3 LID Selection—Structural BMPs

Structural BMPs are implemented to capture, infiltrate, filter, and treat stormwater runoff from a project area to meet the required level of controls in terms of water quality and quantity. Selecting the appropriate BMP for a project area should be based on site-specific conditions and stormwater control targets. Selected BMPs should be sized to capture and treat the design storm according to the numeric sizing requirements for treatment control BMPs that are presented in Appendix A. A general description for each BMP is presented in this chapter. For a more detailed description and design specifications for each BMP, see Appendix B.

3.1 Selecting Structural BMPs

Selecting the proper BMP type and location depends on site-specific precipitation patterns, soil characteristics, slopes, existing utilities, and any appropriate setbacks from buildings or other infrastructures as determined in Step 1 of Section 1.6 1. Further, selecting applicable and feasible BMPs will depend on the type of project, its characteristics, and the planning elements associated with the location of the project.

A general checklist for characterizing drainage areas and BMPs is below.

Drainage Area Characterization

- Total drainage area
- Percent imperviousness: total and directly connected
- Soil characteristics
- Known/expected runoff water quality constituents
- Depth to seasonal high water table and bedrock
- Topography, slope
- Land cover and land use (existing and future)
- Utilities
- Development history and existing buildings
- Storm drainage systems, location of outfalls
- Projected roadway alignment modifications, roadway expansion
- Rainfall records and statistical analysis of storm characteristics and frequency

BMP Characterization

- Type of BMP
- BMP surface area
- Surrounding soil characteristics
- Depth to water table

- Design target(s) according to any combination of volume, flow, or water quality control criteria
- Inlet and outlet features
- Primary stormwater treatment unit process

A BMP selection matrix based on the potential function and configuration of each BMP is presented in Section 3.8. The function and configuration that dictate BMP selection include drainage area size and land use, available site area for BMP implementation, slope, depth to seasonal high water table and bedrock, soil characteristics and infiltration rates, setbacks, and pollutant reduction potential.

3.2 BMP Sizing

LID BMPs are typically sized to manage runoff from frequent smaller storm events (typically in the range of one to two inches over 24 hours). The size of a BMP should be established using the characterization of the drainage area and local hydrology. BMPs should be designed by applying either volume- or flow-based design criteria. Further details regarding BMP sizing and example calculations are in Appendix A.

3.3 General Description of BMP Functions

The objectives of stormwater BMPs are to first slow and filter runoff using natural features. Infiltration and evapotranspiration, along with retention for reuse, offer additional benefits of the BMPs. Identifying and selecting BMPs on the basis of the pollutant(s) of concern is a function of site constraints, properties of the pollutant(s) of concern, BMP performance, stringency of permit requirements, and watershed-specific requirements such as TMDLs or Watershed Protection Plans. Pollutants of concern are especially important in water quality-limited stream segments and must be carefully reviewed in relationship to unit processes and potential BMP performance. Targeted constituents can include sand, silt, and other suspended solids; trash; metals such as copper, lead, zinc; nutrients such as nitrogen and phosphorus; pathogens; and organics such as petroleum hydrocarbons and pesticides. Table 3-1 indicates the major or dominant unit processes used for pollutant removal and secondary and optional processes based on designs of BMPs that incorporate those unit processes (Claytor and Schueler 1999).

Table 3-1. Water quality unit processes for pollutant removal

Pollutants	Removal processes					
	Settling	Filtration/ straining	Absorption/ Adsorption	Bioaccumulation	Biotransformation/ phytoremediation	Other (e.g., photolysis; volatilization)
Sediment	●	●	○	○	○	○
Total Nitrogen	●	◖	◖	(◖)#	●	○
Total Phosphorus	●	◖	●	(◖)#	○	○
Trash	●	●	○	○	○	◖
Metals	●	○	●	●	●	○
Bacteria	●	(●)	○	●	● &	● *
Oil and grease	○	●	●	◖	●	●
Organics	●	◖	◖	●	●	●

Symbols: ● major function; ◖ secondary function; ○ insignificant function; ( ) optional function; #removal from system if vegetation is harvested; & consumed by other organisms; * photolysis

BMPs often provide multiple unit processes, depending on design. Table 3-2 shows the removal processes for each BMP type including the major functions, followed by secondary and possible optional unit operations, depending on design (Claytor and Schueler 1999). BMPs can be used singularly or in series with multiple BMP types integrated as management practices to achieve the desired level of pollutant removal. Using a combination of BMPs with multiple treatment processes in one system is called a treatment train. Meeting targeted treatment objectives can usually be achieved using a series of stormwater treatment systems in a treatment train. That approach can apply to new designs and in retrofitting existing BMPs and sites. Such systems can often be designed along rights-of-way, in parking lots, or incorporated into landscaped areas to fit in relatively small or long, linear areas.

