Village of Homer Glen
Will County, Illinois

WATER RESOURCE BMP GUIDELINES

Village of
HOMER
GLEN
Community and Nature…in Harmony

DATE: 06-03-08

WATER RESOURCES BMP GUIDELINES
VILLAGE HOMER GLEN, ILLINOIS

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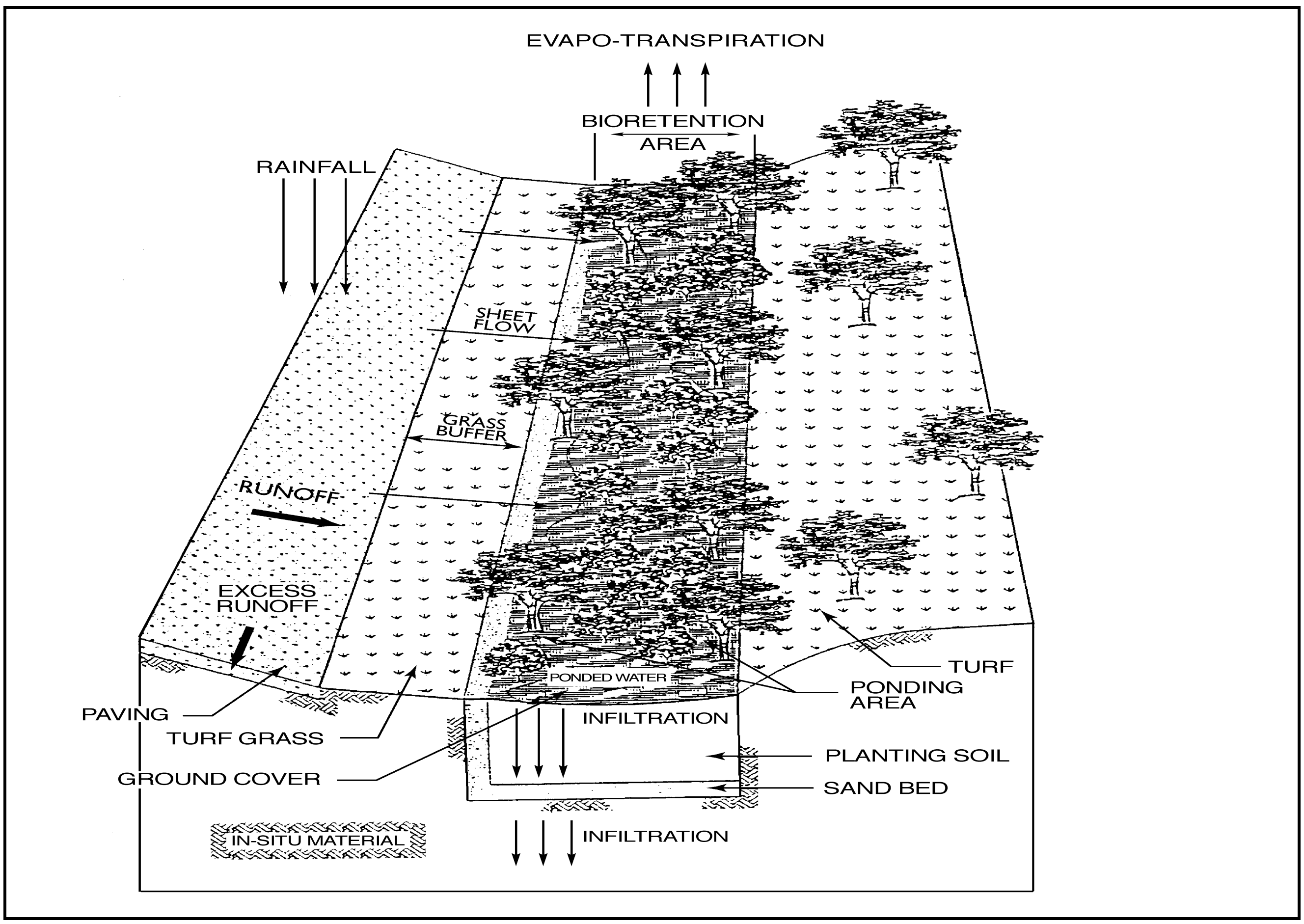
Storm Water Technology Fact Sheet Bioretention

DESCRIPTION

Bioretention is a best management practice (BMP) developed in the early 1990's by the Prince George's County, MD, Department of Environmental Resources (PGDER). Bioretention utilizes soils and both woody and herbaceous plants to remove pollutants from storm water runoff. As shown in Figure 1, runoff is conveyed as sheet flow to the treatment area, which consists of a grass buffer strip, sand bed, ponding area, organic layer or mulch layer, planting soil, and plants. Runoff passes first over or through a sand bed, which slows the runoff's velocity, distributes it evenly along the length of the ponding area, which consists of a surface organic layer and/or ground cover and the underlying planting soil. The ponding area is graded, its center depressed. Water is ponded to a depth of 15 centimeters (6 inches) and gradually infiltrates the bioretention area or is



Source: PGDER, 1993.

FIGURE 1 BIORETENTION AREA

evapotranspired. The bioretention area is graded to divert excess runoff away from itself. Stored water in the bioretention area planting soil exfiltrates over a period of days into the underlying soils.

The basic bioretention design shown in Figure 1 can be modified to accommodate more specific needs. The City of Alexandria, VA, has modified the bioretention BMP design to include an underdrain within the sand bed to collect the infiltrated water and discharge it to a downstream sewer system. This modification was required because impervious subsoils and marine clays prevented complete infiltration in the soil system. This modified design makes the bioretention area act more as a filter that discharges treated water than as an infiltration device. Design modifications are also being reviewed that will potentially include both aerobic and anaerobic zones in the treatment area. The anaerobic zone will promote denitrification.

APPLICABILITY

Bioretention typically treats storm water that has run over impervious surfaces at commercial, residential, and industrial areas. For example, bioretention is an ideal storm water management BMP for median strips, parking lot islands, and swales. These areas can be designed or modified so that runoff is either diverted directly into the bioretention area or conveyed into the bioretention area by a curb and gutter collection system. Bioretention is usually best used upland from inlets that receive sheet flow from graded areas and at areas that will be excavated. The site must be graded in a manner that minimizes erosive conditions as sheet flow is conveyed to the treatment area, maximizing treatment effectiveness. Construction of bioretention areas is best suited to sites where grading or excavation will occur in any case so that the bioretention area can be readily incorporated into the site plan without further environmental damage. Bioretention should be used in stabilized drainage areas to minimize sediment loading in the treatment area. As with all BMPs, a maintenance plan must be developed.

Bioretention has been used as a storm water BMP since 1992. In addition to Prince George's County and Alexandria, bioretention has been used successfully at urban and suburban areas in Montgomery County, MD; Baltimore County, MD; Chesterfield County, VA; Prince William County, VA; Smith Mountain Lake State Park, VA; and Cary, NC.

ADVANTAGES AND DISADVANTAGES

Bioretention is not an appropriate BMP at locations where the water table is within 1.8 meters (6 feet) of the ground surface and where the surrounding soil stratum is unstable. In cold climates the soil may freeze, preventing runoff from infiltrating into the planting soil. The BMP is also not recommended for areas with slopes greater than 20 percent, or where mature tree removal would be required. Clogging may be a problem, particularly if the BMP receives runoff with high sediment loads.

Bioretention provides storm water treatment that enhances the quality of downstream water bodies. Runoff is temporarily stored in the BMP and released over a period of four days to the receiving water. The BMP is also able to provide shade and wind breaks, absorb noise, and improve an area's landscape.

DESIGN CRITERIA

Design details have been specified by the Prince George's County DER in a document entitled *Design Manual for the Use of Bioretention in Storm Water Management* (PGDER, 1993). The specifications were developed after extensive research on soil adsorption capacities and rates, water balance, plant pollutant removal potential, plant adsorption capacities and rates, and maintenance requirements. A case study was performed using the specifications at three commercial sites and one residential site in Prince George's County, Maryland.

Each of the components of the bioretention area is designed to perform a specific function. The grass buffer strip reduces incoming runoff velocity and filters particulates from the runoff. The sand bed also reduces the velocity, filters particulates, and spreads flow over the length of the bioretention area. Aeration and drainage of the planting soil are provided by the 0.5 meter (18 inch) deep sand bed. The ponding area provides a temporary storage location for runoff prior to its evaporation or infiltration. Some particulates not filtered out by the grass filter strip or the sand bed settle within the ponding area.

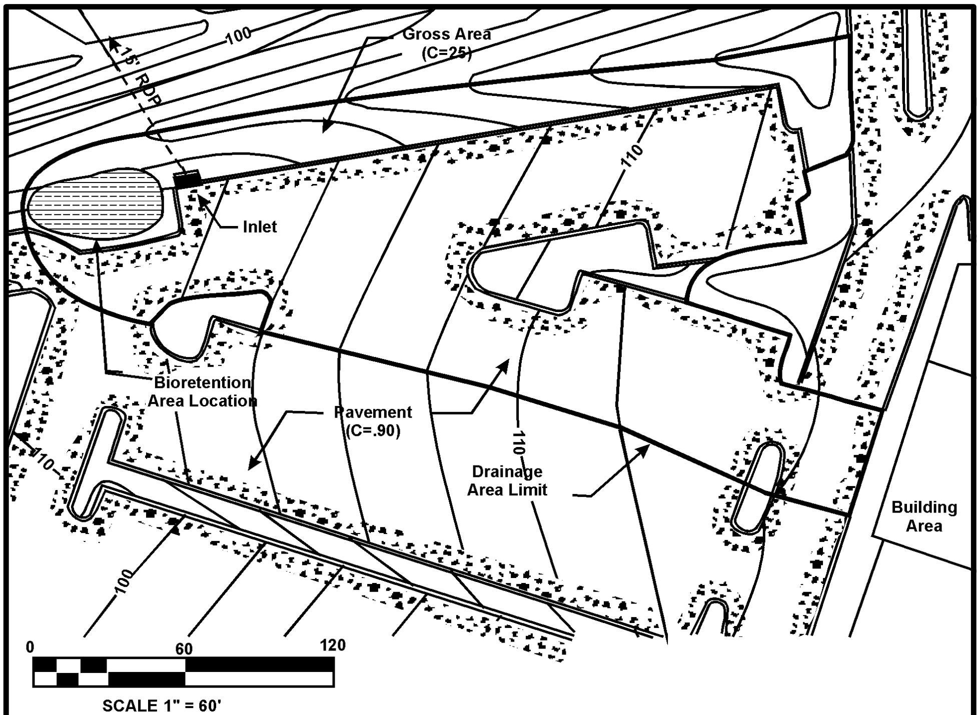
The organic or mulch layer also filters pollutants and provides an environment conducive to the growth of microorganisms, which degrade petroleum-based products and other organic material. This layer acts in a similar way to the leaf litter in a forest and prevents the erosion and drying of underlying soils. Planted ground cover reduces the potential for erosion as well, slightly more effectively than mulch. The maximum sheet flow velocity prior to erosive conditions is 0.3 meters per second (1 foot per second) for planted ground cover and 0.9 meters per second (3 feet per second) for mulch.

The clay in the planting soil provides adsorption sites for hydrocarbons, heavy metals, nutrients and other pollutants. Storm water storage is also provided by the voids in the planting soil. The stored water and nutrients in the water and soil are then available to the plants for uptake.

The layout of the bioretention area is determined after site constraints such as location of utilities, underlying soils, existing vegetation, and drainage are considered. Sites with loamy sand soils are especially appropriate for bioretention because the excavated soil can be backfilled and used as the planting soil, thus eliminating the cost of importing planting soil. An unstable surrounding soil stratum (e.g., Marlboro Clay) and soils with a clay content greater than 25 percent may preclude the use of bioretention, as would a site with slopes greater than 20 percent or a site with mature trees that would be removed during construction of the BMP. Bioretention can be designed to be off-line or on-line of the existing drainage system. The "first flush" of runoff is diverted to the off-line system. The first flush of runoff is the initial runoff volume that typically contains higher pollutant concentrations than those in the extended runoff period. On-line systems capture the first flush but that volume of water will likely be washed out by subsequent runoff resulting in a release of the captured pollutants. The size of the drainage area for one bioretention area should be between 0.1 and 0.4 hectares (0.25 and 1.0 acres). Multiple bioretention areas may be required for larger drainage areas. The maximum drainage area for one bioretention area is determined by the amount of sheet flow generated by a 10-year storm. Flows greater than 141 liters per second (5 cubic feet per second) may potentially erode stabilized areas. In Maryland, such a flow generally occurs with a 10-year storm at one-acre commercial or residential sites. The designer should determine the potential for erosive conditions at the site.

The size of the bioretention area is a function of the drainage area and the runoff generated from the area. The size should be 5 to 7 percent of the drainage area multiplied by the rational method runoff coefficient, "c," determined for the site. The 5 percent specification applies to a bioretention area that includes a sand bed; 7 percent to an area without one. An example of sizing a facility is shown in Figure 2. For this discussion, sizing specifications are based on 1.3 to 1.8 centimeters (0.5 to 0.7 inches) of precipitation over a 6-hour period (the mean storm event for the Baltimore-Washington area), infiltrating into the bioretention area. Other areas with different mean storm events will need to account for the difference in the design of the BMP. Recommended minimum dimensions of the bioretention area are 4.6 meters (15 feet) wide by 12.2 meters (40 feet) in length. The minimum width allows enough space for a dense, randomly-distributed area of trees and shrubs to become established that replicates a natural forest and creates a microclimate. This enables the bioretention area to tolerate the effects of heat stress, acid rain, runoff pollutants, and insect and disease infestations which landscaped areas in urban settings typically are unable to tolerate. The preferred width is 7.6 meters (25 feet), with a length of twice the width. Any facilities wider than 6.1 meters (20 feet) should be twice as long as they are wide. This length requirement promotes the distribution of flow and decreases the chances of concentrated flow.

The maximum recommended ponding depth of the bioretention area is 15 centimeters (6 inches). This



PLAN VIEW

BIORETENTION AREA SIZING COMPUTATION

DEVELOPMENT	AREA SQ. FT.	"C" FACTOR	C X AREA
PAVEMENT	23,800	0.90	21,400
GRASS	10,100	0.25	2,500
TOTALS	33,900		23,900

BIOTENTION AREA SIZE

1. **With Sand Bed (5% Sum of C x Area)**
   = 05 x 23,900 = 1,195 OR SAY 1,200 sq. ft.
2. **Without Sand Bed (7% Sum of C x Area)**
   = 07 x 23,900 = 1,1673 OR SAY 1,700 sq. ft.

*** SEE CHAPTER IV. PRINCE GEORGES COUNTYSTORMWATER MANAGEMENT MANUAL**

Source: PGDER, 1993.

FIGURE 2 BIORETENTION AREA SIZING

depth provides for adequate storage and prevents water from standing for excessive periods of time. Because of some plants' water intolerance, water left to stand for longer than four days restricts the type of plants that can be used. Further, mosquitoes and other insects may start to breed if water is standing for longer than four days.

The appropriate planting soil should be backfilled into the excavated bioretention area. Planting soils should be sandy loam, loamy sand, or loam texture with a clay content ranging from 10 to 25 percent. The soil should have infiltration rates greater than 1.25 centimeters (0.5 inches) per hour, which is typical of sandy loams, loamy sands, or loams. Silt loams and clay loams generally have rates of less than 0.68 centimeters (0.27 inches) per hour. The pH of the soil should be between 5.5 and 6.5. Within this pH range, pollutants (e.g., organic nitrogen and phosphorus) can be adsorbed by the soil and microbial activity can flourish. Other requirements for the planting soil are a 1.5 to 3 percent organic content and a maximum 500 ppm concentration of soluble salts. In addition, criteria for magnesium, phosphorus, and potassium are 39.2 kilograms per acre (35 pounds per acre), 112 kilograms per acre (100 pounds per acre), and 95.2 kilograms per acre (85 pounds per acre), respectively. Soil tests should be performed for every 382 cubic meters (500 cubic yards) of planting soil, with the exception of pH and organic content tests, which are required only once per bioretention area.

Planting soil should be 10.1 centimeters (4 inches) deeper than the bottom of the largest root ball and 1.2 meters (4 feet) altogether. This depth will provide adequate soil for the plants' root systems to become established and prevent plant damage due to severe wind. A soil depth of 1.2 meters (4 feet) also provides adequate moisture capacity. To obtain the recommended depth, most sites will require excavation. Planting soil depths of greater than 1.2 meters (4 feet) may require additional construction practices (e.g., shoring measures). Planting soil should be placed in 18 inches or greater lifts and lightly compacted until the desired depth is reached. The bioretention area should be vegetated to resemble a terrestrial forest community ecosystem, which is dominated by understory trees (high canopy trees may be destroyed during maintenance) and has discrete soil zones as well as a mature canopy and a distinct sub-canopy of understory trees, a shrub layer, and herbaceous ground covers. Three species each of both trees and shrubs are recommended to be planted at a rate of 2500 trees and shrubs per hectare (1000 per acre). For example, a 4.6 meter (15 foot) by 12.2 meter (40 foot) bioretention area (55.75 square meters or 600 square feet) would require 14 trees and shrubs. The shrub-to-tree ratio should be 2:1 to 3:1. On average, the trees should be spaced 3.65 meters (12 feet) apart and the shrubs should be spaced 2.4 meters (8 feet) apart. In the metropolitan Washington, D.C., area, trees and shrubs should be planted from mid-March through the end of June or from mid-September through mid-November. Planting periods in other areas of the U.S. will vary. Vegetation should be watered at the end of each day for fourteen days following its planting.

Native species that are tolerant to pollutant loads and varying wet and dry conditions should be used in the bioretention area. These species can be determined from several published sources, including *Native Trees, Shrubs, and Vines for Urban and Rural America* (Hightshoe, 1988). The designer should assess aesthetics, site layout, and maintenance requirements when selecting plant species. Adjacent non-native invasive species should be identified and the designer should take measures (e.g., provide a soil breach) to eliminate the threat of these species invading the bioretention area. Regional landscaping manuals should be consulted to ensure that the planting of the bioretention area meets the landscaping requirements established by the local authorities.

The optimal placement of vegetation within the bioretention area should be evaluated by the designers. Plants should be placed at irregular intervals to replicate a natural forest. Shade and shelter from the wind will be provided to the bioretention area if the designer places the trees on the perimeter of the area. Trees and shrubs can be sheltered from damaging flows if they are placed away from the path of the incoming runoff. Species that are more tolerant to cold winds (e.g., evergreens) should be placed in windier areas of the site.

After the trees and shrubs are placed, the ground cover and/or mulch should be established. Ground cover such as grasses or legumes can be planted during the spring of the year. Mulch should be placed immediately after trees and shrubs are planted. Five to 7.6 cm (2 to 3 inches) of commercially-available fine shredded hardwood mulch or shredded hardwood chips should be applied to the bioretention area to protect from erosion. Mulch depths should be kept below 7.6 centimeters (3 inches) because more would interfere with the cycling of carbon dioxide and oxygen between the soil and the atmosphere. The mulch should be aged for at least six months (one year is optimal), and applied uniformly over the site.

PERFORMANCE

Bioretention removes storm water pollutants through physical and biological processes, including adsorption, filtration, plant uptake, microbial activity, decomposition, sedimentation and volatilization. Adsorption is the process whereby particulate pollutants attach to soil (e.g., clay) or vegetation surfaces. Adequate contact time between the surface and pollutant must be provided for in the design of the system for this removal process to occur. Therefore, the infiltration rate of the soils must not exceed those specified in the design criteria or pollutant removal may decrease. Pollutants removed by adsorption include metals, phosphorus, and some hydrocarbons. Filtration occurs as runoff passes through the bioretention area media, such as the sand bed, ground cover and planting soil. The media trap particulate matter and allow water to pass through. The filtering effectiveness of the bioretention area may decrease over time. Common particulates removed from storm water include particulate organic matter, phosphorus, and suspended solids. Biological processes that occur in wetlands result in pollutant uptake by plants and microorganisms in the soil. Plant growth is sustained by the uptake of nutrients from the soils, with woody plants locking up these nutrients through the seasons. Microbial activity within the soil also contributes to the removal of nitrogen and organic matter. Nitrogen is removed by nitrifying and denitrifying bacteria, while aerobic bacteria are responsible for the decomposition of the organic matter (e.g., petroleum). Microbial processes require oxygen and can result in depleted oxygen levels if the bioretention area is not adequately aerated.

Sedimentation occurs in the swale or ponding area as the velocity slows and solids fall out of suspension.

Volatilization also plays a role in pollutant removal. Pollutants such as oils and hydrocarbons can be removed from the wetland via evaporation or by aerosol formation under windy conditions. The removal effectiveness of bioretention has been studied during field and laboratory studies conducted by the University of Maryland (Davis et al, 1998). During these experiments, synthetic storm water runoff was pumped through several laboratory and field bioretention areas to simulate typical storm events in Prince George's County, MD. Removal rates for heavy metals an nutrients are shown in Table 1. As shown, the BMP removed between 93 and 98 percent of metals, between 68 and 80 percent of TKN and between 70 and 83 percent of total phosphorus. For all of the pollutants analyzed, results of the laboratory study were similar to those of field experiments. Doubling or halving the influent pollutant levels had little effect on the effluent pollutants levels (Davis et al, 1998). For other parameters, results from the performance studies for infiltration BMPs, which are similar to bioretention, can be used to estimate bioretention's performance. These removal rates are also shown in Table 1. As shown, the BMP could potentially achieve greater than 90 percent removal rates for total suspended solids, organics, and bacteria. The microbial activity and plant uptake occurring in the bioretention area will likely result in higher removal rates than those determined for infiltration BMPs.

TABLE 1 LABORATORY AND ESTIMATED BIORETENTION

Pollutant	Removal Rate
Total Phosphorus	70%-83% [1]
Metals (Cu, Zn, Pb)	93%-98% [1]
TKN	68%-80% [1]
Total Suspended Solids	90% [2]
Organics	90% [2]
Bacteria	90% [2]

Source: [1]Davis et al. (1998)
[2]PGDER (1993)

OPERATION AND MAINTENANCE

Recommended maintenance for a bioretention area includes inspection and repair or replacement of the treatment area components. Trees and shrubs should be inspected twice per year to evaluate their health and remove any dead or severely diseased vegetation. Diseased vegetation should be treated as necessary using preventative and low-toxic measures to the extent possible. Pruning and weeding may also be necessary to maintain the treatment area's appearance. Mulch replacement is recommended when erosion is evident or when the site begins to look unattractive. Spot mulching may be adequate when there are random void areas; however, once every two to three years the entire area may require mulch replacement. This should be done during the spring. The old mulch should be removed before the new mulch is distributed. Old mulch should be disposed of properly.

The application of an alkaline product, such as limestone, is recommended one to two times per year to counteract soil acidity resulting from slightly acidic precipitation and runoff. Before the limestone is applied, the soils and organic layer should be tested to determine the pH and therefore the quantity of limestone required. When levels of pollutants reach toxic levels which impair plant growth and the effectiveness of the BMP, soil replacement may be required (PGDER, 1993).

COSTS

Construction cost estimates for a bioretention area are slightly greater than those for the required landscaping for a new development. Recently-constructed 37.16 square meter (400 square foot) bioretention areas in Prince George's County, MD cost approximately $500. These units are rather small and their cost is low. The cost estimate includes the cost for excavating 0.6 to 1 meters (2 to 3 feet) and vegetating the site with 1 to 2 trees and 3 to 5 shrubs. The estimate does not include the cost for the planting soil, which increases the cost for a bioretention area. Retrofitting a site typically costs more, averaging $6,500 per bioretention area. The higher costs are attributed to the demolition of existing concrete, asphalt, and existing structures and the replacement of fill material with planting soil. The costs of retrofitting a commercial site in Maryland (Kettering Development) with 15 bioretention areas were estimated at $111,600.

The use of bioretention can decrease the cost for storm water conveyance systems at a site. A medical office building in Maryland was able to reduce the required amount of storm drain pipe from 243.8 meters (800 feet) to 70.1 meters (230 feet) with the use of bioretention. The drainage pipe costs were reduced by $24,000, or 50 percent of the total drainage cost for the site (PGDER, 1993). Landscaping costs that would be required at a development regardless of the installation of the bioretention area should also be considered when determining the net cost of the BMP.

The operation and maintenance costs for a bioretention facility will be comparable to those of typical landscaping required for a site. Costs beyond the normal landscaping fees will include the cost for testing the soils and may include costs for a sand bed and planting soil.

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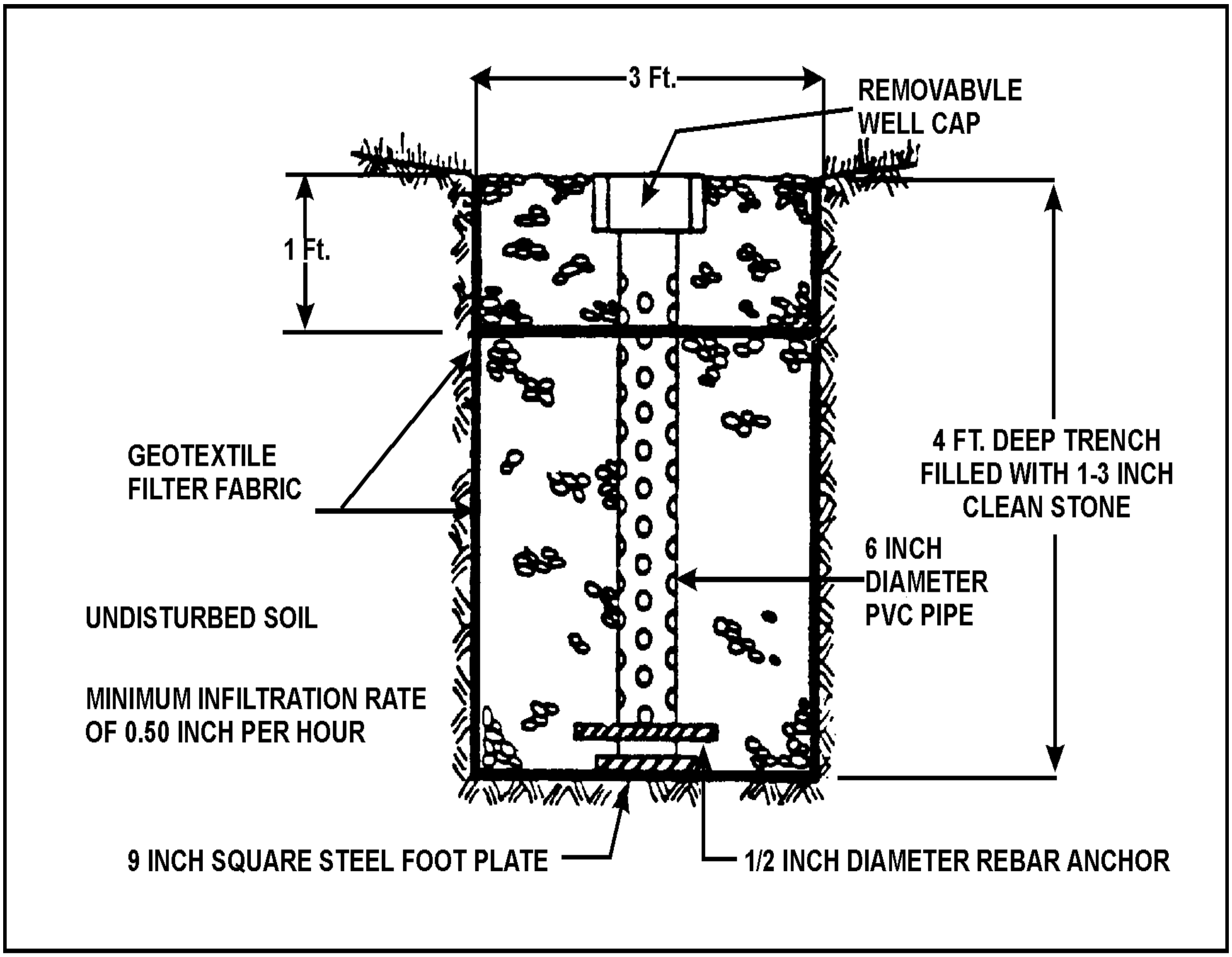
Storm Water Technology Fact Sheet
Infiltration Trench

DESCRIPTION

Urban development is significantly increasing surface runoff and contamination of local watersheds. As a result, infiltration practices, such as infiltration trenches, are being employed to remove suspended solids, particulate pollutants, coliform bacteria, organics, and some soluble forms of metals and nutrients from storm water runoff. As shown in Figure 1, an infiltration trench is an excavated trench, 0.9 to 3.7 meters (3 to 12 feet) deep, backfilled with a stone aggregate, and lined with filter fabric. A small portion of the runoff, usually the first flush, is diverted to the infiltration



Source: Southeastern Wisconsin Regional Planning Commission, 1991.

