Texas A&M AgriLife Extension

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Stormwater Management: Rain Gardens

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A rain garden is a planted shallow depression that collects rainwater runoff from roofs, parking lots, and other surfaces. While a rain garden can blend into the landscape and serve as a garden area, its main function is to retain and treat collected stormwater.

Rain gardens (also known as bioretention areas) are either bowl-shaped or surrounded by berms to retain water. They are typically planted with native or adapted vegetation that tolerates both waterlogging and drought.

Rain gardens can be constructed in a variety of soils from sand to clay. The size varies depending on the catchment area, which is the area where runoff ends up in the rain garden. Rain gardens can be incorporated into a home lawn or a parking lot (Figs. 1 and 2).

Rain garden benefits include:

- Less stormwater runoff
- Slower runoff
- Less pollution in the runoff
- More water to replenish groundwater supplies
- Improved landscape

Figure 1. Rain garden built to capture rainwater from a parking lot and roof.

Figure 2. Rain garden built as an island in a parking lot. (Source: United States Department of Agriculture, Natural Resources Conservation Service)

How Do Rain Gardens Work?

Rain gardens use the chemical, biological, and physical properties of soils, plants, and microbes to remove pollutants from stormwater through four processes:

- Settling
- Chemical reactions in the soil
- Plant uptake
- Biological degradation in root zones

Settling

When runoff enters a rain garden, the water slows down because of the physical depression of the garden and the vegetation in it. The soil and debris that are then deposited cause settling.

The vegetation also traps some of the pollutants attached to the sediment in a process known as filtration. The main pollutants trapped in rain gardens are debris, some microbes, other solids suspended in the water, and soil-particle-bound pollutants such as phosphorus. Because sediments tend to settle on top of the rain garden and clog it, the garden must be maintained regularly to help remove sediments efficiently.

Chemical Reactions in the Soil

The soil in rain gardens interacts with pollutants via two main processes: adsorption and volatilization.

- Adsorption occurs when the pollutants stick to soil particles.
- Volatilization occurs when the pollutants evaporate.

Plant Uptake

Plants take up nutrients through their roots and use the nutrients for growth and other processes. Plants can be selected for high nutrient uptake.

When the plants die, those nutrients may be released back into the rain garden. To prevent this release, remove the dead plants regularly.

Biological Degradation in Root Zones

Microbes in the soil break down organic and inorganic compounds, including oil and grease, and help eliminate disease-causing microorganisms, or pathogens. Two microbial processes that remove nitrogen from the soil are nitrification and denitrification:

In nitrification, bacteria convert nitrogen products that are not readily taken in by plants, such as ammonia and ammonium nitrates, into nitrate, which is soluble in water and easily absorbed by the root system.

Denitrification occurs when bacteria convert nitrate into gases that are released into the atmosphere. Denitrification requires specific conditions such as low oxygen (as in waterlogged conditions), high temperature, and the presence of organic matter.

Design and Construction of Rain Gardens

Two common rain garden designs are used for stormwater retention:

- A planted depression is placed downstream from a drainage area. This design is commonly used in home and retail landscapes to collect rain from roofs or in sandy soil areas with high infiltration rates. For information on designing and building a residential rain garden, see *Rainwater Harvesting: Raingardens*, Texas AgriLife Extension publication L-5482.
- Existing soil is replaced with layers of high-infiltration soils, gravel, and mulch, and a variety of vegetation is planted. This design also commonly includes a perforated drainage pipe placed at the bottom of the growing media but above the gravel layer. It is best suited for clay soil, parking lots, and highway medians.

Selecting a Site

To select the location for a rain garden, consider the existing land use, vegetation, slope, proximity to building foundations, and the aesthetic value of the site. A rain garden should be designed to collect runoff from an area of no more than 1 to 2 acres. Larger areas can produce flows that cause erosion.

If the rain garden will collect runoff from a parking lot, replace some of the paved area instead of putting the rain garden in an existing grassed area that already filters stormwater.

