry detention can improve both the function and aesthetics. Native plants are well adapted to or have evolved under local climate conditions. Native plant species are typically characterized by deep rooting systems which assist with infiltration.

In general plant roots improve the permeability of the soil mixture (Lucas and Greenway, 2007). Vegetation roots can penetrate confining layers, open up soil structure and promotes the formation of macropores. The beneficial effects of native plants on infiltration rates is reported to persist even in depositional situations where sediments accumulates. The Lucas and Greenway study concludes that native vegetation can result in infiltration rates several orders of magnitude higher than predicted by underlying soil properties.

While selection of individual species will vary based on the intended function of a project or preferences of a designer, some particularly aggressive and opportunistic species should be avoided in plantings. Furthermore, if volunteers of these species are identified, a management plan is recommended for their control and prevention. These species, commonly referred to as invasive include the following:

Invasive Plants to Avoid

Common Name	Latin Name
Broad-leaved cattail	Typha *latifolia*
Narrow-leaved cattail	Typha *angustifolia*
Hybrid cattail	Typha *x glauca*
Common Reed	Phragmites *australis*
Purple loosestrife	Lythrum *salicaria*
Johnson Grass	Sorghum *halepense*

Permits

Review local requirements for site grading, erosion and sediment control and potential invasive vegetation.

Maintenance

- Semi-annual inspection of erosion on banks and near inlets and outlets.
- Annual monitoring of sediment accumulation near inlets.
- Invasive species control.
- Outlet inspection and clearing.
- Repair of damaged vegetation or embankments as needed.
- Where dry basins are used as a construction phase best management practice, they must be rehabilitated to design conditions prior to serving as a post-construction stormwater control measure.

Latin Name	Common Name	Submerged & Emergent (water depth in feet)	Pond Edge & Permanent Water	Over sand	Lower slopes & bioretention base	Upper slopes	Height (feet)	Spacing (feet)	Seasonal Interest - Color and Months	J	F	M	A	M	J	J	A	S	O	N	D	Sun	Pt Sun	Pt Shade	Shade	Dry	Medium	Wet	Birds	Butterflies	Fall Color	Winter interest	Flood frequency tolerance	Flood height tolerance	Flood duration tolerance (days)	Salt tolerance	Aggressiveness	Silt tolerance
Grasses/Sedges	Grasses/Sedges																																					
Andropogon virginicus	Broomsedge			x		x	1-2	1.5	orange								x	x	x	x	x	x				x			x		x	x	L		1		M	L
Bouteloua curtipendula	Sideoats grama			x		x	1-2	1	tan							x	x	x	x	x		x				x	x		x			x	L		1		L	L
Carex muskingumensis	Palm sedge		x	x	x		1-2	1.5	tan					x	x	x	x					x	x	x	x	x	x	x	x				H	24	3+		M	H
Carex praegracilis*	Tollway sedge		x		x	x	1-2	2	tan				x	x	x							x	x			x	x	x	x				H	12	2	H	H	H
Carex vulpinoidea	Fox sedge		x		x		2-3	1.5	tan					x	x	x						x	x	x			x	x					H	24	3+	L	L	H
Panicum virgatum	Switchgrass			x	x	x	3-6	2.5	pink	x	x					x	x	x	x	x	x	x	x	x			x	x	x		x		M	12	2	M	M	M
Schizachyrium scoparium	Little bluestem			x		x	2-4	1.5	bronze								x	x	x	x	x	x				x	x		x		x	x	L	12	1	M	L	L
Sporobolus heterolepis	Prairie dropseed				x	x	2-3	1.5	tan								x	x	x	x	x	x				x	x		x			x	L				L	
Forbs																																						
Asclepias tuberosa	Butterfly milkweed			x		x	1-2	1.5	orange						x	x	x					x				x	x			x			L			V	M	
Baptisia australis	Blue wild indigo						3-4	3-4	blue					x	x							x	x	x		x	x			x			L				M	
Blephilia ciliata	Ohio horsemint					x	1-2	1.5	pink				x	x									x	x	x	x	x			x		x	L					
Coreopsis lanceolata	Lanceleaf coreopsis			x		x	1-2	1.5	yellow			x	x	x								x	x			x	x			x			L		1		L	
Echinacea purpurea	Purple coneflower					x	2-3	1.5	t. purple						x	x	x						x	x	x	x	x		x	x			L				L	
Eryngium yuccifolium	Rattlesnake master				x	x	4-5	1.5	green						x	x	x	x				x				x	x			x		x	M	12	2	M	L	
Pycnanthemum tenuifolium	Slender Mountain Mint			x	x	x	2-3	1.5	white							x	x	x				x	x	x		x	x						L		1		M	
Ratibida pinnata	Yellow/Grey coneflower			x	x	x	3-5	1.5	yellow						x	x	x					x	x			x	x		x	x			M	12	1	M	H	L
Rudbeckia subtomentosa	Sweet coneflower				x	x	3-4	2	yellow						x	x	x	x				x	x				x	x		x		x	H	12	2		M	
Scutellaria incana	Hoary skullcap				x		2-3	2	blue						x	x	x							x	x	x	x			x			L					L
Solidago rigida	Stiff goldenrod				x	x	3-5	1.5	yellow								x	x				x					x					x	L	12	2	M	H	L
Verbesina helianthoides	Yellow wingstem			x	x	x	2-3	1.5	yellow						x	x						x	x	x		x	x		x	x							M	
Zizia aurea	Golden alexander					x	1-3	1.5	yellow				x	x								x	x	x			x			x			H	12	1	M	H	U
Trees/Shrubs																																						
Cornus florida	Flowering dogwood			x	x	x	10-20	15	white			x	x					x	x	x	x		x	x	x	x	x		x		x	x	L			L	L	L
Diospyos virginiana	Persimmon			x	x	x	30-40	20	orange				x	x				x	x	x		x	x	x		x	x		x		x	x	M	12	1		M	M
Ostrya virginiana	Hophornbeam				x	x	20-30	20	green									x	x				x	x	x	x	x						L				L	L
Quercus muhlenbergii	Chinquapin oak				x	x	40-50	35	green									x	x				x	x	x	x	x					x	L			H	L	L