FIGURE 1 TYPICAL INFILTRATION TRENCH

trench, which is located either underground or at grade. Pollutants are filtered out of the runoff as it infiltrates the surrounding soils. Infiltration trenches also provide groundwater recharge and preserve baseflow in nearby streams.

APPLICABILITY

Infiltration trenches are often used in place of other Best Management Practices where limited land is available. Infiltration trenches are most widely used in warmer, less arid regions of the U.S. However, recent studies conducted in Maryland and New Jersey on trench performance and operation and maintenance have demonstrated the applicability of infiltration trenches in colder climates if surface icing is avoided (Lindsey, et al, 1991).

Infiltration trenches capture and treat small amounts of runoff, but do not control peak hydraulic flows. Infiltration trenches may be used in conjunction with another Best Management Practice (BMP), such as a detention pond, to provide both water quality control and peak flow control (Harrington, 1989). Figure 2 is an example of such a combined technology. This type of infiltration trench has a concentrated input, as opposed to dispersed input (as shown in Figure 1). This system stores the entire storm water volume with the water quality (BMP) volume connected to the infiltration system. This is commonly achieved with a slow release of the storm water management volume through an orifice set at a specified level in the storage facility. As a result the BMP water quality volume will equal the storm water detention area below the orifice level which must infiltrate to exit.

Runoff that contains high levels of sediments or hydrocarbons (oil and grease) that may clog the trench are often pretreated with other BMPs. Examples of some pretreatment BMPs include grit chambers, water quality inlets, sediment traps, swales, and vegetated filter strips (SEWRPC, 1991, Harrington, 1989).

ADVANTAGES AND DISADVANTAGES

Infiltration trenches provide efficient removal of suspended solids, particulate pollutants, coliform bacteria, organics and some soluble forms of metals and nutrients from storm water runoff. The captured runoff infiltrates the surrounding soils and increases groundwater recharge and baseflow in nearby streams.

Negative impacts include the potential for groundwater contamination and a high likelihood of early failure if not properly maintained.

As with any infiltration BMP, the potential for groundwater contamination must be carefully considered, especially if the groundwater is used for human consumption or agricultural purposes. The infiltration trench is not suitable for sites that use or store chemicals or hazardous materials unless hazardous and toxic materials are prevented from entering the trench. In these areas, other BMPs that do not interact with the groundwater should be considered. The potential for spills can be minimized by aggressive pollution prevention measures. Many municipalities and industries have developed comprehensive spill prevention control and countermeasure (SPCC) plans. These plans should be modified to include the infiltration trench and the contributing drainage area. For example, diversion structures can be used to prevent spills from entering the infiltration trench.

Because of the potential to contaminate groundwater, extensive site investigation must be undertaken early in the site planning process to establish site suitability for the installation of an infiltration trench. The use of infiltration trenches may be limited by a number of factors, including type of native soils, climate, and location of groundwater tables. Site characteristics, such as excessive slope of the drainage area, fine-particled soil types, and proximate location of the water table and bedrock, may preclude the use of infiltration trenches. The slope of the surrounding area should be such that the runoff is evenly distributed in sheet flow as it enters the trench unless specifically designed for concentrated input. Generally, infiltration trenches are not suitable for areas with relatively impermeable soils containing clay and silt or in areas with fill. The trench should be located well above the water table so that the runoff can filter through the trench and into the surrounding soils and eventually into the groundwater. In addition, the drainage area should not convey heavy levels of sediments or hydrocarbons to the trench. For this reason, trenches serving parking lots must be preceded by appropriate pretreatment such as an oil-grit separator. This measure will make effective maintenance feasible. Generally, trenches that are constructed under parking lots must provide access for maintenance.

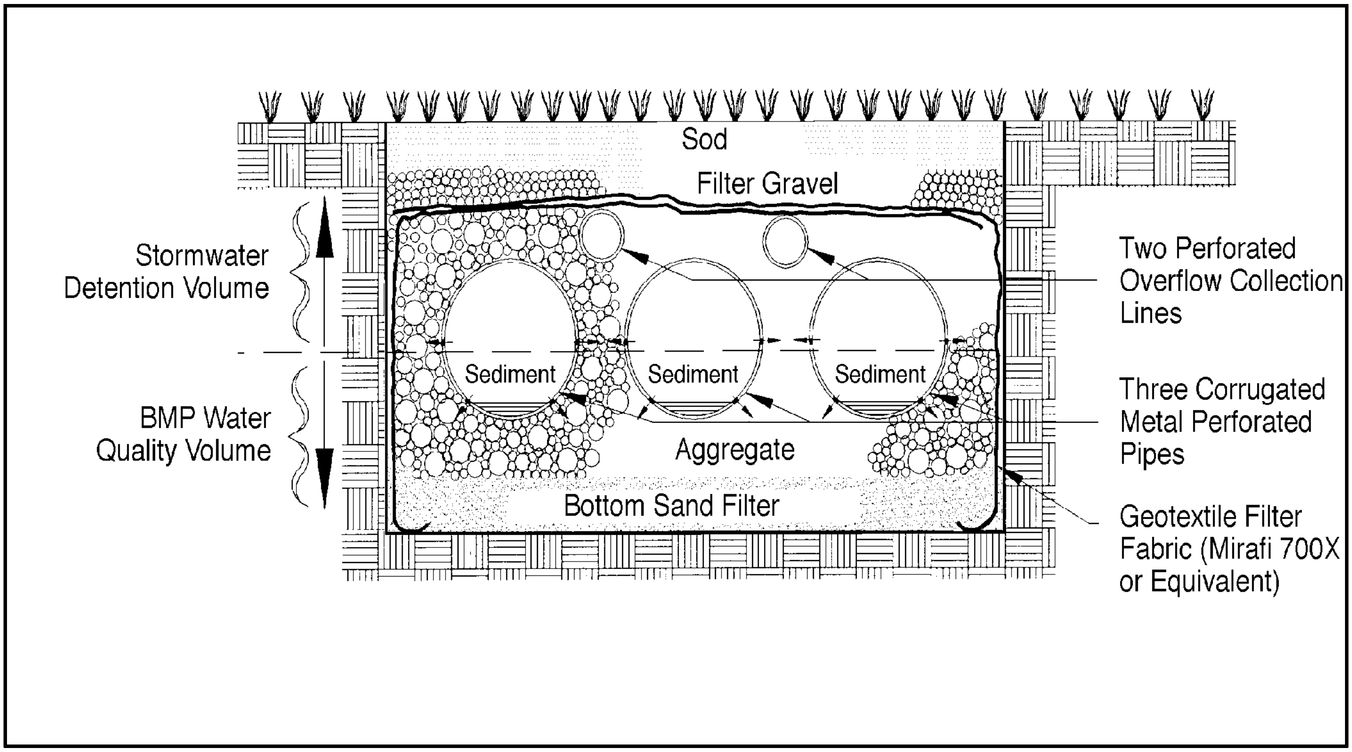
An additional limitation on use of infiltration trenches is the climate. In cold climates, the trench surface may freeze, thereby preventing the runoff from entering the trench and allowing the untreated runoff to enter surface water. The surrounding soils may also freeze, reducing infiltration into the soils and groundwater. However, recent studies indicate that if properly designed and maintained, infiltration trenches can operate effectively in colder climates. By keeping the trench surface free of compacted snow and ice, and by ensuring that part of the trench is constructed below the frost line, the performance of the infiltration trench during cold weather will be greatly improved.

Finally, there have been a number of concerns raised about the long term effectiveness of infiltration trench systems. In the past, infiltration trenches have demonstrated a relatively short life span, with over 50 percent of the systems checked having partially or completely failed after 5 years. A recent study of infiltration trenches in Maryland (Lindsey et al., 1991) found that 53 percent were not operating as designed, 36 percent were partially or totally clogged, and another 22 percent exhibited slow filtration. Longevity can be increased by careful geotechnical evaluation prior to construction and by designing and implementing an inspection and maintenance plan. Soil infiltration rates and the water table depth should be evaluated to ensure that conditions are satisfactory for proper operation of an infiltration trench. Pretreatment structures, such as a vegetated buffer strip or water quality inlet, can increase longevity by removing sediments, hydrocarbons, and other materials that may clog the trench. Regular maintenance, including the replacement of clogged aggregate, will also increase the effectiveness and life of the trench.

DESIGN CRITERIA

Prior to trench construction, a review of the design plans may be required by state and local governments. The design plans should include a geotechnical evaluation that determines the feasibility of using an infiltration trench at the site. Soils should have a low silt and clay content and have infiltration rates greater than 1.3 centimeters (0.5 inches) per hour. Acceptable soil texture classes include sand, loamy sand, sandy loam and loam. These soils are within the A or B hydrologic group. Soils in the C or D hydrologic groups should be avoided. Soil survey reports published by the Soil Conservation Service can be used to identify soil types and infiltration rates. However, sufficient soil borings should always be taken to verify site conditions. Feasible sites should have a minimum of 1.2 meters (4 feet) to bedrock in order to reduce excavation costs. There should also be at least 1.2 meters (4 feet) below the trench to the water table to prevent potential ground water problems. Trenches should also be located at least 30.5 meters (100 feet) upgradient from water supply wells and 30.5 meters (100 feet) from building foundations. Land availability, the depth to bedrock, and the depth to the water table will determine whether the infiltration trench is located underground or at grade. Underground trenches receive runoff through pipes or channels, whereas surface trenches collect sheet flow from the drainage area.

In general, infiltration trenches are suitable for drainage areas up to 4 hectares (10 acres) (SEWRPC, 1991, Harrington, 1989). However, when the drainage area exceeds 2 hectares (5 acres), other BMPs should be carefully considered. The drainage area must be fully developed and stabilized with vegetation before constructing an infiltration trench. High sediment loads from unstabilized areas will quickly clog the infiltration trench. Runoff from unstabilized areas should be diverted away from the trench into a construction BMP until vegetation is established.



Source: Fairfax County Soils Office, 1991.

FIGURE 2 INFILTRATION TRENCH WITH CONCENTRATED INPUT AND AUGMENTED PIPE STORAGE

The drainage area slope determines the velocity of the runoff and also influences the amount of pollutants entrained in the runoff. Infiltration trenches work best when the upgradient drainage area slope is less than 5 percent (SEWRPC, 1991). The downgradient slope should be no greater than 20 percent to minimize slope failure and seepage.

The trench surface may consist of stone or vegetation with inlets to evenly distribute the runoff entering the trench (SEWRPC, 1991, Harrington, 1989). Runoff can be captured by depressing the trench surface or by placing a berm at the down gradient side of the trench.

The basic infiltration trench design utilizes stone aggregate in the top of the trench to promote filtration; however, this design can be modified by substituting pea gravel for stone aggregate in the top 0.3 meter (1 foot) of the trench. The pea gravel improves sediment filtering and maximizes the pollutant removal in the top of the trench. When the modified trenches become clogged, they can generally be restored to full performance by removing and replacing only the pea gravel layer, without replacing the lower stone aggregate layers.

Infiltration trenches can also be modified by adding a layer of organic material (peat) or loam to the trench subsoil. This modification appears to enhance the removal of metals and nutrients through adsorption. The trenches are then covered with an impermeable geotextile membrane overlain with topsoil and grass (Figure 2).

A vegetated buffer strip (6.1 to 7.6 meters, or 20-25 feet, wide) should be established adjacent to the infiltration trench to capture large sediment particles in the runoff. The buffer strip should be installed immediately after trench construction using sod instead of hydroseeding (Schueler, 1987). The buffer strip should be graded with a slope between 0.5 and 15 percent so that runoff enters the trench as sheet flow. If runoff is piped or channeled to the trench, a level spreader must be installed to create sheet flow (Harrington, 1989).

During excavation and trench construction, only light equipment such as backhoes or wheel and ladder type trenchers should be used to minimize compaction of the surrounding soils. Filter fabric should be placed around the walls and bottom of the trench and 0.3 meters (1 foot) below the trench surface. The filter fabric should overlap each side of the trench in order to cover the top of the stone aggregate layer (see Figure 1). The filter fabric prevents sediment in the runoff and soil particles from the sides of the trench from clogging the aggregate. Filter fabric that is placed 0.3 meters (1 foot) below the trench surface will maximize pollutant removal within the top layer of the trench and decrease the pollutant loading to the trench bottom, reducing frequency of maintenance.

The required trench volume can be determined by several methods. One method calculates the volume based on capture of the first flush, which is defined as the first 1.3 centimeters (0.5 inches) of runoff from the contributing drainage area (SEWRPC, 1991). The State of Maryland (MD., 1986) also recommends sizing the trench based on the first flush, but defines first flush as the first 1.3 centimeters (0.5 inches) from the contributing impervious area. The Metropolitan Washington Council of Governments (MWCOG) suggests that the trench volume be based on the first 1.3 centimeters (0.5 inches) per impervious acre or the runoff produced from a 6.4 centimeter (2.5 inch) storm. In Washington D.C., the capture of 1.3 centimeters (0.5 inches) per impervious acre accounts for 40 to 50 percent of the annual storm runoff volume. The runoff not captured by the infiltration trench should be bypassed to another BMP (Harrington, 1989) if treatment of the entire runoff from the site is desired.

Trench depths are usually between 0.9 and 3.7 meters (3 and 12 feet) (SEWRPC, 1991, Harrington, 1989). However, a depth of 2.4 meters (8 feet) is most commonly used (Schueler, 1987). A site specific trench depth can be calculated based on the soil infiltration rate, aggregate void space, and the trench storage time (Harrington, 1989). The stone aggregate used in the trench is normally 2.5 to 7.6 centimeters (1 to 3 inches) in diameter, which provides a void space of 40 percent (SEWRPC, 1991, Harrington, 1989, Schueler, 1987).

A minimum drainage time of 6 hours should be provided to ensure satisfactory pollutant removal in the infiltration trench (Schueler, 1987, SEWRPC, 1991). Although trenches may be designed to provide temporary storage of storm water, the trench should drain prior to the next storm event. The drainage time will vary by precipitation zone. In the Washington, D.C. area, infiltration trenches are designed to drain within 72 hours.

An observation well is recommended to monitor water levels in the trench. The well can be a 10.2 to 15.2 centimeter (4 to 6 inch) diameter PVC pipe, which is anchored vertically to a foot plate at the bottom of the trench as shown in Figure 1 above. Inadequate drainage may indicate the need for maintenance.

PERFORMANCE

Infiltration trenches function similarly to rapid infiltration systems that are used in wastewater treatment. Estimated pollutant removal efficiencies from wastewater treatment performance and modeling studies are shown in Table 1.

Based on this data, infiltration trenches can be expected to remove up to 90 percent of sediments, metals, coliform bacteria and organic matter, and up to 60 percent of phosphorus and nitrogen in the runoff (Schueler, 1992). Biochemical oxygen demand (BOD) removal is estimated to be between 70 to 80 percent. Lower removal rates for nitrate, chlorides and soluble metals should be expected,

TABLE 1 TYPICAL POLLUTANT REMOVAL EFFICIENCY

Pollutant	Typical Percent Removal Rates
Sediment	90%
Total Phosphorous	60%
Total Nitrogen	60%
Metals	90%
Bacteria	90%
Organics	90%
Biochemical Oxygen Demand	70-80%

Source: Schueler, 1992.

especially in sandy soils (Schueler, 1992).

Pollutant removal efficiencies may be improved by using washed aggregate and adding organic matter and loam to the subsoil. The stone aggregate should be washed to remove dirt and fines before placement in the trench. The addition of organic material and loam to the trench subsoil will enhance metals and nutrient removal through adsorption.

OPERATION AND MAINTENANCE

Infiltration, as with all BMPs, must have routine inspection and maintenance designed into the life performance of the facility. Maintenance should be performed as indicated by these routine inspections. The principal maintenance objective is to prevent clogging, which may lead to trench failure. Infiltration trenches and any pretreatment BMPs should be inspected after large storm events and any accumulated debris or material removed. A more thorough inspection of the trench should be conducted at least annually. Annual inspection should include monitoring of the observation well to confirm that the trench is draining within the specified time. Trenches with filter fabric should be inspected for sediment deposits by removing a small section of the top layer. If inspection indicates that the trench is partially or completely clogged, it should be restored to its design condition.

When vegetated buffer strips are used, they should be inspected for erosion or other damage after each major storm event. The vegetated buffer strip should have healthy grass that is routinely mowed. Trash, grass clippings and other debris should be removed from the trench perimeter and should be disposed properly. Trees and other large vegetation adjacent to the trench should also be removed to prevent damage to the trench.

COSTS

Construction costs include clearing, excavation, placement of the filter fabric and stone, installation of the monitoring well, and establishment of a vegetated buffer strip. Additional costs include planning, geotechnical evaluation, engineering and permitting. The Southeastern Wisconsin Regional Planning Commission (SEWRPC, 1991) has developed cost curves and tables for infiltration trenches based on 1989 dollars. The 1993 construction cost for a relatively large infiltration trench (i.e., 1.8 meters (6 feet) deep and 1.2 meters (4 feet) wide with a 68 cubic meter (2,400 cubic feet) volume) ranges from $8,000 to $19,000. A smaller infiltration trench (i.e., 0.9 meters (3 feet) deep and 1.2 meters (4 feet) wide with a 34 cubic meter (1,200 cubic feet) volume) is estimated to cost from $3,000 to $8,500.

Maintenance costs include buffer strip maintenance and trench inspection and rehabilitation. SEWRPC (1991) has also developed maintenance costs for infiltration trenches. Based on the above examples, annual operation and maintenance costs would average $700 for the large trench and $325 for the small trench. Typically, annual maintenance costs are approximately 5 to 10 percent of the capital cost (Schueler, 1987). Trench rehabilitation, may be required every 5 to 15 years. Cost for rehabilitation will vary depending on site conditions and the degree of clogging. Estimated rehabilitation costs run from 15 to 20 percent of the original capital cost (SEWRPC, 1991).

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United States Environmental Protection Agency
Office of Water Washington, D.C.
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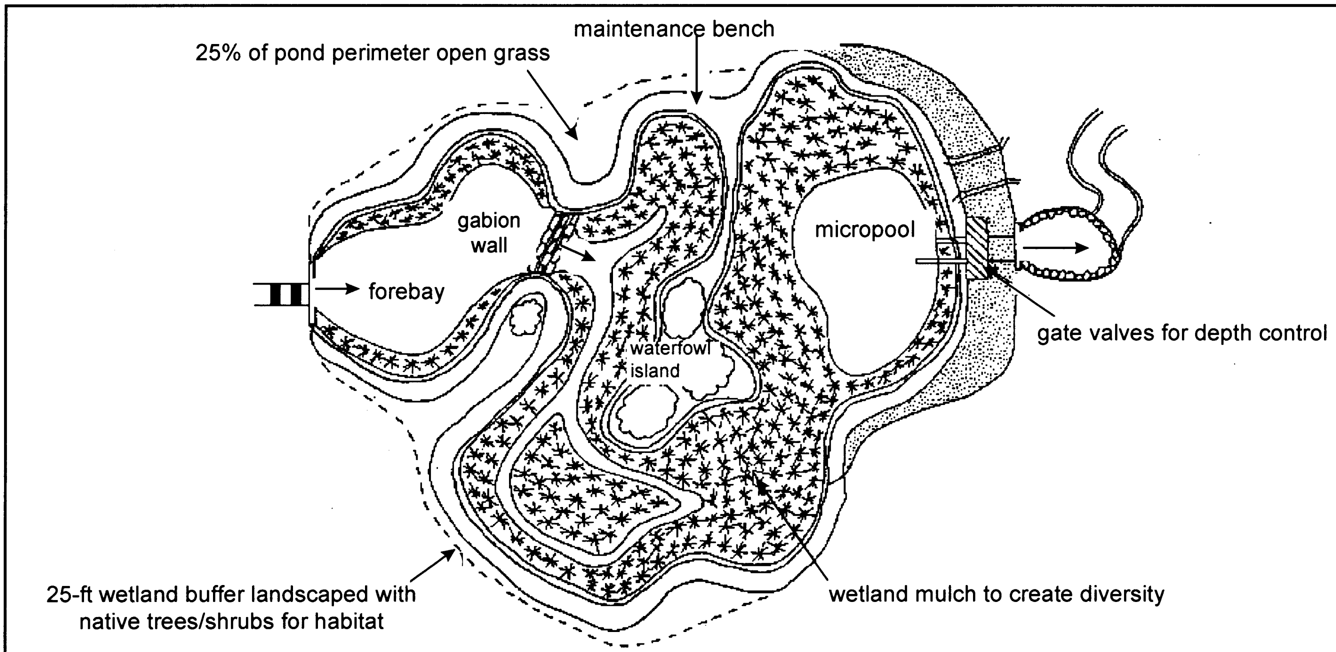
Storm Water Technology Fact Sheet
Storm Water Wetlands

DESCRIPTION

Wetlands are those areas that are typically inundated with surface or ground water and that support plants adapted to saturated soil conditions. A typical shallow marsh wetland is shown in Figure 1. Wetlands have been described as "nature's kidneys" because the physical, chemical, and biological processes that occur in wetlands break down some compounds (e.g., nitrogen-containing compounds, sulfate) and filter others (Hammer, 1989). The natural pollutant-removal capabilities of wetlands have brought them increased attention as storm water best management practices (BMPs).

Wetlands used for storm water treatment can be incidental, natural, or constructed. Incidental wetlands are those wetlands that were created as a result of previous development or human activity. The use of natural wetlands for storm water treatment is discouraged by many experts and/or public interest groups, and may not be an option in many areas. However, some states allow wetlands to be used as storm water BMPs, but only in very restricted circumstances. For example, the State of Florida allows the use of natural wetlands that have been severely degraded or wetlands that are intermittently connected to other waters (i.e., they are connected only when groundwater rises above ground level) (Livingston, 1994). Conversion of natural wetlands to storm water wetlands is done on a case-by-case basis and requires the appropriate state and federal permits (e.g., 401 water quality certification and 404 wetland permit).

Two types of constructed wetlands have been used



Source: MWCOG, 1992a.

FIGURE 1 SHALLOW MARSH WETLAND

successfully for wastewater treatment: the subsurface flow (SF) constructed wetland and the free water surface (FWS) constructed wetland. In the FWS wetland, runoff flows through the soil-lined basin at shallow depths. The wetland consists of a shallow pool planted with emergent vegetation (vegetation which is rooted in the sediment but with leaves at or above the water surface).

In contrast to the FWS wetland, the SF wetland basin is lined with a pre-designed amount of rock or gravel, through which the runoff is conveyed. The water level in an SF wetland remains below the top of the rock or gravel bed. Studies have indicated that the SF wetland is well suited for the diurnal flow pattern of wastewater; however, the peak flows from storm water or combined sewer overflows (CSOs) may be several orders of magnitude higher than the baseflow. The cost for a gravel bed to contain the peak storm event would be very high, which may preclude the use of SF wetlands for storm water or CSO treatment. Therefore, the remainder of this fact sheet addresses the FWS constructed wetland or natural and incidental wetlands for use in storm water applications.

There are four basic designs of FWS constructed wetlands: shallow marsh, extended detention wetland, pond/wetland system, and pocket wetland. As shown in Figure 2, these wetlands store runoff in a shallow basin vegetated with wetland plants. The selection of one design over another will depend on various factors, including land availability, level and reliability of pollutant removal, and size of the contributing drainage area.

The shallow marsh design requires the most land and a sufficient baseflow to maintain water within the wetlands. The basic shallow marsh design can be modified to store extra water above the normal pool elevation. This wetland, known as an extended detention wetland, attenuates flows and relieves downstream flooding.

The pond/wetland system has two separate cells: a wet pond and a shallow marsh. The wet pond traps sediments and reduces runoff velocities prior to entry into the wetland. Less land is required for a pond/wetland system than for the shallow marsh system.

Still less land is required for a pocket wetland. Pocket wetlands should be designed with contributing drainage areas of 0.4 to 4 hectares (1 to 10 acres) and usually require excavation down to the water table for a reliable water source. Unreliable water sources and fluctuating water levels result in low plant diversity and poor wildlife habitat value (MWCOG, 1992b).

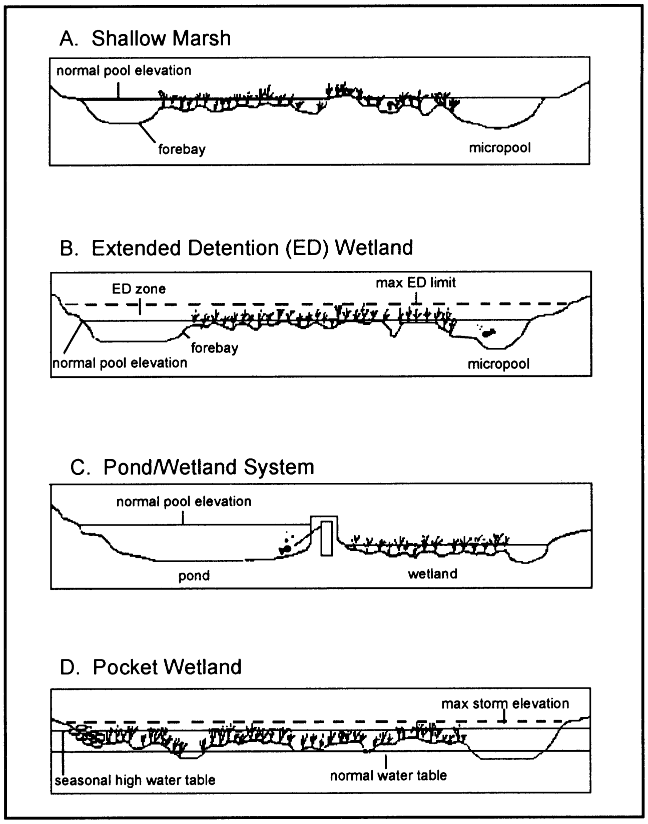


FIGURE 2 COMPARATIVE PROFILES OF FOUR STORM WATER WETLAND DESIGNS

Cross-sectional profiles of the four storm water wetlands not drawn to scale. In Panel A, most of the shallow marsh is shallow, supporting emergent wetland plants. In extended detention wetlands (Panel B), the runoff storage of the wetland is augmented by temporary, vertical extended detention storage. The pond/wetland system (Panel C) is composed of a deep and a shallow pool. Pocket wetlands (Panel D) are excavated to the groundwater table to keep water elevation more consistent.

Source: MWCOG, 1992b.

APPLICABILITY

Wetlands improve the quality of storm water runoff, and can also control runoff volume (e.g., extended detention wetland). Wetlands are one of the more reliable BMPs for removing pollutants and are adaptable to most locations in the U.S. Locations with existing wetlands used for storm water treatment include Alabama, California, Colorado, Florida, Illinois, Maine, Maryland, Michigan, Minnesota, Virginia, and Washington. Wetlands have been used to treat runoff from agricultural, commercial, industrial, and residential areas.

In the past, the natural ability of wetlands to remove pollutants from water has primarily been harnessed to treat wastewater. However, the utilization of wetlands to treat storm water has gained attention in recent years, and many storm water wetlands treatment systems are now operational. Ongoing evaluations are being conducted to determine the effectiveness of wetlands in pollutant removal and to determine the level of maintenance required to sustain their performance, while other studies are evaluating the potential for design modifications to improve wetland performance.

ADVANTAGES AND DISADVANTAGES

Environmental benefits associated with storm water wetlands include improvements in downstream water and habitat quality, enhancement of diverse vegetation and wildlife habitat in urban areas, and flood attenuation. Downstream water quality is improved by the partial removal of suspended solids, metals, nutrients, and organics from urban runoff. Habitat quality is also improved as reduced sediment loads are carried downstream and the erosion of stream banks associated with peak storm water flows is reduced. Wetlands can support a diverse wildlife population, including species such as sandpipers and herons, and can attenuate runoff and alleviate downstream flooding (particularly extended detention wetlands).

Storm water wetlands can cause adverse environmental impacts upstream of the wetland, within the wetland itself, and downstream of the wetland. Storm water wetlands located in a large watershed (larger than 40 hectares (100 acres)) may degrade upstream headwaters, which receive no effective hydrologic control (MWCOG, 1992b). The wetland designer can incorporate upstream modifications to relieve this negative impact.

Possible adverse effects within the wetland itself are the potential for blocking fish passage, potential habitation by undesirable species, and potential groundwater contamination. A wetland constructed in the stream channel may block fish access to part of the stream, thereby decreasing fish diversity in the stream.