Avoid placing the rain garden close to soil disturbed by construction so that the rain garden won't be clogged by sediments from the construction site runoff. If it must be close to a disturbance, use best management practices such as installing silt fences to protect the garden. In clay areas, it should be at least 10 feet (but preferably 30 feet) away from buildings to prevent any damage to foundations.

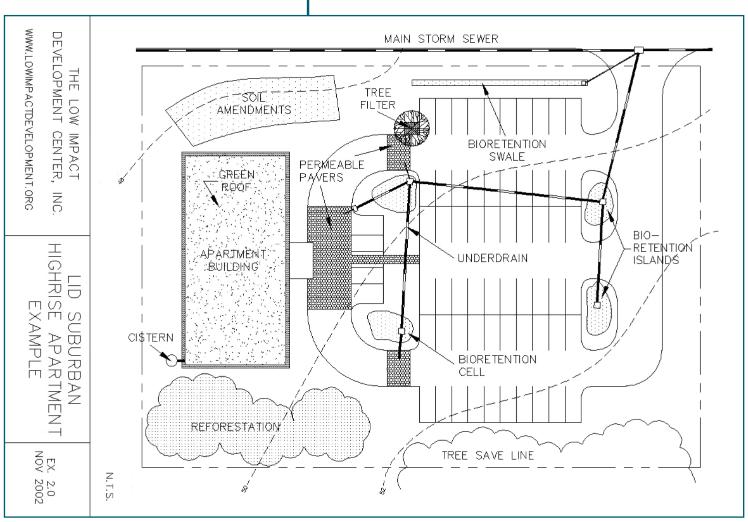

Figure 3. Parking lot design showing several rain garden cells connected with underground drains. (Source: Low Impact Development Center Inc.)

Determining the Catchment (or Contributing) Area

If the rain garden will be used to collect roof runoff, the catchment area will consist of the roof area as well as the area between the building and the rain garden.

For parking lots, determine the drainage pattern or design to estimate the catchment area. If the parking lot is not level or water flows out in more than one location, use a topographic map to delineate the catchment area. A surveyor can do this step manually or by using Geographic Information System (GIS) software.

If the area is larger than 2 acres, consider building two or more rain garden cells (Fig. 3). Rain gardens can be placed as islands in parking lots with concrete-curb cut openings (Fig. 4).

Figure 4. Curb cut opening. (Source: USDA, NRCS)

1. Runoff Volume Calculation

Not all rain becomes stormwater. Some rain is trapped in depressions; some seeps into the soil; some evaporates.

There are various ways to estimate the amount of runoff after a rain. A common method is the Natural Resources and Conservation Service (NRCS) Curve Number Method:

$$\textit{Runoff depth} = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

Where:

P is precipitation (inches).

$$S = \frac{1000}{CN} - 10$$

CN is the curve number.

The curve number is a land use and soil type factor that reflects the imperviousness of the ground surface (Table 1).

Table 1. Curve numbers for various types of land and hydrologic groups.

Cover Type and Hydrologic Soil Group	A	B	C	D
Open space (lawns, parks, golf courses, cemeteries, etc.)	49	69	79	84
Paved parking lots, roofs, driveways, etc.	98	98	98	98
Streets and roads:				
Paved, curbs and storm drains	98	98	98	98
Paved, open ditches	83	89	92	93
Gravel	76	85	89	91
Dirt	72	82	87	89
Urban areas:				
Commercial and business (85% impervious)	89	92	94	95
Industrial (72% impervious)	81	88	91	93
Developing urban areas: Newly graded areas (pervious areas only, no vegetation)	77	86	91	94

(Adapted from TXDOT Hydraulic Design Manual)

Hydrologic Soil Group Descriptions

A: Well-drained sand and gravel, high permeability

B: Moderate to well-drained, moderately fine to moderately coarse texture, moderate permeability

C: Poor to moderately well-drained, moderately fine to fine texture, slow permeability

D: Poorly drained, clay soils with high swelling potential, permanent high water table, claypan, or shallow soils over nearly impervious layer(s)

Most rain gardens are designed for a 1-inch storm, allowing them to perform as a first-flush system. The first flush of runoff is usually the most polluted as it carries all the debris and pollution that accumulated since the previous rainfall. Rainfall in excess of 1 inch goes through an overflow system.