Requirements

Figure 6.61 Source: Landscape Guide for Stormwater Best Management Practice Design - St. Louis, MO.
Note: This table is not an all inclusive list for species that may tolerate proposed growing conditions.

Storm Water Pond Inspections and Maintenance Checklist

Site Name: _____ Owner Change since last inspection? Y N

Location: _____

Owner Name:

Address_____Phone Number

Site Status: _____

Date:_____ Time: _____ Site conditions:

Storm Water Pond Type: Wet Pond ☐ Wet ED Pond ☐ Micropool Pond ☐ Multiple Pond System ☐ Dry Pond ☐

Inspection Frequency Key: A=annual; M=monthly; S=after major storms

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Embankment and Emergency Spillway				
Vegetation healthy?	*A/S*			
Erosion on embankment?	*A/S*			
Animal burrows in embankment?	*A/S*			
Cracking, sliding, bulging of dam?	*A/S*			
Drains blocked or not functioning?	*A/S*			
Leaks or seeps on embankment?	*A/S*			
Slope protection failure functional?	*A/S*			
Emergency spillway obstructed?	*A/S*			
Erosion in/around emergency spillway?	*A/S*			
Other (describe)	*A/S*			
Riser and Principal Spillway				(describe type: concrete pipe, slotted weir, channel, etc.)
Low-flow orifice functional?	*A/S*			
Trash rack (Debris removal needed? Corrosion noted?)	*A/S*			
Sediment buildup in riser?	*A*			
Concrete/masonry condition (Cracks or displacement? Spalling?)	*A*			
Metal pipe in good condition?	*A*			
Control valve operation?	*A*			
Pond drain valve operation?	*A*			
Outfall channels functioning, not eroding?	*A*			
Other (describe)	*A*			
Sediment Forebays				
Sedimentation description				
Sediment cleanout needed (over 50% full)?	*A/S*			

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Outlet/Overflow Spillway				
In good condition?	*A*			
Any evidence of erosion?				
Any evidence of blockages?	*A*			
Has facility been filled or blocked inappropriately?	*A*			

