the Grand Lake Association visitor's center in Grove, OK. It is approximately 1,800 square feet in area and captures runoff from a 1.9-acre catchment composed of roof, pavement and turf. These examples and many more in Oklahoma are listed on the Low Impact Development Atlas (http://lidmap.uconn.edu/embedmap.php?&stt=OK).

Glossary of terms

Bulk density – mass of dry soil divided by its undisturbed volume.

Eutrophication – pollution caused by abundant algae growth because of a nutrient rich environment, typically caused by excess phosphorus and nitrogen.

Exfiltration – is the loss of water into the soil surrounding the bioretention cell by percolation.

Infiltration – the movement of water into the soil from the surface.

Low Impact Development – a stormwater management technique that makes use of site design and best management practices (BMPs) to mimic the natural hydrology of a site.

Nonpoint source pollution – is pollution from many diffuse sources.

Percolation – the movement of water through soil.

Sorption – to take up or hold a substance through chemical and physical processes.

Stormwater – water on or below the ground surface shortly after a precipitation event.

Stormwater Best Management Practices – a practice or structural control that will control or abate the discharge of pollutants.

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Bioretention Cell Design Guidance for Oklahoma

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Introduction

Bioretention cells (BRC) are shallow landscape features that capture stormwater runoff. They utilize biological and physical processes to improve stormwater quality and hydrology of a site. BRCs are one of many Low Impact Development (LID) stormwater control measures. LID is a stormwater management technique that seeks to mimic the natural hydrology of the site that existed prior to development. It consists of practices and stormwater control measures that promote capture and infiltration of stormwater runoff close to the source. By doing so, LID practices reduce negative impacts that stormwater runoff from urban areas can have on ecosystems. See BAE-1758, *Understanding Stormwater Runoff and Low Impact Development (LID)* for more detail.

BRCs are sized to capture runoff from small- to medium-sized storm events, which occur more frequently than large storm events. The surface area of a BRC is typically 3 to 10 percent of the contributing area. Often, the contributing area has a high percentage of impervious surfaces such as roofs, roads and parking lots. BRCs are typically planted with water- and drought-tolerant vegetation. Figure 1 shows a small BRC in a residential setting.

This fact sheet is intended to provide guidance for sizing a BRC to capture a specific runoff volume. The runoff volume to be captured is based on site-specific characteristics about the soils, local rainfall and contributing area. Design steps presented here detail site selection, runoff volume determination, filter media selection, BRC sizing and flow structure guidance.

Environmental Benefits

A study completed by OSU found that BRCs improved water quality and decreased runoff volume. Primarily results from two BRCs in the study, referred to as site 1 and site 2, are summarized here. From inflow to outflow, the volume of

Figure 1. Residential bioretention cell.

runoff was reduced by 59 percent for site 1 and 66 percent for site 2. Stormwater captured by a bioretention cell can become groundwater, which can recharge aquifers, increase soil water for vegetation and boost dry period stream flows.

By capturing stormwater, the total mass of pollutants was reduced. Total suspended solids (includes sediments) for sites 1 and 2 were reduced by 83 percent and 89 percent on a mass basis, respectively. These reductions are higher than just a volume-capture reduction. This is because total suspended solids were filtered out of the stormwater by the filter media within the BRC. The BRCs also reduced *E. coli* levels. Site 1 reduced *E. coli* on a quantity basis by 56 percent. This aligns with the volume-capture reduction. Site 2 reduced *E. coli* on a quantity bases by 88 percent. This is higher than just a volume-capture reduction, indicating filtering occurred in this cell.

