Appendix G

Design Guidance for Structural Stormwater BMPs
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Structural Stormwater BMP Design References

The Town of Greenwich Drainage Manual does not attempt to duplicate the extensive guidance that is available in other existing design manuals including the Connecticut Stormwater Quality Manual and stormwater manuals of other jurisdictions. Because stormwater management is an evolving field, existing stormwater management practices are being refined and new practices are being developed on a regular basis. This appendix contains a summary of recommended references for the selection, design, construction, and maintenance of structural stormwater BMPs (including Low Impact Development or LID practices) that may be used in conjunction with LID site planning and design techniques. The recommended design references in this appendix may be updated by the Town as necessary to reflect new developments and trends in stormwater management. Additionally, the design references in this appendix may contain information, guidance, or requirements that conflict with information, guidance, or requirements specified in the Town of Greenwich Drainage Manual. In these instances, the information, guidance, or requirements specified in the Town of Greenwich Drainage Manual shall apply.

This appendix includes recommended design references for the following stormwater BMPs. Structural practices that are considered LID BMPs in this manual (i.e., small-scale structural practices distributed throughout the site, close to the source of runoff) are also identified below.

For the purpose of this manual, an infiltration practice with an impervious contributing drainage area equal to or less than 1,000 square feet (i.e., allowing one or more roof leaders, with a maximum contributing drainage area of 1,000 square feet, to be piped to a single infiltration practice) is considered a LID BMP. Infiltration practices designed with a larger impervious contributing drainage area are considered conventional or non-LID BMPs.

1. Pretreatment BMPs:
   - Deep sump catch basins
   - Oil grit separators
   - Proprietary devices
   - Sediment forebays
   - Vegetated filter strips (LID BMP)

2. Treatment BMPs:
   - Filtering bioretention systems, including, rain gardens, tree filters, stormwater planters, and curb extensions (LID BMPs)
   - Constructed stormwater wetlands (LID BMP)
   - Gravel wetlands (LID BMP)
   - Extended dry detention basins
   - Proprietary media filters
   - Sand filters/organic filters (LID BMPs)
   - Wet basins (LID BMP)
3. Conveyance BMPs:
   - Grass channels (LID BMP)
   - Wet and dry water quality swales (LID BMPs)

4. Infiltration BMPs:
   - Bioretention systems, including, rain gardens, tree filters, stormwater planters, and curb extensions specifically designed for infiltration (LID BMPs)
   - Infiltration systems when designed as decentralized, small-scale practices distributed throughout the site, which typically include dry wells, leaching catch basins, and smaller subsurface infiltration units (LID BMPs)
   - Infiltration systems when designed as larger centralized or end-of-pipe systems, which typically include infiltration basins, infiltration trenches, and larger subsurface infiltration units

5. Other BMPs:
   - Compost-amended soils (LID BMP)
   - Green roofs (LID BMP)
   - Permeable pavement (LID BMP)
   - Rain barrels and cisterns (LID BMPs)
   - Dry detention basins

6. BMP Accessories:
   - Level spreaders
   - Check dams
   - Outlet structures

Due to the popularity of bioretention systems (bioretention cells, landscape detention, rain gardens, bio-filters, tree box filters, and stormwater planters) and the central role of bioretention in LID design, there is a large body of design guidance available from other stormwater manuals and related literature sources. Many of these sources contain regional design information that may not be applicable to Greenwich, as well as outdated or conflicting information since the design of bioretention systems continues to evolve. Therefore, recommended guidance for the design, construction, and maintenance of bioretention systems in the Town of Greenwich is also included in this appendix. This appendix may be updated by the Town as necessary to provide similarly detailed guidance for other types of stormwater BMPs.
Bioretention Guidance

Bioretention systems are one of the most versatile and effective stormwater Best Management Practices (BMPs) and can be implemented in most areas where landscaping is to be incorporated into new development or redevelopment projects. Bioretention systems consist of a shallow depressed vegetated area with porous engineered soils designed to capture and treat urban runoff and infiltrate treated water to the subsurface where existing soil conditions allow. Bioretention systems include bioretention cells, landscape detention, rain gardens, bio-filters, tree box filters, stormwater planters, and stormwater curb extensions.