Inspector Comments:_____

Overall Condition of Facility: ☐ Acceptable ☐ Unacceptable

If any of the above Inspection Items are checked "Yes" for "Maintenance Needed," list Maintenance actions and their completion dates below:

Maintenance Action Needed	Due Date

The next routine inspection is scheduled for approximately: _____
(date)

Inspected by: (signature) _____
Inspected by: (printed) _____

Figure 6.62 Source: Storm Water Management Manual Volume 1, Appendix D - Memphis Shelby County Governments. (City of Memphis, 2007)

Stormwater Wetlands

Constructed Stormwater Wetlands

Stormwater wetlands are adaptable to small or large storm management and can be designed with or without extended detention controls. Stormwater wetlands can be designed to retain, detain or treat runoff by mimicking the functions and values of natural wetlands. Wetlands provide both aerobic and anaerobic conditions that help degrade hydrocarbons, retain sediment and metals and reduce colonization opportunities for nuisance weeds. Wetlands also manage annual volume through infiltration, increase biodiversity of both flora and fauna and can control peak runoff
rates during large storms. Five variants in wetland design include:

1. Shallow Marsh Wetland has different areas of terrestrial, emergent and submergent vegetation. Deep micropools may be located at inlets to manage sediments and at outlets to help with thermal pollution.

2. Pond/Wetland Systems are combinations of deep open water areas and wetland shelves. This combination can share the advantages of both systems.

3. Extended Detention Shallow Wetland includes a multiple orifice outlet to provide extended detention of small storms. Designers need to consider drawdown times when selecting vegetation.

Benefits

Low = <30% Medium = 30-65% High = 65-100%

	Low	Medium	High
Suspended Solids			■
Nitrogen		■	
Phosphorous	■	■	
Metals		■	■
Bacteriological		■	■
Hydrocarbons			■

Table 6.14 Source: Iowa Stormwater Manual - (Iowa State University, 2009)

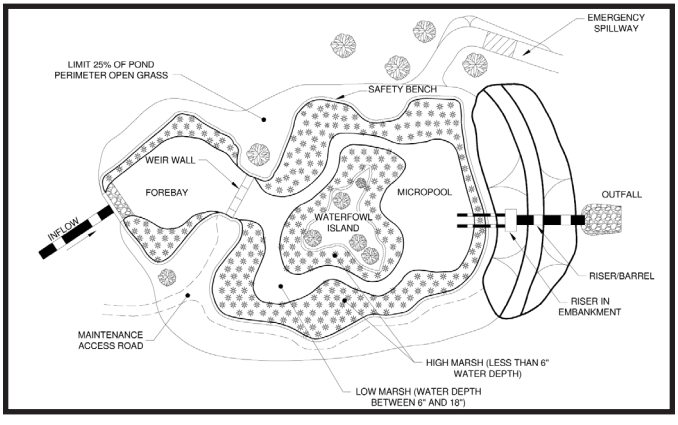

Figure 6.63 Constructed stormwater wetland.
Source: Center for Watershed Protection

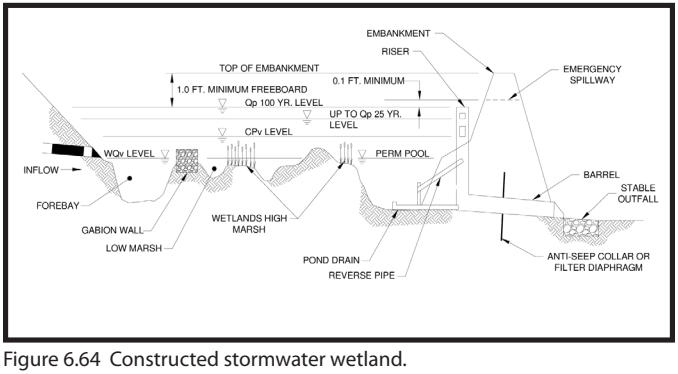

Figure 6.64 Constructed stormwater wetland.
Source: Center for Watershed Protection