As a first-flush system, a rain garden will retain most of the rainfall during the course of a year. For example, storms with more than 1 inch per day happen only 12 times a year, on average, in Dallas, Texas.

To calculate the total volume, multiply the runoff depth by the catchment surface area using the following formula:

$$\underset{\text{(gallons)}}{\text{Runoff volume}} = \underset{\text{(inches)}}{\text{Runoff depth}} \times \text{area (ft}^2\text{)} \times 0.623$$

Example 1: Calculating Runoff Volume

Maggie wants to build a rain garden to collect stormwater flowing off the 3,000-square-foot paved parking lot of her store built on clay soils. She first calculates the runoff depth resulting from a 1-inch rain. From the curve number table, she identifies that her hydrologic soil group is D, and for paved parking lots, the curve number CN is 98. She then calculates the value of S from the curve number method equation:

$$S = \frac{1000}{CN} - 10 = \frac{1000}{98} - 10 = 0.20$$

She then calculates the runoff resulting from a 1-inch rainfall using the following equation:

$$\text{Runoff depth} = \frac{(P - 0.2S)^2}{(P + 0.8S)} = \frac{(1 - 0.2 \times 0.2)^2}{(1 + 0.8 \times 0.2)} = 0.79 \text{ inches}$$

She then determines the volume in gallons that 0.79 inches make on 3,000 square feet of parking lot:

$$\underset{\text{(gallons)}}{\text{Runoff volume}} = \underset{\text{(inches)}}{\text{Runoff depth}} \times \text{area (ft}^2\text{)} \times 0.623 \qquad \boxed{3{,}000 \text{ ft}^2}$$

$$\underset{\text{(gallons)}}{\text{Runoff volume}} = 0.79 \text{ (inches)} \times 3{,}000 \text{ (ft}^2\text{)} \times 0.623 = 1{,}869 \text{ (gallons)}$$

Figure 5. Placing a perforated pipe on top of the gravel.

Rain Garden Design

Follow these steps to build a 3-foot-deep rain garden, the usual size:

1. Fill the bottom foot (the retention zone) with gravel (0.5 to 1.5 inches in diameter—sometimes called #57 stone).
2. At the top of this layer, place a perforated underdrain pipe for drainage purposes (Fig. 5).
3. Lay a filter fabric over the gravel and the drain to reduce the silting of the gravel zone (optional) (Fig. 6).
4. Place 1.5 feet of soil over the filter fabric.

Figure 6. Placing the filter fabric.

5. If the native soil is of low infiltration such as clayey soils, bring in soil from another area. The soil should consist mainly of sand or another coarse material such as crushed expanded shale, yet still contain some fine material and organics to support plant growth. For clay soil, use a mix of 50 percent compost, 25 percent native soil and 25 percent expanded shale (or similar material). For sandy soils, use a 50 to 75 percent native soil and 25 to 50 percent compost mix. Use well-aged yard waste compost.
6. Add 2 inches of mulch, preferably well-aged shredded hardwood, which will not float, on top of the soil around the plants.
7. Build the rain garden to hold 6 to 9 inches of water over the top of the soil (Fig. 7). Assuming that the gravel and soil are 30 percent pore space, calculate the depth of water the rain garden will hold at full capacity. One foot of gravel with 30 percent pore space will hold 3.6 inches of water. One and a half feet of expanded shale/clay/compost mix with a 30 percent pore space will hold 5.4 inches of water.
8. Add the 6 inches of standing water on top of the rain garden soil for a total water depth of 15 inches (Fig. 8).

Figure 7. Completed rain garden.