Bioretention systems are designed to incorporate many of the pollutant removal mechanisms that operate in forested ecosystems, mimicking the ecological functions of an upland forest floor. During storms, runoff ponds temporarily within the shallow depression and subsequently filters down through the various layers in the bioretention area: surface storage area, plants, mulch or ground cover, engineered soil mix, and an underdrain and/or infiltration system. Runoff from larger storms is generally diverted through or around the facility to the storm drain system or overland flow. By capturing, detaining, and retaining runoff, bioretention cells reduce the runoff volume, peak flow rate, and pollutant loading. Bioretention systems can be installed into existing soils or within concrete enclosures, and with or without underdrains (New Hanover County – Wilmington, North Carolina).

A bioretention area is not a stormwater wetland, as the facility is designed to drain relatively quickly after a storm event. Accordingly, the plant community in a bioretention area resembles a wet meadow or bottomland forest rather than a wetland. As with all stormwater BMPs, design, construction, and maintenance practices are critical for the success of bioretention (Biohabitats, Inc., 2005).

1.1 Applications

Bioretention has a variety of potential applications in the Town of Greenwich, including but not limited to:

- **Residential** – Bioretention areas are appropriate for residential settings. For residential applications, bioretention systems (also called “rain gardens”) should be designed as distributed practices within landscaped areas to manage runoff from lawns, driveways, rooftops, and other developed areas of residential properties.

- **Commercial, Industrial, and High-Density Residential** – Bioretention can be used in modified parking lot islands or as a component of landscape areas adjacent to parking lots or buildings. The facilities can be designed to treat runoff from parking lots, roads, rooftops, other impervious surfaces, and/or pervious areas such as managed lawns.

- **Institutional (e.g., schools, government buildings, parks, etc.)** – Institutional settings are particularly good sites for bioretention. Bioretention can be incorporated into bus loops, parking lot islands, roof downspout areas, access road shoulders, and other demonstration sites.
• **Roadways** – Bioretention can be used within roadway corridors (at the curb, depressed street median, driveway perimeters, within cul-de-sacs, etc.) to manage runoff from roadways and adjacent developed areas. Practices such as tree wells, tree box filters, stormwater planters, bioretention swales, and stormwater curb extensions are examples of bioretention systems that are suitable for roadway applications.

*Figures 1 through 6 show examples of bioretention systems for various applications.*


**Figure 1. Bioretention Options for Commercial and Institutional Applications**

**Figure 2. Bioretention Options for Residential Applications**

**Figure 3. Residential Bioretention (Rain Gardens) Examples**
Figure 4. Bioretention for Urban Roadway Design

Figure 5. Bioretention Curb Extension Retrofits Used for Stormwater Treatment and Traffic Calming
Figure 6. Parking Lot Bioretention – Stormwater Planters

1.2 Siting Considerations

- Vertical separation from the bottom of the soil media to seasonal high groundwater or bedrock shall be at least 2 feet (3 feet for land uses with higher potential pollutant loads) for bioretention systems that rely on infiltration.

- For bioretention systems that rely on infiltration, an evaluation of the native soils shall be performed consistent with the methods described in Appendix B, including concept design testing (test pits or soil borings, and saturated hydraulic conductivity testing in some instances) at the actual location where the bioretention system is proposed. Bioretention systems shall not be permitted in Class D soils, unless designed strictly as a filtration system with an underdrain. Designs that use both infiltration and filtration (i.e., an underdrain with an underlying gravel/stone storage area) are recommended to account for potential infiltration failure due to clogging, groundwater mounding, or periods of excessive rainfall.

- The invert of the underdrain pipe should be at or above seasonal high groundwater for systems serving roads, parking lots, and commercial roofs.

- Bioretention areas are usually designed to treat relatively small drainage areas (1 acre or less). Larger drainage areas can lead to clogging and erosion, and discourage the use of decentralized stormwater controls. For larger sites, multiple bioretention cells should be distributed throughout the site to meet the above criteria. Otherwise, off-line designs should be used.

- Bioretention facilities should not be located in floodplains or wetlands.

1.3 Design Considerations

Conveyance

- Overflow provisions from the system shall be provided for the 1-year storm event to either a structural conveyance system or to daylight onto a stable surface, where non-erosive velocities shall be provided (3-5 fps).

- Bioretention systems can be designed as “on-line”, meaning that entire range of storms enters the system and larger storms exit through an overflow device or weir. Alternately, they can be designed as “off-line” facilities, in which case only the design storm (the storm that generates the water quality volume) enters the facility and larger flows are bypassed.

