2.1 PROJECT PURPOSE

The selection and design of green infrastructure practices are driven by a site's physical characteristics including soils, contributing drainage area, groundwater, and development conditions within a watershed. UDFCD (2013) describes physical site characteristics that support or constrain green infrastructure practice selection.

SOILS

Soils with good permeability, typically associated with Hydrologic Soil Groups (HSGs) A and B, provide opportunities for infiltration of runoff and are well-suited for infiltration-based practices such as streetside stormwater planters, bumpout stormwater planters, green gutters, tree trenches/pits, and green alleys often without the need for an underdrain system. Even when soil permeability is low, these types of practices may be feasible if soils are amended to increase permeability or if an underdrain system is used. In some cases, however, soils limit the use of infiltration-based practices. When soils with moderate to high swell potential are present, infiltration should be avoided to minimize damage to adjacent structures due to water-induced swelling. In these cases, filtration designs can still be used if an impermeable liner and underdrain system are included in the design. In all cases, a geotechnical engineer should be consulted when designing infiltration practices near structures to evaluate the suitability of soils for different practice types and establish minimum distances between infiltration practices and structures. Regardless of soil type, a curtain liner may be required if the facility is located close to a building with a basement.

WATERSHED AREA

Best management practices (BMPs) must be designed for the area that drains to the BMP. Undersized BMPs will collect and pond water more frequently impacting the health and appearance of vegetation. Additionally, undersized best BMPs will receive more sediment and debris which will require additional maintenance or cause premature failure. Adequate space for a BMP, especially for retrofit projects, may not be available. Table 1 shows approximate water quality capture volume (WQCV) volume provided by some of the BMPs described in this manual. This table is provided for planning level purposes only. The actual volume provided will vary based on longitudinal slope, actual dimensions for specific installations, and other site-specific conditions.

GROUNDWATER

Shallow groundwater on a site presents challenges for green infrastructure practices that rely on infiltration and for facilities that are intended to be dry between storm events. Shallow groundwater may limit the ability to infiltrate runoff or result in unwanted subsurface storage of groundwater in areas intended for storage of the WQCV (e.g., the porous sub-base of a

<table>
<thead>
<tr>
<th>Description</th>
<th>Approximate Volume Provided (ft³)</th>
<th>Approximate Area Treated (ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Streetside stormwater planter</td>
<td>190</td>
<td>4,680</td>
</tr>
<tr>
<td>Streetside stormwater planter, no parking</td>
<td>230</td>
<td>5,610</td>
</tr>
<tr>
<td>Streetside bumpout stormwater planter, corner</td>
<td>350</td>
<td>8,480</td>
</tr>
<tr>
<td>Streetside bumpout stormwater Planter, mid-block</td>
<td>310</td>
<td>7,930</td>
</tr>
<tr>
<td>Tree trench (three trees, 25 feet O.C. with one control structure, 2% slope)</td>
<td>240</td>
<td>5,770</td>
</tr>
<tr>
<td>Tree trench (two trees, 25 feet O.C. with one control structure, 2% slope)</td>
<td>160</td>
<td>3,860</td>
</tr>
<tr>
<td>Tree trench (one tree with one control structure, 2% slope)</td>
<td>70</td>
<td>1,630</td>
</tr>
</tbody>
</table>
permeable pavement system or in the bottom of an otherwise dry facility such as an extended detention basin). Groundwater quality protection is an issue that should be considered for infiltration-based practices.

Infiltration practices may not be appropriate for land uses that involve storage or use of materials that have the potential to contaminate groundwater underlying a site (i.e., “hot spot” runoff from fueling stations, materials storage areas, etc.). If groundwater or soil contamination exists on a site (i.e., a brownfield), and the contamination will not be remediated or removed as a part of construction, it may be necessary to avoid infiltration based practices or use a durable liner to prevent infiltration into areas contaminated with pollutants that could be mobilized by stormwater.

WATERSHED DEVELOPMENT ACTIVITIES

When development in the watershed is phased or when erosive conditions (steep slopes, sparse vegetation, or sandy soils) exist in the watershed, a treatment train approach may be appropriate. A treatment train approach uses BMPs in a series and treats runoff by physical, chemical, and biological processes. By including as many removal mechanisms as possible in each BMP train, the ability to remove particular pollutants is increased.