Geese and mallards may become undesirable year-round residents of the wetland if structural complexity is not included in the wetland design (i.e., features that limit deep and open water areas and open grassy areas that are favored by these birds). These animals will increase the nutrient and coliform loadings to the wetland and may also become a nuisance to local residents. The takeover of vegetation by invasive nuisance plants is also a potential negative impact. Invasive species pose a threat to native species and may adversely affect the wetland's ability to treat storm water. Maintaining and/or planting upland buffer zones can help to reduce the introduction of nuisance plant species. Planting emergent vegetation may also reduce nuisance algal blooms (Carr, 1995).

The issue of groundwater contamination resulting from the migration of polluted sediments to the groundwater has been considered a potential negative environmental impact. However, studies indicate that there is little risk of groundwater contamination (MWCOG, 1992b).

A storm water wetland can act as a heat sink, especially during the summer, and can discharge warmer waters to downstream water bodies. The increased temperatures can affect sensitive fish species (such as trout and sculpins) and aquatic insects downstream. Therefore, it is not recommended to construct storm wetlands upstream of temperature-sensitive fish populations. Regardless of the sensitivity of downstream species, the designer should always take precautions to reduce the potential warming effects of wetlands construction.

Communities may be opposed to a wetland for fear of mosquitoes and other nuisances, or because of wetlands' appearance. However, wetlands can be designed attractively and features (e.g., fish and vegetation) can be adapted to control mosquitoes and other nuisances. The use of *Gambusia* fish for mosquito control has become a common practice in warmer climates, while colder climates use the black striped topminnow (*Notrophus fundulus*) (U.S. EPA, 1995). To minimize the protection from predators offered by taller plants, the use of low growing plants is recommended where pests are a concern (U.S. EPA, 1996).

Wetlands may remove pollutants less effectively during the non-growing season and in localities with lower temperatures. Decreases in some pollutant-removal efficiencies have been observed when wetlands are covered with ice and when they receive snow melt runoff.

Finally, because of the large land requirement for storm water wetlands systems (See **Design Criteria**), their use may be precluded in urban settings and established communities.

Several possible remedies to these impacts are discussed in the publication *Design of Storm Water Wetland Systems* (MWCOG, 1992).

DESIGN CRITERIA

Local, state and federal permit requirements should be determined prior to wetland design. Required permits and certifications may include 401 water quality certifications, 402 storm water National Pollutant Discharge Elimination System (NPDES) permits, 404 wetland permits, dam safety permits, sediment and erosion control plans, waterway disturbance permits, forest-clearing permits, local grading permits, and land use approvals.

A site appropriate for a wetland must have an adequate water flow and appropriate underlying soils. The baseflow from the drainage area or groundwater must be sufficient to maintain a shallow pool in the wetland and support the wetlands' vegetation, including species susceptible to damage during dry periods. Underlying soils that are type B , C, or R (zone of accumulation, partially altered parent material and unaltered parent material, respectively) will have only small infiltration losses. Sites with type A soils (soils rich in organic matter) may have high infiltration rates. These sites may require geotextile liners or a 15 centimeter (6 inch) layer of clay. After any necessary excavation and grading of the wetland, at least 10 centimeters (4 inches) of soil should be applied to the site. This material, which may be the previously-excavated soil or sand and other suitable material, is needed to provide a substrate in which the vegetation can become established and to which it can become anchored. The substrate should be soft so that plants can be inserted easily.

The Metropolitan Washington Council of Governments (MWCOG, 1992b) has recommended basic sizing criteria for wetland design. The volume of the wetland is determined as the quantity of runoff generated by 90 percent of the runoff-producing storms. This volume will vary throughout the U.S. due to different rainstorm patterns. In the Mid-Atlantic Region, for example, a 1.25-inch storm is used as the sizing criterion.

Watershed imperviousness will also impact the runoff volume generated from a storm. The following equations are used to determine the treatment volume (Vt):

(1) $Rv = 0.05 + 0.009 (I)$
where:
Rv = storm runoff coefficient
I = % (as decimal) site imperviousness

(2) $Vt = [(1.25)(Rv)(A)/12](43{,}560)$
where:
Vt = treatment volume (cubic feet)
A = contributing area (acres)

Sizing criteria for wetlands vary, with some states having their own methods. For example, shallow wetland basins constructed in Maryland are designed to maximize basin surface area. The surface area should be a minimum of 3 percent of the area of the watershed draining to it. Maryland recommends designing for extended detention, using 24-hour detention of the 1-year storm for design purposes. In contrast, the Washington State Department of Ecology sizes wetlands using the runoff generated from the 6-month, 24-hour rainfall event. The minimum surface area established by MWCOG for shallow marshes is 2 percent of the wetland area. The remaining three wetland designs should have wetland to watershed ratios greater than 1 percent.

TABLE 1 GUIDELINES FOR ALLOCATING WETLAND SURFACE AREA AND TREATMENT VOLUME

Target Allocations	Shallow Marsh	Extended Detention Wetland	Pond/Wetland	Pocket Wetland
Percent of Wetland Surface Area				
Forebay	5	5	0	0
Micropool	5	5	5	0
Deepwater	5	0	40	5
Low Marsh	40	40	25	50
High Marsh	40	40	25	40
Semi-Wet	5	10	5	5
Percent of Treatment Volume				
Forebay	10	10	0	0
Micropool	10	10	10	0
Deepwater	10	0	60	20
Low Marsh	45	20	20	55
High Marsh	25	10	10	25
Semi-Wet	0	50	0	0

Depth:
Deepwater - 0.5 - 2 meters (1.5 to 6 feet) below normal pool level
Low Marsh - 0.17- 0.5 meters (0.5 to 1.5 feet) below normal pool level
High Marsh -0.5 feet below normal pool level
Semi-Wet - 0 to 2 feet above normal pool level (includes Extended Detention)

Source: Modified from MWCOG, 1992b.

MWCOG has also established criteria for water balance, maximum flow path, allocation of treatment volume, minimum surface area, allocation of the surface area, and extended detention. As previously discussed, during dry weather, flow must be adequate to provide a baseflow and to maintain the vegetation. The flow path should be maximized to increase the runoff's contact time with plants and sediments. The recommended minimum length to width ratio of the wetland is 2:1. If a ratio of less than 2:1 is necessary, the use of baffles, islands, and peninsulas can minimize short circuiting (allowing runoff to escape treatment) by ensuring a long distance from inlet to outlet.

A suggestion for allocating treatment volumes is shown in Table 1. The wetland surface area is allocated to four different depth zones: deepwater (0.5 to 2 meters, or 1.5 to 6 feet, below normal pool), low marsh (0.17 to 0.5 meters, or 0.5 to 1.5 feet, below normal pool), high marsh (up to 0.17 meters, or 0.5 feet, below normal pool), and semi-wet areas (above normal pool). The allocation to the various depth zones will create a complex internal topography that will maximize plant diversity and increase pollutant removal. The State of Maryland requires that 50 percent of the shallow marsh be less than 0.17 meters (0.5 feet) deep, that 25 percent range from 0.17 to 0.33 meters (0.5 feet to 1 foot) deep, and that the remaining 25 percent range from 0.67 to 1 meter (2 to 3 feet) deep.

Extending detention within the wetland increases the time for sedimentation and other pollutant-removal processes to occur and also provides for attenuation of flows. Up to 50 percent extra treatment volume can be added into the wetland system for extended detention. However, to prevent large fluctuations in the water level that could potentially harm the vegetation, Extended Detention elevation should be limited to 11 meters (33 feet) above the normal pool elevation. The Extended Detention volume should be detained between 12 and 24 hours.

Sediment forebays are recommended to decrease the velocity and sediment loading to the wetland. The forebays provide the additional benefits of creating sheet flow, extending the flow path, and preventing short circuiting. The forebay should contain at least 10 percent of the wetland's treatment volume and should be 2 to 3 meters (4 to 6 feet) deep. The State of Maryland recommends a depth of at least 1 meter (3 feet). The forebay is typically separated from the wetland by gabions or by an earthen berm (MWCOG, 1992b).

Flow from the wetland should be conveyed through an outlet structure that is located within the deeper areas of the wetland. Discharging from the deeper areas using a reverse slope pipe prevents the outlet from becoming clogged. A micropool just prior to the outlet will also prevent outlet clogging. The micropool should contain approximately 10 percent of the treatment volume and be 2 to 3 meters (4 to 6 feet) deep. An adjustable gate-controlled drain capable of dewatering the wetland within 24 hours should be located within the micropool. A typical drain may be constructed with an upward-facing inverted elbow with its opening above the accumulated sediment. The dewatering feature eases planting and follow-up maintenance (MWCOG, 1992b).

Vegetation can be established by any of five methods: mulching; allowing volunteer vegetation to become established; planting nursery vegetation; planting underground dormant parts of a plant; and seeding. Donor soils from existing wetlands can be used to establish vegetation within a wetland. This technique, known as mulching, has the advantage of quickly establishing a diverse wetland community. However, with mulching, the types of species that grow within the wetland are unpredictable.

Allowing species transmitted by wind and waterfowl to voluntarily become established in the wetland is also unpredictable. Volunteer species are usually well established within 3 to 5 years. Wetlands established with volunteers are usually characterized by low plant diversity with monotypic stands of exotic or invasive species. A higher-diversity wetland can be established when nursery plants or dormant rhizomes are planted. Vegetation from a nursery should be planted during the growing season - not during late summer or fall - to allow vegetation time to store food reserves for their dormant period. Separate underground parts of vegetation are planted during the plants' dormant period, usually October through April, but the months will vary with local climate. Another planting technique, the spreading of seeds, has not been very successful and therefore is not widely practiced as a principal planting technique.

Appropriate plant types vary with locations and climate. The wetland designer should select five to seven plants native to the area and design the depth zones in the wetland to be appropriate for the type of plant and its associated maximum water depth. Approximately half of the wetland should be planted. Of the five to seven species selected, three should be aggressive plants or those that become established quickly. Examples of aggressive species used in the Mid-Atlantic Region include softstem bulrush (*Scirpus validus*) and common three-square (*Scirpus americanus*). Aggressive plants as well as other native wetland plants are available from numerous nurseries. Most vendors require an advance order of 3 to 6 months.

After excavation and grading the wetland should be kept flooded until planting. Six to nine months after being flooded and two weeks before planting, the wetland is typically drained and surveyed to ensure that depth zones are appropriate for plant growth. Revisions may be necessary to account for any changes in depth. Next, the site is staked to ensure that the planting crew spaces the plants within the correct planting zone. Species are planted in separate zones to avoid competition. The State of Maryland recommends planting two aggressive or primary species in four specific areas and planting an additional 40 clumps (one or more individuals of a single species) per acre of each primary species over the rest of the wetland. Three secondary species are planted close to the edge of the wetland at an application rate of 10 clumps of 5 individual plants per acre of wetland, for a total of 50 individuals of each secondary species per acre of wetland. At least 48 hours prior to planting, the wetland should be drained; within 24 hours after planting, it should be re-flooded.

The wetland design should include a buffer to separate the wetland from surrounding land. Buffers may alleviate some potential wetland nuisances, such as accumulated floatables or odors. MWCOG recommends a buffer of 8 meters (25 feet) from the maximum water surface elevation, plus an additional 8 meters (25 feet) when wildlife habitat is of concern. Leaving trees undisturbed in the buffer zone will minimize the disruption to wildlife and reduce the chance for invasion of nuisance vegetation such as cattails and primrose willow. If tree removal is necessary, the buffer area should be reforested. Reforestation also discourages the settlement of geese, which prefer open areas.

PERFORMANCE

Wetlands remove pollutants from storm water through physical, chemical, and biological processes. Chemical and physical assimilation mechanisms include sedimentation, adsorption, filtration, and volatilization.

Sedimentation is the primary removal mechanism for pollutants such as suspended solids, particulate nitrogen, and heavy metals. Particulate settling is influenced by the velocity of the runoff through the wetland, the particle size, and turbulence. Sedimentation can be maximized by creating sheet flow conditions, slowing the velocities through the wetland, and providing morphology and vegetation conducive to settling. The vegetation and its root system will also decrease the resuspension of settled particles.

Some pollutants, including metals, phosphorus, and some hydrocarbons, are removed by adsorption- the process whereby pollutants attach to surfaces of suspended or settled sediments and vegetation. For this removal process to occur, adequate contact time between the surface and pollutant must be provided in the design of the system.

Wetland plants filter trash, debris, and other floatables. Particulates (e.g., settleable solids and colloidal solids) are also filtered mechanically as water passes through root masses. Filtration can be enhanced by slow velocities, sheet flow, and sufficient quantities of vegetation. By increasing detention and contact time and providing a surface for microbial growth, wetland plants also increase the pollutant removal achieved through sedimentation, adsorption, and microbial activity.

Volatilization plays a minor role in pollutant removal from wetlands. Pollutants such as oils and hydrocarbons can be removed from the wetland via evaporation or by aerosol formation under windy conditions.

Biological processes that occur in wetlands result in pollutant uptake by wetland plants and algae. Emergent wetland plants absorb settled nutrients and metals through their roots, creating new sites in the sediment for pollutant adsorption. During the fall the plants' above-ground parts typically die back and the plants may potentially release the nutrients and metals back into the water column (MWCOG, 1992b). Recent studies, however, indicate that most pollutants are stored in the roots of aquatic plants, rather than the stems and leaves (CWP, 1995). Additional studies are required to determine the extent of pollutant release during the fall die-back.

Microbial activity helps to remove nitrogen and organic matter from wetlands. Nitrogen is removed by nitrifying and denitrifying bacteria; aerobic bacteria are responsible for the decomposition of the organic matter. Microbial processes require oxygen and can deplete oxygen levels in the top layer of wetland sediments. The low oxygen levels and the decomposed organic matter help immobilize metals.

Soluble forms of phosphorus, as well as ammonia, are partially removed by planktonic or benthic algae. The algae consume the nutrients and convert them into biomass, which settles to the bottom of the wetland.

The removal effectiveness of shallow marsh and pond/wetland systems has been fairly well documented, while the amount of removal efficiency data for Extended Detention wetlands and pocket wetlands is limited. Average long-term pollutant removal rates for constructed wetlands, as a whole, are presented in Table 2 (CWP, 1997).

TABLE 2 PERFORMANCE OF STORM WATER WETLANDS

Pollutant	Removal Rate
Total Suspended Solids	67%
Total Phosphorus	49%
Total Nitrogen	28%
Organic Carbon	34%
Petroleum Hydrocarbons	87%
Cadmium	36%
Copper	41%
Lead	62%
Zinc	45%
Bacteria	77%

Source: CWP, 1997.

As shown, petroleum hydrocarbons (87%), total suspended solids (TSS) (67%), lead (62%), and bacteria (77%) have the highest removal rates. Lower removal rates have been documented for nutrients, organic carbon, and other heavy metals. The removal rates will vary with the loadings to the wetland, retention time in the BMP, and other factors such as BMP geometry, site characteristics, and monitoring methodology (CWP, 1997). Excessive pollutant loadings (e.g., suspended solids) may exceed the wetlands' removal capabilities.

In general, wetlands remove pollutants about as effectively as do conventional pond systems. Constructed storm water wetlands are more effective than natural wetlands, probably because of their intricate design and continued monitoring and maintenance (MWCOG, 1992). The wetlands' effectiveness seems to improve after the first few years of use as the vegetation becomes established and organic matter accumulates.

OPERATION AND MAINTENANCE

Well-designed and maintained wetlands can function as designed for 20 years or longer. However, wetland maintenance must actually begin during the construction phase. During construction and excavation, many constructed wetlands lose organic matter in the soils. The organic matter provides exchange sites for pollutants, and, therefore, plays an important role in pollutant removal. Replacing or adding organic matter after construction improves performance.

After the wetland has been constructed, its vegetation must be maintained on a regular basis. Maintenance requirements for constructed wetlands are particularly high while vegetation is being established (usually the first three years) (U.S. EPA, 1996). Monitoring during these first years is crucial to the future success of the wetland as a storm water BMP. Inspections should be conducted at least twice per year for the first three years and annually thereafter. Maintenance requirements may also include replacement planting, sediment removal, and possibly plant harvesting. Wetland design should include access to facilitate these maintenance activities.

Vegetative cover on embankments and spillways should be dense and healthy. Replacement planting may be required during the first several years if the original plants do not flourish. First year wetland vegetation growth at the water's edge and on the side slopes of the wetland can be protected from birds by surrounding the open water area of the wetland with wire to limit access to the vegetation. The embankment and maintenance bench should be mowed twice each year. Other areas surrounding the wetland should not require mowing. Mowing and fertilizing help promote vigorous growth of plant roots that resist erosion. Mowing also prevents the growth of unwanted woody vegetation. Additional routine maintenance that can be conducted on the same schedule should include removal of accumulated trash from trash racks, outlet structures, and valves, as well as debris on plants that could inhibit growth.

Constructed wetlands should be inspected after major storms during the first year of establishment. The inspector should assess bank stability, erosion damage, flow channelization, and sediment accumulation within the wetland. The inspector shall also take note of species distribution/survival, damage to embankments and spillways from burrowing animals, water elevations, and outlet condition. Water elevations can be raised or lowered by adjusting the outlet's gate valve if plants are not receiving an appropriate water supply.

Accumulated sediments will gradually decrease wetland storage and performance. There are two options to mitigate the effects of accumulated sediments: either the sediments should be removed as necessary or the water level in the wetland should be raised (i.e., the outlet should be adjusted to increase discharge elevation).

The construction of a sediment forebay will decrease the accumulation of sediments within the wetland and increase the wetland's longevity. The forebay will likely require sediment to be cleaned out every three to five years. The forebay design should allow drainage so that a skid loader or backhoe can be used to remove the accumulated deposits (MWCOG, 1992). Accumulation of organic matter can be reduced by plant harvesting or seasonal drawdown to allow organic material to oxidize (U.S. EPA, 1996).

A number of studies have been performed to determine the toxicity of pond sediments and whether they can be landfilled or land applied without having to meet hazardous waste requirements. Many studies to date have found sediments are not hazardous. However, one study showed that toxic levels of zinc had accumulated in sediment from the pretreatment pond (SFWMD, 1995). If toxic levels of metals have not accumulated in the sediment, then on-site land application of the sediments away from the shoreline will probably be the most cost-effective disposal method (no transportation costs or disposal fees are incurred). Wetlands that receive flow from a drainage area containing commercial or industrial land use and/or activities associated with hazardous waste may contain toxic levels of heavy metals in the sediments. Testing may be required for these sediments prior to land application or disposal.

COSTS

Costs incurred for storm water wetlands include those for permitting, design, construction and maintenance. Permitting costs vary depending on state and local regulations, but permitting, design, and contingency costs are estimated at 25 percent of the construction cost. Construction costs for an emergent wetland with a sediment forebay range from \$65,000 to \$137,500 per hectare (\$26,000 to \$55,000 per acre) of wetland. This includes costs for clearing and grubbing, erosion and sediment control, excavating, grading, staking, and planting. The cost for constructing the wetland depends largely upon the amount of excavation required at a site and plant selection. The cost for forested wetlands could be double that of an emergent wetland. Maintenance costs for wetlands are estimated at 2 percent per year of the construction costs (CWP, 1998).

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Storm Water Technology Fact Sheet

Vegetative Covers

DESCRIPTION

Soil erosion and sedimentation caused by vegetation removal, soil disturbances, changes to natural drainage patterns, or increases in impermeable ground cover are two of the primary problems associated with storm water runoff. One of the most effective ways to prevent erosion and sedimentation is to stabilize disturbed land through the addition of vegetation. This practice is referred to as "vegetative covering." Vegetative covers can be used to preserve existing vegetation and/or revegetate disturbed soils. They can provide both dust control and a reduction in erosion potential by increasing infiltration, trapping sediment, stabilizing the soil, and dissipating the energy of hard rain.

One method for establishing vegetative covers is planting either temporary or permanent new vegetation. Specific practices can include applying sod to a site, or temporarily or permanently seeding the site. Sod is a strip of permanent grass cover placed over a disturbed area to provide an immediate and permanent turf that both stabilizes the soil surface and eliminates sediment loss. Temporary seeding consists of planting grass seed immediately after rough grading to provide soil protection until a final cover is established. Permanent seeding establishes perennial vegetation in disturbed areas.

A second method for enhancing vegetative covering is by preserving existing vegetation. This allows a site's natural vegetation (existing trees, vines, bushes, and grasses) to function as a natural buffer zone during land disturbance activities.

APPLICABILITY

Vegetative covers can be applied at any site and are not restricted by the size of the site or local land uses. The type of soil, topography, and climate at the site determine the appropriate tree, shrub, and ground cover species for that particular management practice. Local climatic conditions help determine the appropriate time of year for planting. Temporary seeding is most suitable in areas disturbed by construction where the ground is left exposed for several weeks or more. Permanent seeding and planting is appropriate for any graded or cleared area where long-lived plant cover is desired. Some areas where permanent seeding is especially important are filter strips, buffer areas, vegetated swales, steep slopes, and stream banks.

ADVANTAGES AND DISADVANTAGES

Vegetative covering can be a relatively low-cost and low-maintenance practice for controlling dust and preventing erosion. It also adds to the aesthetics of a storm water control area.

Limitations of vegetative covers as a management practice include:

- Vegetative covering must be coordinated with climatic conditions for proper establishment. For example, cold climate areas have limited growing seasons and arid regions require careful selection of plant species.

- An appropriate maintenance program must be implemented to ensure the optimum performance.

DESIGN CRITERIA

Table 1 summarizes the design criteria for vegetative covers.

PERFORMANCE

Qualitatively, vegetative covers are clearly effective in controlling dust and erosion when properly implemented. The amount of runoff generated from vegetated areas is considerably reduced and of better quality than runoff from unvegetated areas. However, based on data currently available, it is not possible to quantify the water quality benefits of vegetative coverings as a BMP.

OPERATION AND MAINTENANCE

Several measures must be taken after seeding and sodding an area to promote successful growth. It is especially important to check and monitor an area after a rain event to ensure that the seeds and sod have not been damaged. If damage has occurred, the cause of damage must be assessed before repeating seed bed preparation and seeding procedures. Once a vegetative cover has been established, it is important to attend to the following:

- Watering the sod frequently and uniformly.
- Maintaining appropriate grass height for the species selected and the intended use.
- Performing occasional soil tests to determine if the soil is being appropriately fertilized.
- Controlling weeds.
- Spot seeding small and damaged areas.

COSTS

The general base capital costs for constructing a vegetative cover average around $13,800/acre for seeding and $29,000/acre for sodding. A more detailed summary of the cost estimates for sodding and seeding is provided in Table 2. Please note that costs vary depending on regional climates and soil conditions.

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TABLE 1 DESIGN CRITERIA FOR VEGETATIVE COVERS

Measure	Extent and Material	Dimensions	Hydraulic	Avoid	Miscellaneous
Temporary Seeding	Place topsoil as needed, to enhance plant growth. A loamy soil with an organic content of 1.5 percent or greater is preferred. Use rapid-growing annual grasses, small grains, or legumes. Apply seeds using a cyclone seeder, drill, cultipacker seeder, or hydroseeder.	Place topsoil where needed to a minimum compacted depth of 2 inches on 3:1 slopes or steeper; and of 4 inches on flatter slopes.	Divert channelized flow away from temporarily seeded areas to prevent erosion and scouring.	Heavy clay or organic soils as topsoil. Handbroadcasting of seeds (not uniform), except in very small areas. Mowing temporary vegetation. High-traffic areas.	Use where vegetation cover is needed for less than 1 year. Use chisel plow or tiller to loosen compacted soils. As needed, apply water, fertilizer, lime, and mulch. Incorporate lime and fertilizer into top 4-6 inches of soil. Plant small grains 1 inch deep. Plant grasses and legume 1/2 inch deep.
Permanent Seeding	Place topsoil as needed to enhance plant growth. A loamy soil with an organic content of 1.5 percent or greater is preferred. Where possible, use low maintenance local plant species. Apply seeds using a cyclone seeder, drill, cultipacker seeder, or hydroseeder.	Apply mulch to slopes 4:1 or steeper if soil is sandy or clayey, or if weather is excessively hot or dry. Place topsoil where needed.	Divert channelized flow away from temporarily seeded areas to prevent erosion and scouring.	Heavy clay or organic soils as topsoil. Hand broadcasting of seeds (not uniform), except in very small areas. High-traffic areas.	Use chisel plow or tiller to loosen compacted soils. As needed, apply water, fertilizer, lie, and mulch. Incorporate lime and fertilizer into top 4-6 inches of soil. Plant small grains 1 inch deep. Plant grasses and legume 1/2 inch deep.
Sodding	Sod should be machine-cut at a uniform thickness of ½ to 2 inches.		In waterways, select plant types able to withstand design flow velocity.	Gravel or nonsoil surfaces. Unusually wet or hot weather. Frozen soils. Mowing for at least two to three weeks.	Prior to laying sod, clear soil surface of debris, roots, branches, and stones bigger than 2 inches in diameter. Sod should be harvested, delivered, and installed within 36 hours. Lay sod with staggered joints along the contour. Lightly irrigate soils before sod placement during dry or hot periods. After placement, roll sod and wet soil to a depth of 4 inches. On slopes steeper than 3:1, secure sod with stakes. In waterways, lay sod perpendicular to water flow. Secure sod with stakes, wire, or netting.
Preservation of Natural Vegetation	Careful planning is required prior to start of construction.	Wherever possible, maintain existing contours.	Maintain existing hydraulic characteristics.	Activities within the drop line of trees. Concentrating flows at new locations.	Preservation of vegetation should be planned before any site disturbance begins. Proper maintenance is vitally important. Clearly mark areas to be preserved.

Source: HCD, 1989.

TABLE 2 INSTALLATION COSTS

Description	Unit	Location	Material	Labor	Equipment	Indirect Cost	Total Cost	Year of Cost	Comments
Sodding									
Level									
>400 yd^2	yd^2	Loganville, GA[1]	$2.07	$1.80	$0.30	$1.68	$5.85	Jan-99	
	yd^2	Dubuque, IA[2]	$1.15	$0.93	$0.05	$1.07	$3.20	1998	Indirect costs include:$0.11 for indirect time, $0.56 for profit, and $0.40 for shipping/semi load.
101 yd^2	yd^2	Loganville, GA[1]	$2.70	$1.80	$0.30	$1.68	$6.40	Jan-99	
	yd^2	Dubuque, IA[2]	$1.15	$0.94	$0.05	$1.46	$3.60	1998	Indirect costs include: $0.43 for indirect time, $0.64 for profit and $0.40 for shipping/semi load
50 yd^2	yd^2	Loganville, GA[1]	$2.70	$1.80	$0.30	$1.68	$6.48	Jan-99	
	yd^2	Dubuque, IA[2]	$1.15	$0.98	$0.05	$2.00	$4.18	1998	Indirect costs include: $0.86 for indirect time, $0.75 for profit and $0.40 for shipping/semi load
Slopes									
401 yd^2	yd^2	Loganville, GA[1]	$2.70	$1.80	$0.30	$1.68	$6.48	Jan-99	
	yd^2	Dubuque, IA[2]	$1.15	$1.23	$0.05	$1.13	$3.56	1998	Indirect costs include: $0.11 for indirect time, $ 0.62 for profit and $0.40 for shipping/semi load
Seeding									
Mechanical Seeding	Acre	Hollston, MA[3]	$653.00	$435.00	$222.00	$430.00	$1,940.00	1998	pricing includes seed, fertilizer, hydromulch, and water only
	yd^2	Hollston, MA[3]	$0.14	$0.09	$0.05	$0.09	$0.36	1998	pricing includes seed, fertilizer, hydromulch, and water only
	Acre	Loganville, GA[1]	$931.40	$600.00	$300.00	$497.10	$2,328.50	Jan-99	
	yd^2	Loganville, GA[1]	$0.18	$0.12	$0.06	$0.10	$0.46	Jan-99	
	Acre	Dubuque, IA[2]	$1,267.21	$142.94	$258.70	$436.23	$2,105.08	1998	Indirect costs include: $103.50 for indirect time, $ 332.73 for profit, provided that equipment is available. Does not include grading. Includes straw mulch.
	yd^2	Dubuque, IA[2]	$0.26	$0.13	$0.24	$0.10	$0.73	1998	

TABLE 2 (CONTINUED) INSTALLATION COSTS

Description	Unit	Location	Material	Labor	Equipment	Indirect Cost	Total Cost	Year of Cost	Comments
Fine Grade/Seed	yd^2	Loganville, GA[1]	$0.18	$0.12	$0.06	$0.10	$0.46	Jan-99	Includes fertilizer & lime
	yd^2	Dubuque, IA	$0.26	$0.13	$0.24	$0.10	$0.73	1998	Indirect costs include: 0.02 for indirect time and 0.08 for profit; equipment is owned and costs include straw mulch)
Push Spreader									
Grass Seed	1,000 ft^2	Loganville, GA[1]	$15.00	$6.25	$0.30	$3.45	$25.00	Jan-99	
	1,000 ft^2	Dubuque, IA[2]	$15.18	$8.88	$54.00	$100.82	$178.88	1998	Indirect costs include: $80.00 for indirect time and $20.82 for profit; does not include mulch
Limestone	1,000 ft^2	Loganville, GA[1]	$2.85	$6.25	$0.30	$1.00	$10.00	Jan-99	
	1,000 ft^2	Dubuque, IA[2]	$2.50	$8.88	$54.00	$98.28	$163.66	1998	Indirect costs include: $80.00 for indirect time and $12.28 for profit; does not include mulch
Fertilizer	1,000 ft^2	Loganville, GA[1]	$3.33						
	1,000 ft^2	Dubuque, IA[2]	$2.80	$8.88	$54.00	$98.34	$164.02	1998	Indirect costs include: $80.00 for indirect time and $18.34 for profit; does not include mulch
Level Areas	Acre	Loganville, GA[1]	$750.00	$600.00	$139.50	$839.50	$2,328.50	Jan-99	
	Acre	Dubuque, IA[2]	$661.24	$109.26	$120.00	$251.30	$1,141.80	1998	Indirect costs include: $81.00 for indirect time and $170.30 for profit; does not include mulch
Sloped Areas	Acre	Loganville, GA[1]	$750.00	$600.00	$139.50	$839.50	$2,328.50	Jan-99	
	Acre	Dubuque, IA[2]	$661.24	$222.12	$120.00	$257.83	$1,261.19	1998	Indirect costs include: $81.00 for indirect time and $176.83 for profit; does not include mulch

1 information provided by Earthscape Landscaping and Lawn Care

2 information provided by Weathers Landscape Services

3 information provided by New England Hydroseeding, Inc.