  - **Inlet Options:** Water can enter the bioretention system through direct overland flow, curb cuts, trench drains, ditches, or pipes. Concentrated flow into a bioretention system must have adequate energy dissipation to prevent erosion of the filter media and to spread the flow across the filter surface to the extent possible. Flow splitters can also be used within the upstream conveyance system.
to divert only the first-flush design flow to the bioretention area (off-line design).

- **Curb Cuts**: One curb cut should be provided for every 20 feet of curb associated with each bioretention cell, or a minimum of 2 curb cuts per cell (whichever is greater). Curb cuts are particularly susceptible to erosion and clogging. Curb inlets require appropriately sized stone or other erosion protection (reinforced turf) to prevent erosion at the curb openings. The top of the stone should be several inches below the pavement height to prevent clogging of the curb cuts with debris and vegetation. The impervious area draining to the curb cuts should be graded so as to (1) evenly distribute water into and across the bioretention surface; (2) prevent runoff from by-passing the system; and (3) prevent the concentration of runoff at the outlet structure. Site grading should be carefully examined during both design and construction.

- **Outlet Options**: The outlet system often determines whether a facility is on-line or off-line. A common approach is for the facility to fill to the design depth, at which point the flow is diverted to inlet structures in the curb. Other outlet options include an outlet structure in or at the edge of the bioretention facility or an overflow weir, with the overflow elevation set at the design depth.

**Pretreatment**
- Pretreatment should be provided for runoff from connected impervious areas as flow across a vegetated filter strip, a grass swale, a sediment forebay within the bioretention storage area, or several extra inches of depth in the bioretention cell for sediment build-up. No pretreatment is required for runoff from residential or small commercial building roofs (4,000 sq.ft. or less). Pretreatment may be waived at the discretion of the approving authority.

**Sizing and Other Design Considerations**
- The maximum permissible ponding depth shall be 12 inches for a Class A soil, 9 inches for a Class B soil, and 6 inches for a Class C soil. Bioretention systems shall not be permitted in Class D soils, unless designed strictly as filtration systems with underdrains. A ponding depth of up to 18 inches is allowable for systems designed with underdrains, regardless of the native soil type. Two to four inches of freeboard is recommended.

The surface area of the bioretention system shall be determined by the following equation ("Static" Method):

\[
SA = \left(\frac{WQV}{PD + (SD \times n) + (GD \times n)}\right)
\]

where:
- \(SA\) = Surface area of bioretention system (square feet)
- \(WQV\) = Calculated water quality volume (cubic feet)
- \(PD\) = Ponding depth above mulch surface (feet)
- \(SD\) = Soil depth, depth of bioretention soil layer (feet)
- \(GD\) = Gravel depth, depth of underdrain gravel and/or stone layer(s) between bottom of the soil layer and native soil (feet)
$n =$ porosity of the respective soil and gravel/stone layers. Use a default porosity of 0.3 for the bioretention soil mix and 0.4 for the gravel/stone layer, unless testing indicates different values.

**Figure 7. Bioretention Design Schematic**

Source: RIDEM and CRMC, 2010.
Figure 8. Bioretention Design with Internal Water Storage Zone for Enhanced Nitrogen Removal

Figure 9. Tree Box Filter Bioretention Design
The “Simple Dynamic” and “Dynamic Field” Methods may also be used as described in the infiltration/recharge guidance in Appendix B to account for exfiltration from the bioretention system as the storage volume is filling.

- The bioretention system shall be designed to temporarily contain 100% of the required design volume (water quality volume, groundwater recharge volume, or runoff reduction volume) for the contributing area. The total storage of the bioretention system includes storage above the bioretention soil to the elevation of an overflow, temporary storage within the bioretention soil, and temporary storage in the pea stone and underdrain gravel layers.

- The depth of the bioretention soil shall be between 18 and 48 inches depending on the requirements of the proposed vegetation. A minimum soil depth of 18 inches is acceptable for residential applications. A minimum soil depth of 30 inches is recommended for other applications.

- The bioretention soil shall generally consist of a 90% blended engineered media and 10% organics, a 9:1 ratio by volume.
  