Excessive nutrients such as phosphorus and nitrogen are problematic in surface water. When excess nutrients enter a water body, they can cause algae blooms. Phosphorus is often the concern in Oklahoma because it is the limiting nutrient in most aquatic ecosystems. Abundant algae growth leads to eutrophication, which can cause fish kills. Fact sheet PSS-2917, *Phosphorus and Water Quality* provides a more in-depth explanation and discussion of environmental impacts from eutrophication. From the OSU bioretention study, dissolved phosphorus (ortho-phosphate) at site 1 was reduced by 75 percent and by 66 percent at site 2. Total phosphorus was reduced at site 1 by 84 percent and by 93 percent at site 2. These reductions are at or above the volume-capture reductions, indicating that filtering and sorption of phosphorus occurred. The BRCs were less effective at reducing nitrogen. Site 1 reduced total nitrogen by 17 percent, but nitrate (a form of dissolved nitrogen) actually increased by 82 percent. Site 2 performed better with reduced total nitrogen by 62 percent and nitrate by 12 percent. These results illustrate that performance varies from site to site and that design can impact performance. The studied BRC were designed specifically to capture phosphorus. Fly ash was mixed into the filter media to enhance phosphorus sorption. Other pollutants can be targeted with design too. For example, adding an anoxic zone in the bioretention cell enhances nitrogen removal.

Beyond stormwater improvements, the surrounding ecosystem can benefit from BRCs by including flowering plants to attract pollinators. Pollinators are the insects, birds and animals that move pollen within and between flowers. Pollinators can enhance the growth and diversity of the surrounding landscape and ecosystem. In addition, flowering plants and other landscaping can improve the aesthetics of the area.

Types

There are two main categories used to classify BRCs, infiltration and filtration. Infiltration BRCs do not have an underdrain, therefore stormwater that enters leaves as percolation to the surrounding soil or as evapotranspiration. In contrast, filtration systems have underdrains that route water out of the cell after flowing through the filter media. Filtration systems can have different underdrain configurations to encourage water movement down into the native soil below the bioretention cell.

Figure 2 shows the types of BRCs and underdrain configurations. The traditional approach is to place the underdrain near the bottom. Alternatively, adding an upturned elbow to the underdrain creates an Internal Water Storage (IWS) zone. Another configuration is to create a sump by elevating the underdrain above the bottom of the bioretention cell. Both the IWS and sump zone enhance exfiltration and create an anoxic zone, which can enhance nitrogen removal. The difference between the IWS and a sump is that the water stored in the IWS will leave either through exfiltration or be pushed out through the underdrain by a successive storm event, while water stored in a sump will only leave as exfiltration. A sump is better for capturing the first portion of the infiltrated stormwater, assuming the sump zone is empty. IWS captures the last portion of the infiltrated stormwater and is typically used to enhance nitrogen removal.

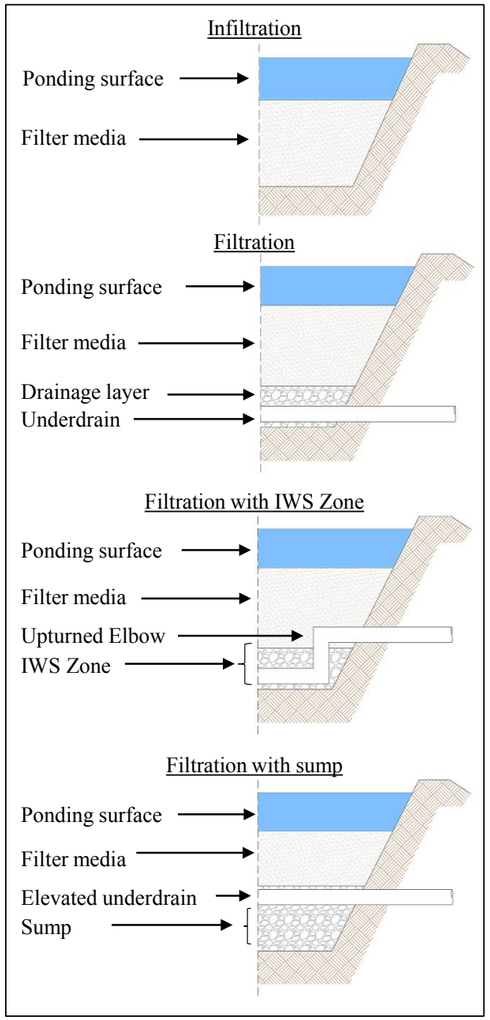

Figure 2. Types of BRCs (infiltration and filtration) and underdrain configurations (at the bottom, upturned elbow, and elevated). Diagrams only show a portion of a bioretention cell cross-section view.

