DRAFT WORK IN PROGRESS

9-22-2021

Bioretention

Insert Figure BR-1 image Sand Filter, indicate SCM components discussed below on conceptual rendering

Figure BR-1. Bioretention Components

Photograph BR-1. This bioretention area treats runoff from the roof and lot, while serving as an aesthetically pleasing landscape feature. Photo: Wright Water Engineers.

Description

SCMs that provide treatment via bioretention consist of engineered, depressed landscape areas designed to capture and filter and/or infiltrate the water quality capture volume (WQCV). These types of SCMs implement the process of bioretention which uses growing media and vegetation to facilitate biological processes that retain stormwater pollutants and enhance infiltration capabilities. The terms porous landscape detention (PLD), rain garden, and bioretention are used interchangeably in the MHFD region. The term rain garden is often used to describe smaller facilities, although bioretention facilities can be constructed from the lot scale to the regional scale. Because of the enhanced treatment provided by bioretention, community connection benefits, and compatibility with the urban environment, MHFD strongly encourages use of bioretention.

Bioretention areas can be designed to provide detention for events exceeding the WQCV by incorporating storage of the EURV and 100-year detention storage volumes above the WQCV, with drain times and release rates in accordance with the *Storage Chapter*.

MS4 Permit Applicability (Dependent on design and level of treatment)	
Meets Runoff Reduction Standard	Yes
Meets WQCV Capture Standard	Yes
Meets Pollutant Removal Standard	Yes
Typical Effectiveness for Targeted Pollutants	
Sediment/Solids	High
Nutrients	Medium
Total Metals	High
Bacteria	Medium
Common Applications	
Step 1: Runoff Reduction	Yes
Pre-treatment (in Treatment Train)	No
WQCV + Flood Control	Yes
Cost	
Life-Cycle Costs	Medium

SCM Components

The primary components of bioretention include inlet(s), energy dissipation and forebay(s), a surcharge volume, growing media, vegetation, an underdrain (no- or partial-infiltration designs), and an outlet structure. The primary outflow for the WQCV is typically an underdrain or infiltration into the underlying soil. When bioretention is designed to provide full spectrum detention design the outlet to release the EURV and 100-year volumes in accordance with the EURV drain time and 100-year release rates. Even if the SCM only incorporates the WQCV, an outlet in the form of a spillway (emergency overflow) is necessary for larger events. See the *Site Assessment* and *Filtration and Infiltration Systems* sections of this chapter for guidance and criteria on determining the appropriate type of bioretention system and designing underdrain and liner systems as needed based on site-specific conditions. The *SCM Inflow Features* and *SCM Outflow Features* sections provide guidance on creative ways to drain runoff into the SCM and release the treated runoff.

Photograph BR-2. Bioretention basin treating urban stormwater during runoff event. Photo: Wright Water Engineers.

Component	Intent
Inlet	Allows stormwater to enter the SCM
Forebay & Energy Dissipation	Facilitates removal of trash and coarse sediments and minimizes potential for erosion of media surface
Storage Volume	WQCV or additional flood storage volume provided above the media to ensure capture of the design volume
Growing Media	Supports plant growth and reduces pollutants by filtering and through other biological treatment processes
Vegetation	Helps maintain infiltration over time through root penetration of media, increases evapotranspiration and biological uptake of pollutants, aerates growing media, catalyzes soil ecology, and creates an attractive SCM
Underdrain with Orifice release	Collects and slowly releases the WQCV over 12 hours to reduce erosion in the receiving stream and enhance treatment by increasing contact time with the media
Outlet Structure	Safely conveys stormwater flows that exceed the design volume

The growing media and vegetation are the core water quality treatment elements of bioretention. The growing media must balance good infiltration capabilities with properties needed to support vegetation. MHFD has conducted significant testing of different mixes for growth media to develop the recommended specifications in this fact sheet.

Site Considerations

Bioretention is an excellent choice for small sites because these SCMs treat the WQCV and serve as landscape features. They are typically a much better choice for small sites than EDBs because they can infiltrate or release low flows through the underdrain rather than through an EDB outlet structure with small orifices that are likely to plug. For treatment of areas less than 5 impervious acres, bioretention or a similar infiltration-based SCM should be used instead of EDBs, which are unsuitable for drainage areas of this size. Bioretention can also be incorporated into larger sites and can be designed to provide full spectrum detention.