Practices that use filtration should follow other measures to collect sediment loads (e.g., a forebay). For phased developments, these measures must be in place until the watershed is completely stabilized. When naturally erosive conditions exist in the watershed, these measures should be permanent. The designer should consider existing, interim and future conditions to select the most appropriate practices.

2.2 DESIGN CRITERIA

These criteria are provided to assist the design team. Details provided in this manual are not intended for construction plans. The design team must consider site-specific conditions and constraints and add an appropriate level of detail to the construction plans including existing utilities, spot elevations, and structural reinforcement for each installation. Plan review checklists provided in Appendix A should also be used to assist with the design.

2.2.1 SIZING

WATER QUALITY CAPTURE VOLUME AND PEAK FLOW RATE

The required WQCV for the upstream area draining to a green infrastructure BMP shall be computed using the procedures in Urban Drainage and Flood Control District’s (UDFCD) Urban Storm Drainage Criteria Manual, Volume 3 (USDCM Vol. 3). Additionally, the filter surface area for streetside stormwater planters, bumpouts and green gutters shall be sized at no less than 2% of the tributary area. When it is beneficial to estimate a peak flow rate associated with the water quality event for sizing hydraulic components, the rational method should be used as described in USDCM Volume 1 using the following parameters:

- Time of concentration, $T_c = 5$ minutes
- Water quality rainfall intensity at a $T_c$ of 5 minutes = 2.04 inches per hour (iph)
- Runoff coefficient for impervious surfaces, $C_{wq} = 0.84$

INLET SIZING

Inlet design is a critical component of many of the green infrastructure BMPs. The street inlet must be located at the upstream end of the BMP, must convey runoff from the curb and gutter across the step-out zone, and be sized to convey the water quality event assuming an appropriate amount of debris blockage. The inlet must also be designed to function in concert with a forebay or pretreatment filter, which is intended to capture the majority of litter, debris, and sediment entering the BMP.

Inlet layout is illustrated in plan and section in the fact sheet details. The inlet features a 2-inch depression in the flow line of the gutter to help direct runoff into the opening and reduce bypass flow. The inlet is shown as a chase type structure with a cover plate. The interior portion of the inlet box (bottom slab of the chase drain) should be sloped as indicated in the details.
2. SITE-SCALE GREEN INFRASTRUCTURE PRACTICE, SELECTION, DESIGN & MAINTENANCE

and a drop off should be provided from the invert of the chase drain to the sediment collection pad or filter surface (for tree trenches), which should be at least 4 inches below the water quality water surface. This allows for some amount of debris and sediment buildup without reducing stormwater conveyance through the inlet.

The opening length of inlet required will vary depending on flow rate and longitudinal slope. Figure 1 can be used to determine the length of inlet required for a given upstream area (assumed to be fully impervious). This figure is based on Equation 3 from the Technical Memorandum, Hydraulic Efficiency of Inlets Common to the UDFCD Region (UDFCD, 2011) for continuous grade applications. A debris factor of 10 percent (as recommended in the Technical Memorandum) is built in.

2.2.2 PEDESTRIAN CONSIDERATIONS AND GEOMETRY

All of the water quality practices provided in this manual are designed for an urban setting and require design considerations for the safety of the public. Considerations specific to individual BMPs are included in the fact sheets. The following pertain to multiple green infrastructure practices.

PLANTER EDGE BARRIER

Edge barriers are applicable for various types of planters that include open landscape areas and are depressed below pedestrian areas. A visual and physical barrier along the perimeter of a planter is necessary to discourage deliberate or inadvertent entry by pedestrians because the top of the planting media in the planters is depressed below the elevation.

FIGURE 1. Inlet width based on drainage area.
of the sidewalk, typically by ten inches or more. In general, a 6 inch or higher barrier parallel to the sidewalk is recommended on the “long” sides of the planter parallel to the street and a 15 inch or higher barrier is required on the “short” sides of the planter perpendicular to the street. These barriers may be concrete or stone curbs/walls, metal railings, or a combination of the two. The maximum barrier height is recommended to be 30 inches. Barriers higher than 6 inches are not appropriate for BMPs located within a street section, such as green gutters. Examples of barriers are shown in Figures 2 and 3.