Step 11. Develop planting plan

The surface of a bioretention cell can be covered with plants and mulch or turfgrass. Develop a list of plants, quantity and general location. Table 5 is a short list of Oklahoma native plants suitable for a BRC. Visit http://lid.okstate.edu/oklahoma-rain-garden-plant-guides for a more in-depth list of bioretention cell plants. Plan to cover the bioretention cell with a 2- to 3-inch layer of hardwood shredded mulch. Mulch helps keep moisture in the soil for plants and provides a layer of protection against erosion. When planting with turfgrass, only install low-clay content sod (<5 percent clay) to prevent clogging. Bermuda sod or native wet- and dry-tolerant grasses are suitable for bioretention. BRCs covered with turfgrass do not need mulch.

Costs

Experience with several BRCs across Oklahoma showed that the base cost is under $8,000 and there are additional costs on top of this based on the size of the BRC at about $1.50 per each additional cubic foot of volume. Costs have been estimated by others as $3 to $4 per square foot for residential BRCs and $10 to $40 per square foot for commercial BRCs (lid-stormwater.net). Designs with engineered media and an underdrain will be on the higher end of cost estimates. Additionally, plant selection and quantity can greatly change total cost. Planting costs can be minimized by consulting local nurseries prior to finalizing the planting plan and providing a list of alternative plants.

Oklahoma Examples

OSU Botanic Garden. Figure 6 is a picture of a bioretention cell at the OSU Botanic Garden in Stillwater, OK. This bioretention cell captures runoff from the gravel parking. It is approximately 1,700 square feet and the drainage area is 0.9 acres.

Grand Lake Association Visitors Center. A bioretention cell constructed as part of an OSU research and demonstration project is shown in Figure 7. This bioretention cell is located at

Figure 6. Bioretention cell at the OSU botanic garden.

Figure 7. Bioretention cell at the Grand Lake Association visitors center in Grove, OK.

area for infiltration into the filter media. A rule of thumb is to size the BRC with a surface area that is equal to or greater than 3 percent of the contributing area. The surface area (A_{cell}) needed to store the stormwater volume (SWV) produced by the 90th percentile storm event is calculated using the design infiltration rate and ponding depth as:

$$A_{cell} = \frac{SWV}{\text{Ponding depth}+(\text{Inifltraiton rate} \times 4 \text{ hours})}$$

This equation accounts for storage as ponded water on the surface and as storage in the media after four hours of infiltration. Increase the BRC area if the result from the area calculation is much less than 3 percent of the contributing area.

Step 9. Inlet and overflow design

Incoming water is directed to the BRC through an inlet. The inlet may be the existing natural drainage channel, a pipe or other structure. In general, the size of the inlet should be as large as or larger than the existing flow path. Erosion may occur if the inlet is too small.

All BRCs should have an outlet for excess stormwater runoff. Similar to the inlet, the overflow should be as large as or larger than existing flow paths. If the outlet is too small, flow velicites will be high. This can lead to erosion. Examples of outlet types include overflow weirs, high flow diversion on the inlet and structural outlet connected to an underdrain system. Overflow weirs are commonly constructed in the berm and made of stone or similar material. High-flow diversion overflows can be used for off-line systems. An off-line BRC receives only low stormwater runoff flows while high flows bypass the system. This type of design is good when erosion from large events is a concern. Structural overflows need a protective grate for safety and to keep floatables out if they are directly connected to the underdrain system.