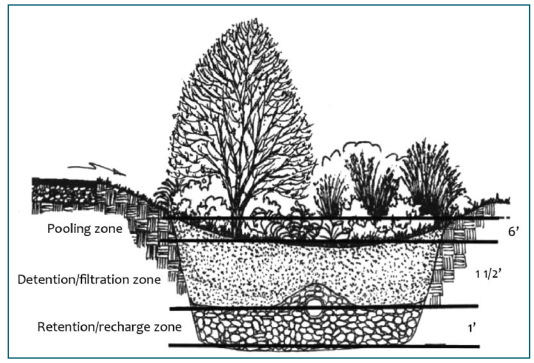

Figure 8. Typical cross section of a rain garden. (Source: George’s County, Maryland)

Rain Garden Sizing

To determine the surface area of the rain garden, divide the total amount of runoff by the depth of water held at full capacity. The water volume in gallons held in a square foot of rain garden is:

$$\text{Volume per square foot (gallons)} = \text{Water depth (inches)} \times 0.623$$

$$\text{Surface area of rain garden (ft}^2\text{)} = \frac{\text{Volume of runoff (gallons)}}{\text{Volume per square foot (gallons per ft}^2\text{)}}$$

Example 2: Calculating the Size of the Rain Garden

After determining the runoff volume generated from her parking lot, Maggie needs to calculate the size of her rain garden. Knowing that her rain garden holds a water depth of 15 inches, she first calculates the volume of water held in each square foot of rain garden using the following equation:

$$\text{Volume per square foot (gallons)} = \text{Water depth (inches)} \times 0.623$$

$$\text{Volume per square foot (gallons)} = 15 \text{ (inches)} \times 0.623 = 9.35 \text{ gallons}$$

Using this number and the total runoff volume from Example 1, she calculates the surface area required to build her rain garden:

$$\text{Surface area of rain garden (ft}^2\text{)} = \frac{\text{Volume of runoff (gallons)}}{\text{Volume per square foot (gallons per ft}^2\text{)}}$$

$$\text{Surface area of rain garden (ft}^2\text{)} = \frac{1{,}869 \text{ (gallons)}}{9.35 \text{ gallons per ft}^2} = 200 \text{ ft}^2$$

Maggie needs 200 square feet to build a rain garden that will hold runoff from 1 inch of rainfall falling on her parking lot. This amounts to 6.67 percent of the total catchment area. Typically, rain gardens range from 3 to 10 percent of the total catchment area.

Table 2. Typical hydraulic conductivity (K) ranges for various soil types.

Soil Texture	Saturated Conductivity (in./hr)
Sand	8.27
Loamy sand	2.41
Sandy loam	1.02
Sandy clay loam	0.17
Loam	0.52
Silt loam	0.27
Clay loam	0.09
Silty clay loam	0.06
Silty clay	0.04
Clay	0.02

(Adapted from *Handbook of Soil Science*, Sumner ME, 2000)

Table 3. Manning's roughness coefficient for various types of pipes.

Surface Material	Manning's Roughness Coefficient n
Brass	0.011
Brick	0.015
Cast iron, new	0.012
Copper	0.011
Corrugated metal	0.022
Galvanized iron	0.016
Plastic	0.009
Steel, coal-tar enamel	0.010
Steel, new unlined	0.011
Steel, riveted	0.019

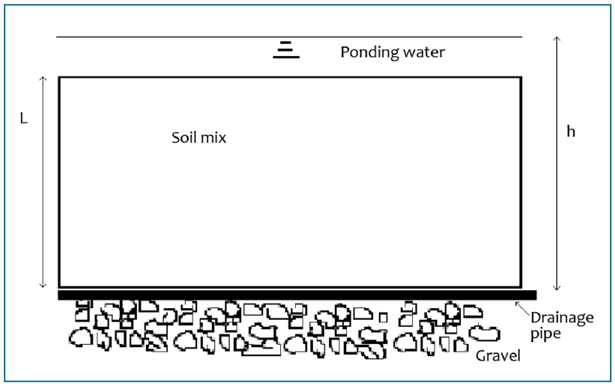

Figure 9. Cross section of a rain garden showing the height of water above the drain (h) and the depth of the soil (L) of Darcy's Law.