  - The 90% blended engineered media must conform to the following particle size distribution:

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<tr>
<th>Name</th>
<th>Particle Diameter</th>
<th>Recommendation (by weight)</th>
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</thead>
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<tr>
<td>Fine Gravel</td>
<td>2.0 – 3.4 mm</td>
<td>Not more than 10% of the total particles in this range, including a maximum of 3% fine gravel (preferably none)</td>
</tr>
<tr>
<td>Very coarse sand</td>
<td>1.0 – 2.0 mm</td>
<td>Minimum of 60% of the particles must fall in this range</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>0.5 – 1.0 mm</td>
<td>Not more than 20% of the particles may fall within this range</td>
</tr>
<tr>
<td>Medium sand</td>
<td>0.25 – 0.50 mm</td>
<td></td>
</tr>
<tr>
<td>Fine sand</td>
<td>0.15 – 0.25 mm</td>
<td>Not more than 5%</td>
</tr>
<tr>
<td>Very Fine Sand</td>
<td>0.05 – 0.15 mm</td>
<td>Not more than 5%</td>
</tr>
<tr>
<td>Silt</td>
<td>0.002 – 0.05 mm</td>
<td>Not more than 5%</td>
</tr>
<tr>
<td>Clay</td>
<td>less than 0.002 mm</td>
<td>Not more than 3%</td>
</tr>
<tr>
<td>Total Fines</td>
<td>Very fine sand + silt + clay</td>
<td>Less than or equal to 10%</td>
</tr>
</tbody>
</table>

This blended engineered media essentially follows the U.S. Golf Association specification for putting green soils and can be obtained from most sand and gravel operators that supply golf courses. The key to the proper function and longevity of the blended engineered media is keeping the silt and clay content below 5% and 3% respectively.

- The 10% organics can be leaf compost or peat moss. The organic sources can be from municipal leaf composting facilities or commercially available sources.
of peat. Compost using municipal sludge should not be used as it is highly contaminated with nutrients and heavy metals and will export nutrients.

- The bioretention soil mixture shall have a P-Index (Phosphorous Index) of 0 – 30 or a Total Phosphorous test of 0 – 23mg/kg (a low P-Index creates an enhanced environment to remove phosphorous from stormwater).

- The mulch layer shall consist of a 2 to 3-inch layer of commercially-available shredded hardwood mulch. The mulch protects the underlying media and helps to retain some water in the media for the health of the plants.

- A detailed planting plan shall be provided for each bioretention system. The landscape plan should reflect the appropriate landscape setting for the bioretention area. These settings may include:
  - Landscape bed with native trees, shrubs, and herbaceous layer and mulch.
  - Turf cover with native trees and shrubs, intended to be mowed.
  - Low-maintenance native herbaceous cover, resembling a wet meadow.

Appropriate plants for the hydrologic conditions shall be taken from the plant lists found in the Connecticut Stormwater Quality manual ("Zone 4 Riparian Fringe" plants are most appropriate for rain gardens). A suggested list of rain garden plants for Connecticut has been compiled by staff at the University of Connecticut (http://nemo.uconn.edu/tools/stormwater/pdf/Rain%20Garden%20Plant%20Choice%20s_short.pdf). The Plainville, CT Low Impact Development and Stormwater Management Design Manual also has a recommended plant list for LID BMPs including bioretention systems.

- An underdrain is generally not required for bioretention systems in Class A soils. However, use of an underdrain with an underlying gravel/stone storage area (see Figures 7 and 8) and observation well is recommended for bioretention systems in all soil types to account for potential infiltration failure due to clogging, groundwater mounding, or periods of hydraulic over-loading due to excessive rainfall.

- The underdrain system should consist of a 4-inch diameter perforated PVC pipe, within a 12-inch layer of 1-1/4 inch crushed stone or clean, preferably double-washed, #57 stone (1/2-inch to 1-1/2 inch diameter). A larger depth of stone may be used to provide greater storage volume below the underdrain. A 3-inch pea gravel layer should be installed above the underdrain. Underdrains shall be placed across the entire bottom of the bioretention facility, above or within the top of the underlying gravel/stone storage area, with approximate spacing of 20 feet on-center and with a minimum slope of 1%.

- A raised underdrain may be used to create an internal water storage zone within the bioretention soil (6 to 12 inches of soil media submerged), which can enhance the removal of nitrogen (see Figure 8).

- Non-woven filter fabric should be used only on top of the portion of the pea gravel layer that is over the underdrain, 1 to 2 feet on either side (see Figures 7 and 8). Synthetic
filter fabrics should not be used to completely separate the soil filter media from the underdrain bedding material. Experience has shown this to be a major source of failure for underdrained filters. Filter fabric should also not be installed at the base of bioretention systems or at the bottom of excavated basins to separate engineered soils from existing site soils.