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Storm Water Technology Fact Sheet
Vegetated Swales

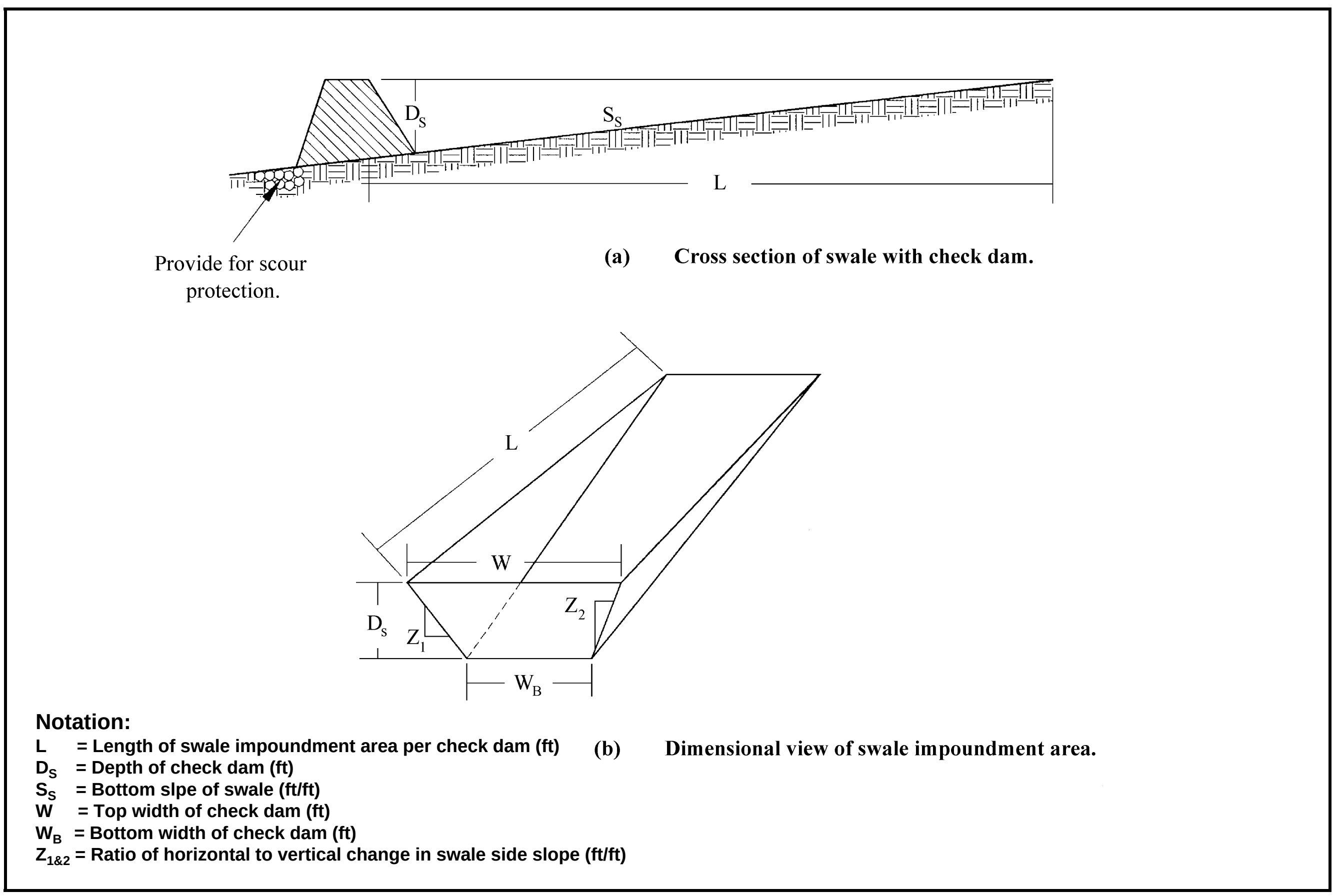
DESCRIPTION

A vegetated swale is a broad, shallow channel with a dense stand of vegetation covering the side slopes and bottom. Swales can be natural or manmade, and are designed to trap particulate pollutants (suspended solids and trace metals), promote infiltration, and reduce the flow velocity of storm water runoff. A typical design is shown in Figure1.

Vegetated swales can serve as part of a storm water drainage system and can replace curbs, gutters and storm sewer systems. Therefore, swales are best suited for residential, industrial, and commercial areas with low flow and smaller populations.

APPLICABILITY

Vegetated swales can be used wherever the local climate and soils permit the establishment and maintenance of a dense vegetative cover. The feasibility of installing a vegetated swale at a



Source: NVPDC, 1996.

FIGURE 1 EXAMPLE OF A VEGETATED SWALE

particular site depends on the area, slope, and perviousness of the contributing watershed, as well as the dimensions, slope, and vegetative covering employed in the swale system.

Vegetated swales are easy to design and can be incorporated into a site drainage plan. While swales are generally used as a stand-alone storm water Best Management Practice (BMP), they are most effective when used in conjunction with other BMPs, such as wet ponds, infiltration strips, wetlands, etc.

While vegetated swales have been widely used as storm water BMPs, there are also certain aspects of vegetated swales that have yet to be quantified. Some of the issues being investigated are whether their pollutant removal rates decline with age, what effect the slope has on the filtration capacity of vegetation, the benefits of check dams, and the degree to which design factors can enhance the effectiveness of pollutant removal.

ADVANTAGES AND DISADVANTAGES

Swales typically have several advantages over conventional storm water management practice, such as storm sewer systems, including the reduction of peak flows; the removal of pollutants, the promotion of runoff infiltration, and lower capital costs. However, vegetated swales are typically ineffective in, and vulnerable to, large storms, because high-velocity flows can erode the vegetated cover.

Limitations of vegetated swales include the following:

- They are impractical in areas with very flat grades, steep topography, or wet or poorly drained soils.
- They are not effective and may even erode when flow volumes and/or velocities are high.
- They can become drowning hazards, mosquito breeding areas, and may emit odors.
- Land may not be available for them.
- In some places, their use is restricted by law: many local municipalities prohibit vegetated swales if peak discharges exceed 140 liters per second (five cubic feet per second) or if flow velocities are greater than 1 meter per second (three feet per second).
- They are impractical in areas with erosive soils or where a dense vegetative cover is difficult to maintain.

Negative environmental impacts of vegetated swales may include:

- Leaching from swale vegetation may increase the presence of trace metals and nutrients in the runoff.
- Infiltration through the swale may carry pollutants into local groundwater.
- Standing water in vegetated swales can result in potential safety, odor, and mosquito problems.

DESIGN CRITERIA

Design criteria for implementation of the vegetated swales are as follows:

Location

Vegetated swales are typically located along property boundaries along a natural grade, although they can be used effectively wherever the site provides adequate space. Swales can be used in place of curbs and gutters along parking lots.

Soil Requirements

Vegetated swales should not be constructed in gravelly and coarse sandy soils that cannot easily support dense vegetation. If available, alkaline soils and subsoils should be used to promote the removal and retention of metals. Soil infiltration rates should be greater than 0.2 millimeters per second (one-half inch per hour); therefore, care must be taken to avoid compacting the soil during construction.

Vegetation

A fine, close-growing, water-resistant grass should be selected for use in vegetated swales, because increasing the surface area of the vegetation exposed to the runoff improves the effectiveness of the swale system. Pollutant removal efficiencies vary greatly depending on the specific plants involved, so the vegetation should be selected with pollution control objectives in mind. In addition, care should be taken to choose plants that will be able to thrive at the site. Examples of vegetation appropriate for swales include reed canary grass, grass-legume mixtures, and red fescue.

General Channel Configuration

A parabolic or trapezoidal cross-section with side slopes no steeper than 1:3 is recommended to maximize the wetted channel perimeter of the swale. Recommendations for longitudinal channel slopes vary within the existing literature. For example, Schueler (1987) recommends a vegetated swale slope as close to zero as drainage permits. The Minnesota Pollution Control Agency (1991) recommends that the channel slope be less than 2 percent. The Storm Water Management Manual for the Puget Sound Basin (1992) specifies channel slopes between 2 and 4 percent. This manual indicates that slopes of less than 2 percent can be used if drain tile is incorporated into the design, while slopes greater than 4 percent can be used if check dams are placed in the channel to reduce flow velocity.

Flows

A typical design storm used for sizing swales is a six-month frequency, 24-hour storm event. The exact intensity of this storm must be determined for your location and is generally available from the U.S. Geological Survey. Swales are generally not used where the maximum flow rate exceeds 140 liters/second (5 cubic feet per second).

Sizing Procedures

The width of the swale can be calculated using various forms of the Manning equation. However, this methodology can be simplified to the following rule of thumb: the total surface area of the swale should be one percent of the area (500 square feet for each acre) that drains to the swale.

Unless a bypass is provided, the swale must be sized both to treat the design flows and to pass the peak hydraulic flows. However, for the swale to treat runoff most effectively, the depth of the storm water should not exceed the height of the grass.

Construction

The subsurface of the swale should be carefully constructed to avoid compaction of the soil. Compacted soil reduces infiltration and inhibits growth of the grass. Damaged areas should be restored immediately to ensure that the desired level of treatment is maintained and to prevent further damage from erosion of exposed soil.

Check Dams

Check dams can be installed in swales to promote additional infiltration, to increase storage, and to reduce flow velocities. Earthen check dams are not recommended because of their potential to erode. Check dams should be installed every 17 meters (50 feet) if the longitudinal slope exceeds 4 percent.

PERFORMANCE

The literature suggests that vegetated swales represent a practical and potentially effective technique for controlling urban runoff quality. While limited quantitative performance data exists for vegetated swales, it is known that check dams, slight slopes, permeable soils, dense grass cover, increased contact time, and small storm events all contribute to successful pollutant removal by the swale system. Factors decreasing the effectiveness of swales include compacted soils, short runoff contact time, large storm events, frozen ground, short grass heights, steep slopes, and high runoff velocities and discharge rates.

Conventional vegetated swale designs have achieved mixed results in removing particulate pollutants. A study performed by the Nationwide Urban Runoff Program (NURP) monitored three grass swales in the Washington, D.C., area and found no significant improvement in urban runoff quality for the pollutants analyzed. However, the weak performance of these swales was attributed to the high flow velocities in the swales, soil compaction, steep slopes, and short grass height. Another project in Durham, NC, monitored the performance of a carefully designed artificial swale that received runoff from a commercial parking lot. The project tracked 11 storms and concluded that particulate concentrations of heavy metals (Cu, Pb, Zn, and Cd) were reduced by approximately 50 percent. However, the swale proved largely ineffective for removing soluble nutrients. A conservative estimate would say that a properly designed vegetated swale may achieve a 25 to 50 percent reduction in particulate pollutants, including sediment and sediment-attached phosphorus, metals, and bacteria. Lower removal rates (less than 10 percent) can be expected for dissolved pollutants, such as soluble phosphorus, nitrate, and chloride. Table 1 summarizes some pollutant removal efficiencies for vegetated swales.

TABLE 1 EFFECTIVENESS OF DESIGN SWALES

Pollutant	Median % Removal
Total Suspended Solids	81
Oxygen Demanding Substances	67
Nitrate	38
Total Phosphorus	9
Hydrocarbons	62
Cadmium	42
Copper	51
Lead	67
Zinc	71

The effectiveness of vegetated swales can be enhanced by adding check dams at approximately 17 meter (50 foot) increments along their length (See Figure 1). These dams maximize the retention time within the swale, decrease flow velocities, and promote particulate settling. Structures to skim off floating debris may also be added to the swales. Finally, the incorporation of vegetated filter strips parallel to the top of the channel banks can help to treat sheet flows entering the swale.

OPERATION AND MAINTENANCE

The useful life of a vegetated swale system is directly proportional to its maintenance frequency. If properly designed and regularly maintained, vegetated swales can last indefinitely.

The maintenance objectives for vegetated swale systems include keeping up the hydraulic and removal efficiency of the channel and maintaining a dense, healthy grass cover. Maintenance activities should include periodic mowing (with grass never cut shorter than the design flow depth), weed control, watering during drought conditions, reseeding of bare areas, and clearing of debris and blockages. Cuttings should be removed from the channel and disposed in a local composting facility. Accumulated sediment should also be removed manually to avoid the transport of resuspended sediments in periods of low flow and to prevent a damming effect from sand bars. The application of fertilizers and pesticides should be minimal.

Another aspect of a good maintenance plan is repairing damaged areas within a channel. For example, if the channel develops ruts or holes, it should be repaired utilizing a suitable soil that is properly tamped and seeded. The grass cover should be thick; if it is not, reseed as necessary.

Any standing water removed during the maintenance operation must be disposed to a sanitary sewer at an approved discharge location. Residuals (e.g., silt, grass cuttings) must be disposed in accordance with local or State requirements.

COSTS

Vegetated swales typically cost less to construct than curbs and gutters or underground storm sewers. Schueler (1987) reported that costs may vary from $16-$30 per linear meter ($4.90 to $9.00 per linear foot) for a 4.5 meter (15-foot) wide channel (top width).

The Southeastern Wisconsin Regional Planning Commission (SEWRPC, 1991) reported that costs may vary from $28 to $164 per linear meter ($8.50 to $50.00 per linear foot) depending upon swale depth and bottom width. These cost estimates are higher than other published estimates because they include the cost of activities (such as clearing, grubbing, leveling, filling, and sodding) that may not be included in other published estimates. Construction costs depend on specific site considerations and local costs for labor and materials. Table 2 shows the estimated capital costs of a vegetated swale.

Annual costs for maintaining vegetated swales are approximately $1.90 per linear meter ($0.58 per linear foot) for a 0.5 meter (1.5-foot) deep channel, according to SEWRPC (1991). Average annual operating and maintenance costs of vegetated swales can be estimated using Table 3.

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TABLE 2 ESTIMATED CAPITAL COST OF A 1.5- FOOT DEEP, 10-FOOT-WIDE GRASSED SWALES[a]

Component	Unit	Extent	Unit Cost			Total Cost		
			Low	Moderate	High	Low	Moderate	High
Mobilization / Demobilization-Light	Swale	1	$107	$274	$441	$107	$274	$441
Site Preparation								
Clearing[b]...............	Acre	0.5	$2,200	$3,800	$5,400	$1,100	$1,900	$2,700
Grubbing[c].............	Acre	0.25	$3,800	$5,200	$6,600	$950	$1,300	$1,650
General Excavation[d]...........	Yd^3	372	$2.10	$3.70	$5.30	$781	$1,376	$1,972
Level and Till[e]........	Yd^2	1,210	$0.20	$0.35	$0.50	$242	$424	$605
Sites Development								
Salvaged Topsoil Seed, and Mulch[f]..	Yd^2	1,210	$0.40	$1.00	$1.60	$484	$1,210	$1,936
Sod[g].....................	Yd^2	1,210	$1.20	$2.40	$3.60	$1,452	$2,904	$4,356
Subtotal	--	--	--	--	--	$5,116	$9,388	$13,660
Contingencies	Swale	1	25%	25%	25%	$1,279	$2,347	$3,415
Total	--	--	--	--	--	$6,395	$11,735	$17,075

Source: (SEWRPC, 1991)

Note: Mobilization/demobilization refers to the organization and planning involved in establishing a vegetative swale.

[a] Swale has a bottom width of 1.0 foot, a top width of 10 feet with 1:3 side slopes, and a 1,000-foot length.

[b] Area cleared = (top width + 10 feet) x swale length.

[c] Area grubbed = (top width x swale length).

[d] Volume excavated = (0.67 x top width x swale depth) x swale length (parabolic cross-section).

[e] Area tilled = $\left(\text{top width} + \frac{8(\text{swale depth}^2)}{3(\text{top width})}\right)$ x swale length (parabolic cross-section).

[f] Area seeded = area cleared x 0.5.

[g] Area sodded = area cleared x 0.5.

TABLE 3 ESTIMATED OPERATION AND MAINTENANCE COSTS

Component	Unit Cost	Swale Size (Depth and Top Width)		Comment
		1.5 Foot Depth, One-Foot Bottom Width, 10-Foot Top Width	3-Foot Depth, 3-Foot Bottom Width, 21-Foot Top Width	
Lawn Mowing	$0.85 / 1,000 ft^2/ mowing	$0.14 / linear foot	$0.21 / linear foot	Lawn maintenance area=(top width + 10 feet) x length. Mow eight times per year
General Lawn Care	$9.00 / 1,000 ft^2/ year	$0.18 / linear foot	$0.28 / linear foot	Lawn maintenance area = (top width + 10 feet) x length
Swale Debris and Litter Removal	$0.10 / linear foot / year	$0.10 / linear foot	$0.10 / linear foot	--
Grass Reseeding with Mulch and Fertilizer	$0.30 / yd^2	$0.01 / linear foot	$0.01 / linear foot	Area revegetated equals 1% of lawn maintenance area per year
Program Administration and Swale Inspection	$0.15 / linear foot / year, plus $25 / inspection	$0.15 / linear foot	$0.15 / linear foot	Inspect four times per year
Total	**--**	**$0.58 / linear foot**	**$ 0.75 / linear foot**	**--**

Source: SEWPRC, 1991.

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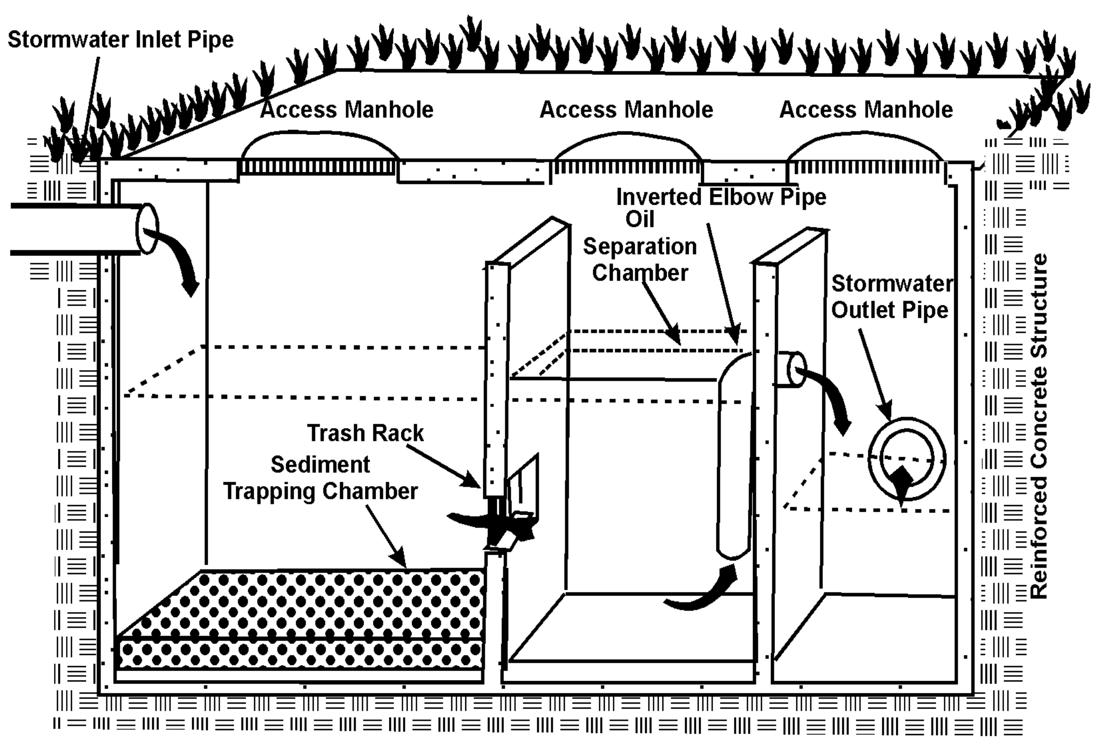
United States Environmental Protection Agency
Office of Water Washington, D.C.
EPA 832-F-99-029 September 1999

Storm Water Technology Fact Sheet
Water Quality Inlets

DESCRIPTION

Water quality inlets (WQIs), also commonly called oil/grit separators or oil/water separators, consist of a series of chambers that promote sedimentation of coarse materials and separation of free oil (as opposed to emulsified or dissolved oil) from storm water. Most WQIs also contain screens to help retain larger or floating debris, and many of the newer designs also include a coalescing unit that helps to promote oil/water separation. WQIs typically capture only the first portion of runoff for treatment and are generally used for pretreatment before discharging to other best management practices (BMPs).

A typical WQI, as shown in Figure 1, consists of a sedimentation chamber, an oil separation chamber, and a discharge chamber. The basic WQI design is often modified to improve performance. Possible



Source: Berg, 1991.

FIGURE 1 PROFILE OF A TYPICAL WATER QUALITY INLET

modifications include: an additional orifice and chamber that replace the inverted pipe elbow; the extension of the second chamber wall up to the top of the structure; or the addition of a diffusion device at the inlet. The diffusion device is intended to dissipate the velocity head and turbulence and distribute the flow more evenly over the entire cross-sectional area of the sedimentation chamber (API, 1990).

The addition of a coalescing unit to the WQI can dramatically increase its effectiveness in oil/water separation while also greatly reducing the size of the required unit. Coalescing units are made from oil-attracting materials, such as polypropylene or other materials. These units attract small oil droplets, which begin to concentrate until they are large enough to float to the surface and separate from the storm water. Without these units, the oil and grease particles must concentrate and separate naturally. This requires a much larger surface area; and therefore, units that do not use the coalescing process must be larger than units utilizing a coalescing unit.

WQIs can be purchased as pre-manufactured units (primarily oil/water separator tanks) or constructed on site. Suppliers of pre-manufactured units (e.g., Highland Tank and Manufacturing, Jay R. Smith Manufacturing, etc.) can also provide modifications of the typical design for special conditions.

APPLICABILITY

WQIs are widely used in the U.S. and can be adapted to all regions of the country. They are often used where land requirements and cost prohibit the use of larger BMP devices, such as ponds or wetlands. WQIs are also used to treat runoff prior to discharge to other BMPs.

Because of their ability to remove hydrocarbons, WQIs are typically located at sites with automotive-related contamination or at other sites that generate high hydrocarbon concentrations (MWCOG, 1993). For example, WQIs may be ideal for small, highly impervious areas, such as gas stations, loading areas, or parking areas (Schueler, 1992). Many WQIs, particularly those installed at industrial sites, serve the dual purpose of treating storm water runoff from contaminated areas, and serving as collection and treatment units for washdown processes or petroleum spills.

Higher residual hydrocarbon concentrations in trapped sediments cause maintenance and residual disposal costs associated with WQIs to be higher than those of other BMPs. Therefore, planners should carefully evaluate maintenance and residual disposal issues for the site before selecting a WQI. Possible alternatives to the WQI include sand filters, oil absorbent materials, and other innovative BMPs (e.g., Stormceptor System).

ADVANTAGES AND DISADVANTAGES

WQIs can effectively trap trash, debris, oil and grease, and other floatables that would otherwise be discharged to surface waters (Schueler, 1992). In addition, a properly designed and maintained WQI can serve as an effective BMP for reducing hydrocarbon contamination in receiving water sediments. While WQIs are effective in removing heavy sediments and floating oil and grease, they have demonstrated limited ability to separate dissolved or emulsified oil from runoff. WQIs are also not very effective at removing pollutants such as nutrients or metals, except where the metals removal is directly related to sediment removal.

Several major constraints can limit the effectiveness of WQIs. The first is the size of the drainage area. WQIs are generally recommended for drainage areas of 0.4 hectares (1 acre) or less (Berg, 1991, NVPDC, 1992). Construction costs often become prohibitive for larger drainage areas. However, because WQIs are primarily designed for specific industrial sites that have the potential for petroleum-contaminated process washdown, spills, and storm water runoff, sizing considerations are not usually a problem.

Sediment can also cause problems for WQIs. There are several reasons for this. First, high sediment loads can interfere with the ability of the WQI to effectively separate oil and grease from the runoff. Second, during periods of high flow, sediment residuals may be resuspended and released from the WQI to surface waters. A 1993 Metropolitan Washington Council of Governments (MWCOG) long-term study evaluating the performance and effectiveness of more than 100 WQIs found that pollutants in the WQI sediments were similar to those pollutants found in downstream receiving water sediments (the tidal Anacostia River). This information suggests that downstream sediment contamination is linked to contaminated runoff and pass-through from WQIs (MWCOG, 1993). Third, WQI residuals accumulate quickly and require frequent removal. There is also some concern that because the collected residuals contain hydrocarbon by-products, the residuals may be considered too toxic for conventional landfill disposal. The 1993 MWCOG study found that the residuals from WQIs typically contain many priority pollutants, including polyaromatic hydrocarbons, trace metals, phthalates, phenol, toluene, and possibly methylene chloride (MWCOG, 1993). Based on these considerations, WQIs should not be implemented at sites that generate large amounts of sediment in the runoff unless the runoff has been pretreated to reduce the sediment loads to manageable levels.

WQIs are also limited by maintenance requirements. Maintenance of underground WQIs can be easily neglected because the WQI is often "out of sight and out of mind." Regular maintenance is essential to ensuring effective pollutant removal. As discussed above, lack of maintenance will often result in resuspension of settled pollutants.

Finally, WQIs generally provide limited hydraulic and residuals storage. Due to the limited storage, WQIs do not provide adequate storm water quantity control.

DESIGN CRITERIA

Prior to WQI design, the site should be evaluated to determine if another BMP would be more cost-effective in removing the pollutants of concern. WQIs should be used when no other BMP is feasible. The WQI should be constructed near a storm drain network so that flow can be easily diverted to the WQI for treatment (NVPDC, 1992). Any construction activities within the drainage area should be completed before installation of the WQI, and the drainage area should be revegetated so that the sediment loading to the WQI is minimized. Upstream sediment control measures should be implemented to decrease sediment loading.

WQIs are most effective for small drainage areas. Drainage areas of 0.4 hectares (1 acre) or less are often recommended. WQIs are typically used in an off-line configuration (i.e., portions of runoff are diverted to the WQI), but they can be used as on-line units (i.e., receive all runoff). Generally, off-line units are designed to handle the first 1.3 centimeters (0.5 inches) of runoff from the drainage areas. Upstream isolation/diversion structures can be used to divert the water to the off-line structure (Schueler, 1992). On-line units receive higher flows that will likely cause increased turbulence and resuspension of settled material, thereby reducing WQI performance.