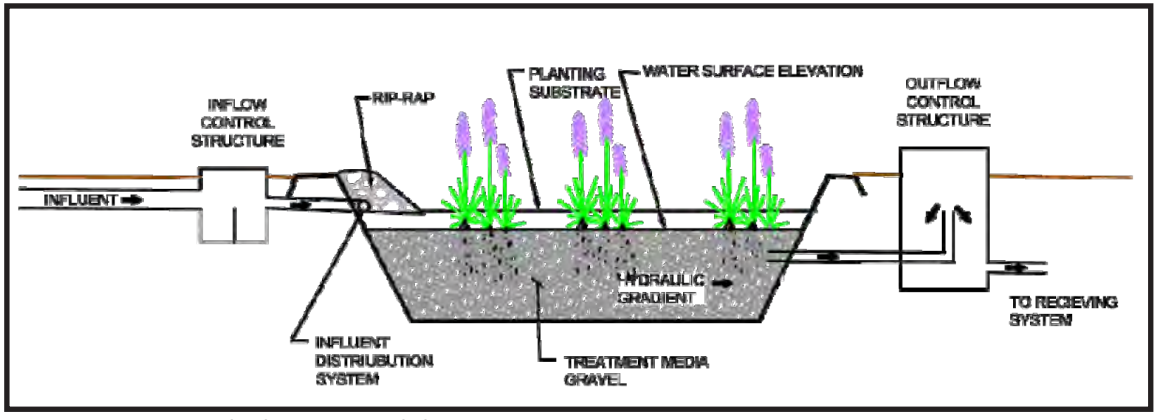

Figure 6.65 Source: Maryland Design Manual Chapter 5 (2009).

4. Submerged Gravel Wetlands are one or more treatment cells backfilled with gravel that allow stormwater to flow subsurface through the root zone of the vegetation. This is beneficial in areas where vector control is an issue, such as urban areas.

5. Pocket Wetland is intended for smaller drainage areas of two to ten acres and typically requires excavation down to the water table for a reliable water source to support the wetland system.

Green Infrastructure Application Strategy

Surface stormwater wetlands can provide stormwater control, public education and recreation opportunities and increased habitat value. A type of wetland green infrastructure strategy is to retrofit stormwater control measures by installing wetland plants in the low, frequently inundated areas of dry basins or along the shelves of wet ponds.

Surface stormwater wetlands are also well suited to regional stormwater management applications. The large footprint of regional basins create opportunities for trails, observation decks and other amenities to allow the public to take advantage of the many wildlife features found in a large diverse wetland.

Submerged gravel wetlands function as water quality treatment through filtering in highly urbanized sites with space restrictions.

Benefits

- Surface wetlands provide significant water quality improvement, including reduction or removal of dissolved nutrients, metals and hydrocarbons. Pollutants are removed through uptake by wetland vegetation, algae and bacterial. Vegetation filters and helps prevent resuspension of sediment. Volatilization and chemical break down of other stormwater contaminants such as hydrocarbons also occurs.
- Wetland vegetation is low maintenance, resists colonization by upland nuisance weeds, is adapted to thrive in saturated and flooded conditions and can be drought tolerant once established.
- Submerged gravel wetlands provide for the opportunity to treat stormwater runoff in areas with space limitation such as highly urbanized sites.

- Surface wetlands can provide both retention and detention to help improve groundwater recharge, decrease downstream channel erosion and reduce peak runoff rates.
- Can increase biodiversity relative to other centralized stormwater control measures such as dry detention or wet ponds.
- Surface wetlands do not suffer seasonal maintenance issues such as wet pond spring or fall algae blooms or dry basin mowing.
- Surface wetlands can provide aesthetic and recreational value.
- Surface wetlands provide aquatic habitat and long term sediment storage without the drowning safety risks associated with wet ponds.
- Provides public outreach opportunities.