- Discharge from the underdrain should be routed to a downgradient storm drain pipe or channel or another BMP. The underdrain pipe system should have a vertical solid section that extends above the surface of the ponding area to provide an observation well and clean-out access port.

### 1.4 Construction Specifications

- The design engineer shall oversee the preparation of the area and the installation of the various components of the bioretention system (soil mixture, pea stone layer, underdrain, and stone/gravel storage zone).

- The design engineer shall provide an as-built plan of the bioretention system along with a certification that the system was designed in accordance with the specifications contained in the Town of Greenwich Drainage Manual and installed in accordance with the approved plans.

- A dense and vigorous vegetative cover shall be established over the contributing pervious drainage areas before runoff can be accepted into the bioretention system.

#### Testing the Bioretention Soil Mix Prior to Placement

- The bioretention soil shall be a uniform mix, free of stones, stumps, roots or other similar objects larger than two inches. No other materials or substances shall be mixed or dumped within the bioretention area that may be harmful to plant growth, or prove a hindrance to the planting or maintenance operations. The bioretention soil shall be free of noxious weeds. The bioretention soil mix shall be tested prior to placement according to the specifications in the previous section (at least one test per bioretention facility, including soil textural analysis and phosphorous index or total phosphorous test). The design engineer shall certify that the bioretention soil mix meets the specifications in the previous section based on soil testing results. For pre-mixed bioretention soils available from vendors, the mix shall first be approved by the Town as meeting the specifications in the previous section.

#### Excavation

- The bioretention system shall be fenced off during the construction period to prevent disturbance of the soils. For infiltration designs, avoid the use of heavy equipment during construction on areas where bioretention systems are to be installed. If soils are compacted, additional measures may be necessary to re-establish soil permeability.

- The bioretention facility shall be excavated to the dimensions, side slopes, and elevations shown on the Plans. The method of excavation shall minimize the compaction of the bottom of the bioretention facility. Excavators and backhoes,
operating on the ground adjacent to the bioretention facility, shall be used to excavate the facility if possible. Low ground-contact pressure equipment may also be used for excavation.

**Placing the Soil Mix**

- After excavation, do not compact the native underlying soils. When installing the bioretention soil mix, drop it from the bucket and do not compact it. The mix shall be placed in horizontal layers not to exceed 12 inches for the entire area of the bioretention facility. Grade bioretention materials by hand or with light equipment such as a compact loader or a dozer/loader with marsh tracks. The soil mix can be expected to settle, especially after becoming saturated. For this reason, the elevation of the mix can be a couple of inches higher at installation than the design elevation in anticipation of settling.

**Plant Installation**

- After placing the soil mix and approval, trees, shrubs and herbs shall be planted. Planting shall be conducted between May 1 and June 15 or September 15 and November 1. Root stock of the plant material should be kept moist during transport, from the source to the job site and until planted.
- Bioretention facilities should be planted in accordance with the planting plan and plant schedule on the plans which provides specific spacing requirements.
- All planting pits shall be dug by hand and excavated to 1-1/2 times the width of the root mass.
- The planting pit shall be deep enough to allow the first lateral root of the root mass to be flush with the existing grade. Remove all non-organic debris from the pit and tamp loose soil in the bottom of the pit by hand.
- Remove the plant from its container either by cutting or inverting the container. Do not handle the plant by the branches, leaves, trunk or stem. Place the plant straight in the center of the planting pit, carrying the plant by the root mass. Never lift or carry a plant by the trunk or branches.
- Backfill planting pit with existing soil and hand tamp as pit is being backfilled to completely fill all voids and air pockets. Do not over compact soil. Make sure plant remains straight during backfilling/tamping procedure. Do not cover the top of the root mass with soil.
- An 18-inch diameter area of commercially-available, preferably well-aged (6 to 12 months), shredded hardwood mulch shall be placed around each plant 2-3 inches thick. Mulch should not be placed directly against the stem of the plant.
- Water plant thoroughly immediately after planting. The bioretention soil specification provides enough organic material to adequately supply nutrients from natural cycling. The primary function of the bioretention structure is to improve water quality. Adding fertilizers defeats, or at a minimum, impedes this goal.
Monitoring the Bioretention System After Construction