Pedestrian safety must also be kept in mind when establishing the maximum depth of the planter, as measured from the adjacent pavement/walking surface to the top of the bioretention media. This depth should generally not exceed 16 inches. In general, it is recommended that the top of the bioretention media be flat, regardless of street slope. This reduces longitudinal flow velocities and the potential for erosion of the media. The depth from the sidewalk to the top of the media will decrease as the street slopes in a downstream direction, “raising” vegetation relative to pedestrians.

**SIDEWALK DRAINAGE**

Small openings or gaps in the edge barrier opposite the street are typically provided in planters to provide drainage from the sidewalk into the planter. These are typically openings 1 to 2 inches high and 4 to 6 inches long or gaps in the sidewall 1 to 2 inches wide. Openings are recommended at approximately 10 feet intervals and the furthest downstream opening should be at least 10 feet from the downstream end of the planter to reduce outflows from the opening in events exceeding the water quality event.

**STEP-OUT ZONE**

Denver requires a 2.5 foot step-out zone behind the back of curb in all locations where parking is (or will be) adjacent to the curb. Where parking is not planned adjacent to the curb, a 1.5 foot setback is required. Details in this manual show a 1.5 foot stepout for bumpout stormwater planters and a 2.5 foot stepout for streetside planters. This can be reduced to 1.5 feet where the streetside planter is not located adjacent to parking. Stepout zones are not required on green gutters.

**PLANTER LENGTH**

Planter length is set as necessary to:

1. Provide periodic access from one side of a planter to the other;
2. Provide required treatment volume; and
3. Contain stormwater in the planter on sloping streets.

The maximum length of streetside and bumpout stormwater planters based on pedestrian access is 40 feet. Denver street standards associated with raised objects call for an access path every 40 feet to provide reasonable access for pedestrians to exit a vehicle and get to the sidewalk. All access points adjacent to streetside and bumpout stormwater planters shall provide a minimum of 4 feet clear. This means that if signage or any other object is placed in the access path, distance between planters must increase to provide a minimum clear width of 4 feet. Although these points are not part of the ADA accessible route, it is recommended that (when required) reserved accessible parking spots be located adjacent to access points. In highly active areas it may be appropriate to provide more frequent or wider access points. Existing utilities may also limit

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**FIGURE 2. Example of stormwater planter**

**FIGURE 3. Example of stormwater planter**
the length of the planter. Access points for green gutters should be evaluated for each site. Access points within green gutters should not invite a pedestrian to cross at an inappropriate location. Where green gutters are located adjacent to parallel parking, a maximum spacing of 40 feet is appropriate and access points should be at grade with the parking space and at least five feet wide. Where green gutters are located adjacent to a travel lane, a length of 40 feet may be exceeded as long as consideration is given to the required length to retain the water quality water surface based on street slope. Alternatively, drops can be used to “stairstep” the WQCV as shown in the details, providing a long continuous green gutter while maximizing capture volume.

The maximum length of streetside and bumpout stormwater planters based on street slope is shown in Figure 4, assuming sidewalk drains are provided as shown in the details. This is the maximum length the planter can be and still contain the water quality volume without spilling out of the sidewalk drains. In rainstorms greater than the water quality event, runoff will overflow back to the curb and gutter through a spillway, as described below.

On streets with steeper slopes (greater than 2 percent), or if sidewalk drains are not used to provide drainage into the planter, the top of the walls can be designed to be horizontal and parallel to the top of the media for the whole length of the planter. In this case, the water quality water surface can be retained within the planter even with steeper street slopes and a planter length up to 40 feet can be used rather than limiting length based on Figure 4. A spillway should still be provided as described below, with the crest at or above the water quality water surface, to direct flows in excess of a water quality event back to the curb and gutter.

**FIGURE 4.** Planter length versus street slope.
2. SITE-SCALE GREEN INFRASTRUCTURE PRACTICE, SELECTION, DESIGN & MAINTENANCE

SPILLWAY
In storms exceeding the water quality event, the water surface in planters will rise above the water quality water surface and at some point will spill out of the planter at the downstream end. For this reason, a break in the side wall closest to the street is recommended, as shown in the details, to allow excess flows to spill back to the curb and gutter. The recommended spillway length is 2 feet, although this could be adjusted by the designer. Spillways are not recommended for a green gutter. If the storm is very intense, runoff may spill out of drain openings on the sidewalk side of the planter.