Drainage Pipe Sizing

The drainage pipe placed under the soil area (1.5 feet) should be designed to carry up to 10 times the minimum flow through the soil calculated using Darcy's Law:

$$Q = AK\frac{h}{L}$$

Where:
Q is the flow through the soil media (cfs).
A is the rain garden surface area.
K is the hydraulic conductivity of the soil or how fast water flows through the soil.
h is the height of water above the drain.
L is the depth of the soil (Fig. 9).

The hydraulic conductivities for various soils are in Table 2.

To determine the size of the perforated pipe, use the Manning's equation:

$$D = 16 \times \left[\frac{n \times Q}{S^{0.5}}\right]^{3/8}$$

Where:
D is the diameter of the pipes (inches).
Q is the flow to be carried (cfs).
n = Manning roughness coefficient (0.01 for smooth plastic pipe)
S = slope of the pipe (for this site, assume 0.1 percent)

A list of Manning's roughness coefficients for various pipe types is in Table 3.

Example 3: Sizing the Drainage Pipe

In Example 2, Maggie determined that her rain garden needs to be 200 square feet. To size the underdrain, she needs to calculate the flow going through the loamy sand soil at capacity. The depth of her soil L is 1.5 feet. The height of the water above the drain h is the 1.5 feet of soil plus the 6 inches of standing water, which is equal to 2 feet. From Table 2, a loamy sand will have a hydraulic conductivity of 2 inches per hour. Applying the Darcy equation:

$$q = K\frac{h}{L}$$

$$q = 2.41\ in./hr\left(\frac{2\ ft}{1.5\ ft}\right) = 3.21\ \text{in./hr per square foot of rain garden.}$$

For 200 square feet, the total flow is

$$Q = 200\ ft^2 \times 3.21\ in./hr \times \left(\frac{1}{12}\ in./ft\right) \times \left(\frac{1}{3600}\ hour/sec\right) = 0.015\ cfs$$

The pipe needs to be designed for 10 times the calculated flow, that is 0.15 cfs. To determine the pipe size, using a plastic pipe, determine the roughness coefficient from Table 3 for plastic n = 0.009. If the pipe is laid at a 0.1% (0.001) slope, you can calculate the size of the pipe using Manning's equation:

$$D = 16 \times \left[\frac{n \times Q}{S^{0.5}}\right]^{3/8}$$

$$D = 16 \times \left[\frac{0.009 \times 0.15}{0.001^{0.5}}\right]^{3/8} = 4.90\ inches$$

Rounded up to the nearest available pipe size, we find that a 6-inch pipe is needed to carry the water ten times the minimum flow rate from this site.

Overflow Design

If more rain falls than can be filtered by the rain garden, it may overflow. Design your rain garden to account for this possibility. The solution can be as simple as allowing the water overflow at the downstream end. This design requires a large enough vegetated area to absorb the overflowing water.

If the rain garden is next to an impervious area such as a road, you will need an alternative strategy such as redirecting overflow. To route overflow into an adjacent drain or ditch:

1. Install an overflow drop box (catch basin) (Fig. 10).
2. Place the top (inflow) of the drop box at least 6 inches higher than the top of the rain garden soil. This allows for holding 6 inches of water on top of the rain garden.
3. Connect the outlet of the drop box to a pipe that routes the water to the adjacent drainage system.

Figure 10. Drop box for overflow in a rain garden.

Plant Selection

Plants placed in rain gardens should be able to withstand short periods of inundation (up to 48 hours), as well as drought conditions. The vegetation you select will depend on regional weather conditions and the adaptability of the plants. Ask a county horticulture Extension agent, local horticulturist, Texas Master Gardener, or local nursery manager for a list of plants suitable for rain gardens in Texas. A partial list is shown in Table 4.