- Following construction, the bioretention system shall be monitored to verify that the system was constructed and functions as designed. The post-construction monitoring shall consist of visual observation of the bioretention system after a storm event that results in at least 5 inches of ponding in the bioretention area (or the maximum design ponding depth if designed for less than 5 inches of ponding). If the drawdown time indicates a flow rate of less than 5 inches per hour, the bioretention soil should be removed and replaced. The observations shall be conducted (or overseen) and certified by the design engineer. The purpose of the certification is to ensure proper installation and discourage contractor substitutions (e.g., using onsite soil that does not meet the bioretention soil specifications). The Town reserves the right to inspect and/or collect soil samples of bioretention systems, or require additional in-situ testing by the property owner or design engineer.

1.5 Inspection and Maintenance

One of the major advantages of bioretention over underground BMPs is its relative ease of inspection and maintenance. Once plants are established, only minimal plant maintenance and occasional removal of sediment and debris is necessary.

Upon installation and during the first year, bioretention systems should be inspected monthly and after relatively large storm events for potential erosion and/or extended ponding. Key inspection/maintenance areas include inlet and overflow areas for potential erosion, the ponding area for trash and debris, and the clean out port for potential early signs of stagnant water in the system if an underdrain system is included. Inspections can be reduced to a semi-annual schedule once the bioretention system has proven to work properly and vegetation is well-established.

Long-term inspection and maintenance consists of the following:

- Filter bed functions and drains at a proper rate. Standing water is not an issue between storms. The filter has not settled in pockets, or “piping” created through filter media.
- The filter bed is not eroding.
- Vegetation is maintained. Dead or diseased plants are removed and replaced. Mulch is replaced as necessary. Vegetation is pruned as needed.
- Pretreatment is functioning properly and is not more than 50% full of sediment.
- Inlets are not eroding, by-passing flow, or clogged.
- Outlet structures are not eroding, by-passing flow, or clogged.
- Underdrains do not appear to be clogged and flow after a storm event.
- No evidence of contamination with oil, grease, or other contaminants from drainage area.
- The cell continues to have a concave shape rather than being mounded up.
- Snow load is not an issue during the winter. There are designated areas for snow to be piled (not on the filter itself, but in the grass filter strip or other adjacent area). If deemed necessary, snow fence is installed during the winter around the perimeter of the actual filter bed.
1.6 References


## Structural Stormwater BMP Design References

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<td><strong>Oil Grit Separator</strong></td>
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<td>• Massachusetts Stormwater Handbook</td>
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## Structural Stormwater BMP Design References

### Proprietary Separators

**Primary Reference:**
- Connecticut Stormwater Quality Manual (Innovative/Emerging Technologies)
- See the Town of Greenwich Drainage Manual for evaluation of proprietary BMPs

**Additional Information Sources:**
- Massachusetts Stormwater Handbook
- Rhode Island Stormwater Design and Installation Standards Manual

**Proprietary Separator Image**

Source: UNH Stormwater Center

### Sediment Forebays

**Primary Reference:**
- Rhode Island Stormwater Design and Installation Standards Manual

**Additional Information Sources:**
- Connecticut Stormwater Quality Manual
- Massachusetts Stormwater Handbook

**Sediment Forebay Image**

Source: RIDEM, 2010
Structural Stormwater BMP Design References

**Vegetated Filter Strips**

*Primary Reference:*
- Connecticut Stormwater Quality Manual (Vegetated Filter Strips/Level Spreaders)

*Additional Information Sources:*
- Massachusetts Stormwater Handbook
- Rhode Island Stormwater Design and Installation Standards Manual
- Michigan LID Manual

**Treatment BMPs**

**Bioretention - Rain Gardens, Tree Filters, Stormwater Planters, and Curb Extensions**

*Primary Reference:*
- See design guidance in Appendix G of the Greenwich Drainage Manual

*Additional Information Sources:*
- Plainville, CT Low Impact Development and Stormwater Management Design Manual
- San Mateo County Sustainable Green Streets and Parking Lots Design Guidebook
- Connecticut Stormwater Quality Manual
- Rhode Island Stormwater Design and Installation Standards Manual
- UNH Stormwater Center (Tree Box Filter), [http://www.unh.edu/erg/cstev/fact_sheets/tree_filter_fact_sheet_08.pdf](http://www.unh.edu/erg/cstev/fact_sheets/tree_filter_fact_sheet_08.pdf)
- New Hampshire Stormwater Management Manual (Tree Box Filters)
- Portland, Oregon Stormwater Management Manual
### Structural Stormwater BMP Design References