Bioretention systems typically are installed in locations such as:

- Plazas
- Parks
- Parking lot islands
- Street medians
- Landscape areas between the road and a detached walk
- Planter boxes that collect roof drain flows.

To avoid plugging of the bioretention media, these SCMs require a stable watershed, which is a reason that they are often successful in retrofit applications. When the watershed includes phased construction, sparsely vegetated areas, or steep slopes, consider another SCM or provide pretreatment or slope stabilization to facilitate source controls and sedimentation before runoff from these areas reaches the SCM. Additionally, bioretention should not be used when a baseflow to the SCM is anticipated, as these SCMs are intended to dry out between runoff events.

The surface of the bioretention media should be flat or at a mild slope in street-side stormwater planters. For this reason, bioretention can be more difficult to

Benefits

- Maintenance is relatively straight-forward.
- Bioretention incorporates multiple treatment processes including sedimentation, filtering, adsorption, evapotranspiration, and biological uptake of constituents.
- Stormwater treatment occurs within attractive landscaped areas.
- Bioretention can be integrated into space-constrained urban areas in a variety of shapes and sizes such as a series of linear curbside planters or as larger landscape features.
- Avoids problems with clogging of small orifices that are common with EDBs on small sites.

Limitations

- Additional design and construction steps are required for placement of any ponding or infiltration area near or upgradient from a building foundation and/or when expansive (low to high swell) soils exist.
- In a developing or otherwise erosive watershed, high sediment loads can clog the facility.

Is Pretreatment Needed?

Designing the inflow gutter to the bioretention area at a minimal slope of 0.5% can facilitate sediment and debris deposition prior to flows entering the SCM. Be aware that this will reduce maintenance of the SCM but may require more frequent sweeping of the gutter to ensure that the sediment does not impede flow into the bioretention area.

incorporate into steeply sloping terrain; however, terracing can be used to create flat areas suitable for bioretention even with sloped topography.

When bioretention areas are located adjacent to structures or infrastructure that could be adversely affected by infiltrating runoff or in areas with expansive soils, consult with a geotechnical engineer. A geotechnical engineer can evaluate the suitability of soils, identify potential impacts, and establish minimum distances or other physical barriers to implement between the SCM and structures. See the *Site Assessment* and *Filtration and Infiltration Systems* sections of this chapter for guidance and criteria on geotechnical considerations and testing requirements, underdrain and filter layers, perimeter barriers, and other aspects common to infiltration-based SCMs including bioretention.

Community Values

Bioretention provides opportunities to provide a high level of treatment for stormwater while also creating landscape features that add value to a site by enhancing the landscape aesthetics and experience. Bioretention areas that are an integral part of the site's landscape provide far more benefits than areas dedicated solely to stormwater treatment, such as small extended detention basins because bioretention areas are multifunctional and can serve other purposes including meeting landscape area requirements, providing attractive pockets of interesting plants, screening of parking lots, and others.

It is important to establish pre-design planning objectives to facilitate a successful design. At an early stage, determine the aesthetic design approach that best meets the overall project objectives. There are many opportunities for creativity in grading, plant selection, and design of inflow and outflow features for bioretention. Design approaches typically endeavor either to integrate the SCM into its surroundings with a "contextual design," or consciously contrast with the surroundings to highlight the SCM as a "stand-alone element," providing a counterpoint to the context of the site.

In a contextual design, the design responds to and builds on the character of the surroundings. Forms and shapes are related to and harmonious with surrounding structures and site improvements and fit into their environment through use of similar or complementary materials, scale, and design detailing. Materials used in this approach may directly reflect materials used in the surrounding architectural and engineering improvements. Coordinate design details for the bioretention area, such as concrete or stone edgers and retaining walls, with the surrounding site improvements to provide a unifying effect with the surroundings. Plant materials should also relate to surrounding landscape in overall character, massing, and degree of formal or naturalistic arrangement, while selecting plants that will thrive in the periodically wet environment.

A “stand-alone” or counterpoint design aims to create a feature that contrasts with its surroundings through uses of form, scale, materials, color, and other features. A counterpoint design can create a strong dramatic effect, but to be successful, it must be done in a way that creates an overall balanced site design.