Table 4. List and characteristics of rain garden plants

Botanical Name	Common Name	Height/Width	S/SH	W/D
Perennials				
Achillea millefolium	Yarrow	1 ft/1 ft	S	D
Acorus calamus	Sweet flag	4 ft/2 ft	S	W
Alstroemeria pulchella	Peruvian	3 ft/2 ft	S/PSH	W/D
Aquilegia hinckleyana	Texas columbine	12 in./12 in.	S	W/D
Asclepias tuberosa	Butterfly weed	3 ft/6 in.	S	D
Aspidistra elatior	Cast iron plant	24 in./24 in.	SH	W/D
Amorpha fruticiosa *	False indigo	5 ft to 10 ft/8 in.	S/PSH	W
Baptisia australis	Blue false indigo	3 ft to 6 ft/24 in.	S	W
Calyptocarpus vialis	Horseherb	4 in./18 in.	SH	W/D
Canna generalis	Canna	2 ft to 6 ft/2 ft to 6 ft	S	W
Coreopsis verticillata 'Moonbeam'	Moonbean coreopsis	1 ft/1 ft	S/PSH	W/D
Dichondra argentea 'Silver Falls'	Silver falls	2 in./4 in.	S/PSH	D
Echinacea purpurea	Purple cone flower	2 ft/2 ft	S	W/D
Eupatorium coelestinum	Blue mistflower	8 in./16 in.	S	W/D
Eupatorium purpureum	Joe-Pye weed	4 in. to 4 ft/2 ft	S/SH	W
Heliopsis helianthoides	Ox-eyed sunflower	3 in. to 5 in./30 in.	S	W
Hibiscus coccineus	TX Star hibiscus-red	6 ft/4 ft	S	W/WD
Hibiscus coccineus 'Lone Star'	TX Star hibiscus-white	6 ft/4 ft	S	W/WD
Hibiscus moscheutos	Swamp rose mallow	3 ft to 4 ft	S	W/D
Hymenocallis liriosme	Spider lily	2 ft/1 ft	S	W/D
Ipomopsis rubra	Standing cypress	2 ft to 6 ft/6 in. to 12 in.	S	W
Iris spp. *bearded* and hybrids	Iris	12 in./6 in.	S	D
Iris brevicaulis Louisiana species and hybrids	Louisiana iris	Up to 40 in./6 in.	S/PSH	W
Kosteletzkya virginica	Marsh mallow	6 ft/6 ft	S	W
Liatris spicata	Gayfeather	2 in./18 in.	S	W
Lobelia cardinalis	Cardinal flower	2 ft to 4 ft/2 ft	S/PSH	W
Lythrum salicaria	Loosestrife	3 ft/3 ft	S	W/D
Monarda fistulosa	Bee balm	2 ft/2 ft	S	W/D
Rudbeckia hirta	Black-eyed Susan	1 ft to 2 ft/1 ft	S	W/D
Rudbeckia fulgida 'Goldstrum'	Black-eyed Susan	2 ft/2 ft	S	W/D
Rudbeckia maxima	Giant coneflower	4 ft to 6 ft/2 ft to 3 ft	S	W
Ruellia brittoniana 'Katie's'	Ruella Katie	6 in./12 in.	S	W/D
Salvia coccinea	Scarlet sage	3 ft to 5 ft/1 ft to 2 ft	S/SH	W/D
Setcreasea pallida	PurpleHeart	12 in./24 in.	S/PSH	W/D
Sisyrinchium angustifolium	Blue-eyed grass	6 in. to 12 in./12 in.	S	W/D
Solidago altissima	Goldenrod	2 ft to 4 ft/3 ft to 5 ft	S	W/D

continued on next page

Table 4 continued.