Siting Considerations for Surface Flow Constructed Wetlands

- Large areas are recommended, but not necessary, for surface constructed wetlands. Large wetlands provide greater opportunity for large storm management and increased habitat value. Smaller or "pocket wetlands" provide many of the same benefits as bioretention but may not significantly reduce runoff volume (by infiltration).
- Loamy soils are preferred, but not necessary, for most wetland plants. Alternate species may be needed for "drier" wetlands, and live plant material may be needed in lieu of seed in "tight" soils in order to help ensure propagation.
- Surface constructed wetland bottoms should not be flat. Microtopography helps encourage biodiversity, which helps create a more resilient plant community. To help ensure long-term diversity and performance under varying climate conditions (droughts to very wet years), a wetland can be designed with four zones:
    - Open water zone: Greater than 18 inches deep, this zone can be planted with submergent species and help provide long term sediment storage.
    - Low marsh zone: 6 to 18 inches deep, this zone is suitable for emergent wetland plant species, provides substrate for biological activity on plant stems.
    - High marsh zone: Up to 6 inches deep, this zone will support a greater density and diversity of wetland species than the low marsh zone.
- Semi-wet zone: Areas above the permanent pool that are inundated during frequent small storms can be planted with wet-mesic or mesic species pending the depth, duration and frequency of inundation to help stabilize banks at the normal pool water line.

Karst Prone Areas and Sinkhole Features

This stormwater control measure can promote infiltration of stormwater. Low permeability or impermeable liners may be required. Consult a geotechnical engineer or other qualified expert prior to applying this stormwater control measure in Karstic geographic regions.

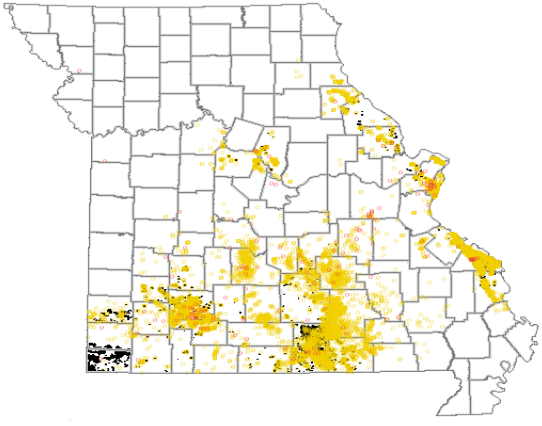

Figure 6.66 Source: Generated from Missouri CARES Website www.cares.Missouri.edu/

Relative Cost

Construction costs for surface wetlands can vary greatly pending site characteristics (Weiss, 2007), but can be correlated to water quality volumes. Correlations indicate that wetland unit storage cost decreases as storage volume increases (see figure). Relative to other stormwater control measures in the study, constructed wetlands unit volume costs are similar in magnitude to dry basins and wet ponds, but an order of magnitude lower than bioretention.

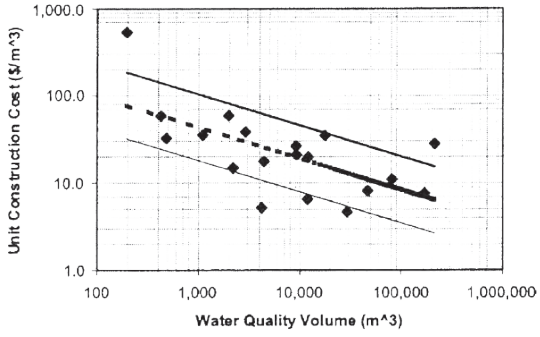

Figure 6.67 Source: Generated from Missouri CARES Website www.cares.Missouri.edu/

C = 30.6V(0.705) where:

C = Construction, design and permitting cost.
V = Wetland volume needed to control the 10-yr storm (ft3).

Costs developed with this equation can be inflated to the present value and can be used for conceptual comparisons among alternate stormwater control measures early in a planning process. For example, the same study provides a formula for wet pond cost that indicates wetlands cost approximately 25 percent more than a similarly sized wet pond.

Case Study Cost

National databases or local case studies can be used to estimate costs. The 2008 Minnesota Stormwater Manual estimates that constructed wetlands cost from $30,000 to $60,000 per acre-foot of storage. This study projects the annual cost of routine maintenance to be approximately 5 percent of the construction cost and the typical design life is longer than 20 years. These costs do not include the cost of land, which can be extensive.