Step 10. Determine Underdrain needs and size

An underdrain must be installed when engineered media is needed because captured stormwater cannot drain through the native soil fast enough to prevent long-term ponding problems. Use an underdrain with a diameter of at least 3 inches when the bioretention cell area is less than 1,000 square feet. The underdrain should have a diameter of at least 4 inches when the bioretention cell area is between 1,000 and 2,000 square feet. Use two 6-inch or three 4-inch underdrain pipes for BRCs with a surface area greater than 2,000 square feet. Use perforated PVC pipe for the underdrain. Surround the underdrain with #57 stone aggregate to prevent clogging. At least 4 inches of the stone aggregate should cover the underdrain and at least 2 inches of stone aggregate should be below the underdrain. Include a 2- to 4-inch layer of #89 stone aggregate between the filter media and the #57 stone aggregate to prevent material mixing. Additionally, a geotextile should be placed between the #57 stone aggregate and the native soil to prevent mixing. Underdrains should be spaced laterally at a maximum of 10 feet apart with at least two laterals per BRC. Installation of an underdrain is shown in Figure 5. Connect the underdrain pipe to an outlet pipe. Use solid PVC pipe for the outlet.

Figure 5. Installation of an underdrain.

Table 5. Oklahoma native plants suitable for BRC (OSU 2009).

SHRUBS
American Beautyberry – *Callicarpa Americana*
Elderberry – *Sambucus canadensis*
Possumhaw – *Viburnum nudum*
Red Chokeberry – *Aronia arbutifolia*
Yaupon – *Ilex vomitoria*

ORNAMENTAL GRASSES
River Oats – *Chasmanthium latifolium*
Muhly Grass – *Muhlenbergia capillaries*
Sweetgrass – *Muhlenbergia filipes*
Switch Grass – *Panicum virgatum*

SEDGES AND RUSHES
Lurid Sedge – *Carex lurida*
Fringed Sedge – *Carex crinita*
Southern Waxy Sedge – *Carex glaucescens*
White-topped Sedge – *Rhynchospora latifolia*
Woolgrass - *Scirpus cyperinus*

PERENNIALS
Black-eyed Susan– *Rudbeckia fulgida*
Columbine --*Aquilegia canadensis*
Homestead Purple Verbena – *Verbena Canadensis*
Joe Pye Weed – *Eupatorium fistulosum*
Prairie Blazing Star --*Liatris pycnostachya*
Showy Goldenrod --*Solidago speciosa*
Tickseed – *Coreopsis angustifolia*

FERNS
Southern Lady Fern— *Athyrium aplenoides*
Cinnamon Fern – *Osmunda cinnamomea*
Royal Fern—*Osmunda regalis*

Design process

Step 1. Select a site

Select a location on the downslope of the site to be treated. The selected site should be at least 10 feet from a building's foundation, if positioned downslope of the building and no closer than 30 feet from buildings that are down slope of the selected site. Avoid sites that have shallow ground water, as the bottom of a bioretention cell should be at least 2 feet above the seasonally high water table (Figure 3). Additionally, locate utilities in or near the proposed site. Do so by requesting a utility locate through OKIE811 (www.okie811.org). When possible, avoid placing a bioretention cell in a location where utilities are near the excavated depth. Identify overhead utilities because they limit the height of plants and can make construction challenging.

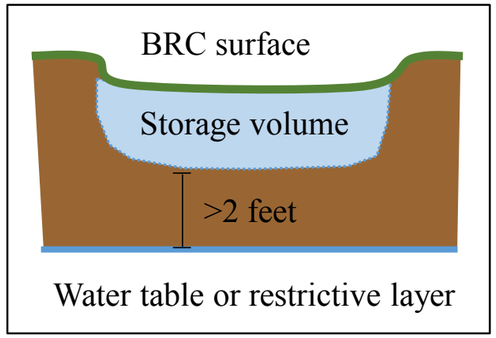

Figure 3. Diagram showing the depth to water table or restrictive layer. The depth should be greater than 2 feet and is measured from the bottom of the stormwater storage volume.