Of these two approaches, contextual design is more common and is generally easier to accomplish. With either approach the emphasis should be on creating a feature that adds value to the site while effectively treating the WQCV. Maintenance is critical for assuring long-term function of bioretention, so planning for maintenance and selecting plants that are suitable for the hydrologic conditions in the SCM are important design aspects to avoid burdensome maintenance. Design objectives to create bioretention areas that thrive and perform over the long-term without excessive maintenance include:

1. **Plan for Maintenance:** Understand and design for access the level of maintenance that will be provided over for the long term. Bioretention features designed as aesthetic amenities in public areas may require more frequent maintenance than those with more naturalized designs in suburban settings. Do not design a select plantings that require frequent maintenance if the owner does not have the resources to perform such maintenance because poorly maintained bioretention areas can become weedy eye sores that function poorly, diminish site aesthetics, and contribute to poor public acceptance.

   During design, consider how the SCM will be accessed for routine and restorative maintenance, what equipment will be required, and how routine maintenance activities can be performed in a way that minimizes impacts to vegetation.

2. **Select plants that will thrive with the variable hydroperiod and micro-climate.** To select plants, consider the site’s unique micro-climatic conditions and bioretention design features, construction techniques, and maintenance levels of service. Consider the following:

   - Use natives plant species when feasible. Native species tend to tolerate the region’s hot summers and cold winters better than most non-natives. Native grasses have deep roots that can reach residual moisture in the quick-draining bioretention media during times of drought.
   - Plants must be able tolerate prolonged periods of inundation. Given a 12-hour drain time for bioretention and the potential for storms to occur sequentially, the media in the SCM may be saturated (or nearly saturated) for multiple days before pore water has drained out via gravity.
   - Microclimate, including solar aspect, exposure to wind, and shading or sun reflections from adjacent buildings, can have a significant effect on the conditions that plants must tolerate. Visiting the site during different times of the day in summer months is very informative for understanding sun and shading as well as urban heat island effects.
   - Consider planting vegetation in groupings or masses of single or similar species**.** Generally, large masses of plants grouped relatively close together create dense stands of vegetation that grow together to out-compete weed growth, while

enhancing infiltration through root penetration that creates macropores as roots die and decay.

- Provide irrigation. Depending on plant selection, irrigation may only be required during the vegetation establishment period and supplementally during extended droughts. However, providing a permanent irrigation system provides greater flexibility in plant selection and aesthetics. Even if regular irrigation is not planned once vegetation is established, laying irrigation pipe during landscaping is a small additional cost that makes temporary irrigation during establishment and droughts easier (system designed to hook up to water truck). During establishment, all plants should receive approximately 1 inch of moisture (combined rain and irrigation) per week for the first growing season to promote establishment.

3. **Include trees in or adjacent to bioretention facilities if desired.** Trees can provide significant added value to bioretention areas, including runoff reduction and mitigation of urban heat island effects. When considering trees, assess the compatibility of different species with the hydrologic, soil, and solar aspect of the SCM. Seek local guidance on minimum size requirements for trees in confined beds such as bioretention areas. Recommendations for planting trees in bioretention areas include:

    - Provide irrigation for trees.
    - Consider planting trees on side slopes, above the more frequently inundated areas.
    - Select trees that can withstand periods of inundation (consider trees that thrive in riparian areas).
    - Provide access for tree maintenance, which may include removal of growing media, trees, and other vegetation.
    - Keep trees away from underdrains because tree roots may clog the perforated underdrain openings.
    - Select appropriate, shade-tolerant species for tree understory plants.

Maintenance

Routine maintenance of bioretention is similar to landscape maintenance, consisting of trash and sediment removal from the forebay and care for vegetation. Chapter 6 of this manual provides recommended maintenance practices for all SCMs. During design, consider the following to ensure ease of maintenance over the long-term:

- Make the bioretention area as shallow as needed. Increasing the depth unnecessarily can create erosive side slopes and complicate maintenance. Shallow bioretention areas are also more attractive.
- The best surface cover for bioretention is full vegetation. Use rock mulch sparingly because rock mulch limits infiltration and is more difficult to maintain. Wood mulch handles sediment build-up better than rock mulch; however, wood mulch floats and can settle unevenly or clog the overflow depending on the configuration of the outlet. Some municipalities may not allow wood mulch for this reason.

- Provide pre-treatment when it will reduce the extent and frequency of maintenance necessary to maintain function over the life of the SCM. Provide a forebay for any concentrated inflows. For small inflows, the forebay may consist of a pad for sediment accumulation and removal surrounded by grasses to help keep sediment from migrating onto the filter area.
- In areas where deicers are applied, it is very important to understand the composition of the media and the underlying soils because research has shown that deicers can cause reduced infiltration rates in media and soils with clay content (Pitt et al. XXX). Additionally, deicers in runoff can stress vegetation, which may result in increased maintenance requirements.
- Establishing healthy vegetation is critical for the SCM to properly function. Design and adjust the irrigation system (temporary or permanent) to provide appropriate water for the establishment and maintenance of selected vegetation.
- Do not put a filter sock on the underdrain. This is not necessary and can cause the underdrain to clog.