Primary Cost Components for Surface Stormwater Wetlands			
Implementation Stage	**Primary Cost Components**	**Basic Cost Estimated**	**Other Considerations**
Site Preparation	Tree and plant protection	Protection cost ($/acre) x Affected area (acre)	Removal of existing structures, topsoil removal and stockpiling.
	Topsoil salvage	Salvage cost ($/acre) x Affected area (acre)	
	Clearing and grubbing	Clearing cost ($/acre) Affected area (acre)	
Site Formation	Excavation/ grading	4-ft depth Excavation cost ($/acre) x Area (acre)	Soil and rock fill material, tunneling.
	Hauling material off-site	Excavation cost x (% of material to be hauled away)	
Structural Components	Inlet structure	$/Structure	Pipes, catch basins, manholes, valves.
	Outlet structure	$/Structure	
Site Restoration	Soil preparation	Topsoil or amendment cost ($/acre) x Area (acre)	Tree protection, soil amendments, seed bed preparation, trails.
	Seeding	Seeding cost ($/acre) x Seeded area (acre)	
	Planting/ transplanting	Planting cost ($/acre) x Planted area (acre)	
Annual Operation, Maintenance and Inspection	Debris removal	Removal cost ($/acre) x Area (acre) x Frequency (1x/2 yr)	Vegetation maintenance, cleaning of structures.
	Invasive plant removal	Labor cost ($/hr) x Time x Frequency	
	Sediment removal	Removal cost ($/acre) x Area (acre) x Frequency (1x/5 yrs)	
	Erosion repair	Repair cost ($/acre) x Affected area	
	Gate/Valve operation	Operation cost ($) x Operation frequency (2x/1 yr)	
	Inspection	Inspection cost ($) x Inspection frequency (6x/1 yr)	
	Mowing	Mowing cost ($) x Mowing frequency (6x/1 yr)	

Table 6.15 Source: Minnesota Stormwater Manual Version 2, 2008.

Site Specific Cost

Where site specific plans are available, costs can be calculated using engineering quantity takeoffs. For example, excavating three feet below existing grade at $9 per cubic yard and installing live wetland plugs on two foot centers at $4 each, yields a cost of $2 per square foot of wetland. Assuming this wetland stages approximately 1.5 to three per acre-foot, the cost of storage is approximately $30,000 to $60,000 per acre foot of storage (similar to the Minnesota study previously discussed).

For comparison, a submerged gravel wetland has similar excavation and planting requirements ($2 per square foot), but costs an additional $2 per square foot for a liner and $3 per square foot for gravel and can only store one cubic foot per square foot below its surface. These values yield a cost of storage of approximately $300,000 per acre foot (five to ten times greater than a surface flow wetland.

Permits

Review local requirements for site grading, drainage structures, erosion and sediment control, vector control and potential invasive vegetation.

Landscaping

Landscaping of wetlands is a critical design element to improve both the function and aesthetics of stormwater wetlands. Native plants are well adapted to or have evolved under local climate conditions. Native plant species are typically characterized by deep rooting systems which assist with infiltration.

Because native species exhibit a broad spectrum of tolerances to flooding, specifying plant material suitable for the anticipated duration of inundation or saturation is critical for a successful design. The U.S. Fish and Wildlife Service has developed an indicator status list for most vascular plants throughout the U.S. The indicators include:

- Obligate wetland: Plants, which nearly always (more than 99 percent of the time) occur in wetlands under natural conditions.
- Facultative Wetland: Plants, which usually occur in wetlands (from 67 to 99 percent of the time), but occasionally found in non wetlands.
- Facultative: Plants, which are equally likely to occur in wetlands and non wetlands and are found in wetlands from 34 to 66 percent of the time.
- Facultative Upland: Plants, which usually occur in non wetlands (from 67 to 99 percent of the time), but occasionally found in wetlands.
- Upland: Plants, which almost always (more than 99 percent of the time) under natural conditions occur in non wetlands.

Indicator status of particular plants can assist the designer in specifying that will tolerate the depth, duration and frequency of saturation within each hydrologic zone of the wetland design. Furthermore, blooming period may be used as a selection criterion to improve the aesthetics of a design throughout the growing season. Indicator status can be reviewed at www.plants.usda.gov.