Step 2. Determine the contributing area

Identify the boundary of the area that drains to the proposed site. This can be done by following the flow paths from the selected site up through the drainage area. Other resources, such as aerial maps, may be helpful to identify the boundaries. Finding the boundaries with survey equipment will provide precise results but may be impractical for some designers. When in doubt, run a water hose to determine if an area drains the selected site. Regardless of the method, it is very important to correctly identify roof and pavement areas that drain to the site. The total contributing area consists of all roof, pavement and lawn areas that drain to the BRC. Be sure to calculate the area of sloped roofs as the vertical projection as viewed from an aerial viewpoint.

Step 3. Determine the design storage volume

A common design storage volume is the runoff produced from the 90th percentile storm event, which means that 90 percent of storms in a given year are less than this depth and 10 percent of storms are larger than this depth. Table 1 list

Table 1. Ninetieth percentile precipitation depth for selected cities in Oklahoma, using data from Mesonet.

City (Mesonet designation)	*90th Percentile (inch)*	*City (Mesonet designation)*	*90th Percentile (inch)*
Altus	0.92	OKC East	1.19
Bixby	1.08	OKC North	1.11
Bristow	1.07	OKC West	1.15
Catoosa	1.15	Okmulgee	1.13
Claremore	1.16	Spencer	1.03
Marshal	0.99	Stillwater	1.06
McAlester	1.16	Tahlequah	1.13
Medicine Park	0.97	Talala	1.35
Miami	1.07	Tullahassee	1.11
Norman	1.09	Tulsa	1.12

the precipitation depth for the 90th percentile storm event for select cities in Oklahoma. Runoff from the site is a function of the surface type and the contributing area. Runoff from impervious surfaces and vegetative spaces are determined separately. The Natural Resources Conservation Service Curve Number (CN) method is used to determine the runoff depth for each (NRCS, 1986). The CN method estimates the average depth of precipitation that becomes runoff based on land surface type and soil moisture. Runoff calculated with the CN method is defined as:

$$Q = \frac{(P - 0.2\,S)^2}{(P + 0.8\,S)}$$

where Q is the runoff depth in inches, P is the precipitation depth in inches, and S is the depth of stormwater retained by the catchment area. S is calculated using the curve number (CN) value as:

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

The CN values for various soils and landuses are published by the NRCS in Technical Report 55 (NRCS 1986). Common CN for urban land uses are listed in Table 2.

The volume of stormwater captured by the bioretention cell is the sum of runoff from the impervious surfaces and the open spaces, and is calculated as,

$$SWV=[(\text{Impervious area}) \times Q_{impervious} \times (1 \text{ ft} \div 12 \text{ in})] + [(\text{Area of open spaces}) \times Q_{open\ spaces} \times (1 \text{ ft} \div 12 \text{ in})]$$

Step 4. Determine the infiltration rate of the native soil

When possible, use the native soil at the site as the filter media. This reduces cost by eliminating material purchase, excavation and disposal of excavated material. Two methods can be employed to determine whether the native soil is suitable for a bioretention cell; a percolation test or soil properties. Determine the percolation rate at the surface and near the proposed bottom of the bioretention. Testing both locations is needed because stormwater must infiltrate at the surface and percolate through the bottom of the system to avoid needing an underdrain. The ponding depth is not determined until Step

Table 2. Curve numbers for common residential areas based on hydrologic soil group or soil texture (adapted from NRCS 1986).