Design Procedures and Criteria

Criteria and guidance for bioretention components including inlets, forebays, underdrains, liners, and outlets are provided in the front section of this chapter and should be referenced for design of these specific features.

The MHFD-BMP workbook, available at www.mhfd.org, is an Excel-based workbook that steps through the criteria listed below and performs design calculations for bioretention. Use this workbook to ensure designs meet criteria for treating the WQCV. Use a separate tool, MHFD-Detention, to develop and route storm hydrographs for a range of events through bioretention basins.

The following steps outline the design procedures and criteria for bioretention:

1. **Subsurface Exploration and Determination of a Full Infiltration, Partial Infiltration or No-Infiltration Section.** See the *Site Assessment* and *Filtration and Infiltration Systems* sections of this chapter to determine the most appropriate type of filtration and/or infiltration system for the bioretention area based on site conditions.

2. **Bioretention Storage Volume**: Provide a storage volume above the bed of the bioretention media equal to the WQCV based on a 12-hour drain time following this procedure:
    - Determine the imperviousness of the watershed.
    - Calculate the required storage volume, accounting for Step 1 runoff-reduction SCMs in the contributing watershed. Determine the required WQCV or EURV (watershed inches of runoff) using Figure 3-2 located in Chapter 3 of this manual (for WQCV) or equations provided in the Storage Chapter of Volume 2 (for EURV).
    - Calculate the design volume (surcharge volume above the media surface) as follows:

$$V = \left[\frac{\text{WQCV}}{12}\right] A \qquad \text{Equation BR-1}$$

Where:

V = design volume (ft^3)

WQCV = water quality capture volume (watershed inches)

A = watershed area tributary to the SCM (ft^2)

3. **Bioretention Basin Geometry:** MHFD recommends a maximum WQCV ponding depth of 12 inches to minimize stress to vegetation for frequent inundation and to manage the hydraulic loading. Locate the overflow spillway crest at or above this elevation. Depending on the type of vegetation planted, a greater depth may be used to detain larger, more infrequent events. While not always feasible, if inlets to the SCM can be designed to enter the SCM above the WQCV, this will reduce maintenance requirements for the inflow pipes related to sediment deposition due to backwater conditions. The media surface of the bioretention area typically should be flat. The exception to this is when a mild slope from the inlet to the outlet will help distribute runoff to the vegetation and reduce sediment deposit at the inlet. Linear basins such street-side stormwater planters may benefit from a mild slope from inlet to outlet. The intent is to fully use the filter area to avoid higher sediment deposit in lower areas of the basin. Equation BR-2 provides a minimum media surface area allowing for some of the volume to be stored beyond the area of the media (i.e., above the side slopes of the bioretention basin).

$$A_F = 0.02 \cdot A \cdot I \qquad \text{Equation BR-2}$$

Where:

A_F= minimum (flat) filter area (ft^2)

A = area tributary to the SCM (ft^2)

I = imperviousness of area tributary to the SCM (percent expressed as a decimal)

Use vertical walls or slope the sides of the basin to achieve the required volume. Side slopes should be no steeper than 4:1. Where needed to meet the required volume, also consider the porosity of the media at 15 percent[1]. This is only allowed on sites that meet the *Constrained Redevelopment Sites Standard* in the MS4 permit.

4. **Underdrain System, Impermeable Liner, and Geotextile Separator Fabric:** See the *Filtration and Infiltration Systems* section of this chapter for guidance and criteria based on the type of filtration and infiltration system selected.

5. **Growing Media:** The recommended growing media is intended to balance high infiltration capacity with properties needed to support healthy vegetation.

[1] The amount of pore storage in the bioretention media that may be considered as part of the WQCV is equal to one half of the overall porosity of the media minus the field capacity (water held after gravitational water drains).

Table BR-1 outlines recommended parameters for bioretention growing media. It is important that the media contain organic material with living soil organisms such as earthworms, bacteria, and fungi to enhance agronomic and infiltration properties and create a healthy, living media.