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<td></td>
<td>• New Hampshire Stormwater Management Manual</td>
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**Gravel Wetlands**

![Gravel Wetland Diagram](source: UNHSC)

**Primary Reference:**

- UNH Stormwater Center, [http://www.unh.edu/erg/cstev/fact_sheets/gw_fact_sheet_08.pdf](http://www.unh.edu/erg/cstev/fact_sheets/gw_fact_sheet_08.pdf)

**Additional Information Sources:**

- Rhode Island Stormwater Design and Installation Standards Manual

**Extended Dry Detention Basins**

**Primary Reference:**

- Massachusetts Stormwater Handbook
<table>
<thead>
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<td><strong>Proprietary Media Filters</strong></td>
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| **Sand/Organic Filters**                    |
| **Primary Reference:**                     |
| • Connecticut Stormwater Quality Manual (Filtering Practices) |
| **Additional Information Sources:**         |
| • UNH Stormwater Center (Surface Sand Filter), [http://www.unh.edu/erg/cstev/fact_sheets/sand_filter_fact_sheet_08.pdf](http://www.unh.edu/erg/cstev/fact_sheets/sand_filter_fact_sheet_08.pdf) |
| • Massachusetts Stormwater Handbook         |
| • Rhode Island Stormwater Design and Installation Standards Manual |

Source: UNH Stormwater Center

Source: City of Proctor, MN
Structural Stormwater BMP Design References

<table>
<thead>
<tr>
<th>Wet Basins</th>
<th>Primary Reference:</th>
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<tbody>
<tr>
<td></td>
<td>• Connecticut Stormwater Quality Manual (Stormwater Ponds)</td>
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<td></td>
<td>Additional Information Sources:</td>
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<td></td>
<td>• Massachusetts Stormwater Handbook</td>
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<thead>
<tr>
<th>Grass Channels</th>
<th>Primary Reference:</th>
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<tr>
<td></td>
<td>• Connecticut Stormwater Quality Manual (Grass Drainage Channels)</td>
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<tr>
<td></td>
<td>Additional Information Sources:</td>
</tr>
<tr>
<td></td>
<td>• UNH Stormwater Center, <a href="http://www.unh.edu/erg/cstev/fact_sheets/veg_swale_fact_sheet_08.pdf">http://www.unh.edu/erg/cstev/fact_sheets/veg_swale_fact_sheet_08.pdf</a></td>
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<thead>
<tr>
<th>Wet &amp; Dry Water Quality Swales</th>
<th>Primary Reference:</th>
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<tr>
<td></td>
<td>• Connecticut Stormwater Quality Manual (Grass Drainage Channels)</td>
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<td></td>
<td>Additional Information Sources:</td>
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<tr>
<td></td>
<td>• New Hampshire Stormwater Management Manual (Treatment Swales)</td>
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<tr>
<td></td>
<td>• Rhode Island Stormwater Design and Installation Standards Manual</td>
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</table>
### Structural Stormwater BMP Design References

<table>
<thead>
<tr>
<th>Infiltration BMPs</th>
<th>Primary Reference:</th>
<th>Additional Information Sources:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bioretention - Rain Gardens, Tree Filters, Stormwater Planters, and Curb Extensions (infiltration design)</td>
<td>• See design guidance in <em>Appendix G</em> of the Town of Greenwich Drainage Manual</td>
<td>• See references for Treatment BMPs – Bioretention: Rain Gardens, Tree Filters, Stormwater Planters, and Curb Extensions</td>
</tr>
<tr>
<td>Dry Wells</td>
<td>• Connecticut Stormwater Quality Manual (Dry Wells)</td>
<td>• New Hampshire Stormwater Management Manual (Dry Wells &amp; Infiltration Basins)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Rhode Island Stormwater Design and Installation Standards Manual</td>
</tr>
<tr>
<td>Infiltration Basins &amp; Infiltration Trenches</td>
<td>• Connecticut Stormwater Quality Manual (Grass Drainage Channels)</td>
<td>• New Hampshire Stormwater Management Manual (Dry Wells &amp; Infiltration Basins)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Rhode Island Stormwater Design and Installation Standards Manual</td>
</tr>
</tbody>
</table>