2.2.3 MATERIALS
See Table 2 (page 10) for a summary of material specifications for bioretention including underdrain pipe, filter material, and liners for all BMPs presented in this manual.

BIORETENTION MEDIA
Bioretention media should be consistent with the criteria outlined in the specifications in Table 2 of this section. A minimum media depth of 18 inches is appropriate for most applications. When trees are used, increase the depth of the media to 36 inches.

UNDERDRAIN AND FILTER MATERIAL
An underdrain system is used to collect and drain the filtered stormwater from beneath the bioretention media or permeable pavement system. The underdrains should be slotted wall PVC pipe within the BMP and transition to solid wall PVC pipe outside of the BMP. The underdrain pipe, both slotted and solid wall, and the filter material specified, should be consistent with the criteria outlined in the Bioretention Fact Sheet in Volume 3 of the USDCM.

FLOW CONTROL STRUCTURE
A flow control structure is shown at the downstream end of several of the BMP underdrains to house an orifice to limit outflow to the release rate specified in the USDCM Vol. 3. It also provides a means of overflow and an opportunity to monitor and adjust the top of the WQVC within the BMP.

PLANTER WALLS
Walls surrounding the planters and green gutters are recommended to contain the media and WQCV, to facilitate easier maintenance and constructibility (especially in retrofit projects), and to decrease the potential for saturation of the adjacent soils. Several options for wall construction are available in today’s marketplace. Walls can be constructed out of concrete; both cast in place or pre-cast, and can be colored, stained, and stamped. Walls may also be constructed out of blocks/bricks with mortar and could integrate stone elements. Regardless of the type of construction, a structural engineer shall be responsible for designing and detailing the walls and other structural elements of the BMPs.

The designer should take into account the desired aesthetic, structural integrity, and street slope, among other factors, when laying out and designing planter walls. The details show the bottom of the walls even with the bottom of the planting media with an 8 inch deep excavation between the walls to place the layer of filter material. Alternatively, the walls could extend to the bottom of the 8 inch deep filter layer. In either case, the designer needs to specify subgrade conditions necessary to ensure a suitable foundation for the walls and reduce the potential for settling.

LINERS
It is the responsibility of the designer/geotechnical engineer to specify whether a liner is required for a green infrastructure BMP. Liners are appropriate in areas of contaminated groundwater, where expansive soils pose a threat to nearby structures, and in other locations as determined by a geotechnical engineer. Liners reduce infiltration of stormwater and do not provide as much volume reduction compared to unlined systems. For this reason, liners are associated with a lesser treatment level and should not be used unless necessary. Liners can consist of a concrete bottom with appropriate sealing of joints or a PVC liner of adequate thickness attached to the planter walls.

Alternatively, to encourage vertical percolation into the subgrade rather than lateral percolation into the wall of an
excavation, a curtain liner can be used as shown in the tree trench detail. Curtain liners are placed vertically on one or more walls to allow infiltration into the subgrade and limited lateral percolation toward a building. Curtain liners should be used for all facilities within 15 feet of a building that has a basement. When a full liner is recommended by the geotechnical engineer, it is important to specify installation requirements including thermal welding and testing of all seams. It should be noted that most of the design details in this manual do not include a full liner. Refer to the USDCM Vol. 3 for additional details and guidance regarding the installation of full liners.
## TABLE 2: Material Specification for Bioretention/Rain Garden Facilities