Hydrologic Soil Group (HSG)	*Soil texture*[1]	*Surface cover type*						
		Residential districts by average lot size						
		Impervious areas	*1/8 acre or less*	*1/4 acre*	*1/3 acre*	*1/2 acre*	*1 acre*	*2 acres*
A	Sand, loamy sand, or sandy loam	98	77	61	57	54	51	46
B	Sandy clay loam	98	85	75	72	70	68	65
C	Silt loam or loam	98	90	83	81	80	79	77
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay	98	92	87	86	85	84	82

[1]actual HSG for a specific soil may vary based on the bulk density and aggregate formation. Specific HSGs for the soils in your location can be found at websoilsurvey.sc.egov.usda.gov

6, therefore the depth at which testing takes place must be estimated. The maximum recommended depth for a bioretention cell is 4 feet. Determine the number of tests needed from Table 3. Again, the area is not determined until Step 8, so the surface area must be estimated. The final BRC area will most likely be 3 to 10 percent of the contributing area. For infiltration rate testing purposes, assume the cell will be 8 percent of the contributing area.

Method 1. Measure infiltration with a percolation test

A percolation test will directly measure the rate at which water will move into the soil. The following procedure is adapted from the Michigan LID Manual (SEMCOG 2008). First, dig a 6- to 10-inch diameter hole. The depth should match the anticipated bioretention cell depth. Dig the hole to a minimum of 12 inches deep. Scratch the sides and bottom hole with a sharp-pointed instrument to eliminate smeared soil surfaces and remove loose soil from the bottom of the hole. A 2-inch layer of coarse gravel may be placed in the bottom of the hole to prevent erosion and smearing when water is added. Figure 4 shows the configuration of a percolation test hole.

Saturate the soil by maintaining a minimum water depth of at least 6 inches in the hole for 30 minutes and then allow the water to soak in for an additional 30 minutes without refilling the water. Ideally, the water level for the test should match the surface ponding level of the bioretention cell, approximately 6 to 12 inches. Immediately after the soaking period, perform the test by adjusting the water level in the hole to the anticipated

Table 3. Soil testing density (adopted from the Minnesota LID Manual).

Bioretention surface area (ft²)	*Number of tests*
<1,000	1
1,000 to 5,000	2
5,000 to 10,000	3
>10,000	4

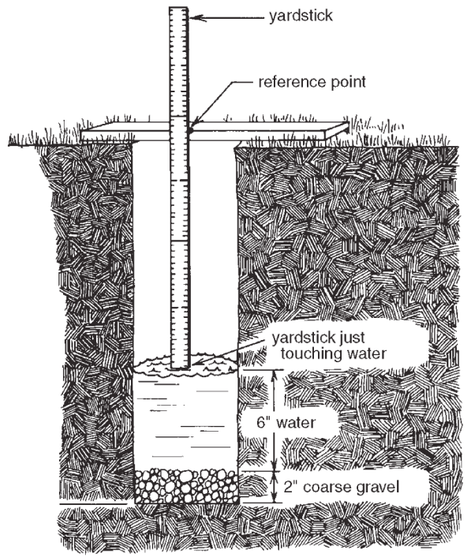

Figure 4. Percolation test setup example (Scherer 2015).

ponding depth. The minimum depth for the test should be 6 inches. Record the change in water level every 10 minutes if the hole was dry at the end of the soaking period, or every 30 minutes if water remained in the hole after the soaking period. After collecting each water level measurement, refill the hole to bring the water level back up to the starting depth. Collect readings until the change in water level between readings stabilizes or collect a minimum of eight readings, whichever comes first. The water level drop is stable when the difference between the highest and lowest reading of four consecutive readings is a ¼-inch or less.

Calculate the percolation rate (PR) as the average of all readings during the stabilized period as:

$$PR = \frac{\sum \left(\frac{\text{change in water level}}{\text{reading interval}} \right)}{\text{number of readings}}$$

A Reduction Factor (RF) is calculated to account for water movement through the sides of the test hole as:

$$RF = \frac{(2 \times \text{intial water depth-average water level change})}{(\text{diameter of test hole})} + 1$$