Source: Rhode Island Stormwater Design and Installation Standards Manual
### Structural Stormwater BMP Design References

#### Leaching Catch Basins

![Leaching Catch Basin Diagram](image)

**Primary Reference:**
- Massachusetts Nonpoint Source Pollution Management Manual (Chapter 13, Roads, Highways, and Bridges)

**Additional Information Sources:**
- Massachusetts Stormwater Handbook

**Source:** Maria Cahill, Green Girl LDS

#### Subsurface Infiltration Systems

![Subsurface Infiltration System](image)

**Primary Reference:**
- Connecticut Stormwater Quality Manual (Underground Infiltration Systems)

**Additional Information Sources:**
- LID Manual for Michigan (Infiltration Practices)

**Source:** CULTEC
### Other BMPs

#### Compost-Amended Soils

**Primary Reference:**
- Virginia DCR Stormwater Design Specification No. 4, Soil Compost Amendment, Version 1.7, 2010

**Additional Information Sources:**
- Guidelines for Landscaping with Compost-Amended Soils, City of Redmond, Washington,

#### Green Roofs

**Primary Reference:**
- LID Manual for Michigan
- Rhode Island Stormwater Design and Installation Standards Manual

**Additional Information Sources:**
- NEMO: Planning for Stormwater
- Massachusetts Stormwater Handbook
### Structural Stormwater BMP Design References

#### Permeable Pavement

**Primary Reference:**
- Rhode Island Stormwater Design and Installation Standards Manual

**Additional Information Sources:**
- UNH Stormwater Center (Porous Asphalt), [http://www.unh.edu/erg/cstev/fact_sheets/pa_fact_sheet_08.pdf](http://www.unh.edu/erg/cstev/fact_sheets/pa_fact_sheet_08.pdf)
- American Concrete Institute (Porous Concrete)
- Massachusetts Stormwater Handbook

#### Rain Barrels and Cisterns

**Primary Reference:**
- LID Manual for Michigan

**Additional Information Sources:**
- Massachusetts Stormwater Handbook
### Structural Stormwater BMP Design References

<table>
<thead>
<tr>
<th>Dry Detention Basins</th>
<th>Primary Reference:</th>
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<tbody>
<tr>
<td></td>
<td>Connecticut Stormwater Quality Manual</td>
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</tbody>
</table>

**Additional Information Sources:**
- Massachusetts Stormwater Handbook
- Rhode Island Stormwater Design and Installation Standards Manual

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<thead>
<tr>
<th>BMP Accessories</th>
<th>Primary Reference:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level Spreaders</td>
<td>LID Manual for Michigan (perforated pipe spreader design)</td>
</tr>
<tr>
<td></td>
<td>Massachusetts Stormwater Handbook (surface spreader design)</td>
</tr>
<tr>
<td></td>
<td>Spreader weir must be constructed of non-erodible material</td>
</tr>
</tbody>
</table>

**Additional Information Sources:**
- Connecticut Stormwater Quality Manual (Vegetated Filter Strips and Level Spreaders)
## Structural Stormwater BMP Design References

### Check Dams

<table>
<thead>
<tr>
<th>Diagram Description</th>
<th>Primary Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Check dams are placed every 6' to retain stormwater runoff.</td>
<td>Connecticut Guidelines for Erosion and Sediment Control (Stone Check Dams)</td>
</tr>
<tr>
<td>Some water volume is created in between check dams.</td>
<td>San Mateo County Sustainable Green Streets and Parking Lots Design Guidebook</td>
</tr>
<tr>
<td>Vertical check dams are placed every 6' to retain stormwater runoff.</td>
<td>Massachusetts Stormwater Handbook</td>
</tr>
</tbody>
</table>

### Outlet Structures

<table>
<thead>
<tr>
<th>Diagram Description</th>
<th>Primary Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>The slope of the swale bottom matches the natural slope of 8%.</td>
<td>Connecticut Department of Transportation Drainage Manual</td>
</tr>
<tr>
<td>The slope of the planters is flat and each cell is terraced to match the existing slope conditions.</td>
<td>Massachusetts Stormwater Handbook</td>
</tr>
<tr>
<td>More water volume is retained in the planter system than a vegetated swale.</td>
<td>San Mateo County Sustainable Green Streets and Parking Lots Design Guidebook</td>
</tr>
</tbody>
</table>