<table>
<thead>
<tr>
<th>Material</th>
<th>Specification</th>
<th>Submittals</th>
<th>Testing</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bioretention Growing Media (soil + organics)</td>
<td>Particle size distribution (by weight): 80-90% sand (0.05 - 2.0 mm diameter) 3-14% silt (0.002-0.5 mm diameter) 3-14% clay (&lt;0.002 diameter) 3 to 5% shredded mulch (see notes) Chemical attribute and nutrient analysis: pH 6.8 - 7.5 organic matter &lt; 1.5% nitrogen &lt; 15 ppm phosphorus &lt; 15 ppm salinity &lt; 6 mmhos/cm</td>
<td>Particle size distribution and nutrient analysis required.</td>
<td></td>
<td>Shedded mulch shall be aged 6 months (minimum) and uniformly mixed into media.</td>
</tr>
<tr>
<td>Landscape mulch (where applicable)</td>
<td>Shredded mulch</td>
<td></td>
<td></td>
<td>Aged 6 months (minimum). No weed fabric allowed.</td>
</tr>
<tr>
<td><strong>Underdrain aggregate</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDOT filter material (Class B or C as specified)</td>
<td>Particle size distribution and nutrient analysis required.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>37.5 mm (1.5&quot;)</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>19.0 mm (0.76&quot;)</td>
<td>20-60</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.75 mm (No.4)</td>
<td>10-30</td>
<td>60-100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.18 um (No.16)</td>
<td>0-10</td>
<td>10-30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>300 um (No. 50)</td>
<td>0-10</td>
<td>10-30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>150 um (No. 100)</td>
<td>0-10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>75 um (No. 200)</td>
<td>0-3</td>
<td>0-3</td>
<td></td>
</tr>
<tr>
<td>Underdrain Pipe</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pipe diameter and type</td>
<td>Maximum slot width (inches)</td>
<td>Minimum open area (per foot)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-inch slotted PVC</td>
<td>0.032</td>
<td>1.90 in.$^2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-inch slotted PVC</td>
<td>0.032</td>
<td>1.98 in.$^2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impermeable liner</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness, % Tolerance</td>
<td>Thickness 0.76 mm (30 mil)</td>
<td>Test method ASTM D 1593</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tensile strength, kN/m (lb/in)</td>
<td>12.25 (70)</td>
<td>ASTM D8 82, method B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modulus at 100% elongation, kN/m (lb/in)</td>
<td>5.25 (30)</td>
<td>ASTM D8 82, method B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ultimate elongation, %</td>
<td>350</td>
<td>ASTM D8 82, method A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tear resistance, N/lb</td>
<td>8.5 (85)</td>
<td>ASTM D 1004</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low temperature impact, °C (°F)</td>
<td>-29 (-20)</td>
<td>ASTM D 1790</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volatile loss, % maximum</td>
<td>0.7</td>
<td>ASTM D8 82, method A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phitoxes, no. per 8 m² (no. per 10 yd.$^2$)</td>
<td>1 (max)</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bonded seam strength, % of tensile strength</td>
<td>80</td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Vegetation is a key component of green infrastructure BMPs. Plants improve infiltration rates, provide water and nutrient uptake through plant roots, and generally improve water quality through biological processes. Plant species selection and planting design for the planters is a critical design consideration that can greatly affect the overall success and public acceptance of these BMPs within the public right-of-way. Growing conditions in planters in ultra-urban environments are often harsh, so plant selection is important. In general, plants for use in planters should be:

- Drought tolerant;
- Flood/inundation tolerant;
- Mid-sized (taller than 12 inches, lower than 4 feet);
- Upright in form;
- Salt tolerant (especially for planters on streets treated with magnesium chloride deicer);
- Able to thrive in low-fertility, sandy soils (no fertilizer or supplemental compost allowed in planters); and
- Non-invasive.

In addition, ideal plant material should be native, have long flowering periods (if applicable), be attractive year-round, be long-lived (5 to 10 years), and be an aggressive grower.

### PLANT CONSIDERATIONS

Each fact sheet provides planting recommendations and example planting plans. A recommended plant list is included in Appendix C and tree list is included in Appendix D.

- When selecting vegetation, consider the depth of the planter as well as the potential plant height so that plantings do not exceed 42 inches above the sidewalk elevation near intersections to provide required visibility.
- Irrigation is necessary to establish the vegetation and sustain plant health during periods of dry weather.
- All plants should receive approximately 1 inch of moisture (combined rain and irrigation) per week for the first growing season to promote establishment. This requires an automatic irrigation system, or close monitoring by a maintenance staff, an available water source, and hand watering.
- Watering/irrigation of plants after establishment shall be on an as-needed basis. Plants should be monitored a minimum of once every 10 days in the second season, and once every 2 weeks thereafter for watering needs.
- To facilitate ease of maintenance, a neat appearance, and to reduce areas available for weed growth, it is recommended that planting designs employ masses of fairly tightly spaced plantings. Spreading plant materials can be used but require an increased level of maintenance early in the life of the facility so that weeds do not become established.
- Planting beds may be mulched with 1 to 2 inches of shredded wood mulch to reduce weed growth, or left un-mulched if plant density is sufficient to cover 75% or more of the bioretention media. The wood mulch should be finely shredded in a manner that creates a fibrous mass that meshes together and resists movement. The thickness of the mulch should be considered part of the bioretention media depth; if 2 inches of mulch are used, the actual thickness of bioretention media should be adjusted from 18 inches to 16 inches. The top of the mulch layer is considered the bottom of the WQCV.