As discussed above, oil/water separation tank units are often utilized in specific industrial areas, such as airport aprons, equipment washdown areas, or vehicle storage areas. In these instances, runoff from the area of concern will usually be diverted directly into the unit, while all other runoff is sent to the storm drain downstream from the oil/water separator. Oil/water separation tanks are often fitted with diffusion baffles at the inlets to prevent turbulent flow from entering the unit and resuspending settled pollutants.

WQIs are available as pre-manufactured units or can be cast in place. Reinforced concrete should be used to construct below-grade WQIs. The WQIs should be water tight to prevent possible ground water contamination.

Chamber Design

Structural loadings should be considered in the WQI design (Berg, 1991), particularly with respect to the sizing of the chambers. When the combined length of the first two chambers exceeds 4 meters (12 feet), the chambers are typically designed with the length of the first and second chamber being two-thirds and one-third of the combined length of the unit, respectively. Each of the chambers should have a separate manhole to provide access for cleaning and inspection.

The State of Maryland design standards indicate that the combined volume of the first and second chambers should be determined based on 1.1 cubic meters (40 cubic feet) per 0.04 hectares (0.10 acres) draining to the WQI. In Maryland, this is equivalent to capturing the first 0.33 centimeters (0.133 inches) of runoff from the contributing drainage area.

Permanent pools within the chambers help prevent the possibility of sediment resuspension. The first and second chambers should have permanent pools with depths of 1.2 meters (4 feet). If possible, the third chamber should also contain a permanent pool (NVPDC, 1992).

The first and second chambers are generally connected by an opening covered by a trash rack, a PVC pipe, or other suitable material pipe (Berg, 1991). If a pipe is used, it should also be covered by a trash rack or screen. The opening or pipe between the first and second chambers should be designed to pass the design storm without surcharging the first chamber (Berg, 1991). The design storm will vary depending on geographical location and is generally defined by local regulations.

In the standard WQI, an inverted elbow is installed between the second and third chamber. The elbow should extend a minimum of 1 meter (3 feet) into the second chamber's permanent pool. Because oil will naturally separate from, and float on top of, the water, water will be forced through the submerged elbow and into the third chamber while oil will be retained in the second chamber (NVPDC, 1992). The depth of the elbow into the permanent pool should should be. The size of the elbow or the number of elbows can be adjusted to accommodate the design flow and prevent discharge of accumulated oil(Berg, 1991).

Pre-manufactured oil/water separation tanks do not usually follow the separated-chamber design; instead, these units often rely on baffle units to separate the different removal process. Particulates are thus retained near the inlet to the tank, while oil/water separation takes place closer to the tank outlet.

PERFORMANCE

WQIs are primarily utilized to remove sediments from storm water runoff. Grit and sediments are partially removed by gravity settling within the first two chambers. A WQI with a detention time of 1 hour may expect to have 20 to 40 percent removal of sediments. Hydrocarbons associated with the accumulated sediments are also often removed from the runoff through this process. The WQI achieves slight, if any, removal of nutrients, metals and organic pollutants other than free petroleum products (Schueler, 1992).

The 1993 MWCOG study discussed above found that an average of less than 5 centimeters (2 inches) of sediments (mostly coarse-grained grit and organic matter) were trapped in the WQIs. Hydrocarbon and total organic carbon (TOC) concentrations of the sediments averaged 8,150 and 53,900 milligrams per kilogram, respectively. The mean hydrocarbon concentration in the WQI water column was 10 milligrams per liter. The study also indicated that sediment accumulation did not increase over time, suggesting that the sediments become re-suspended during storm events. The authors concluded that although the WQI effectively separates oil and grease from water, re-suspension of the settled matter appears to limit removal efficiencies. Actual removal only occurs when the residuals are removed from the WQI (Schueler 1992).

A 1990 report by API found that the efficiency of oil and water separation in a WQI is inversely proportional to the ratio of the discharge rate to the unit's surface area. Due to the small capacity of the WQI, the discharge rate is typically very high and the detention time is very short. For example, the MWCOG study found that the average detention time in a WQI is less than 0.5 hour. This can result in minimal pollutant settling (API, 1990). However, the addition of coalescing units in many current WQI units may increase oil/water separation efficiency. Most coalescing units are designed to achieve a specific outlet concentration of oil and grease (for example, 10-15 parts per million oil and grease).

OPERATION AND MAINTENANCE

The key to the performance of WQIs is maintenance. When properly maintained, WQIs should experience very few separation, clogging, or structural problems.

Basic maintenance should consist of regularly checking and cleaning out the sediment that has accumulated in the WQI. A lack of regular clean-outs can lead to the resuspension of collected sediments; therefore, WQIs should be inspected after every storm event to determine if maintenance is required. At a minimum, each WQI should be cleaned at the beginning of each season (Berg, 1991). The required maintenance will be site-specific due to variations in sediment and hydrocarbon loading. Maintenance should include clean out, disposal of the sediments, and removal of trash and debris. The clean out and disposal techniques should be environmentally acceptable and in accordance with local regulations. Since WQI residuals contain hydrocarbon by-products, they may require disposal as hazardous waste. Many WQI owners coordinate with waste haulers to collect and dispose of these residuals. Since WQIs can be relatively deep, they may be designated as confined spaces. Caution should be exercised to comply with confined space entry safety regulations if it is required.

Oil/water separator tank units can be fitted with sensing units that will indicate when the units need to be cleaned. Because most of oil/water separator tank units are designed for specific industrial applications, their maintenance schedule should be closely tied to the industrial process schedule. However, these units should also be inspected after rain events.

COSTS

The construction costs for WQIs will vary greatly depending on their size and depth. The construction costs (in 1993 dollars) for cast-in-place WQIs range from $5,000 to $16,000, with the average WQI costing around $8,500 (Schueler, 1992). For the basic design and construction of WQIs, the pre-manufactured units are generally less expensive than those that are cast in place (Berg, 1991).

Maintenance costs will also vary greatly depending on the size of the drainage area, the amount of the residuals collected, and the clean out and disposal methods available (Schueler, 1992). The cost of residuals removal, analysis, and disposal can be a major maintenance expense, particularly if the residuals are toxic and are not suitable for disposal in a conventional landfill.

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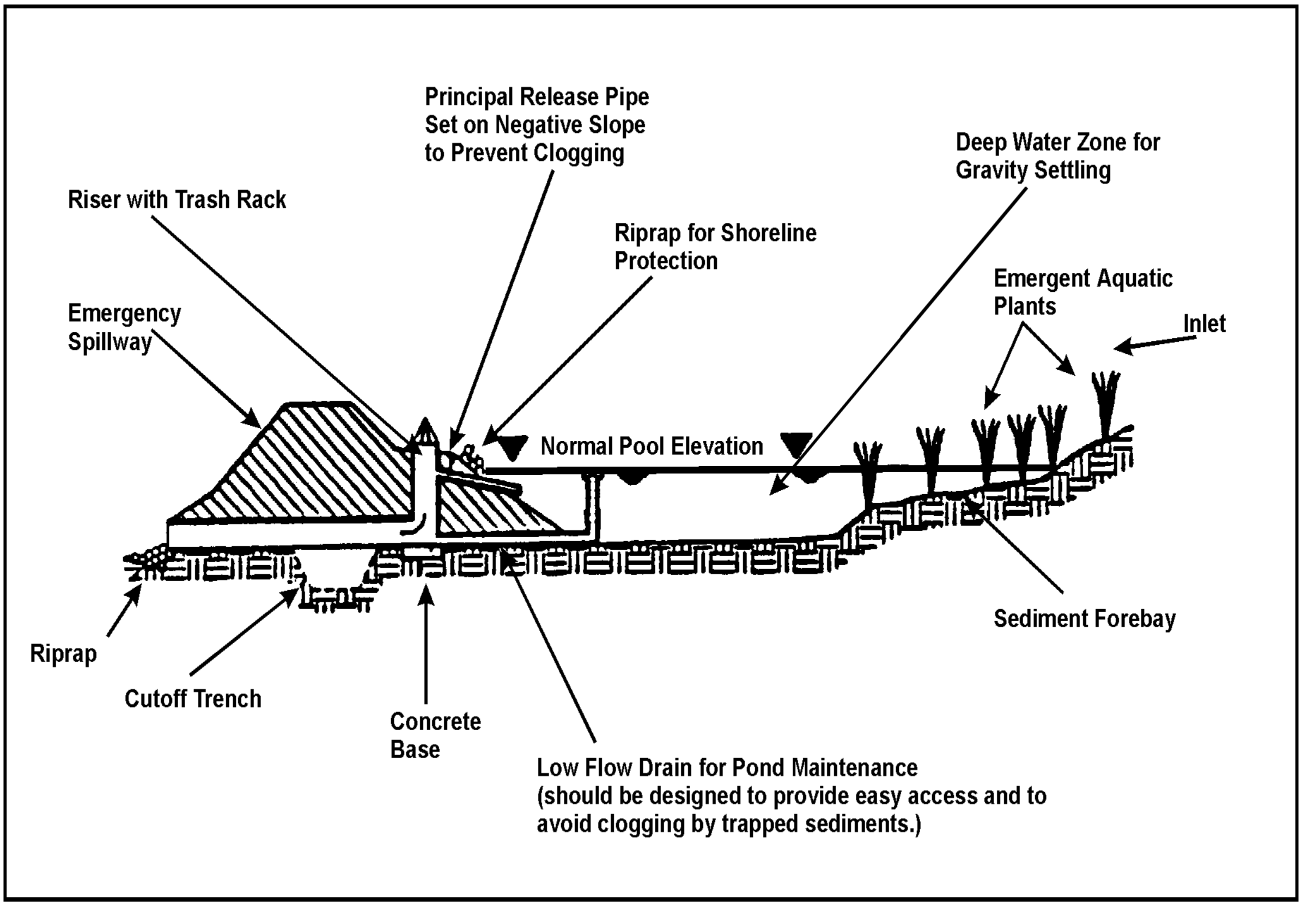
United States Environmental Protection Agency
Office of Water Washington, D.C.
EPA 832-F-99-048 September 1999

Storm Water Technology Fact Sheet
Wet Detention Ponds

DESCRIPTION

Wet detention ponds are storm water control structures providing both retention and treatment of contaminated storm water runoff. A typical wet detention pond design is shown in Figure 1. The pond consists of a permanent pool of water into which storm water runoff is directed. Runoff from each rain event is detained and treated in the pond until it is displaced by runoff from the next storm. By capturing and retaining runoff during storm events, wet detention ponds control both storm water quantity and quality. The pond's natural physical, biological, and chemical processes then work to remove pollutants. Sedimentation processes remove particulates, organic matter, and metals, while dissolved metals and nutrients are removed through biological uptake. In general, a higher level of nutrient removal and better storm water quantity control can be achieved in wet



Source: Maryland Department of the Environment, 1986.

FIGURE 1 TYPICAL LAYOUT OF A WET DETENTION POND

detention ponds than can be achieved with other Best Management Practices (BMPs), such as dry ponds, infiltration trenches, or sand filters.

There are several common modifications that can be made to the ponds to increase their pollutant removal effectiveness. The first is to increase the settling area for sediments through the addition of a sediment forebay, as shown in Figure 1. Heavier sediments will drop out of suspension as runoff passes through the sediment forebay, while lighter sediments will settle out as the runoff is retained in the permanent pool. A second common modification is the construction of shallow ledges along the edge of the permanent pool. These shallow peripheral ledges can be used to establish aquatic plants that can impede flow and trap pollutants as they enter the pond. The plants also increase biological uptake of nutrients. In addition to their function as aquatic plant habitat, the ledges also have several other functions, which can include including acting as a safety precaution to prevent accidental drowning and providing easy access to the permanent pool to aid in maintenance. Finally, perimeter wetland areas can also be created around the pond to aid in pollutant removal.

APPLICABILITY

Wet detention ponds have been widely used throughout the U.S. for many years. Many of these ponds have been monitored to determine their performance. EPA Region V is currently performing a study on the effectiveness of 50 to 60 wet detention ponds. Other organizations, such as the Washington, D.C., Council of Governments (WMCOG) and the Maryland Department of the Environment, have also conducted extensive evaluations of wet detention pond performance.

ADVANTAGES AND DISADVANTAGES

Wet detention ponds provide both storm water quantity and quality benefits, and provide significant retrofit coverage for existing development. Benefits include decreased potential for downstream flooding and stream bank erosion and improved water quality due to the removal of suspended solids, metals, and dissolved nutrients.

While the positive impacts from a wet detention ponds will generally exceed any negative impacts, wet detention ponds that are improperly designed, sited, or maintained, may have potential adverse affects on water quality, groundwater, cold water fisheries, or wetlands. Improperly designed or maintained ponds may result in stratification and anoxic conditions that can promote the resuspension of solids and the release of nutrients and metals from the trapped sediments. In addition, precautions should be taken to prevent damage to wetland areas during pond construction. Finally, the potential for groundwater contamination should be carefully evaluated. However, studies to date indicate that wet detention ponds do not significantly contribute to groundwater contamination (Schueler, 1992).

The following limitation should also be considered when determining the feasibility of installing a wet detention pond:

1. Wet detention ponds must be able to maintain a permanent pool of water. Therefore, ponds cannot be constructed in areas where there is insufficient precipitation to maintain the pool or in soils that are highly permeable. In wetter regions, a small drainage area may be sufficient to ensure that there is enough water to maintain a permanent pool; whereas in more arid regions, a larger drainage area may be required. In some cases, soils that are highly permeable may be compacted or overlaid with clay blankets to make the bottom less permeable.

2. Land constraints, such as small sites or highly developed areas, may preclude the installation of a pond.

3. Discharges from ponds usually consist of warm water, and thus pond use may be limited in areas where warm water discharges from the pond will adversely impact a cold water fishery.

4. The local climate (i.e., temperature) may affect the biological uptake in the pond.

5. Without proper maintenance, the performance of the pond will drop off sharply. Regular cleaning of the forebays is particularly important. Maintaining the permanent pool is also important in preventing the resuspension of trapped sediments. The accumulation of sediments in the pond will reduce the pond's storage capacity and cause a decline in its performance. Therefore, the bottom sediments in the permanent pool should be removed about every 2 to 5 years. In most cases, no specific limitations have been placed on disposal of sediments removed from wet detention ponds. Studies to date indicate that pond sediments are likely to meet toxicity limits and can be safely landfilled (NVPDC, 1992). Some states have allowed sediment disposal on-site, as long as the sediments are deposited away from the shoreline to prevent their re-entry into the pond.

DESIGN CRITERIA

In general, pond designs are unique for each site and application. Criteria for selecting the site for installation of the pond should include the site's ability to support the pond environment, as well as the cost effectiveness of locating a pond at that specific site. In addition, the pond should be located where the topography of the site allows for maximum storage at minimum construction costs (NVPDC, 1992). Site-specific constraints for pond construction may include wetlands impacts, existing utilities (e.g., electric or gas) that would be costly to relocate, and underlying bedrock that would require expensive blasting operations to excavate.

The site must have adequate base-flow from the groundwater or from the drainage area to maintain the permanent pool. Typically, underlying soils with permeabilities of between 10^{-5} and 10^{-6} cm/sec will be adequate to maintain a permanent pool.

All local, state and federal permit requirements should be established prior to initiating the pond design. Depending on the location of the pond, required permits and certifications may include wetland permits, water quality certifications, dam safety permits, sediment and erosion control plans, waterway permits, local grading permits, land use approvals, etc.(Schueler, 1992). Since many states and municipalities are still in the process of developing or modifying storm water permit requirements, the applicable requirements should be confirmed with the appropriate regulatory authorities.

Wet detention ponds should be designed to meet both storm water quality and quantity control requirements. Storm water quantity requirements are typically met by designing the pond to control post-development peak discharge rates to pre-development levels. Usually the pond is designed to control multiple design storms (e.g. 2- and/or 10-year storms) and safely pass the 100-year storm event. However, the design storm may vary depending on local conditions and requirements.

Storm water quality control is achieved through pollutant removal in the permanent pool. Removal efficiency is primarily dependent on the length of time that runoff remains in the pond, which is known as the pond's Hydraulic Residence Time (HRT). As discussed above, wet detention ponds remove pollutants through both sedimentation and biological uptake processes, both of which increase with the length of time runoff remains in the pond. These processes can be modeled to determine a design HRT using either the solids settling method or the eutrophication method, respectively (Hartigan, 1988).

The calculated HRT will be dependent on the method selected. HRTs calculated by the eutrophication method can be up to three times greater than HRTs calculated by the solids settling method. The longer HRTs associated with the eutrophication method appear to be due to the slower reaction rates associated with the biological removal of dissolved nutrients (Hartigan, 1988).

Once the design HRT has been determined, the actual dimensions of the pond must be calculated to achieve the design HRT. The primary factor contributing to a pond's HRT is its volume. Because many wet detention ponds are restricted in area, pond depth can be an important factor in the pond's overall volume. However, the depth of the pool also affects many of the pond's removal processes, and so it must be carefully controlled. It is important to maintain a sufficient permanent pool depth in order to prevent the resuspension of trapped sediments (NVPDC, 1992). Conversely, thermal stratification and anoxic conditions in the bottom layer might develop if permanent pool depths are too great. Stratification and anoxic conditions may decrease biological activity. Anoxic conditions may also increase the potential for the release of phosphorus and heavy metals from the pond sediments (NVPDC, 1992). These factors dictate that the permanent pool depth should not exceed 6 meters (20 feet). The optimal depth ranges between 1 and 3 meters (3 and 9 feet) for most regions, given a 2 week HRT (Hartigan, 1988).

Other key factors to be considered in the pond design are the volume and area ratios. The volume ratio, VB/VR, is the ratio of the permanent pool storage (VB) to the mean storm runoff (VR). Larger VBs and smaller VRs provide for increased retention and treatment between storm events. Low VB/VR ratios result in poor pollutant removal efficiencies.

The area ratio, A/As, is the ratio of the contributing drainage area (A) to the permanent pool surface area (As). The area ratio is also an indicator of pollutant removal efficiency. Data from previous studies indicates that area ratios of less than 100 typically have better pollutant removal efficiencies (MD DEQ, 1986).

The contours of the pond are also important. The pond should be constructed with adequate slopes and lengths. While a length-to-width ratio is usually not used in the design of wet detention ponds for storm water quantity management, a 2:1 length-to-width ratio is commonly used when water quality is of concern. In general, high length-to-width ratios (greater than 2:1) will decrease the possibility of short-circuiting and will enhance sedimentation within the permanent pool. Baffles or islands can also be added within the permanent pool to increase the flow path (Hartigan, 1988). Shoreline slopes between 5:1 and 10:1 are common and allow easy access for maintenance, such as mowing and sediment removal (Hartigan, 1988). In addition, wetland vegetation is difficult to establish and maintain on slopes steeper than 10:1. Ponds should be wedge-shaped so that flow enters the pond and gradually spreads out. This minimizes the potential for zones with little or no flow (Urbonas, 1993).

The design of the wet pond embankment is another key factor to be considered. Proper design and construction of the embankments will prolong the integrity of the pond structure. Subsidence and settling will likely occur after an embankment is constructed. Therefore during construction, the embankment should be overfilled by at least 5 percent (SEWRPC, 1991). Seepage through the embankment can also affect the stability of the structure. Seepage can generally be minimized by adding drains, anti-seepage collars, and core trenches. The embankment side slopes can be protected from erosion by using minimum side slopes of 2:1 and by covering the embankment with vegetation or rip-rap. The embankment should also have a minimum top width of 2 meters (6 feet) to aid in maintenance.

Finally, the internal flow control of the pond must be considered. Discharge from the pond is controlled by a riser and an inverted release pipe. Normal flows will be discharged through the wet pond outlet, which consists of a concrete or corrugated metal riser and barrel. The riser is a vertical pipe or inlet structure that is attached to the base with a watertight connection. Risers are typically placed in or adjacent to the embankment rather than in the middle of the pond. This provides easy access for maintenance and prevents the use of the riser as a recreation spot (e.g. diving platform for kids) (Schueler, 1988). The barrel is a horizontal pipe attached to the riser that conveys flow under the embankment.

Typically, flow passes through an inverted pipe attached to the riser, as shown in Figure 1, while higher flows will pass through a trash rack installed on the riser. The inverted pipe should discharge water from below the pond water surface to prevent floatables from clogging the pipe and to avoid discharging the warmer surface water. Clogging of the pipe could result in overtopping of the embankment and damage to the embankment (NVPDC, 1992). Flow is conveyed through the near horizontal barrel and is discharged to the receiving stream. Rip-rap, plunge pools, or other energy dissipators, should be placed at the outlet to prevent scouring and to minimize erosion. Rip-rap also provides a secondary benefit of re-aeration of the pond discharges.

Planners should consider both the design storm and potential construction materials when designing and constructing the riser and barrel. Generally, the riser and barrel are sized to meet the storm water management design criteria (e.g. to pass a 2-year or a 10-year storm event). In many installations, the riser and barrel are designed to convey multiple design storms (Urbonas, 1993). To increase the life of the outlet, the riser and barrel should be constructed of reinforced concrete rather than corrugated metal pipe (Schueler, 1992). The riser, barrel, and base should also provide have sufficient weight to prevent flotation (NVPDC, 1992).

In most cases, emergency spillways should be included in the pond design. Emergency spillways should be sized to safely pass flows that exceed the design storm flows. The spillway prevents pond water levels from overtopping the embankment, which could cause structural damage to the embankment. The emergency spillway should be located so that downstream buildings and structures will not be negatively impacted by spillway discharges. The pond design should include a low flow drain, as shown in Figure 1. The drain pipe should be designed for gravity discharge and should be equipped with an adjustable gate valve.

PERFORMANCE

The primary pollutant removal mechanism in a wet detention pond is sedimentation. Significant loads of suspended pollutants, such as metals, nutrients, sediments, and organics, can be removed by sedimentation. Other pollutant removal mechanisms include algal uptake, wetland plant uptake, and bacterial decomposition (Schueler, 1992). Dissolved pollutant removal also occurs as a result of biological and chemical processes (NVPDC, 1992).

The removal rates of conventional wet detention ponds (i.e., without the sediment forebay or peripheral ledges) are well documented and are shown in Table 1. The wide range in the removal rates is a result of varying hydraulic residence times (HRTs), which is further discussed in the Design Criteria section. Increased pollutant removal by biological uptake and sedimentation is correlated with increased HRTs. Proper design and maintenance also effect pond performance.

Studies have shown that more than 90 percent of the pollutant removal occurs during the quiescent period (the period between the rainfall events) (MD DEQ, 1986). However, some removal occurs during the dynamic period (when the runoff enters the pond). Modeling results have indicated that two-thirds of the sediment, nutrients and trace metal loads are removed by sedimentation within 24

TABLE 1 REMOVAL EFFICIENCIES FROM WET DETENTION PONDS

Parameter	Percent Removal	
	Schueler, 1992	Hartigan, 1988
Total Suspended Solid	50-90	80-90
Total Phosphorus	30-90	
Soluble Nutrients	40-80	50-70
Lead	70-80	
Zinc	40-50	
Biochemical Oxygen Demand or Chemical Oxygen Demand	20-40	

1 hydraulic residence time varies
2 hydraulic residence time of 2 weeks

Source: Schueler, 1992 & MD DEQ, 1986.

hours. These projections are supported by the results of the EPA's 1993 National Urban Runoff Program (NURP) studies. However, other studies indicate that an HRT of two weeks is required to achieve significant phosphorus removal (MD DEQ, 1986).

The pond's treatment efficiency can be enhanced by extending the detention time in the permanent pool to up to 40 hours. This allows for a more gradual release of collected runoff, resulting in both increased pollutant removal and control of peak flows (Hartigan, 1988).

OPERATION AND MAINTENANCE

Wet detention ponds function more effectively when they are regularly inspected and maintained. Routine maintenance of the pond includes mowing of the embankment and buffer areas and inspection for erosion and nuisance problems (e.g. burrowing animals, weeds, odors) (SEWRPC, 1991). Trash and debris should be removed routinely to maintain an attractive appearance and to prevent the outlet from becoming clogged. In general, wet detention ponds should be inspected after every storm event. The embankment and emergency spillway should also be routinely inspected for structural integrity, especially after major storm events. Embankment failure could result in severe downstream flooding. When any problems are observed during routine inspections, necessary repairs should be made immediately. Failure to correct minor problems may lead to larger and more expensive repairs or even to pond failure. Typically, maintenance includes repairs to the embankment, emergency spillway, inlet, and outlet; removal of sediment; and control of algal growth, insects, and odors (SEWRPC, 1991). Large vegetation or trees that may weaken the embankment should be removed. Periodic maintenance may also include the stabilization of the outfall area (e.g. adding rip-rap) to prevent erosive damage to the embankment and the stream bank. In most cases, sediments removed from wet detention ponds are suitable for landfill disposal. However, where available, on-site use of removed sediments for soil amendment will reduce maintenance costs.

COSTS

Typical costs for wet detention ponds range from $17.50-$35.00 per cubic meter ($0.50-$1.00 per cubic foot) of storage area (CWP, 1998). The total cost for a pond includes permitting, design and construction, and maintenance costs. Permitting costs may vary depending on state and local regulations. Typically, wet detention ponds are less costly to construct in undeveloped areas than to retrofit into developed areas. This is due to the cost of land and the difficulty in finding suitable sites in developed areas. The cost of relocating pre-existing utilities or structures is also a major concern in developed areas. Several studies have shown the construction cost of retrofitting a wet detention pond into a developed area may be 5 to 10 times the cost of constructing the same size pond in an undeveloped area. Annual maintenance costs can generally be estimated at 3 to 5 percent of the construction costs (Schueler, 1992). Maintenance costs include the costs for regular inspections of the pond embankments, grass mowing, nuisance control, debris and liter removal, inlet and outlet maintenance and inspection, and sediment removal and disposal. Sediment removal cost can be decreased by as much as 50 percent if an on-site disposal areas are available (SEWRPC, 1991).

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GUIDANCE FOR SELECTION OF NATIVE PLANTS

The following lists of Native Plants are derived from the *Native Plant Guide for Streams and Stormwater Facilities in Northeastern Illinois* and are provided to aid in the selection of appropriate plantings. Additional information can be found in the *Native Plant Guide*. The suggested plant species mix lists which follow are intended to provide users with an idea of species that could be used together. These lists should NOT be used without consideration of the specific information provided within the *Native Plant Guide* for each species.