The recommended soil texture indicates an incremental increase in the proportion of silts and clays and a decrease in the sand percentage compared to prior MHFD media specifications; this is to increase moisture and nutrient holding capacity to aid in the establishment of a dense vegetation cover, which ultimately helps to sustain infiltration capacity. However, water applied to this bare media can mobilize and rearrange fine silt and clay particles on the surface to create a lower permeability layer. For this reason, vegetation is a critical component in maintaining infiltration in the basin over time. When establishing vegetation from seed, install seed and blanket immediately after media is placed to reduce the mobilization of fines and facilitate germination of the seed.

Provide a minimum of 18 inches of growing media to enable establishment of the roots of the vegetation (see Figure BR-1). A high level of quality control for the media is necessary. Quality control measures include reviewing media particle size distribution data, soil chemistry data, and results of nutrient analysis to ensure that the media meets specifications. The media can either be sampled after delivery and prior to placement or sampled by the supplier just prior to site delivery. In any case, the samples should be collected within several days of placement of the media so that the results are representative of the media placed.

Bioretention Growing Media Changes and Possible Amendments

Relative to previous versions of this fact sheet, MHFD's recommended growing media now contains more organic and fine materials to retain water and provide nutrients to plants.

Some performance studies have shown the potential for bioretention media to export nutrients, especially when facilities are new and when performance evaluation is focused on concentrations rather than loads. Careful selection of bioretention growing media and filter media (for partial- and no-infiltration basins) in accordance with the specifications in this fact sheet will help minimize the potential for significant export of nutrients.

An area of evolving research for bioretention media includes evaluation of various amendments that enhance performance for specific pollutants (e.g., bacteria, metals, nutrients). Designers may consider use of novel amendments to improve water quality performance or vegetative growth, provided that the functions and performance of media are maintained or improved. For example, novel amendments should not cause increases in nutrient export or decrease the infiltration rate relative to MHFD's recommended media.

Table BR-1. Growing Media Properties

Parameter Classification	Parameter No.	Soil Parameter	Test Name	Growing Media Properties
Texture				
	1	Texture/Gradation	Particle sizes based on the USDA soil classification system, silt and clay percent based on the hydrometer method	Particle Size Distribution: 70-80% Sand (0.05-2.0 mm diameter) 5-25% Silt (0.002-0.5 mm diameter) 5-15% Clay (<0.002 mm diameter) *(distribution is measured after gravel > 2 mm is removed from sample)*
	2			Gravel <10% (> 2.0 mm diameter) *(max % based on total volume of original sample)*
Salts/Sodium				
	3	Salinity/Salts (EC) dS/m or mmhos/cm	Saturated Paste	<3
	4	Sodium Adsorption Ratio (SAR)	USDA 60 6(20b)	<8
Organic Matter Content				
	5	Organic Matter (%)	ASTM D2974	<5%
Soil pH				
	6	pH	ASA/ASHTO	6.0 - 8.5
Nutrients				
	7	Calcium Carbonate ($CaCO_3$)/Lime	Calcium Carbonate Equivalent (USDA 60 6(23c))	<2%
	8	Nitrate Nitrogen (ppm)	ASA2 33-3	<30
	9	Phosphorus (ppm)	Mehlich-3, Olsen, or Ammonium bicarbonate-DTPA test	<30
	10	Potassium (ppm)	Ammonium bicarbonate-DTPA test	>60
	11	Copper (ppm)		<1.0
	12	Zinc (ppm)		<3.0
	13	Iron (ppm)		<10.0

6. **Vegetation:** MHFD recommends that the media (filter area) be vegetated with drought-tolerant species that thrive in sandy soils. Approaches to vegetating bioretention areas can include planting sod-forming native grasses from seed or use of sand-grown sod, perhaps supplemented with container-grown plants or trees. Consult with a vegetation specialist to understand which types of vegetation will be successful in a given location, considering shade, heat island effects, application of deicers in the watershed, and other site-specific factors. Consider using trees that are compatible with bioretention as discussed above in the *Community Values* section.

   Table BR-2 provides a suggested seed mix for sites that typically will not need to be irrigated after the grass has been established, except for periods of extended drought. Guidelines for establishing vegetation from seed include:

   - Mix seed well and broadcast, followed by hand raking to cover seed and then apply mulch.
   - Immediately after seeding, install a biodegradable 100-percent coconut erosion control blanket over the growing media. Erosion control blanket will reduce the likelihood that fine silts and clays are mobilized by applied water which can form a lower-permeability layer on the planting surface.
   - Do not place seed when standing water or snow is present or if the ground is frozen.
   - Weed control is critical in the first two to three years, especially when starting with seed.