### VEGETATION MAINTENANCE CONSIDERATIONS

- Inspections for sufficient moisture will be required as needed throughout the growing season (March through October).
- Inspections should also consider limitations with regard to the height of vegetation above the sidewalk elevation as it relates to visibility.
- All plantings require monthly inspection during the growing season to ward off infestations of deep rooted perennial weeds such as smooth brome, Russian thistle, leafy spurge, bindweed, and bluegrass.
- Prolifically seeding weeds such as cheatgrass, dandelions, prickly lettuce, spotted spurge, purslane, black medic, alfalfa, yellow and white sweet clover also require monthly policing to prevent them from going to seed and creating long term infestations. Horticultural personnel taking care of these gardens will need to be professionals highly familiar with weed species, able to recognize them as seedlings...
to ward off infestation. In most instances weeds will need to be extracted and physically removed from the site, not sprayed or pulled and left to wither (and scatter seeds).

- In addition to weed management, planters will require removal of leafy debris each fall (October) and cutting back of perennials and grasses in late winter/early spring (March).

**BMPs.** Ideally, sediment and debris is removed from sediment collection pads prior to entering the vegetated area. Removal of sediment from the vegetated area is much more disruptive and may require replacement of vegetation.

In some areas, additional consideration to facilitate maintenance may be achieved. Denver has success with forebays that can be maintained as part of the street sweeping program.

Forebays that can be cleaned as part of the street sweeping program require a depression at the location of the BMP. This will ensure capture of the volume to be treated while slowing entry into the vegetated portion. This concept is effective by restricting entry and forcing some sedimentation to occur in the forebay area. This can be achieved by using a curb with several small orifices as shown in Figure 5 rather than one large inlet opening. When located on a street sweeping route, this will ensure routine removal of sediment and debris from the forebay. See Appendix B for maintenance and operation checklists relevant to the BMPs included in this manual.

**TREE SPECIES AND PLACEMENT**

Trees are encouraged and can be included in Streetside Stormwater Planters, Bumpouts, and Tree Trenches. All tree species planted in Denver street rights-of-way must be approved by the City Forester. A list of recommended species is included in Appendix D. Trees are typically centered in the amenity zone between the step-out zone and the sidewalk. Consideration needs to be given to width requirements for the sidewalk when placing trees. Per City Forester, trees may only be placed in areas with a minimum width of 5 feet. In general, it is recommended that trees be placed 4 to 6 feet from the back of curb. Tree spacing along the street is discussed further in the Tree Trench Fact Sheet.

**2.3 DESIGNING FOR MAINTENANCE**

All of the BMPs in this manual have been designed with consideration for maintenance. Sediment collection pads and forebays have been included to facilitate proactive and routine maintenance. These types of treatment facilities allow for routine maintenance to be done frequently and by personnel with limited expertise in green infrastructure BMPs. Ideally, sediment and debris is removed from sediment collection pads prior to entering the vegetated area. Removal of sediment from the vegetated area is much more disruptive and may require replacement of vegetation.

2.4 ACCOMMODATING UTILITIES

Utility conflicts may be the greatest physical constraint for implementation of ultra-urban green infrastructure. Proper investigation of utilities during the planning and design phase can save both time and money in construction. In addition to locating and accommodating existing utilities, the design of green infrastructure facilities must also consider future repair and replacement of all utilities in the area. It
Site-Scale Green Infrastructure Practice, Selection, Design & Maintenance

should be determined during the planning and design phase. What party is responsible for repairing damage to the green infrastructure facility during maintenance on other utilities.

Denver has adopted a 4-step approach to accommodating utilities. This approach begins with solutions that are both cost-effective and easily implemented. As the steps progress, solutions become both more costly and more difficult to implement. This approach was adapted from the San Mateo County Sustainable Green Streets and Parking Lots Guidebook (San Mateo, 2009).