Stormwater Detention Basins, Upper Shoreline Zone (Saturated)

Scientific Name	Common Name
Alisma subcordatum	COMMON WATER PLANTAIN
Aster lanceolatus	PANICLED ASTER
Aster novae-angliae	NEW ENGLAND ASTER
Bidens cernua	NODDING BEGGARSTICKS
Bidens frondosa	COMMON BEGGARSTICKS
Calamagrostis canadensis	BLUE JOINT GRASS
Carex comosa	BRISTLY SEDGE
Carex cristatella	CRESTED OVAL SEDGE
Carex granularis	PALE SEDGE
Carex lanuginosa	WOOLY SEDGE
Carex stipata	AWL-FRUITED SEDGE
Carex vulpinoidea	FOX SEDGE
Celtis occidentalis	HACKBERRY
Cephalanthus occidentalis	COMMON BUTTONBUSH
Cornus racemosa	GRAY DOGWOOD
Cornus sericea	RED OSIER DOGWOOD
Cyperus esculentus	FIELD NUT SEDGE
Eleocharis obtusa	BLUNT SPIKE RUSH
Eleocharis smallii	CREEPING SPIKE RUSH
Elymus canadensis	NODDING WILD RYE
Elymus virginicus	VIRGINIA WILD RYE
Eupatorium maculatum	SPOTTED JOE PYE WEED
Eupatorium perfoliatum	COMMON BONESET
Glyceria striata	FOWL MANNA GRASS
Helenium autumnale	COMMON SNEEZEWEED
Helianthus grosseserratus	SAWTOOTH SUNFLOWER
Juncus effusus	COMMON RUSH
Juncus torreyi	TORREY'S RUSH
Leersia oryzoides	RICE CUT GRASS
Pycnanthemum virginianum	COMMON MOUNTAIN MINT
Quercus bicolor	SWAMP WHITE OAK
Salix amygdaloides	PEACHLEAF WILLOW
Salix nigra	BLACK WILLOW
Solidago gigantea	LATE GOLDENROD
Spartina pectinata	PRAIRIE CORDGRASS
Verbena hastata	BLUE VERVAIN
Vernonia fasciculata	COMMON IRON WEED
Viburnum lentago	NANNYBERRY

Stormwater Detention Basins, Lower Shoreline Zone (Emergent)

Scientific Name	Common Name
Acorus calamus	SWEET FLAG
Alisma subcordatum	COMMON WATER PLANTAIN
Cephalanthus occidentalis	COMMON BUTTONBUSH
Cyperus esculentus	FIELD NUT SEDGE
Iris virginica	BLUE FLAG IRIS
Juncus effusus	COMMON RUSH
Polygonum amphibium	WATER SMARTWEED
Sagittaria latifolia	BROADLEAF ARROWHEAD
Scirpus acutus	HARDSTEM BULRUSH
Scirpus americanus	CHAIRMAKER'S RUSH
Scirpus fluviatilis	RIVER BULRUSH
Scirpus tabernaemontani	SOFT-STEM BULRUSH
Sparganium eurycarpum	COMMON BURREED

Streambank Stabilization

Scientific Name	Common Name
Alisma subcordatum	COMMON WATER PLANTAIN
Carex vulpinoidea	FOX SEDGE
Celtis occidentalis	HACKBERRY
Cephalanthus occidentalis	COMMON BUTTONBUSH
Cornus racemosa	GRAY DOGWOOD
Cornus sericea	RED OSIER DOGWOOD
Eleocharis obtusa	BLUNT SPIKE RUSH
Eleocharis smallii	CREEPING SPIKE RUSH
Elymus canadensis	NODDING WILD RYE
Elymus virginicus	VIRGINIA WILD RYE
Fraxinus pennsylvanica	GREEN ASH
Glyceria striata	FOWL MANNA GRASS
Helenium autumnale	COMMON SNEEZEWEED
Leersia oryzoides	RICE CUT GRASS
Panicum virgatum	SWITCH GRASS
Salix amygdaloides	PEACHLEAF WILLOW
Salix nigra	BLACK WILLOW
Scirpus americanus	CHAIRMAKER'S RUSH
Solidago gigantea	LATE GOLDENROD
Spartina pectinata	PRAIRIE CORDGRASS
Verbena hastata	BLUE VERVAIN
Viburnum lentago	NANNYBERRY

Upland Slope Buffers-Stormwater Ponds & Streambanks

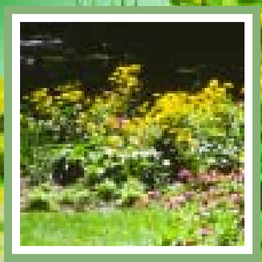
Scientific Name	**Common Name**
Andropogon gerardii	BIG BLUESTEM
Aster laevis	SMOOTH BLUE ASTER
Aster lanceolatus	PANICLED ASTER
Aster novae-angliae	NEW ENGLAND ASTER
Bidens frondosa	COMMON BEGGARSTICKS
Bouteloua curtipendula	SIDE-OATS GRAMA
Celtis occidentalis	HACKBERRY
Coreopsis tripteris	TALL COREOPSIS
Cornus racemosa	GRAY DOGWOOD
Cornus sericea	RED OSIER DOGWOOD
Elymus canadensis	NODDING WILD RYE
Elymus virginicus	VIRGINIA WILD RYE
Fraxinus pennsylvanica	GREEN ASH
Monarda fistulosa	WILD BERGAMOT
Panicum virgatum	SWITCH GRASS
Petalostemum purpureum	PURPLE PRAIRIE CLOVER
Pycnanthemum virginianum	COMMON MOUNTAIN MINT
Quercus bicolor	SWAMP WHITE OAK
Quercus macrocarpa	BUR OAK
Quercus palustris	PIN OAK
Ratibida pinnata	YELLOW CONE FLOWER
Rudbeckia hirta	BLACK-EYED SUSAN
Schizachyrium scoparium	LITTLE BLUESTEM
Silphium laciniatum	COMPASS PLANT
Silphium terebinthinaceum	PRAIRIE DOCK
Solidago rigida	STIFF GOLDENROD
Sorghastrum nutans	INDIAN GRASS
Spartina pectinata	PRAIRIE CORDGRASS
Tradescantia ohiensis	SPIDERWORT
Vernonia fasciculata	COMMON IRON WEED
Viburnum dentatum lucidum	ARROW WOOD VIBURNUM
Viburnum lentago	NANNYBERRY

Vegetated Swales

Scientific Name	Common Name
Acorus calamus	SWEET FLAG
Alisma subcordatum	COMMON WATER PLANTAIN
Aster lanceolatus	PANICLED ASTER
Bidens cernua	NODDING BEGGARSTICKS
Bidens frondosa	COMMON BEGGARSTICKS
Calamagrostis canadensis	BLUE JOINT GRASS
Carex cristatella	CRESTED OVAL SEDGE
Carex lanuginosa	WOOLY SEDGE
Carex stipata	AWL-FRUITED SEDGE
Carex vulpinoidea	FOX SEDGE
Eleocharis obtusa	BLUNT SPIKE RUSH
Elymus canadensis	NODDING WILD RYE
Elymus virginicus	VIRGINIA WILD RYE
Eupatorium maculatum	SPOTTED JOE PYE WEED
Eupatorium perfoliatum	COMMON BONESET
Glyceria striata	FOWL MANNA GRASS
Helenium autumnale	COMMON SNEEZEWEED
Helianthus grosseserratus	SAWTOOTH SUNFLOWER
Iris virginica	BLUE FLAG IRIS
Juncus effusus	COMMON RUSH
Juncus torreyi	TORREY'S RUSH
Leersia oryzoides	RICE CUT GRASS
Panicum virgatum	SWITCHGRASS
Pycnanthemum virginianum	COMMON MOUNTAIN MINT
Scirpus acutus	HARD STEM BULRUSH
Scirpus americanus	CHAIRMAKER'S RUSH
Scirpus fluviatilis	RIVER BULRUSH
Scirpus tabernaemontani	SOFT-STEM BULRUSH
Solidago gigantea	LATE GOLDENROD
Spartina pectinata	PRAIRIE CORDGRASS
Verbena hastata	BLUE VERVAIN

RAIN GARDENS

A how-to manual for homeowners



RAIN GARDENS

Your personal contribution to cleaner water

Homeowners in many parts of the country are catching on to rain gardens – landscaped areas planted to wild flowers and other native vegetation that soak up rain water, mainly from the roof of a house or other building. The rain garden fills with a few inches of water after a storm and the water slowly filters into the ground rather than running off to a storm drain. Compared to a conventional patch of lawn, a rain garden allows about 30% more water to soak into the ground.

Why are rain gardens important? As cities and suburbs grow and replace forests and agricultural land, increased stormwater runoff from impervious surfaces becomes a problem. Stormwater runoff from developed areas increases flooding; carries pollutants from streets, parking lots and even lawns into local streams and lakes; and leads to costly municipal improvements in stormwater treatment structures.

By reducing stormwater runoff, rain gardens can be a valuable part of changing these trends. While an individual rain garden may seem like a small thing, collectively they produce substantial neighborhood and community environmental benefits. Rain gardens work for us in several ways:

- Increasing the amount of water that filters into the ground, which recharges local and regional aquifers;
- Helping protect communities from flooding and drainage problems;
- Helping protect streams and lakes from pollutants carried by urban stormwater – lawn fertilizers and pesticides, oil and other fluids that leak from cars, and numerous harmful substances that wash off roofs and paved areas;
- Enhancing the beauty of yards and neighborhoods;
- Providing valuable habitat for birds, butterflies and many beneficial insects.

Who should use this manual?

This manual provides homeowners and landscape professionals with the information needed to design and build rain gardens on residential lots. Guidelines presented in this manual can also be used to treat roof runoff at commercial and institutional sites. However, the manual should not be used to design rain gardens for parking lots, busy streets and other heavily used paved areas where stormwater would require pretreatment before entering a rain garden.

Frequently asked questions

Does a rain garden form a pond?

No. The rain water will soak in so the rain garden is dry between rainfalls. (Note: some rain gardens can be designed to include a permanent pond, but that type of rain garden is not addressed in this publication).

Are they a breeding ground for mosquitoes?

No. Mosquitoes need 7 to 12 days to lay and hatch eggs, and standing water in the rain garden will last for a few hours after most storms. Mosquitoes are more likely to lay eggs in bird baths, storm sewers, and lawns than in a sunny rain garden. Also rain gardens attract dragonflies, which eat mosquitoes!

Do they require a lot of maintenance?

Rain gardens can be maintained with little effort after the plants are established. Some weeding and watering will be needed in the first two years, and perhaps some thinning in later years as the plants mature.

Is a rain garden expensive?

It doesn't have to be. A family and a few friends can provide the labor. The main cost will be purchasing the plants, and even this cost can be minimized by using some native plants that might already exist in the yard or in a neighbor's yard.

Step 1 Sizing and Siting the Rain Garden

This section of the manual covers rain garden basics – where to put the rain garden, how big to make it, how deep to dig it, and what kind of soils and slope are best. Following the instructions in this section is the best way to ensure a successful rain garden project.

An extension of PVC pipe helps direct downspout water to this rain garden.

If you already know the size you want your rain garden to be, then skip ahead to the section about building the rain garden. However, take time read the pointers about location, and do find the slope of the lawn. If the location has a slope more than about 12%, it's best to pick a different location because of the effort it will take to create a level rain garden.

Where should the rain garden go?

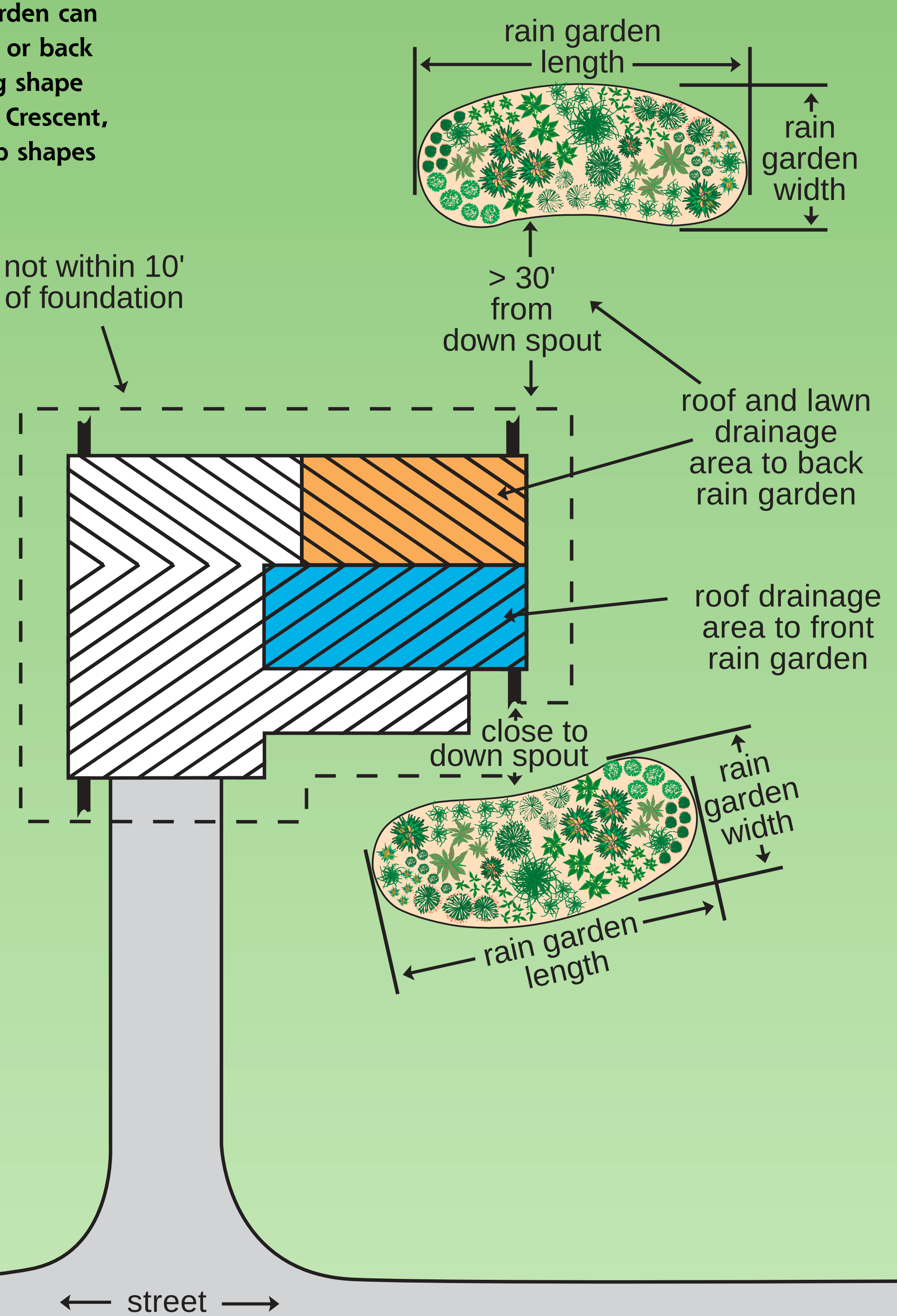
Home rain gardens can be in one of two places – near the house to catch only roof runoff or farther out on the lawn to collect water from the lawn and roof. (Figure 1 shows the possible locations on a residential lot.) To help decide where to put a rain garden, consider these points:

- The rain garden should be at least 10 feet from the house so infiltrating water doesn't seep into the foundation.
- Do not place the rain garden directly over a septic system.
- It may be tempting to put the rain garden in a part of the yard where water already ponds. Don't! The goal of a rain garden is to encourage infiltration, and your yard's wet patches show where infiltration is slow.
- It is better to build the rain garden in full or partial sun, not directly under a big tree.
- Putting the rain garden in a flatter part of the yard will make digging much easier. For example, a rain garden 10 feet wide on a 10% slope must be 12 inches deep to be level, unless you import topsoil or use cut and fill.

Consider your overall landscape

When considering placement of your rain garden, design with the end in mind. Carefully consider how the rain garden can be integrated into existing and future landscaping. Also, pay attention to views from inside the house as well as those throughout the landscape. Determine how far or how close you want your rain garden to outdoor gathering spaces or other play areas. Why not locate it near a patio where you can take advantage of the colors and fragrances for hours on end!

Figure 1 **A rain garden can be built in the front or back yard. Pick a pleasing shape for the rain garden. Crescent, kidney, and teardrop shapes seem to work well.**



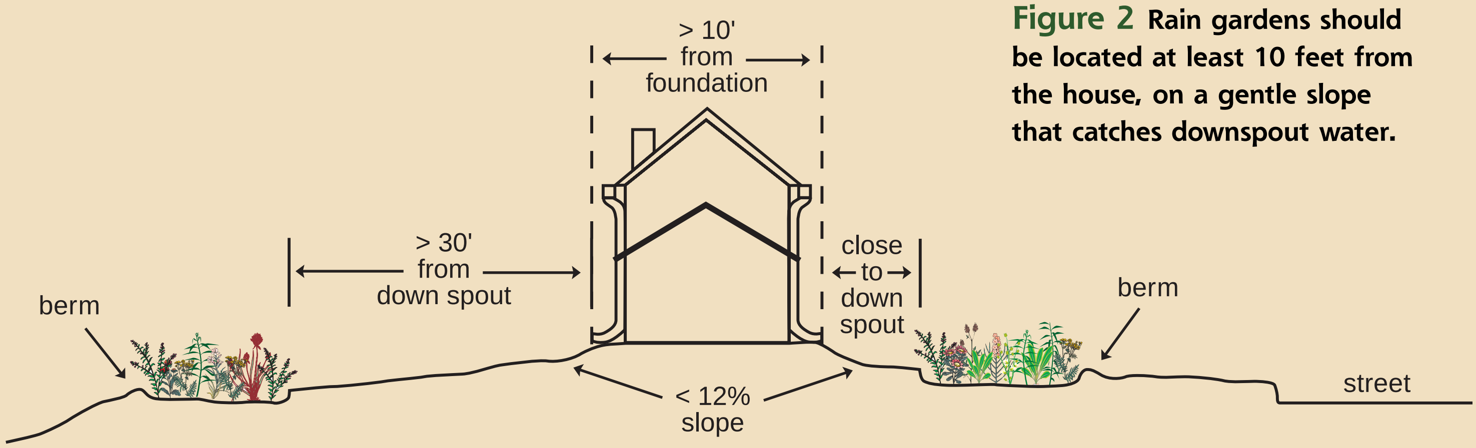


Figure 2 **Rain gardens should be located at least 10 feet from the house, on a gentle slope that catches downspout water.**

How big should the rain garden be?

The surface area of the rain garden can be almost any size, but time and cost will always be important considerations in sizing decisions. Any reasonably sized rain garden will provide some stormwater runoff control. A typical residential rain garden ranges from 100 to 300 square feet. Rain gardens can be smaller than 100 square feet, but very small gardens have little plant variety. If a rain garden is larger than 300 square feet it takes a lot more time to dig, is more difficult to make level, and could be hard on your budget.

The size of the rain garden will depend on

- how deep the garden will be,
- what type of soils the garden will be planted in, and
- how much roof and/or lawn will drain to the garden.

This information, along with the sizing factor from the tables on page 9, will determine the surface area of the rain garden.

Digging with a rented backhoe.

Guidelines are not rules...

The sizing guidelines described in this manual are based on a goal of controlling 100% of the runoff for the average rainfall year while keeping the size of the rain garden reasonable. Establishing a 100% runoff goal helps compensate for some of the errors that creep into the design and construction of any rain garden.

If you follow the guidelines in the manual and decide the calculated surface area is just too large for your goals, it is perfectly acceptable to make the rain garden smaller. The rain garden can be up to 30% smaller and still control almost 90% of the annual runoff. On the other hand, it is fine to make the rain garden bigger than the guidelines indicate.

How Deep Should the Rain Garden Be?

A typical rain garden is between four and eight inches deep. A rain garden more than eight inches deep might pond water too long, look like a hole in the ground, and present a tripping hazard for somebody stepping into it. A rain garden much less than four inches deep will need an excessive amount of surface area to provide enough water storage to infiltrate the larger storms.

No matter what the depth of the rain garden, the goal is to keep the garden level. Digging a very shallow rain garden on a steep lawn will require bringing in extra topsoil to bring the downslope part of the garden up to the same height as the up-slope part of the garden. As the slope gets steeper, it is easier to dig the rain garden a little deeper to make it level.

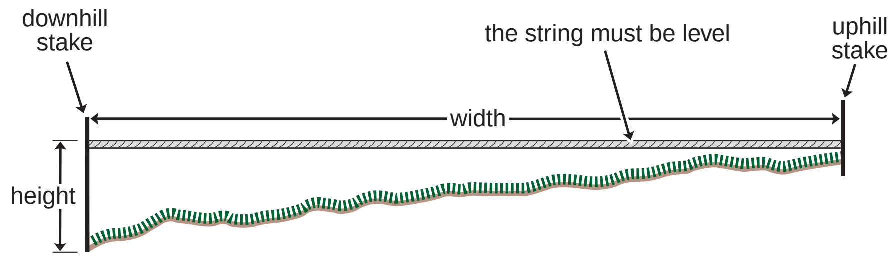


Figure 3 The string should be tied to the base of the uphill stake, then tied to the downhill stake at the same level.

The slope of the lawn should determine the depth of the rain garden. Find the slope of your lawn by following these steps. (Figure 3 shows how the stakes and string should look.)

1. Pound one stake in at the uphill end of your rain garden site and pound the other stake in at the downhill end. The stakes should be about 15 feet apart.
2. Tie a string to the bottom of the uphill stake and run the string to the downhill stake.
3. Using a string level or the carpenter's level, make the string horizontal and tie the string to the downhill stake at that height.
4. Measure the width (in inches) between the two stakes.
5. Now measure the height (in inches) on the downhill stake between the ground and string.
6. Divide the height by the width and multiply the result by 100 to find the lawn's percent slope. If the slope is more than 12%, it's best to find another site or talk to a professional landscaper.

Using the slope of the lawn, select the depth of the rain garden from the following options:

- If the slope is less than 4%, it is easiest to build a 3 to 5-inch deep rain garden.
- If the slope is between 5 and 7%, it is easiest to build one 6 to 7 inches deep.
- If the slope is between 8 and 12%, it is easiest to build one about 8 inches deep.

EXAMPLE

Todd measures the length of the string between the stakes; it is 180 inches long. The height is 9 inches. He divides the height by the width to find his lawn's percent slope.

$$\frac{\text{height}}{\text{width}} \times 100 = \% \text{ slope} \qquad \frac{9 \text{ inches}}{180 \text{ inches}} \times 100 = 5\% \text{ slope}$$

With a 5% slope, Todd should build a 6 inch deep rain garden.

What type of soils are on the rain garden site?

After choosing a rain garden depth, identify the lawn's soil type as sandy, silty, or clayey. Sandy soils have the fastest infiltration; clayey soils have the slowest. Since clayey soils take longer to absorb water, rain gardens in clayey soil must be bigger than rain gardens in sandy or silty soil. If the soil feels very gritty and coarse, you probably have sandy soil. If your soil is smooth but not sticky, you have silty soil. If it is very sticky and clumpy, you probably have clayey soil.

How big is the area draining to the rain garden?

The next step in choosing your rain garden size is to find the area that will drain to the rain garden. As the size of the drainage area increases so should the size of the rain garden. There is some guesswork in determining the size of a drainage area, especially if a large part of the lawn is up-slope from the proposed garden site. Use the suggestions below to estimate the drainage area without spending a lot of time.

Rain gardens less than 30 feet from the downspout

1. In this case, where the rain garden is close to the house, almost all water will come from the roof downspout. Walk around the house and estimate what percent of the roof feeds to that downspout. Many houses have four downspouts, each taking about 25% of the roof's runoff.
2. Next find your home's footprint, the area of the first floor. If you don't already know it, use a tape measure to find your house's length and width. Multiply the two together to find the approximate area of your roof.
3. Finally, multiply the roof area by the percent of the roof that feeds to the rain garden downspout. This is the roof drainage area.

▸ **If the rain garden is far from the house, and you don't want a swale or downspout cutting across the lawn, run a PVC pipe underground from the downspout to the rain garden. In this case do calculations as for a rain garden less than 30 feet from the house.**

Rain gardens more than 30 feet from the downspout

1. If there is a significant area of lawn uphill that will also drain to the rain garden, add this lawn area to the roof drainage area. First find the roof drainage area using the steps above for a rain garden less than 30' from the downspout.
2. Next find the area of the lawn that will drain to the rain garden. Stand where your rain garden will be and look up toward the house. Identify the part of the lawn sloping into the rain garden.
3. Measure the length and width of the uphill lawn, and multiply them to find the lawn area.
4. Add the lawn area to the roof drainage area to find the total drainage area.

EXAMPLE

Todd's house is 60 feet by 40 feet, so the roof area is 2400 square feet. He estimates that the downspout collects water from 25% of the roof, so he multiplies 2400 by 0.25 to get a downspout drainage area of 600 square feet.

Roof Area: 60 ft by 40 ft = 2400 square ft.

Drainage Area: 2400 square ft. x 0.25 = 600 square ft.

Simple soil tests

Two small tests can ensure your soil can handle a rain garden:

- Dig a hole about 6 inches deep where the rain garden is to go and fill the hole with water. If the water takes more than 24 hours to soak in, the soil is not suitable for a rain garden.
- Take a handful of soil and dampen it with a few drops of water. After kneading the soil in your fingers, squeeze the soil into a ball. If it remains in a ball, then work the soil between your forefinger and thumb, squeezing it upward into a ribbon of uniform thickness. Allow the ribbon to emerge and extend over the forefinger until it breaks from its own weight. If the soil forms a ribbon more than an inch long before it breaks, and it also feels more smooth than gritty, the soil is not suitable for a rain garden.

The map is a starting point for assessing what type of soils you might find in your yard. However, the soil on a small plot of a yard can be very different from the soils indicated on the map. Use the simple soil test described here for a more accurate representation of the soils in the possible rain garden location. More information about sampling and testing lawn and garden soils can be obtained at county UW-Extension offices.

Using the Rain Garden Size Factors

Having estimated the drainage area, soil type, and depth for your rain garden, use Table 1 or Table 2 to determine the rain garden's surface area. Use Table 1 if the rain garden is less than 30 feet from the downspout, and use Table 2 if it is more than 30 feet from the downspout.

Table 1 Rain gardens less than 30 feet from downspout.

	3-5 in. deep	6-7 in. deep	8 in. deep
Sandy soil	0.19	0.15	0.08
Silty soil	0.34	0.25	0.16
Clayey soil	0.43	0.32	0.20

Table 2 Rain gardens more than 30 feet from downspout.

	Size Factor, for all depths
Sandy soil	0.03
Silty soil	0.06
Clayey soil	0.10

1. Find the size factor for the soil type and rain garden depth.
2. Multiply the size factor by the drainage area. This number is the recommended rain garden area.
3. If the recommended rain garden area is much more than 300 square feet, divide it into smaller rain gardens.

EXAMPLE

Todd's rain garden is less than 30 feet from the downspout, and his lawn has a 5% slope, so he will have a 6-inch deep rain garden. His lawn is silty, so Table 1 recommends a size factor of 0.25. He multiplies the downspout drainage area, 600 square feet, by 0.25 to find the recommended rain garden area, 150 square feet.

600 square ft. by 0.25 = 150 square ft.

Runoff flows into a new rain garden (shown before plants are fully grown).

How long and how wide should the rain garden be?

Before building the rain garden, think about how it will catch water. Runoff will flow out of a downspout and should spread evenly across the entire length of the rain garden. The rain garden must be as level as possible so water doesn't pool at one end and spill over before it has a chance to infiltrate.

Choose a size that is best for your yard

Remember that these are only guidelines. The size of the rain garden also depends on how much money you want to spend, how much room you have in your yard, and how much runoff you want to control. Again, you can reduce the size of your rain garden by as much as 30% and still control almost 90% of the runoff. If the sizing table suggests that the rain garden be 200 square feet, but there is only enough room for a 140-square-foot rain garden, that's fine. A smaller rain garden will usually work to control most stormwater runoff, although some bigger storms might over-top the berm.

The longer side of the rain garden should face upslope; that is, the length of the rain garden should be perpendicular to the slope and the downspout. This way the garden catches as much water as possible. However, the rain garden should still be wide enough for the water to spread evenly over the whole bottom and to provide the space to plant a variety of plants. A good rule of thumb is that the rain garden should be about twice as long (perpendicular to the slope) as it is wide.

When choosing the width of the garden, think about the slope of the lawn. Wide rain gardens and rain gardens on steep slopes will need to be dug very deep at one end in order to be level. If the rain garden is too wide, it may be necessary to bring in additional soil to fill up the downhill half. Experience shows that making a rain garden about 10 feet wide is a good compromise between the effect of slope and how deep the rain garden should be. A rain garden should have a maximum width of about 15 feet, especially for lawns with more than about an 8 percent slope.

To determine the length of the rain garden:

1. Pick the best rain garden width for your lawn and landscaping.
2. Divide the size of your rain garden by the width to find your rain garden's length.

✓EXAMPLE

Todd wants a 10-foot wide rain garden, so he divides 150 by 10 to find the rain garden length, 15 feet.

$$\frac{\text{rain garden area}}{\text{width}} = \text{length} \qquad \frac{150\ \text{ft}^2}{10\ \text{ft}} = 15\ \text{ft}$$

Step 2 Building the Rain Garden

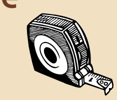
Now that the size and place for the rain garden are set, it's time to get a shovel and start digging. Working alone, it will take about six hours to dig an average-size rain garden. If friends help it will go much faster, possibly only an hour or two.

Before you start digging, call Digger's Hotline at 1-800-242-8511.

▸ **If you are building the rain garden into an existing lawn, digging time can be reduced by killing the grass first. A chemical such as Round-Up can be used, but a more environmentally friendly approach is to place black plastic over the lawn until the grass dies. Also, the best time to build the rain garden is in the spring. It will be easier to dig, and the plants are more likely to thrive.**

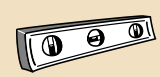
A note on tools

The following tools will help in building the rain garden. Some of the tools are optional.

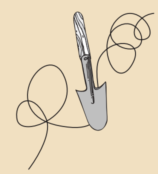


- **Tape measure**
- **Shovels**
- **Rakes**

- **Trowels**
- **Carpenter's level**



- **Wood stakes, at least 2 ft long**
- **String**



- **2x4 board, at least 6 ft long (optional)**
- **Small backhoe with cater- pillar treads (optional)**

Leveling the rain garden

One way to check the level of the rain garden is to just "eyeball" it. To do it more accurately follow these steps:

- **When the whole area has been dug out to about the right depth, lay the 2x4 board in the rain garden with the carpenter's level sitting on it. Find the spots that aren't flat. Fill in the low places and dig out the high places.**
- **Move the board to different places and different directions, filling and digging as necessary to make the surface level.**
- **When the rain garden is as level as you can get it, rake the soil smooth.**

The perimeter of a rain garden is defined with string before digging.