While selection of individual species will vary based on the intended function of a project or preferences of a designer, some particularly aggressive and opportunistic species should be avoided in wetland plantings. Furthermore, if volunteers of these species are identified, a management plan is recommended for their control and prevention. These species, commonly referred to as invasive include the following:

Invasive Plants to Avoid

Common Name	Latin Name
Broad-leaved cattail	Typha *latifolia*
Narrow-leaved cattail	Typha *angustifolia*
Hybrid cattail	Typha *x glauca*
Common Reed	Phragmites *australis*
Purple loosestrife	Lythrum *salicaria*
Eurasian water-milfoil	Myriophyllum *spicatum*
Johnson Grass	Sorghum *halepense*

Maintenance

- Sediment should be removed as needed near inlets and outlets to prevent blocking or clogging.
- Outlet structure should be kept free of debris to prevent blocking.
- Remove trash as needed.
- Invasive and exotic species should be removed.
- Inspect berms for nuisance wildlife damage.
- Inspect berms for erosion.

Latin Name	Common Name	Submerged & Emergent (water depth in feet)	Pond Edge & Permanent Water	Over sand	Lower slopes & bioretention base	Upper slopes	Height (feet)	Spacing (feet)	Seasonal Interest - Color and Months	J	F	M	A	M	J	J	A	S	O	N	D	Sun	Pt Sun	Pt Shade	Shade	Dry	Medium	Wet	Birds	Butterflies	Fall Color	Winter Interest	Flood frequency tolerance	Flood height tolerance	Flood duration tolerance (days)	Salt tolerance	Aggressiveness	Silt tolerance
Grasses/Sedges	Grasses/Sedges																																					
Carex annectans	Yellow fruited sedge		x		x		2-3	1.5	tan				x	x	x							x	x	x		x	x	x			x	H	12	3		L	
Carex grayi	Bur sedge		x		x		1-2	1.5	tan				x	x	x								x	x	x	x	x	x				M	12	2		L	M
Carex crinita	Fringed sedge		x		x		2-3	1.5	brown					x	x							x	x	x		x	x	x				H	12	3	U	L	
Carex muskingumensis	Palm sedge		x	x	x		2-3	1.5	tan				x	x	x	x	x					x	x	x	x	x	x	x			x	H	24	3		M	M
Carex vulpinoidea	Fox sedge		x		x		2-3	1.5	tan					x	x	x						x	x	x		x	x				x	H	24	3	L	L	
Juncus effusus	Soft rush	0-1	x				2-3	1.5	green									x	x	x	x	x	x			x	x	x			x	H	24	4	L	M	M
Scirpus atrovirens	Great green bullrush		x	x	x		2-3	1.5	green				x	x	x							x	x			x	x	x			x	M	12	3		L	
Scirpus cyperinus*	Wool grass		x				3-4	1.5	orange					x	x	x	x	x	x	x	x	x	x				x	x		x	x	H	24	3		M	
Forbs																																						
Asclepias incarnata	Marsh milkweed		x	x	x		2-4	2	pink							x	x	x	x			x	x			x	x		x			M	18	3	M	M	
Chelone obliqua	Rose turtlehead		x		x		3-4	2	rose/purple								x	x	x			x	x	x	x	x	x					M	12	1		M	
Equisetum hyemale	Horsetail		x	x	x		2-4	2.5	green				x	x					x	x		x	x	x		x	x			x	x	H	36	5		H	H
Helenium autumnale	Sneezeweed		x		x		3-4	2	yellow							x	x	x	x			x	x	x		x	x	x	x			M	18	3	M	M	
Hibiscus lasiocarpos	Rose mallow		x	x	x		3-7	2.5	white/pink							x	x	x	x			x	x	x		x	x		x	x		H	36	5		M	M
Iris fulva	Copper iris		x	x	x		2-3	1.5	copper					x	x							x	x			x	x	x				M	12	1		M	
Iris virginica	Southern blueflag iris		x		x		2-3	2	blue							x	x					x	x				x	x			x	H	36	4		M	M
Lobelia cardinalis	Cardinal flower		x	x	x		2-3	1.5	red							x	x	x				x	x	x	x	x	x	x	x			H	18	5	L	M	U
Mimulus ringens*	Allegehny monkey flower		x	x	x		1-2	1.5	lavender							x	x	x				x	x			x	x					M	24	1		M	
Nymphaea odorata	Fragrant water lily	1-5					1	10	white								x	x	x			x					x					H	36			H	
Pontedaria cordata	Pickeral weed	0-1	x				1-2	2.5	blue						x	x	x	x	x			x	x	x			x					M	12	4	L	L	U
Sagittaria latifolia	Arrowleaf	0-1	x				1-4	2.5	white								x	x	x			x					x	x				M	18	3	M	M	L
Saururus cernuus	Lizard tail	0-1	x				1-2	2.5	white							x	x	x	x			x	x	x	x		x					H	24			H	
Thalia dealbata	Wild canna	0-2	x				4-7	5	purple								x	x	x			x					x					H	24			M	H
Trees/Shrubs																																						
Aesculus pavia	Red buckeye		x		x		10-20	15	red			x	x									x	x	x			x	x	x			H	18	2		L	M
Cephalanthus occidentalis	Buttonbush	x	x		x		5-10	7.5	white							x	x	x				x	x	x			x	x		x		H	36	7		M	H
Quercus macrocarpa	Bur oak		x		x	x	40-60	35	green										x	x		x	x	x			x	x			x	H	36	5	H	L	H
Taxodium disticum	Bald cypress	x	x	x	x		40-60	20	orange										x	x		x	x	x			x	x			x	H	36	7		L	H