4-Step Approach for Accommodating Utilities:
Step 1: Avoidance
Where possible, locate green infrastructure facilities clear of all utility conflicts. This may dictate the type of green infrastructure design strategy due to space limitations and could require an approach that is more expensive in an effort to avoid utilities. Avoidance can also mean a change in the facilities’ dimensions in order to provide adequate setback from existing utilities.

Step 2: Acceptance
Green infrastructure facilities may conflict with existing utility locations, but involved entities accept that utility constraints do not preclude the green infrastructure facility from being built. This requires consensus from involved entities that the design provides acceptable clearance between the facility and a utility line and that if a utility line needs to be accessed, it will be acceptable for the green infrastructure facility to be temporarily impacted and then restored to its original condition.

Step 3: Mitigation
Green infrastructure facilities are allowed to coexist near a particular utility, but the original design or layout of the green infrastructure facility is adjusted in order to mitigate any concerns about the proximity to the utility. A green infrastructure facility design may need to be significantly altered to provide enough separation or cover over a utility line. Key features of the facility may also need to be moved to avoid conflict. These facilities will be reviewed by Denver on a case-by-case basis.

Step 4: Replacement
In order to have the green infrastructure facility work, the utility lines must be replaced and/or relocated. This is the most complex, cost-prohibitive and difficult design option to implement. However, in some cases, the age or pipe material of the utility line is a factor in selecting the solution. It might be more advantageous to plan on replacing an aging utility line during water quality improvements than to wait and replace it at a later date.

Potential Utility Conflicts
- Water mains and services
- Gas lines
- Underground power lines
- Above ground power and telephone poles
- Light poles and street signals
- Fiber optic and telecommunication cables
- Steam lines
- Valves and vaults for assorted utilities

2.4.1 WATER SERVICES
Due to a number of requirements outlined in the Denver Water standard details for service lines, Denver recommends that stormwater planters and tree pits/tree trenches not be placed over water services if feasible. However, service lines 2.5 inches and under may be allowed under certain conditions. The following limitations and requirements should be considered when placing green infrastructure planters and tree pit/tree trenches:

- Meters cannot be placed in the designated pedestrian sidewalk area or within the planter, but may be placed between the curb and the planter.
- Since required offsets for the curb stop and meter exceed the minimum step-out zone widths (with and without parking), the step-out zone needs to be widened to accommodate the meter. This may require moving the whole planter further from the curb or aligning the sidewalk to avoid the meter.
- Service lines 2.5 inches and under must be sleeved per Denver Water specifications.
2. SITE-SCALE GREEN INFRASTRUCTURE PRACTICE, SELECTION, DESIGN & MAINTENANCE

In order for ultra-urban green infrastructure practices to be effective, proper maintenance is necessary. Maintenance needs should be considered and addressed during the design phase. The maintenance program begins as soon as construction is complete. Routine maintenance, such as sediment and trash removal and weed control, occurs at regular intervals throughout the year. There will also be maintenance activities that are determined based on inspection, such as plant replacement and erosion repair. Restorative maintenance activities include structural repair, filter media replacement, or other significant repairs which should only happen near the end of the expected life of the facility. Maintenance activities will vary from site to site and are dependent on site specific factors such as runoff volume and pollutant loads (sediment, litter), seasonal variations, and adjacent land uses.

2.5 MAINTENANCE RESPONSIBILITY

In order for ultra-urban green infrastructure practices to be effective, proper maintenance is necessary. Maintenance needs should be considered and addressed during the design phase. The maintenance program begins as soon as construction is complete. Routine maintenance, such as sediment and trash removal and weed control, occurs at regular intervals throughout the year. There will also be maintenance activities that are determined based on inspection, such as plant replacement and erosion repair. Restorative maintenance activities include structural repair, filter media replacement, or other significant repairs which should only happen near the end of the expected life of the facility. Maintenance activities will vary from site to site and are dependent on site specific factors such as runoff volume and pollutant loads (sediment, litter), seasonal variations, and adjacent land uses.

RESPONSIBILITY

There are a number of scenarios in which ultra-urban green infrastructure practices can be used in Denver. These include Denver sponsored construction projects (public) and on private development projects (private). It is important to identify maintenance responsibility early in the design phase. An operations and maintenance plan must be approved prior to project approval.