Digging the rain garden

While digging the rain garden to the correct depth, heap the soil around the edge where the berm will be. (The berm is a low "wall" around three sides of the rain garden that holds the water in during a storm.) On a steeper lawn the lower part of the rain garden can be filled in with soil from the uphill half, and extra soil might need to be brought in for the berm.

Start by laying string around the perimeter of your rain garden. Remember that the berm will go outside the string. Next, put stakes along the uphill and downhill sides, lining them up so that each uphill stake has a stake directly downhill. Place one stake every 5 feet along the length of the rain garden.

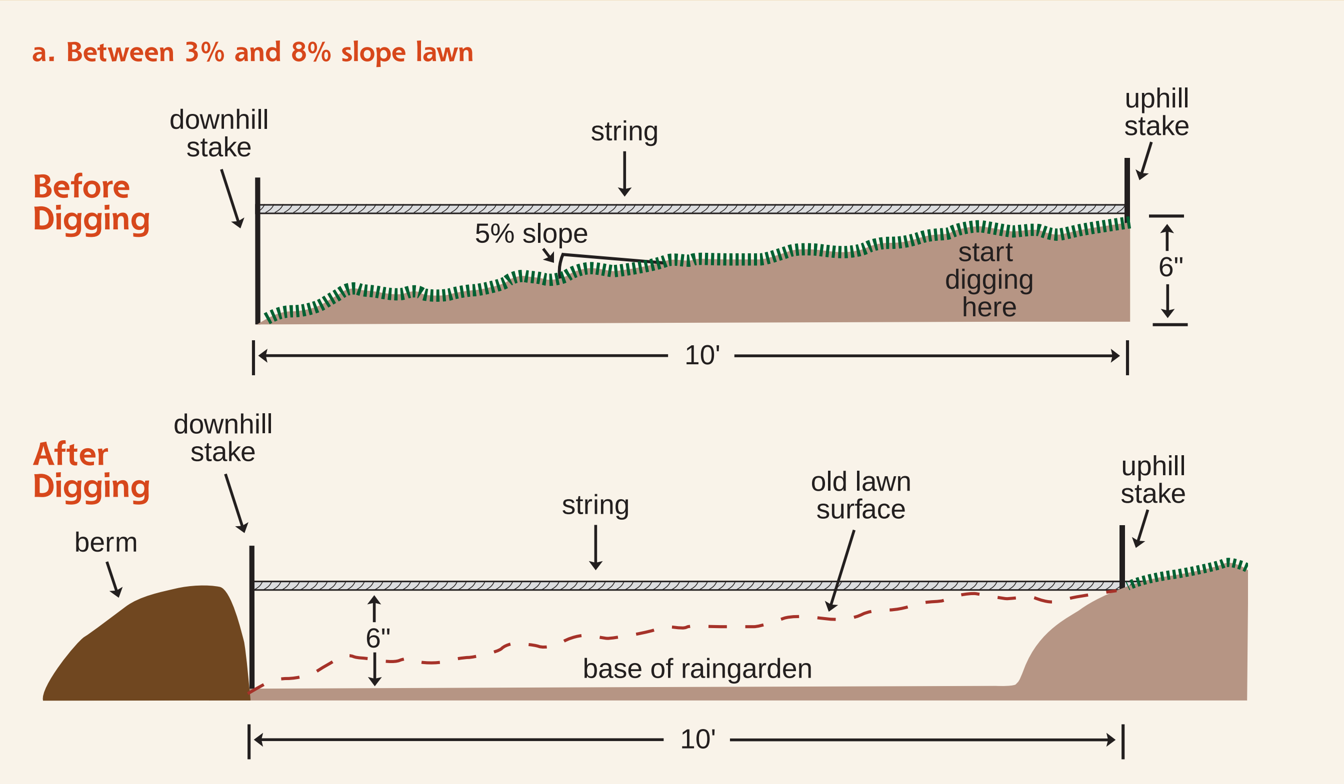
Start at one end of the rain garden and tie a string to the uphill stake at ground level. Tie it to the stake directly downhill so that the string is level. Work in 5-foot-wide sections, with only one string at a time. Otherwise the strings will become an obstacle.

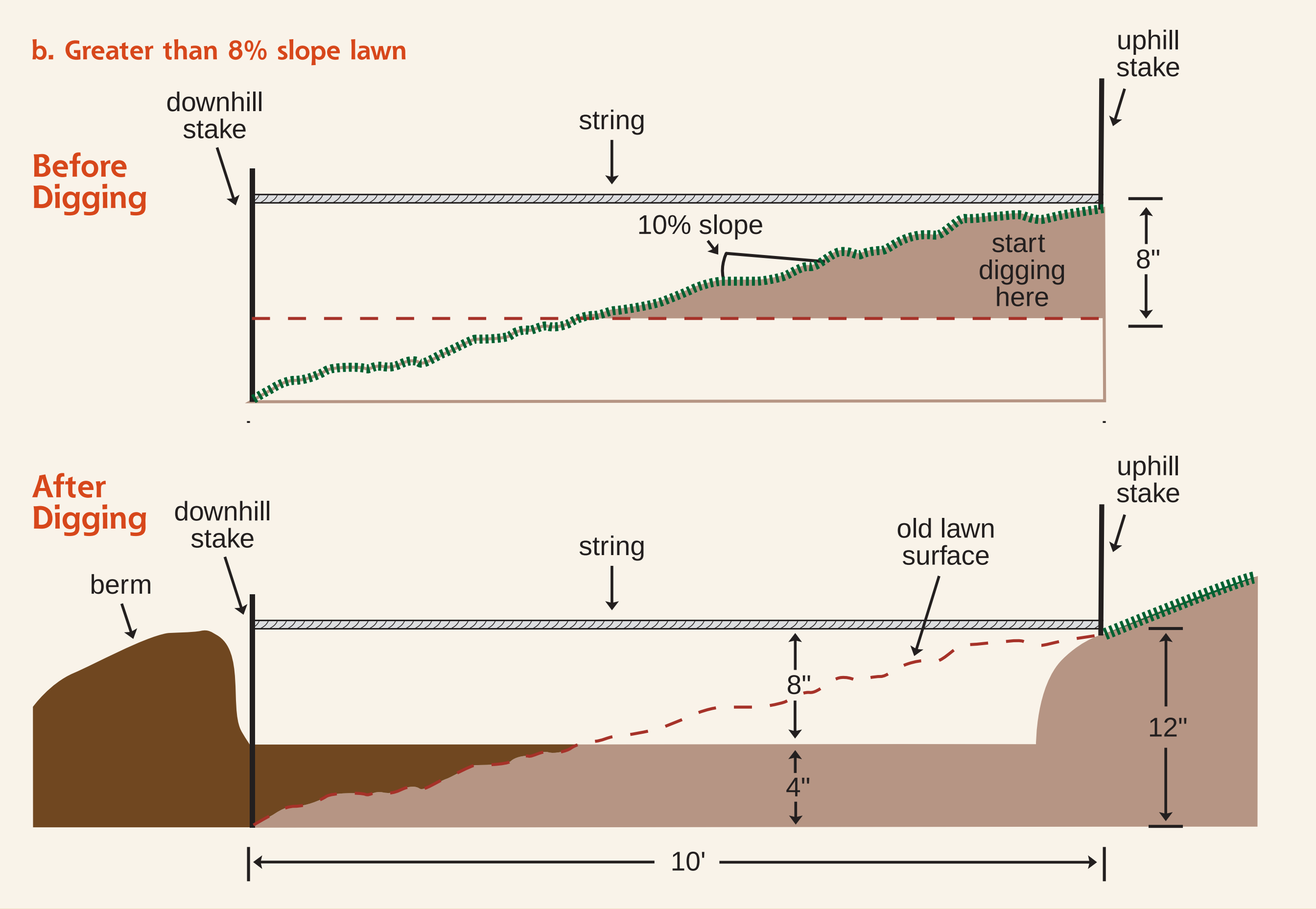
Start digging at the uphill side of the string. Measure down from the string and dig until you reach the depth you want the rain garden to be. If the rain garden will be four inches deep, then dig four inches down from the string. Figure 4 shows how.

If the lawn is almost flat, you will be digging at the same depth throughout the rain garden and using the soil for the berm. If the lawn is steeper, the high end of the rain garden will need to be dug out noticeably more than the low end, and some of the soil from the upper end can be used in the lower end to make the rain garden level. Continue digging and filling one section at a time across the length of your rain garden until it is as level as possible.

In any garden, compost will help the plants become established and now is the time to mix in compost if needed. Using a roto-tiller can make mixing much easier, but isn't necessary. If you do add compost, dig the rain garden a bit deeper. To add two inches of compost, dig the rain garden one to two inches deeper than planned.

Figure 4 **Where to dig and where to put the soil you've dug.**





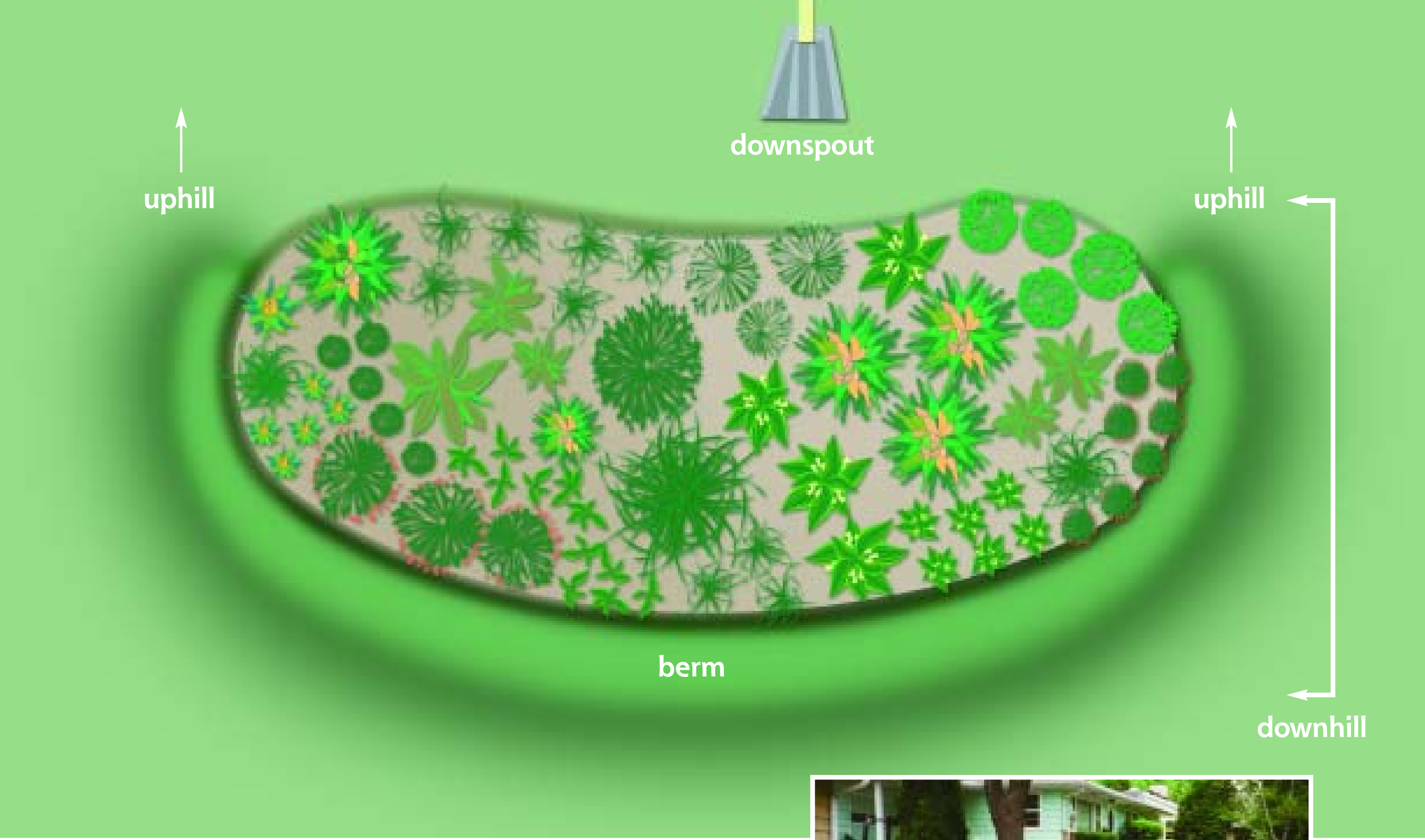


Figure 5 **The top of the downhill part of the berm should come up to the same elevation as the entry to the rain garden at the uphill end.**

On a gentle slope, soil from digging out the garden can be used to create the berm. This rain garden is 4 inches deep.

Making the Berm

Water flowing intro the rain garden will naturally try to run off the downhill edge. A berm is needed to keep the water in the garden, The berm is a "wall" across the bottom and up the sides of the rain garden. The berm will need to be highest at the downhill side. Up the sides of the rain garden, the berm will become lower and gradually taper off by the time it reaches the top of the rain garden. Figure 5 shows how the berm should look.

On a flat slope there should be plenty of soil from digging out the rain garden to use for a berm. On a steeper slope, most of the soil from the uphill part of the rain garden was probably used to fill in the downhill half, and soil will have to be brought in from somewhere else. After shaping the berm into a smooth ridge about a foot across, stomp on it. It is very important to have a well-compacted berm, so stomp hard. The berm should have very gently sloping sides; this helps smoothly integrate the rain garden with the surrounding lawn and also makes the berm less susceptible to erosion.

To prevent erosion, cover the berm with mulch or plant grass. Use straw or erosion-control mat to protect the berm from erosion while the grass is taking root.

If you don't want to plant grass or mulch over the outside of the berm, you can also plant dry-tolerant prairie species. Some potential berm species are prairie dropseed, little bluestem, prairie smoke, blue-eyed grass, prairie phlox, and shooting star.

Note: If the downspout is a few feet from the entry to the rain garden, make sure the water runs into the garden by either digging a shallow grass swale or attaching an extension to the downspout.

Tips for designing an attractive rain garden

While rain gardens are a highly functional way to help protect water quality, they are also gardens and should be an attractive part of your yard and neighborhood. Think of the rain garden in the context of your home's overall landscape design. Here are a few tips:

When choosing native plants for the garden, it is important to consider the height of each plant, bloom time and color, and its overall texture. Use plants that bloom at different times to create a long flowering season. Mix heights, shapes, and textures to give the garden depth and dimension. This will keep the rain garden looking interesting even when few wildflowers are in bloom.

When laying plants out, randomly clump individual species in groups of 3 to 7 plants to provide a bolder statement of color. Make sure to repeat these individual groupings to create repetition and cohesion in a planting. This will provide a more traditional formal look to the planting.

Try incorporating a diverse mixture of sedges, rushes, and grasses with your flowering species (forbs). This creates necessary root competition that will allow plants to follow their normal growth patterns and not outgrow or out-compete other species. In natural areas, a diversity of plant types not only adds beauty but also create a thick underground root matrix that keeps the entire plant community in balance. In fact, 80% of the plant mass in native prairie communities is underground. Once the rain garden has matured and your sedges, rushes and grasses have established a deep, thick root system, there will be less change in species location from year to year, and weeds will naturally decline.

Finally, consider enhancing the rain garden by using local or existing stone, ornamental fences, trails, garden benches, or additional wildflower plantings. This will help give the new garden an intentional and cohesive look and provide a feeling of neatness that the neighbors will appreciate.

Step 3 Planting and Maintaining the Rain Garden

Planting the rain garden is the fun part! A number of planting designs and lists of suggested plants are included at the end of this publication. Use these for ideas, but don't be afraid to be creative – there's no single best way to plant a rain garden. Anyone who has ever done any gardening will have no problem planting a rain garden, but a few basic reminders are listed below.

Planting the rain garden

Select plants that have a well established root system. Usually one or two-year-old plants will have root systems that are beginning to circle or get matted. (Note: use only nursery-propagated plants; do not collect plants from the wild).

Make sure to have at least a rough plan for which plants will be planted where. Lay out the plants as planned one foot apart in a grid pattern, keeping them in containers if possible until they are actually planted to prevent drying out before they get in the ground.

Dig each hole twice as wide as the plant plug and deep enough to keep the crown of the young plant level with the existing grade (just as it was growing in the cell pack or container). Make sure the crown is level and then fill the hole and firmly tamp around the roots to avoid air pockets.

Apply double-shredded mulch evenly over the bed approximately two inches thick, but avoid burying the crowns of the new transplants. Mulching is usually not necessary after the second growing season unless the "mulched look" is desired.

Stick plant labels next to each individual grouping. This will help identify the young native plants from non-desirable species (weeds) as you weed the garden.

As a general rule plants need one inch of water per week. Water immediately after planting and continue to water twice a week (unless rain does the job) until the plugs are established. You should not have to water your rain garden once the plants are established. Plugs can be planted anytime during the growing season as long as they get adequate water.

Fire safety

Make sure burning is allowed in your locale. If so, be sure to notify the local fire department and obtain a burn permit if needed. It's also wise – not to mention neighborly – to make sure the neighbors know that you're burning and that all safety precautions are being taken. Basic fire precautions include:

- **Make sure there is a fire-break (non-burnable area, such as turfgrass) at least 10-feet wide surrounding the area to be burned.**
- **Never burn on windy days.**
- **Never leave an actively burning fire unattended.**
- **Keep a garden hose handy in case fire strays where it is not wanted. Also have a metal leaf rake in hand to beat out flames that creep beyond the burn zone.**

Maintaining the rain garden

Weeding will be needed the first couple of years. Remove by hand only those plants you are certain are weeds. Try to get out all the roots of the weedy plants. Weeds may not be a problem in the second season, depending on the variety and tenacity of weeds present. In the third year and beyond, the native grasses, sedges, rushes, and wildflowers will begin to mature and will out-compete the weeds. Weeding isolated patches might still be needed on occasion.

After each growing season, the stems and seedheads can be left for winter interest, wildlife cover and bird food. Once spring arrives and new growth is 4-6-inches tall, cut all tattered plants back. If the growth is really thick, hand-cut the largest plants and then use a string trimmer to mow the planting back to a height of six to eight inches. Dead plant material can also be removed with a string trimmer or weed whacker (scythe) and composted or disposed of as appropriate.

The best way to knock back weeds and stimulate native plant growth is to burn off the dead plant material in the rain garden. However, burning is banned in most municipalities. Another option is to mow the dead plant material. If the mowing deck of your lawn mower can be raised to a height of six inches or so, go ahead and simply mow your rain garden. Then, rake up and compost or properly dispose of the dead plant material.

If the mower deck won't raise that high, use a string trimmer or weed-eater to cut the stems at a height of 6-8 inches. On thicker stems, such as cup plant, goldenrods and some asters, a string trimmer may not be strong enough. For these, use hand clippers or pruning shears to cut the individual stems.

What does a rain garden cost?

The cost of a rain garden will vary depending on who does the work and where the plants come from. If you grow your own plants or borrow plants from neighbors there can be very little or no cost at all. If you do all the work but use purchased prairie plants, a rain garden will cost approximately $3 to $5 per square foot. If a landscaper does everything, it will cost approximately $10 to $12 per square foot.

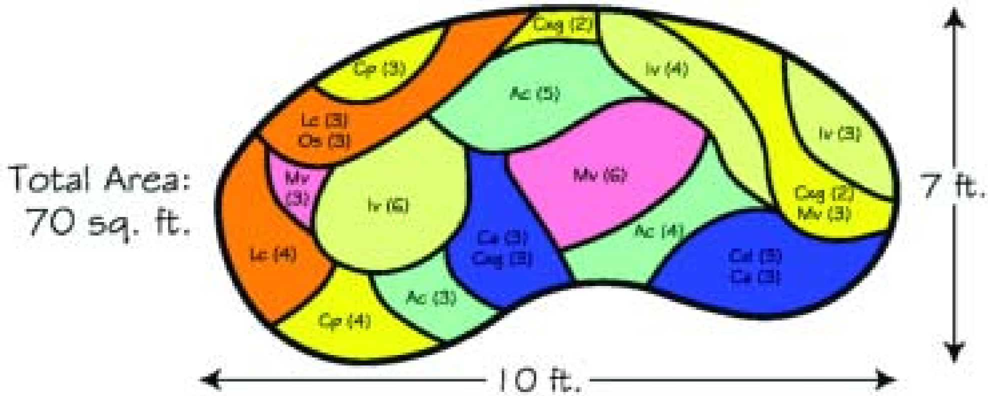
It might seem easiest to sow native wildflower seed over the garden, but experience shows that seeding a rain garden has its problems. Protecting the seeds from wind, flooding, weeds, and garden pests is very difficult, and the rain garden will be mostly weeds for the first two years. Growing plugs from seed indoors or dividing a friend's plants is much better. If you grow plugs, start them about four months before moving them to the rain garden. When the roots have filled the pot and the plants are healthy, they may be planted in the rain garden

Rain Garden Designs and Plant Lists

The following pages contain conceptual planting designs and plant lists for rain gardens with varying sun and soil conditions. Keep in mind that design possibilities for rain gardens are almost limitless. Many landscape nurseries, particularly those specializing in native plants and landscaping, can provide other ideas, designs and suggested plants.

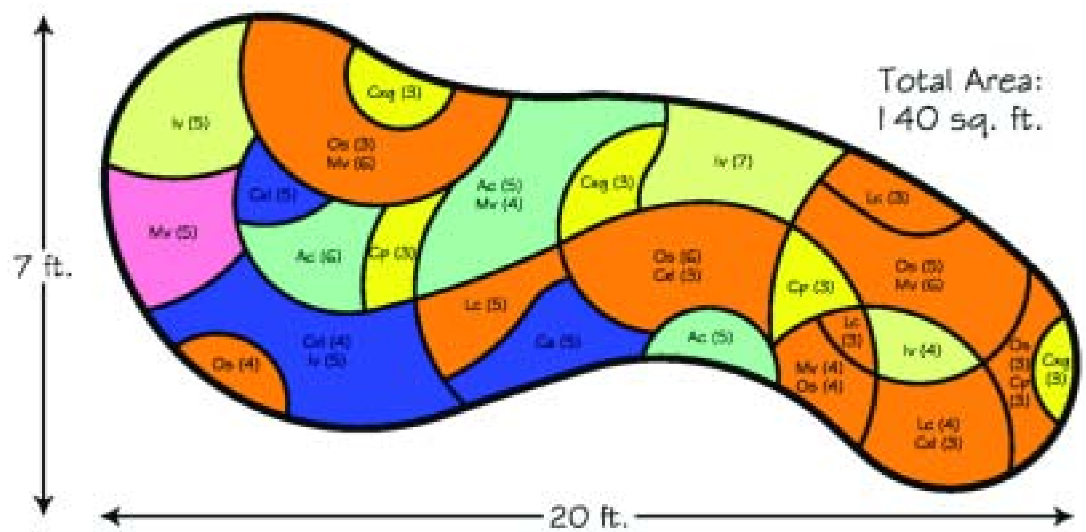
The following eight designs and plant lists have been provided by Applied Ecological Services, Inc., Brodhead, WI.

10 feet wide; full to partial shade with clay soils



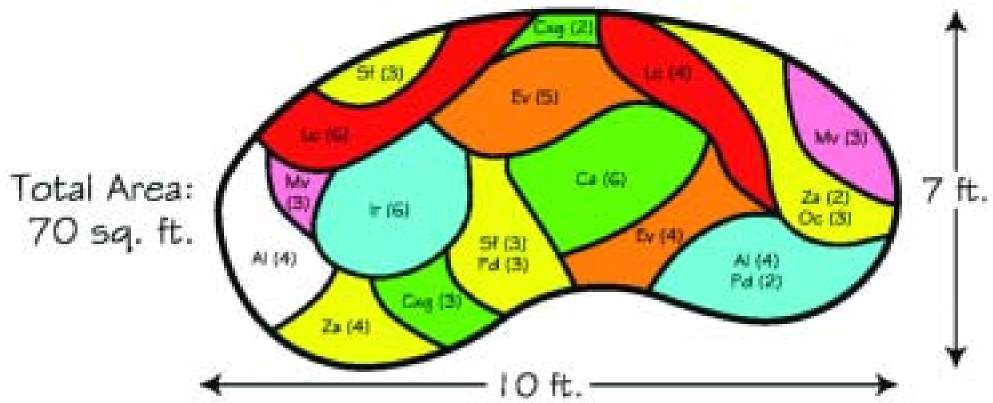
Symbol	Species Name	Common Name	No. of Plants
Ac	Acorus calamus	Sweet flag	12
Ca	Campanula americana	Tall bellflower	6
Cp	Caltha palustris	Marsh marigold	7
Cxg	Carex Grayii	Bur sedge	7
Cxl	Carex lupulina	Hop sedge	3
Iv	Iris virginica-shrevei	Wild blue flag iris	13
Lc	Lobelia cardinalis	Cardinal flower	7
Mv	Mertensia virginica	Virginia bluebells	12
Os	Onoclea sensibilis	Sensitive fern	3
		Total Plants Needed	70

20 feet wide; full to partial shade with clay soils



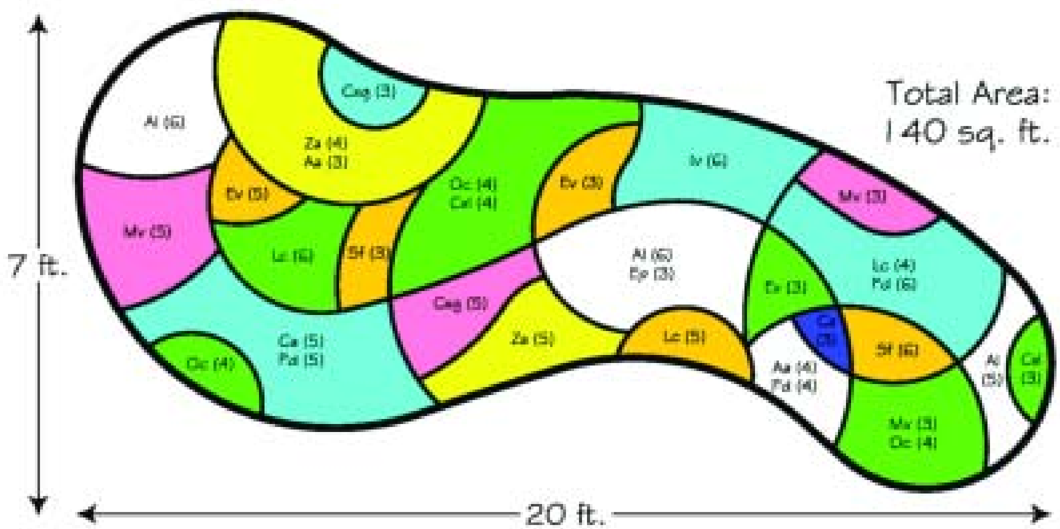
Symbol	Species Name	Common Name	No. of Plants
Ac	Acorus calamus	Sweet flag	16
Cp	Caltha palustris	Marsh marigold	9
Ca	Campanula americana	Tall bellflower	5
Cxg	Carex Grayii	Bur sedge	9
Cxl	Carex lupulina	Hop sedge	15
Iv	Iris virginica-shrevei	Wild blue flag iris	21
Lc	Lobelia cardinalis	Cardinal flower	15
Mv	Mertensia virginica	Virginia bluebells	25
Os	Onoclea sensibilis	Sensitive fern	25
		Total Plants Needed	140