   When using sod, specify sand-grown sod which is available in Colorado although not as common as conventional sod. Do not use conventional sod. Conventional sod is grown in clay soil that can seal the filter area, greatly reducing overall function of the SCM.

   When using an impermeable liner, select plants with diffuse (or fibrous) root systems, not taproots. Taproots can damage the liner and/or underdrain pipe. Avoid trees with an impermeable liner and when specifying trees, place them at a conservative distance from the underdrain.

Table BR-2. Native Seed Mix for Bioretention

Common Name	Scientific Name	Variety	Pure Live Seed (PLS)	
			pounds/acre	ounces/acre
Sand bluestem	*Andropogon hallii*	Garden	3.5	
Sideoats grama	*Bouteloua curtipendula*	Butte	3	
Prairie sandreed	*Calamovilfa longifolia*	Goshen	3	
Indian ricegrass	*Oryzopsis hymenoides*	Paloma	3	
Switchgrass	*Panicum virgatum*	Blackwell	4	
Western wheatgrass	*Pascopyrum smithii*	Ariba	3	
Little bluestem	*Schizachyrium scoparium*	Patura	3	
Alkali sacaton	*Sporobolus airoides*		3	
Sand dropseed	*Sporobolus cryptandrus*		3	
Pasture sage[1]	*Artemisia frigida*			2

Blue aster[1]	*Aster laevis*			4
Blanket flower[1]	*Gaillardia aristata*			8
Prairie coneflower[1]	*Ratibida columnifera*			4
Purple Prairie Clover[1]	*Dalea (Petalostemum) purpurea*			4
Sub-Totals:			27.5	22
Total pounds per acre:			**28.9**	
[1] Wildflower seed (optional) for a more diverse and natural look.				

7. **Irrigation:** Install spray irrigation at or above the WQCV elevation when permanent irrigation is provided or place temporary irrigation on top of the bioretention media surface. Do not place sprinkler heads on the flat surface. Remove temporary irrigation pipes that are laid on the surface once vegetation is established. If left in place, temporary irrigation will become buried over time and will be damaged during maintenance operations. Adjust irrigation schedules during the growing season to provide the minimum amount of water necessary to maintain plant health, while maintaining free pore space for infiltration.

8. **Inlet and Outlet Design**: See the *SCM Inflow Features* section of this chapter for guidance and criteria for inlets, energy dissipation, and forebays. See the *SCM Outflow Features* section of this chapter for design of outlets for the WQCV and larger flood events.

Construction Considerations

Proper construction of bioretention areas involves careful attention to material specifications, final grades, and construction details. For a successful project, implement the following practices:

Photograph BR-3. Inadequate construction staking may have contributed to flows bypassing this bioretention area. Replace photo with new image illustrating construction issues.

- Protect the bioretention area from excessive sediment loading during construction. This is the most common cause of clogging of bioretention systems. The portion of the site draining to the SCM must be stabilized before allowing flow into the bioretention area. This includes completion of paving operations.
- Avoid over-compaction of the bioretention area to preserve infiltration rates (for partial and full infiltration sections).

- Provide construction observation to ensure compliance with design specifications. It is important to avoid improper installation, particularly related to elevations of the inlet, underdrain and outlet. Observation/oversight is recommended for the following:
  - Conformance of subgrade with design assumptions.
  - Installation of impermeable liner (for no infiltration sections).
  - Construction of underdrain and installation of media layer.
  - Review of growing media test data to verify conformance with specifications prior to installation.

Photograph BR-4. Runoff passed the upgradient bioretention area, shown in Photo BR-3 and flooded this downstream bioretention area. Replace photo with new image illustrating construction issues.

- Provide adequate construction staking to ensure that the site properly drains into the SCM, particularly with respect to surface drainage away from adjacent buildings.

References

MHFD. 2021. *MHFD Detention Version 4.04, February 2021*. MHFD: Denver, CO. Download and use current version on MHFD website for analysis.

MHFD. 2018. *UD-BMP Version 3.07, March 2018*. Urban Drainage and Flood Control District (now MHFD): Denver, CO. Download and use current version on MHFD website for analysis.

Pitt et al. (or Traver) reference on clay soil and salt

Add appropriate media mix references from Geosyntec

Add references from Muller

Add Geosyntec Media Literature review

Figures

Figure BR-1. Bioretention Components