BMPs can be used singularly or in combination, or shared by multiple drainage areas, pursuant to local regulatory criteria (depending on project location and its jurisdiction), as outlined in Chapter 2.

Table 3-2. Hydrologic and water quality unit processes for BMPs

	Hydrologic controls			Removal processes					
Structural BMPs	**Storage/detention or flow attenuation**	**Infiltration**	**Evapotranspiration**	**Settling**	**Filtration**	**Sorption**	**Bioaccumulation**	**Biotransformation/ phytoremediation**	**Other (e.g., photolysis; volatilization)**
Infiltration BMPs									
Bioretention	●	(●)	◖	◖	●	◖	●	●	(◖)
Bioswale	(●)	(●)	◖	◖	◖	◖	◖	◖	(◖)
Permeable pavement	●	(●)	○	●	◖	(◖)	○	◖	○
Filtration BMPs									
Planter boxes	●	(●)	◖	◖	●	◖	(●)	(●)	(◖)
Green roofs	(●)	○	●	◖	○	○	(◖)	(◖)	○
Sand filter	◖	(◖)	○	○	●	(◖)	○	○	(◖)
Volume-Storage and Reuse BMPs									
Cisterns/rain barrels	●	○	○	*Treatment typically provided by downstream BMP*					
Stormwater wetlands	(●)	○	◖	●	●	◖	●	●	(◖)
Conveyance and Pretreatment BMPs									
Vegetated filter strip	○	●	●	◖	◖	◖	○	○	○
Vegetated swale	(◖)	(◖)	◖	●	●	○	○	○	○

Symbols: ● major function; ◖ secondary function; ○ insignificant function; ( ) optional function

An example of how BMPs can be implemented in combination to provide the maximum potential treatment for a site configuration include a treatment train utilizing vegetated filter strips draining to a vegetated swale that then convey the stormwater to a bioretention area where stormwater is infiltrated or filtered through a soil media. An example of a treatment train is shown in Figure 3-1. Such a treatment train can be integrated into the site to maximize hydrologic and water quality treatment using the unit processes of each BMP type. Effectiveness of individual or multiple integrated practices can be compared in terms of removing substances or groups of pollutants. Water quality performance data from multiple sources is presented for each BMP type in Section 3.4. Typical sources present an average of water quality performance data collected from multiple storm events over a multi-year period. BMPs sized to treat the volume produced by wet weather events will have the capacity to treat the smaller volume produced by dry weather flow with the same water quality performance. Water quality data is typically a combination of effluent and overflow samples.

Raleigh, North Carolina. Source: Tetra Tech

Figure 3-1. Treatment train featuring a vegetated filter strip pretreating runoff before entering a grassed bioretention area.

When no specific pollutant has been targeted for removal, regulators should work with designers to address pollutant removal through flow- or volume-based requirements or both. Under such circumstances, cost may become the most important deciding factor in BMP selection rather than pollutant removal performance.

3.4 Infiltration BMPs

Infiltration BMPs are designed to encourage percolation and ground water recharge and can provide volume reduction. Infiltration BMPs mainly use the interaction of the chemical, physical, and biological processes between soils and water to filter out sediments and sorb constituents from stormwater (FHWA 2002). As stormwater percolates into the ground, the soil captures the dissolved and suspended material in stormwater.

Infiltration BMPs are subject to several important limitations and cannot be used in all locations. Native soils must be tested to determine if the infiltration rates of the soils are acceptable for infiltration BMPs. Infiltration BMPs are not applicable at locations where ground water is close to the surface and would prevent stormwater infiltration from draining between storm events or where ground water pollution potential is high because of high pollution loads (*hotspots*) or sensitive ground water areas (*areas of concern*) (see Appendix G for rules governing infiltration in the Edwards Aquifer zones). Pollution prevention should be carefully implemented to protect ground water quality at sites where infiltration BMPs are used. It is important that infiltration BMPs have sufficient clearance from the bottom of the BMPs to the seasonal high ground water level or any impermeable soil layers. An internal water storage (IWS) zone can be incorporated into any BMP with an underdrain to improve nitrogen removal and enhance infiltration in HSG type C and D soils. For more information on underdrains, see Appendix B.11.4. An IWS zone can be designed as either a permanent zone or a variable zone with the upturned elbow at the outlet of the underdrain. This "sump" can store stormwater and release it slowly through infiltration/exfiltration and evapotranspiration, while maintaining an aerobic root zone for plant health. Details on designing IWS zones are in Appendix B.1.1.