Figure 6.68 Source: Landscape Guide for Stormwater Best Management Practice Design - St. Louis, MO.
Note: This table is not an all inclusive list for species that may tolerate proposed growing conditions.

Constructed Wetlands Inspections and Maintenance Checklist

Site Name: _____ Owner Change since last inspection? Y N

Location: _____

Owner Name: _____

Address _____ Phone Number _____

Site Status: _____

Date: _____ Time: _____ Site conditions:

Constructed Wetland Type: ED Wetland ☐ Pocket Wetland ☐ Wetland ☐

Inspection Frequency Key: A=annual; M=monthly; S=after major storms

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Embankment and Emergency Spillway				
Vegetation healthy?	*A/S*			
Erosion on embankment?	*A/S*			
Animal burrows in embankment?	*A/S*			
Cracking, sliding, bulging of dam?	*A/S*			
Drains blocked or not functioning?	*A/S*			
Leaks or seeps on embankment?	*A/S*			
Slope protection failure functional?	*A/S*			
Emergency spillway obstructed?	*A/S*			
Erosion in/around emergency spillway?	*A/S*			
Other (describe)	*A/S*			
Riser and Principal Spillway				(describe type: concrete pipe, slotted weir, channel, etc.)
Low-flow orifice functional?	*A/S*			
Trash rack (Debris removal needed? Corrosion noted?)	*A/S*			
Sediment buildup in riser?	*A*			
Concrete/masonry condition (Cracks or displacement? Spalling?)	*A*			
Metal pipe in good condition?	*A*			
Control valve operation?	*A*			
Pond drain valve operation?	*A*			
Outfall channels function, not eroding?	*A*			
Other (describe)	*A*			
Sediment Forebays				
Sedimentation description				
Sediment cleanout needed (over 50% full)?	*A/S*			

Inspection Items	Inspection Frequency	Inspected? (Yes/No/NA)	Maintenance Needed? (Yes/No/NA)	Comments/Description
Constructed Wetland Ponding Areas				
Wetland vegetation present and healthy?	*M*			
Vegetation removal needed?	*A/M*			
Floatable debris removal needed?	*M*			
Visible pollution?	*M*			
Shoreline problem?	*M*			
Erosion at outfalls into pond?	*M*			
Headwalls and endwalls in good condition?	*M*			
Encroachment into pond or easement area?	*M*			
Hazards				
Have there been complaints from residents?	*M*			
Public hazards noted?	*M*			

Inspector Comments:_____

_____

_____

_____

Overall Condition of Facility: ☐ Acceptable ☐ Unacceptable

If any of the above Inspection Items are checked "Yes" for "Maintenance Needed," list Maintenance actions and their completion dates below:

Maintenance Action Needed	Due Date

The next routine inspection is scheduled for approximately: _____
(date)

Inspected by: (signature) _____

Inspected by: (printed) _____

Figure 6.69 Source: Storm Water Management Manual Volume 1, Appendix D - Memphis Shelby County Governments. (City of Memphis, 2007)