All variables should use the same units. The design infiltration rate is then calculated as:

$$I = PR \div RF$$

Method 2. Estimate infiltration from soil properties

The second method is to estimate the infiltration rate based on the soil texture and bulk density. Estimating infiltration from soil texture only is possible, but research by OSU showed that including bulk density increases design accuracy, which will prevent overdesign and increased cost (Christianson et al., 2012). Soil texture is defined by the percentages of sand, silt and clay. Soil samples can be submitted to the Soil, Water and Forage Analytical Laboratory at Oklahoma State University to determine soil texture. Details for submitting samples and cost of analysis can be found at soiltesting.okstate.edu. Bulk density is determined by collecting a known volume of soil and determining the weight of the volume of soil. Bulk density can be determined following the procedure in the USDA Natural Resources Conservation Service Soil Quality Test Kit Guide (USDA 1999). Use Table 4 to estimate the infiltration rate from soil properties.

Step 5. Determine filter media needs

If the infiltration rate determined in Step 3 is greater than or equal to 0.25 inches per hour, use the native soil as the filter media. Otherwise, an engineered filter media and underdrain should be used. Engineered filter media should consist of 85 to 88 percent washed sand, 8 to 12 percent fines and 3 to 5 percent organic matter. Assume an infiltration rate of 6 inches per hour for engineered media when determining the ponding depth and media depth as in Steps 6 and 7, respectively. It may be a good idea to test the phosphorus levels in the media to ensure that the bioretention cell does not act as a phosphorus source. It is recommended that the phosphorus level of the filter media be less than or equal to 30 milligrams per kilogram, based a Mehlich-3 phosphorus test. Phosphorus levels can be determined by the Soil, Water and Forage Analytical Laboratory at Oklahoma State University. Visit soiltesting.okstate.edu for details on submitting samples and cost of analysis.

Step 6. Determine the ponding depth

The ponding depth is manually selected if an engineered media will be used. Otherwise the ponding depth is based on the infiltration rate and is determined as:

$$\text{depth of ponding} \leq \text{Infiltration rate} \times 24 \text{ hours}$$

This equation determines the maximum ponding depth so all standing water will drain within 24 hours. A drainage time of 24 hours or less prevents the growth of mosquitoes. Ponding depth should be between 4 and 18 inches, regardless of the media selection.

Step 7. Determine the media depth

The media depth is manually selected if an engineered media will be used. Otherwise, the media depth is based on a volume of water that infiltrates into the soil in a 24 hour period. The media depth is determined based on the infiltration rate, ponding time and filter media porosity as:

$$\text{depth of media} \leq \frac{\text{Infiltration rate} \times 24 \text{ hours}}{0.3}$$

where 0.3 in the equation is assumed porosity of the filter media. Media depth should be between 1 foot and 4 feet, regardless of the media selection. When the native soil is used for the media, the calculated depth defines the bottom elevation used to check site limitations in Step 1.

Step 8. Determine the bioretention cell surface area

Increasing the surface area increases the opportunity for infiltration. Good performance from a BRC requires sufficient

Table 4. Estimated infiltration rate based on soil texture and bulk density (Saxton and Rawls 2006).

Texture	*Normal Bulk Density* (g/cc)	*Design Infiltration Rate (in/hr.)* *Percent of Normal Bulk Density* 80	90	100	110	120
Sand	1.43	8.12	6.00	4.26	2.87	1.82
Loamy Sand	1.43	7.40	5.42	3.81	2.53	1.57
Sandy Loam	1.46	4.48	3.07	1.98	1.18	0.62
Loam	1.43	1.89	1.13	0.61	0.28	0.09
Silt Loam	1.38	1.90	1.16	0.63	0.29	0.10
Silt	1.38	2.41	1.52	0.87	0.42	0.16
Sandy Clay Loam	1.50	1.58	0.90	0.44	0.17	0.04
Clay Loam	1.39	0.80	0.41	0.17	0.05	0.01
Silty Clay Loam	1.30	0.88	0.48	0.22	0.08	0.02
Silty Clay	1.26	0.65	0.34	0.14	0.04	0.01
Sandy Clay	1.47	0.47	0.19	0.05	0.01	<0.01
Clay	1.33	0.36	0.15	0.05	0.01	<0.01