3.4.1 Bioretention

Bioretention areas are landscaped, shallow depressions that capture and temporarily store stormwater runoff. Bioretention areas are the most commonly implemented LID technique because they mimic predevelopment hydrologic conditions, enhance biodiversity and water quality, and can be easily incorporated into both new and existing development (Davis et al. 2009). Runoff intercepted by the practice is temporarily captured in shallow, vegetated depressions then filtered through the soil (often engineered soil) media. Pollutants are removed through a variety of physical, biological, and chemical treatment processes. Bioretention areas usually consist of a pretreatment system, surface ponding area, mulch layer, and planting soil media. The depressed area is planted with small- to medium-sized vegetation including trees, shrubs, and groundcover that can withstand urban environments and tolerate periodic inundation and dry periods. Plantings also provide habitat for beneficial pollinators and aesthetic benefits for stakeholders and can be customized to attract butterflies or particular bird species. Ponding areas can be designed to increase flow retention and flood control capacity. Bioretention areas are well suited to the San Antonio region because they can be adapted to a variety of site constraints and take advantage of the semi-arid climate for evapotranspiration. Advantages and limitations of bioretention areas are outlined below in Table 3-3.

Table 3-3. Advantages and limitations of bioretention areas

Advantages	Limitations
• Efficient removal of suspended solids, heavy metals, adsorbed pollutants, nitrogen, phosphorus, and pathogens • Can effectively reduce peak runoff rates for relatively frequent storms, reduce runoff volumes, and recharge ground water if soil conditions allow • Flexible to adapt to urban retrofits • Applicable for use in recharge zones, karst, expansive clays, and hotspots when properly designed with impermeable liners • Well suited for use in small areas, and multiple, distributed units can provide treatment in large drainage areas • Can be integrated naturally into landscaping to enhance aesthetics and provide habitat • Standing water only present for 12-24 hours to minimize vector control concerns	• Surface soil layer will require restoration if clogged over time • Frequent trash removal might be required, especially in high-traffic areas • Vigilance in protecting native soils from compaction during construction is essential • Single units can serve only small drainage areas • Requires maintenance of plant material and mulch layer

3.4.1.1 Hydrologic Functions

Temporary surface storage is provided in a shallow basin to accommodate the capture of runoff from the drainage area. The captured runoff infiltrates through the bottom of the depression and a layer of planting soil, approximately 2 to 4 feet deep, that has an infiltration rate capable of draining the bioretention area within a specified design drawdown time (usually surface water should draw down in 12–24 hours, and subsurface water should drain in 48–72 hours (Davis et al 2009; Hunt and Lord 2006).

After the stormwater percolates through the soil media, it infiltrates into the underlying subsoil if site conditions allow for adequate infiltration rates (typically greater than 0.5 in/hr). The volume-reduction capability of bioretention areas can be enhanced by providing a gravel drainage layer beneath the bioretention area. When subsoil infiltration rates are slower than 0.5 in/hr, filtered water is directed toward a stormwater conveyance system or other BMP via underdrain pipes. Volume reduction via partial infiltration and storage in the soil (approximately 20 to 70 percent, depending on soil conditions) can still occur when underdrains are present as long as an impermeable liner is not installed (Davis et al. 2012); partial infiltration occurs in those cases because some of the stormwater bypasses the underdrain and percolates into the subsoil (Strecker et al. 2004; Hunt et al. 2006; Davis et al. 2012). Volume reduction can be enhanced by treating the subgrade with scarification, ripping, or trenching (as discussed in Appendix B.1.2.1; Tyner et al. 2009; Brown and Hunt 2010). Additionally, underdrains can be modified to create a sump or IWS zone which enhances stormwater volume and pollutant load reduction, while maintaining an aerated root zone for plant health (Brown and Hunt 2011).

Where conditions altogether prevent infiltration (such as in the Edwards Aquifer Recharge Zone, karst geology, or near building foundations), bioretention areas should be lined with an impermeable barrier (see Section 2.1.2 for Edwards Aquifer zone delineations). Moderate volume reduction can still be achieved by lined systems because significant stormwater volumes can be stored in the available pore space of the media to be used by vegetation between storm events (Li et al. 2009; Davis et al. 2012).