10 feet wide; full to partial shade with silty & sandy soils



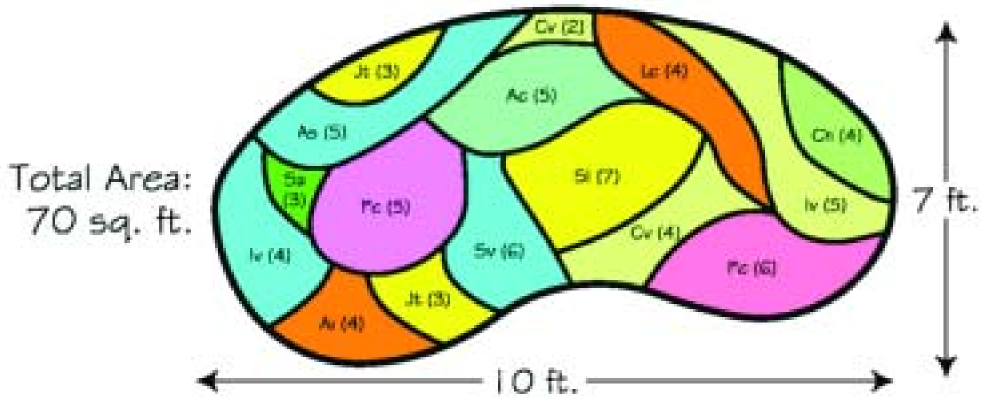
Symbol	Species Name	Common Name	No. of Plants
Al	Aster lateriflorus	Side-flowering aster	8
Ca	Campanula americana	Tall bellflower	6
Cxg	Carex Grayii	Bur sedge	5
Ev	Elymus virginicus	Virginia wild rye	9
Iv	Iris virginica-shrevei	Wild blue flag iris	6
Lc	Lobelia cardinalis	Cardinal flower	10
Mv	Mertensia virginica	Virginia bluebells	6
Oc	Osmunda claytoniana	Interupted fern	3
Pd	Phlox divaricata	Woodland phlox	5
Sf	Solidago flexicaulis	Zig zag goldenrod	6
Za	Zizia aurea	Golden Alexander	6
		Total Plants Needed	70

20 feet wide; full to partial shade with silty & sandy soils



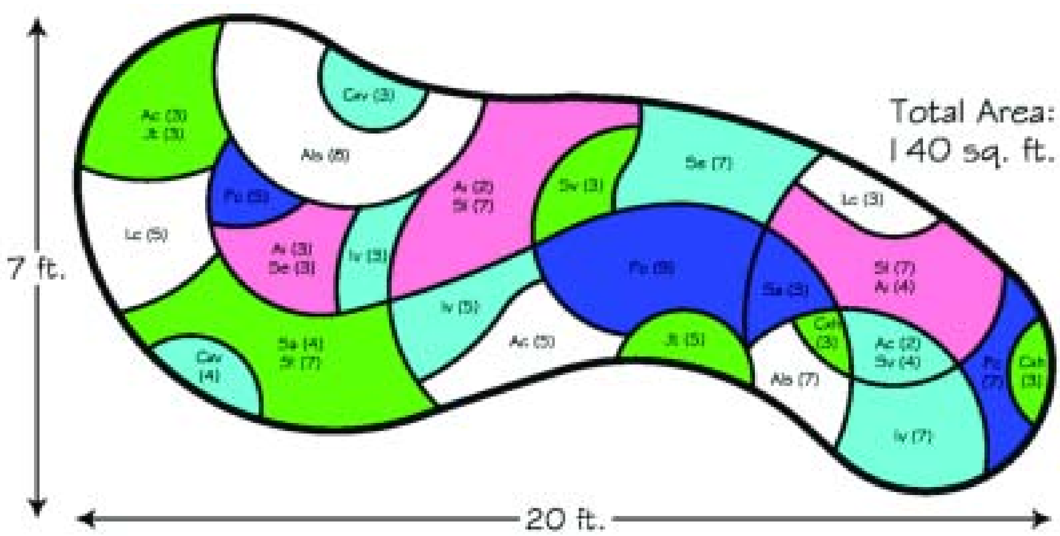
Symbol	Species Name	Common Name	No. of Plants
Aa	Arisaema atrorubens	Jack-in-the-pulpit	7
Al	Aster lateriflorus	Side-flowering aster	17
Ca	Campanula americana	Tall bellflower	8
Cxg	Carex Grayii	Bur sedge	8
Cxl	Carex lupulina	Hop sedge	7
Ev	Elymus virginicus	Virginia wild rye	11
Ep	Eupatorium purpureum	Purple Joe-Pye weed	3
Iv	Iris virginica-shrevei	Wild blue flag iris	6
Lc	Lobelia cardinalis	Cardinal flower	15
Mv	Mertensia virginica	Virginia bluebells	11
Oc	Osmunda claytoniana	Interupted fern	12
Pd	Phlox divaricata	Woodland phlox	15
Sf	Solidago flexicaulis	Zig zag goldenrod	9
Za	Zizia aurea	Golden Alexander	14
		Total Plants Needed	143

10 feet wide; full to partial sun with clay soils



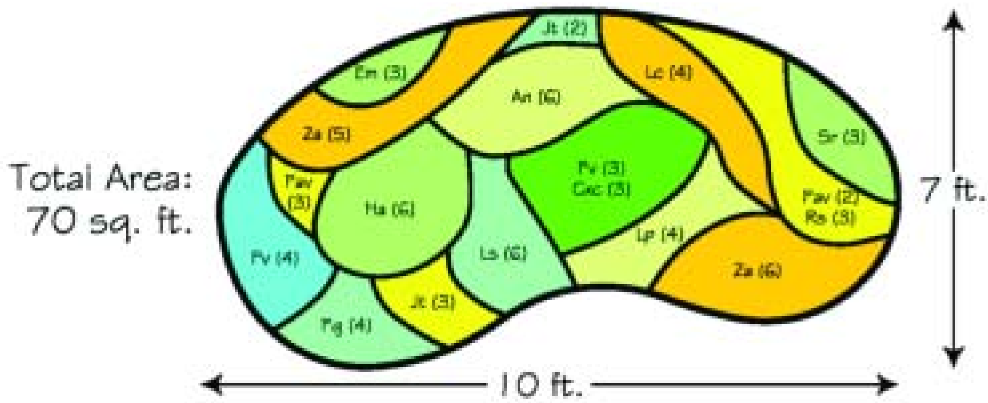
Symbol	Species Name	Common Name	No. of Plants
Ac	Acorus calamus	Sweet flag	5
As	Asclepias incarnata	Swamp milkweed	4
Als	Alisma subcordatum	Water plantain	5
Cxh	Carex hystricina	Bottle brush sedge	4
Cxv	Carex vulpinoidea	Fox sedge	6
Iv	Iris virginica-shrevei	Wild blue flag iris	9
Jt	Juncus torreyi	Torrey's rush	6
Lc	Lobelia cardinalis	Cardinal flower	4
Pc	Pontedaria cordata	Pickerel weed	11
Sl	Sagittaria latifolia	Arrowhead	7
Sa	Scirpus atrovirens	Green bulrush	3
Sv	Scirpus validus creber	Soft-stemmed bulrush	6
		Total Plants needed	70

20 feet wide; full to partial sun with clay soils



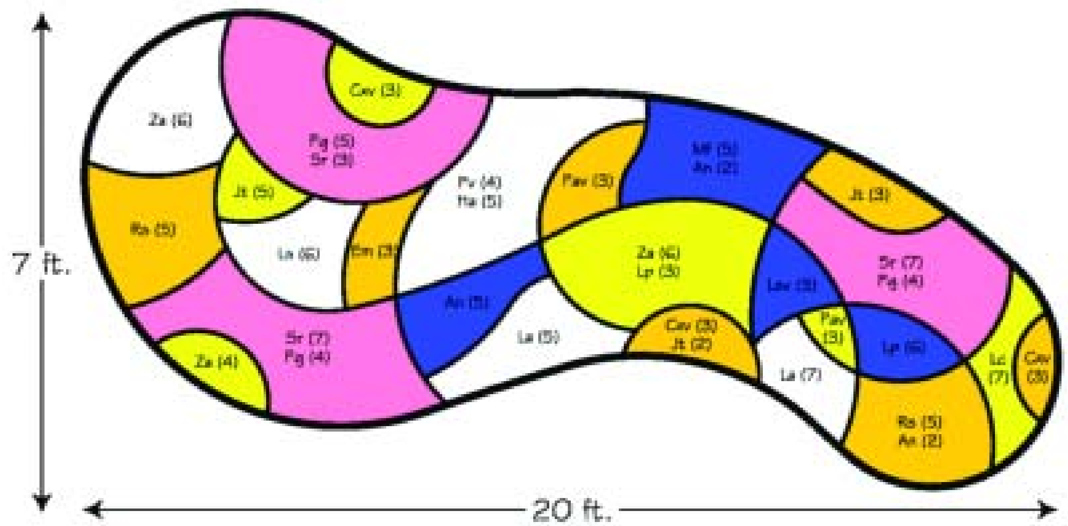
Symbol	Species Name	Common Name	No. of Plants
Ac	Acorus calamus	Sweet flag	10
Ai	Asclepias incarnata	Swamp milkweed	9
Als	Alisma subcordatum	Water plantain	15
Cxh	Carex hystricina	Bottle brush sedge	6
Cxv	Carex vulpinoidea	Fox sedge	7
Iv	Iris virginica-shrevei	Wild blue flag iris	15
Jt	Juncus torreyi	Torrey's rush	8
Lc	Lobelia cardinalis	Cardinal flower	8
Pc	Pontedaria cordata	Pickerel weed	21
Sl	Sagittaria latifolia	Arrowhead	21
Sa	Scirpus atrovirens	Green bulrush	7
Sv	Scirpus validus creber	Soft-stemmed bulrush	7
Se	Sparganium eurycarpum	Common bur-reed	10
		Total Plants needed	144

10 feet wide; full to partial sun with silt and sandy soils



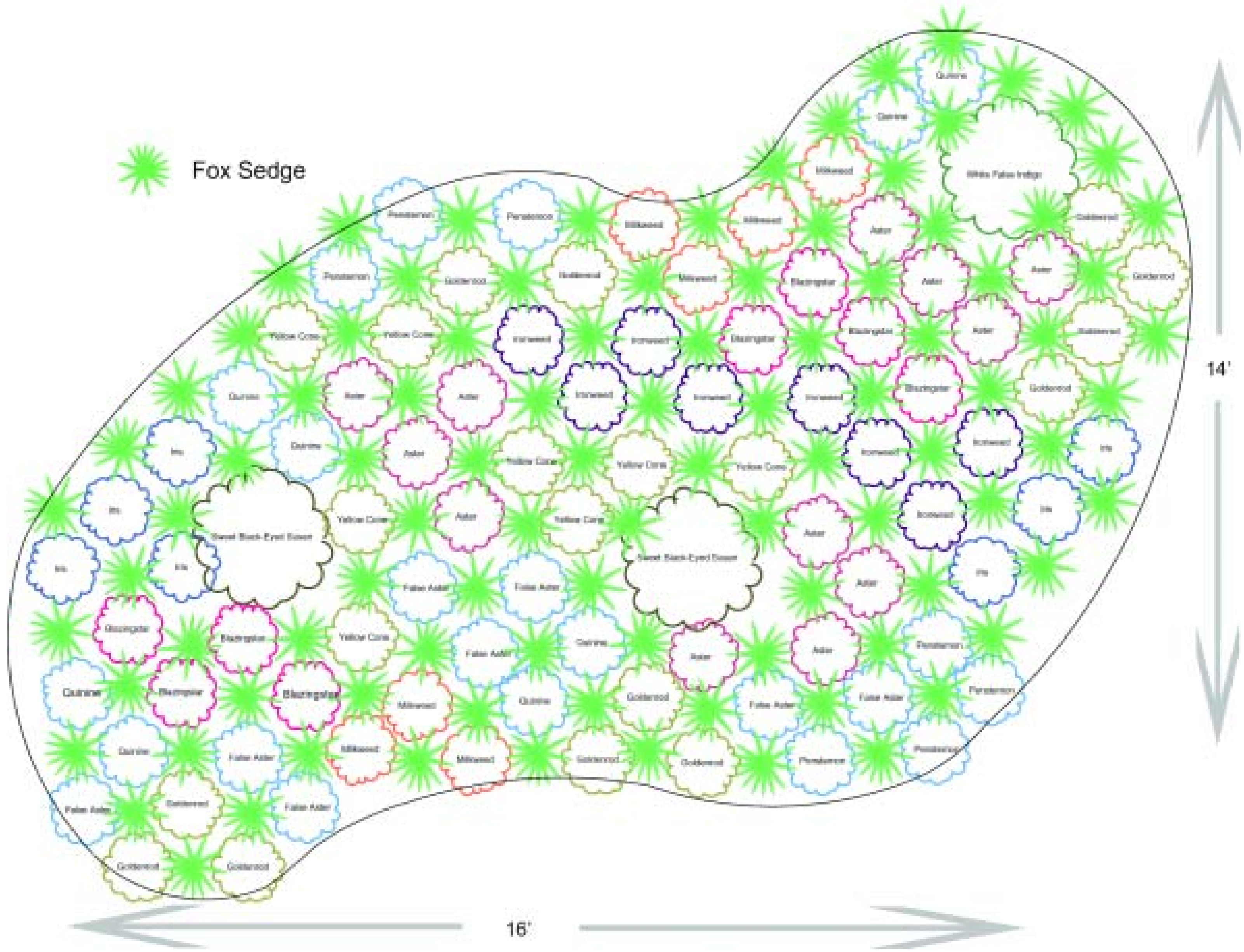
Symbol	Species Name	Common Name	No. of Plants
An	Aster novae-angliae	New England Aster	6
Cxc	Carex comosa	Bottlebrush sedge	3
Ep	Eupatorium maculatum	Spotted Joe-Pye weed	3
Ha	Helenium autumnale	Sneezeweed	6
Jt	Juncus torreyi	Torrey's rush	5
Lp	Liatris pycnostachya	Gayfeather	4
Lc	Lobelia cardinalis	Cardinal flower	4
Ls	Lobelia siphlitica	Great blue lobelia	6
Pav	Panicum virgatum	Switch grass	5
Pg	Phlox glaberrima	Marsh phlox	4
Pv	Pycnanthemum virginianum	Mountain mint	7
Rs	Rudbeckia subtomentosa	Sweet coneflower	5
Sr	Solidago Riddelli	Riddell's goldenrod	3
Za	Zizia aurea	Golden Alexander	11
		Total Plants needed	72

20 feet wide; full to partial sun with silt and sandy soils



Symbol	Species Name	Common Name	No. of Plants
An	Aster novae-angliae	New England Aster	9
Cav	Carex vulpinoidea	Fox sedge	9
Ep	Eupatorium maculatum	Spotted Joe-Pye weed	3
Ha	Helenium autumnale	Sneezeweed	5
Jt	Juncus torreyi	Torrey's rush	10
Lp	Liatris pycnostachya	Gayfeather	9
Lc	Lobelia cardinalis	Cardinal flower	7
Ls	Lobelia siphlitica	Great blue lobelia	9
La	Lythrum alatum	Winged loosestrife	12
Mf	Monarda fistulosa	Wild Bergamot	5
Pav	Panicum virgatum	Switch grass	6
Pg	Phlox glaberrima	Marsh phlox	13
Pv	Pycnanthemum virginianum	Mountain mint	4
Rs	Rudbeckia subtomentosa	Sweet coneflower	10
Sr	Solidago Riddelli	Riddell's goldenrod	17
Za	Zizia aurea	Golden Alexander	16
		Total Plants needed	144

The following three designs and plant lists have been provided by Prairie Nursery, Inc., Westfield, WI

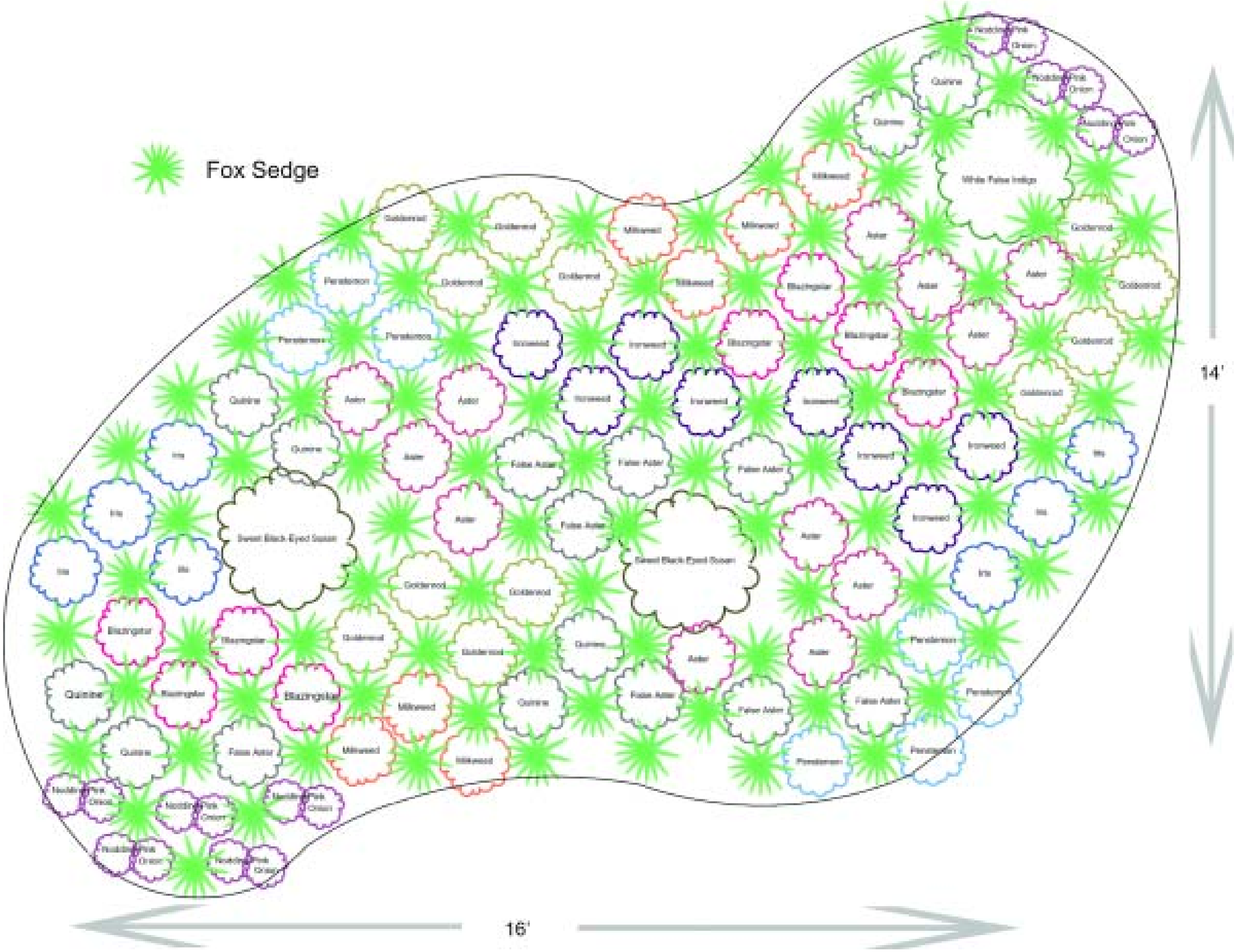

Fox Sedge
14’
16’

RAIN GARDEN FOR CLAY SOILS AND FULL SUN

AREA: 192 Square Feet

Designed to thrive through conditions of periodic water infiltrations as well as dry periods
Designed to control 45% of annual runoff from an average sized rooftop (500 to 700 square feet)
Install at least 10′ from your foundation, in-line with a down-spout and/or downslope to intercept the rooftop water
Depth of the garden designed to be 3.5″ to 4″ deep to hold about 200 gallons of water during periods of heavy rainfall

LATIN NAME	COMMON NAME	AMT	BLOOM TIME	BLOOM COLOR	HEIGHT	SPACING
Asclepias incarnata	Red Milkweed	7	early summer	red	3′-5′	1′
Baptisia lactea	White False Indigo	1	early summer	white	3′-5′	2′
Iris versicolor	Blue Flag Iris	7	early summer	blue	2′-3′	1′
Penstemon digitalis	Smooth Penstemon	7	early summer	white	2′-3′	1′
Liatris pycnostachya	Prairie Blazingstar	8	summer	pink	3′-5′	1′
Parthenium integrifolium	Wild Quinine	8	summer	white	3′-5′	1′
Ratibida pinnata	Yellow Coneflower	8	summer	yellow	3′-6′	1′
Boltonia asteroides	False Aster	8	late summer	white/pink	2′-4′	1′
Rudbeckia subtomentosa	Sweet Black-Eyed Susan	2	late summer	yellow	4′-6′	2′
Vernonia fasciculata	Ironweed	8	late summer	magenta	4′-6′	1′
Aster novae-angliae	New England Aster	12	fall	pink/purple	3′-6′	1′
Solidago rigida	Stiff Goldenrod	12	fall	yellow	3′-5′	1′
Carex vulpinoidea	Fox Sedge	96			1′-3′	1′
		184 plants				


Fox Sedge
14'
16'

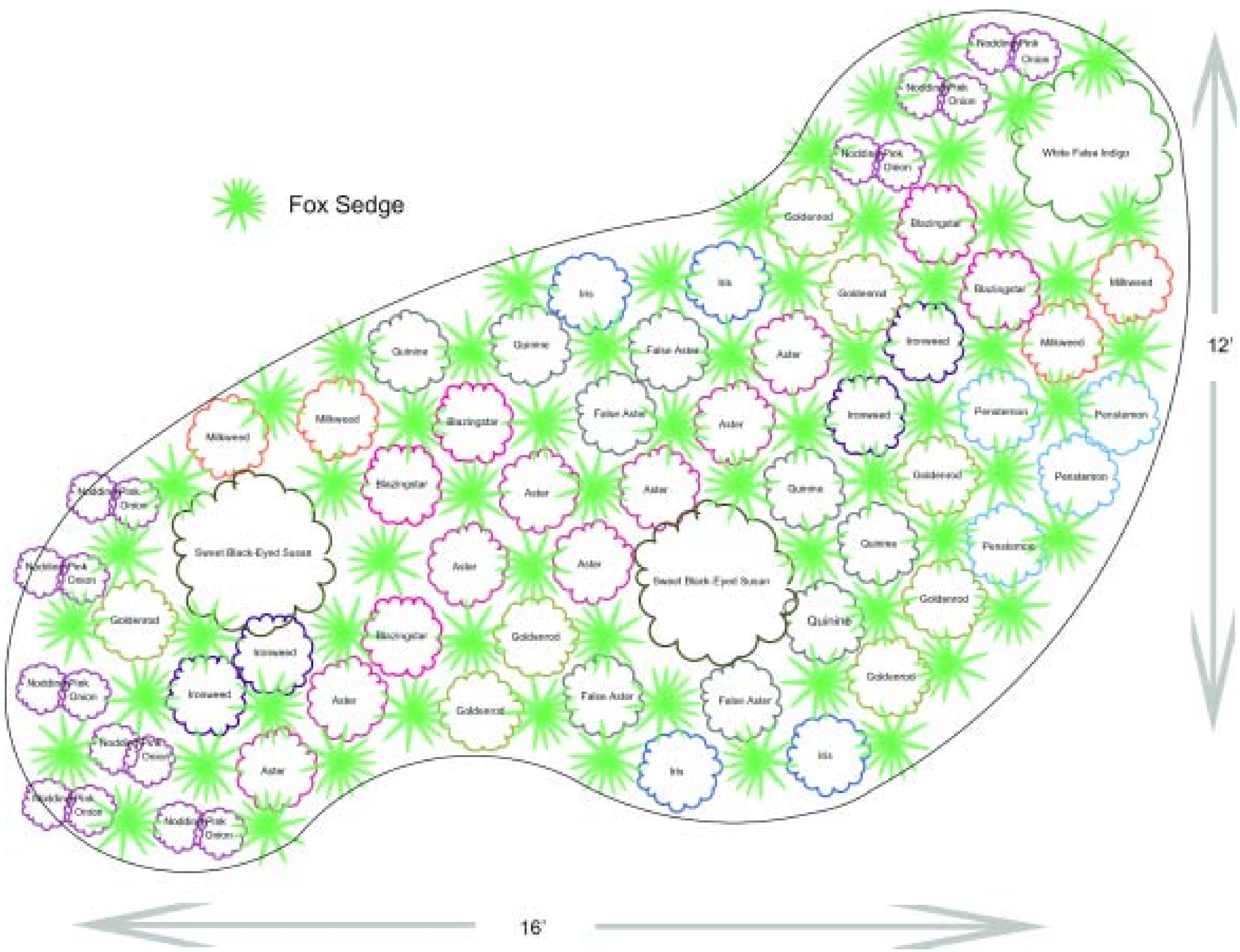
RAIN GARDEN FOR LOAM TO SANDY/LOAM SOILS AND FULL SUN

AREA: 192 Square Feet

Designed to thrive through conditions of periodic water infiltrations as well as dry periods
Designed to control 90% of annual runoff from an average sized rooftop (500 to 700 square feet)
Install at least 10' from your foundation, in-line with a down-spout and/or downslope to intercept the rooftop water
Depth of the garden designed to be 3.5" to 4" deep to hold about 400 gallons of water during periods of heavy rainfall

LATIN NAME	COMMON NAME	AMT	BLOOM TIME	BLOOM COLOR	HEIGHT	SPACING
Asclepias incarnata	Red Milkweed	7	early summer	red	3'-5'	1'
Baptisia lactea	White False Indigo	1	early summer	white	3'-5'	2'
Iris versicolor	Blue Flag Iris	7	early summer	blue	2'-3'	1'
Penstemon digitalis	Smooth Penstemon	7	early summer	white	2'-3'	1'
Allium cernuum	Nodding Pink Onion	16	summer	pink	1'-2'	6"
Liatris pycnostachya	Prairie Blazingstar	8	summer	pink	3'-5'	1'
Parthenium integrifolium	Wild Quinine	8	summer	white	3'-5'	1'
Boltonia asteroides	False Aster	8	late summer	white/pink	2'-4'	1'
Rudbeckia subtomentosa	Sweet Black-Eyed Susan	2	late summer	yellow	4'-6'	2'
Vernonia fasciculata	Ironweed	8	late summer	magenta	4'-6'	1'
Aster novae-angliae	New England Aster	12	fall	pink/purple	3'-6'	1'
Solidago ohioensis	Ohio Goldenrod	12	fall	yellow	3'-4'	1'
Carex vulpinoidea	Fox Sedge	96			1'-3'	1'

192 plants


Fox Sedge
12'
16'
White False Indigo
Nodding Pink Onion
Goldenrod
Blazingstar
Milkweed
Iris
Quinine
False Aster
Aster
Ironweed
Penstemon
Sweet Black-Eyed Susan

RAIN GARDEN FOR SANDY SOILS AND FULL SUN

AREA: 128 Square Feet

Designed to thrive through conditions of periodic water infiltrations as well as dry periods
Designed to control 90% of annual runoff from an average sized rooftop (500 to 700 square feet)
Install at least 10' from your foundation, in-line with a down-spout and/or downslope to intercept the rooftop water
Depth of the garden designed to be 3.5" to 4" deep to hold about 400 gallons of water during periods of heavy rainfall

LATIN NAME	COMMON NAME	AMT	BLOOM TIME	BLOOM COLOR	HEIGHT	SPACING
Asclepias incarnata	Red Milkweed	4	early summer	red	3'-5'	1'
Baptisia lactea	White False Indigo	1	early summer	white	3'-5'	2'
Iris versicolor	Blue Flag Iris	4	early summer	blue	2'-3'	1'
Penstemon digitalis	Smooth Penstemon	4	early summer	white	2'-3'	1'
Allium cernuum	Nodding Pink Onion	18	summer	pink	1'-2'	6"
Liatris pycnostachya	Prairie Blazingstar	5	summer	pink	3'-5'	1'
Parthenium integrifolium	Wild Quinine	5	summer	white	3'-5'	1'
Boltonia asteroides	False Aster	4	late summer	white/pink	2'-4'	1'
Rudbeckia subtomentosa	Sweet Black-Eyed Susan	2	late summer	yellow	4'-6'	2'
Vernonia fasciculata	Ironweed	4	late summer	magenta	4'-6'	1'
Aster novae-angliae	New England Aster	8	fall	pink/purple	3'-6'	1'
Solidago ohioensis	Ohio Goldenrod	8	fall	yellow	3'-4'	1'
Carex vulpinoidea	Fox Sedge (sedge)	64			1'-3'	1'

128 plants

Special Rain Garden Locations

In addition to conventional lawns, there are other locations where rain gardens can be created. A rectangular-shaped rain garden (above) was located in a narrow sideyard between two homes. A new rain garden (below), now helps control runoff that would flow into a parking lot.

Rain garden designs and plant lists provided by John Gishnock, Applied Ecological Services, Inc. (pages 19-22) and Jennifer Baker, Prairie Nursery Inc. (pages 24-29).

RAIN GARDENS

A how-to manual for homeowners

A frosted rain garden in autumn.

This publication developed by Roger Bannerman, Wisconsin Department of Natural Resources and Ellen Considine, U.S. Geological Survey. Special thanks to John Gishnock, Applied Ecological Services, Inc., Jennifer Baker, Prairie Nursery Inc. and Joyce Powers, CRM Ecosystems Inc.

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The publication can also be viewed and printed from pdf format on the web at clean-water.uwex.edu/pubs/raingarden

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