1. Public Projects: Denver will be responsible for the ‘hard’ infrastructure associated with green infrastructure facilities in the right-of-way which is often considered the minor and major maintenance activities. This includes repair or replacement of planter walls, joints between sidewalk and walls, sidewalk drains, inlets, sediment collection pads, water control structures (i.e., cleanouts, underdrains, PVC pipes tied to storm drain system), tree trench forebays, and replacement of the media. The adjacent property owners will be responsible for the ‘soft’ infrastructure or more routine maintenance activities. This includes removal of trash and debris to minimize clogging of the system and media. It also includes maintenance of vegetation (i.e., trees, shrubs, and perennials) and the irrigation system. Most common vegetation practices will include pruning, weeding, redistribution of mulch/media after a rain event, and watering during dry periods. Ensuring long-term maintenance of the soft infrastructure will likely require a mechanism, such as the establishment of a business or maintenance improvement district, be put in place. The contractor who installs the facility will be responsible for the warranty period as stated in the construction contract.

2. Private Projects: Private development assumes all maintenance responsibility for green infrastructure assets on private property. City inspectors will ensure projects are completed per plans and inspect yearly to ensure facilities that are built to meet permit requirements and are functioning properly.

2.6 CONSTRUCTION OBSERVATION

Construction observation and coordination with the contractor by the designer and owner is recommended to ensure the functionality of all green infrastructure BMPs. Construction observation is recommended to ensure that the following steps are performed in accordance with the design plans:

A. Up-front work
   • preparing, submitting for review, and revising materials and equipment submittals to secure approvals
   • obtaining required permits and approvals
   • surveying in the field the location of the green infrastructure BMP
2. SITE-SCALE GREEN INFRASTRUCTURE PRACTICE, SELECTION, DESIGN & MAINTENANCE

• locating utilities
• defining construction limits and storage/stockpile areas
• setting up pedestrian and traffic control
• implementing measures to control erosion and sedimentation

B. Excavation and preparation of subgrade
• demolition of existing sidewalk or pavement
• relocating utilities as necessary
• excavating-stockpiling and removing excess excavated material from site
• ensuring specified compaction of subgrade material

C. Installation of underdrain tie-in pipelines, water supply pipelines, and electrical
• laying out horizontal alignments and vertical grade of pipeline leading from green infrastructure BMP underdrain outlet to downstream outfalls or tie-in points and water supply pipeline/electrical for irrigation system (if used)
• excavation, placement of bedding, installation of pipe, joints, fittings, and tie-ins
• placement and compaction of backfill

D. Construction of walls and inlets
• placing formwork, reinforcing steel, and concrete, curing and finishing concrete (for cast-in-place walls, if applicable)
• placing masonry block or brick and mortar (for masonry walls, if applicable)
• placing and fastening wall units (for precast walls, if applicable)
• placing and compacting backfill material outside walls
• forming, placing steel, and concrete placement and finishing for inlet (if applicable)
• installing inlet grate or plate (if applicable)
• installing PICP
• placing and finishing concrete flatwork for stepout/splash
• zone and sidewalk adjacent to BMP (where applicable), constructing pavement adjacent green infrastructure BMP
• (where applicable) and constructing concrete and/or pavement over pipeline leading from underdrain to downstream outfall location

E. Placement of underdrain, flow control structure (if applicable), and filter
• placing specified thickness of filter material in bottom of BMP
• installing underdrain pipeline, joints, fittings, cleanouts, and connection to downstream outlet pipeline
• installing flow control structure, including drilling or cutting in control orifice and setting weir at specified elevation

F. Provision and placement of planting media (where applicable)
• providing specified mix of planting media, including amendments
• placing planting media and watering to consolidate to design thickness
• placing sedimentation pad

G. Provision and placement of permeable pavement section (where applicable)
• providing specified aggregate layers under pavers
• placing concrete edgers
• placing permeable pavers

H. Provision and placement of structural media
• providing specified mix of bioretention media, including amendments
• mixing structural media
• placing structural media and watering in to consolidate to design thickness
• placing upper layer materials

I. Installation of irrigation system and seeding/planting
• installing irrigation system and connecting to water supply line
• completing electrical/control for irrigation system
• seeding and planting of specified vegetation