Botanical Name	Common Name	Height/Width	S/SH	W/D
Perennials continued				
Stachys byzantina	Lamb's ear	6 in./12 in.	S	D
Tradescantia occidentalis	Spiderwort	2 ft/1 ft	SH/PSH	W/D
Vernonia fasciculata	Ironweed	4 ft to 6 ft	S	W
Zephyranthes spp.	Rain lily	6 in. to 10 in.	S	W
Grasses				
Carex spp.	Sedge	Varies	Varies	W/D
Chasmanthium latifolium	Inland seaoats	2 ft to 4 ft	SH	W
Muhlenbergia reverchonii	Seep muhly	2 ft to 4 ft	S	W
Panicum virgatum	Switch grass	3 ft to 4 ft	S	W/D
Shrubs				
Aesculus pavia	Scarlet buckeye	10 ft to 15 ft/6 ft to 10 ft	PSH/SH	W/D
Callicarpa Americana	American beauty berry	4 ft to 6 ft/5 ft to 8 ft	S/SH	W/D
Cephalanthus occidentalis *	Buttonbush	5 ft to 15 ft/6 ft to 8 ft	S/PSH	W
Clethra alnifolia	Summersweet clethra	3 ft to 10 ft/5 ft	S/PSH	W/W/D
Ilex decidua	Possumhaw holly	20 ft/15 ft	S/SH	W/D
Ilex vomitoria	Yaupon	20 ft/20 ft	S/SH	W/D
Itea virginica	Virgina sweetspire	3 ft to 5 ft/3 ft	PSH	W/D
Leucothoe recemosa *	Leucothoe, Sweetbell	3 ft to 10 ft/6 ft	S/PSH	W/W/D
Myrica cerifera	Southern wax myrtle	15 ft/10 ft	S/SH	W/D
Sabal minor	Dwarf palmetto	4 ft/5 ft	SH	W/D
Symphoricarpos orbiculatus	Coralberry	1 ft to 6 ft/1 ft to 2 ft	PSH/SH	D
Spirea x bumalda 'Anthony Waterer'	Anthony water spirea	2 ft to 3 ft/3 ft	S	D
Trees				
Acer rubrunm var. *drummondii*	Southern swamp maple	70 ft/30 ft	S	W/D
Betula nigra	River birch	30 ft to 50 ft/20 ft to 30 ft	S/PSH	W/D
Cyrilla racemiflora *	Leatherwood (Titi)	15 ft/10 ft to 15 ft		W/D
Magnolia virginiana	Sweet bay magnolia	2 ft to 30 ft/20 ft	S/PSH	W/W/D
Sophora affinis	Eve's necklace	30 ft/20 ft	S	W/D
Taxodium distichum	Bald cypress	70 ft/30 ft	S	W/D

S – Sun SH – Shade PSH – Part Shade W – Wet D – Dry
* Suitable for Texas Gulf Coast

Cost

Construction activity and materials required to build a rain garden include:

- Excavation and hauling of existing soil
- Importing new soil
- Gravel
- Filter fabric
- Mulch
- Perforated pipes
- Overflow drop box
- Plants

The per-unit area (square feet) cost of building a rain garden will vary based on the size of the rain garden, the type of soil, and the design (bowl shaped vs. gravel and soil design).

An estimate of the costs for the activities and materials in the previous example are listed in Table 5. The cost of building this rain garden are also calculated and normalized per square foot.

Table 5. Cost estimate for rain garden construction.

Activity/Material	Unit	Unit cost	Cost for 200 ft^2
Excavation/hauling	Cubic yard	$6.30	$150
New soil import and installation	Cubic foot	$.5	$200
Gravel import and installation	Cubic foot	$.5	$150
Filter fabric	Square foot	$.5	$100
Mulch	Square foot	$0.5	$100
Perforated pipe	Linear foot	$2	$50
Overflow drop box	1 box	$50	$50
Plants	Square foot	$2	$400
Total			**$1,200**
Cost/ft^2			**$6**

Operation and Maintenance

Rain gardens work best when they are maintained regularly. Completing the following practices on a regular basis is essential.

- Remove or thin weeds and invasive and overly aggressive plants regularly, preferably by hand, to reduce water contamination.
- Monitor diseases and insects and remove infected plants as soon as you see them.
- Aerate and add compost regularly to reduce compaction and decreases in the infiltration rate.
- Shovel out any clay layer that forms from sedimentation on the top of the rain garden.
- Water during drought and high heat, usually if less than 0.5 inches of rain has fallen in the previous 3 weeks.

Resources

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Texas Water Resources Institute
make every drop count

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