Bioretention areas are typically planted with grasses, shrubs, and trees that can withstand short periods of saturation (i.e., 12–72 hours) followed by longer periods of drought. In addition to transpiring significant stormwater volumes, vegetation can enhance pollutant removal, reduce soil compaction, and provide ecological and aesthetic value (Hatt et al. 2009; Li et al. 2009; Barrett et al. 2013). Vegetation adapted to the San Antonio region is preferable for use in bioretention areas because native ecotypes, such as prairie grasses and forbs, can typically tolerate extreme hydroperiods and can promote infiltration and evapotranspiration with their deep root systems. Bioretention vegetation can be specified to mimic predevelopment communities while being aesthetically pleasing. IWS is recommended to improve soil moisture retention and plant survival in the San Antonio region (Li et al. 2010; Barrett et al. 2012; Houdeshel et al. 2012). A plant list to guide vegetation selection is located in Appendix E.

Bioretention areas are designed to capture a specified design volume and can be configured as online or offline systems. Online bioretention areas require an overflow system for passing larger storms. Offline bioretention areas do not require an overflow system but do require some freeboard (the distance from the overflow device and the point where stormwater would overflow the system). Bioretention can also be designed for peak flow mitigation to satisfy local requirements. Controlled experiments in Texas demonstrated reductions in peak discharge from fully lined (non-infiltrating) bioretention cells with as little as 2 feet of filter media (Li et al. 2010). Peak attenuation is most effectively achieved by infiltrating practices with high surface storage and media pore volume, and by pairing bioretention in a treatment train with a detention-type BMP (Hunt et al. 2012; Davis et al. 2012; Brown et al. 2012).

3.4.1.2 Water Quality Performance

Bioretention areas remove pollutants at various depths through physical, chemical, and biological mechanisms. Specifically, they use absorption, microbial activity, plant uptake, sedimentation, and filtration. Bioretention areas provide relatively consistent and high pollutant removal for sediment, metals, and organic pollutants (e.g., hydrocarbons). Most sediment removal occurs in pretreatment practices, in the mulch layer, and in the top 2 to 8 inches of soil media (Hatt et al. 2008; Li and Davis 2008; Stander and Borst 2010). The Texas Commission on Environmental Quality (TCEQ) recommends bioretention for compliance with the sediment removal requirements of the *Complying with the Edwards Aquifer Rules: Technical Guidance on Best Management Practices* (TCEQ 2005). Metals are commonly sediment-bound and are removed in the top 8 inches of media (Hsieh and Davis 2005; Hunt et al. 2012).

Nitrogen and phosphorus removal is less consistent. Total phosphorus percent removal has been found to vary between a 240 percent increase (production) and a 99 percent decrease (removal). The significant increase is suspected to be the result of excessive phosphorus levels in the furnished soil media (Hsieh and Davis 2005; Hunt et al. 2006; Davis 2007). Greater total phosphorus removal can be achieved by using soil media with total phosphorus concentrations below 15 parts per million (ppm) (Hunt and Lord 2006). A study in Texas indicated that nutrient export can also occur when bioretention soils are amended with excessive compost (Li et al. 2010). Nitrate removal has been found to vary between a 1 and 80 percent decrease (Kim et al. 2003; Hunt et al. 2006). Total Kjeldhal nitrogen (TKN) has been found to vary between a 5 percent increase and 65 percent decrease (Kim et al. 2003; Hunt and Lord 2006). Greater nitrate and TKN removal can be achieved by reducing the infiltration rate in the planting soil to 1–2 in/hr and ensuring that the soil media is at least 3 feet deep (Hunt and Lord 2006). Nitrate removal can be improved by incorporating a saturated layer in the soil media to promote anaerobic conditions for denitrification (Kim et al. 2003; Hunt and Lord 2006; Passeport et al. 2009). Additionally, studies performed in Texas demonstrated significantly improved nutrient reduction efficiency, relative to unvegetated filters, when bioretention soil was planted with a native prairie grass (Barrett et al. in press).

Several streams in the San Antonio region (including the Upper and Lower San Antonio River) are impaired by bacteria for contact recreation and high aquatic life use (TCEQ 2007, 2008). Bioretention represents a technology to mitigate pathogens from urban watersheds (especially when volume reduction is considered), although limited data exist for bacteria, virus, and protozoa removal. Most scientists and engineers agree that bacteria die-off occurs at the surface where organisms are exposed to solar radiation and dry (desiccating) conditions; dense vegetation in the bioretention area can limit the penetration of sunlight, but it can provide habitat for bacterivores and other beneficial pathogen predators (Hunt and Lord 2006; Hunt et al. 2008; Hathaway et al. 2009). Microbes are also sequestered by sedimentation and sorption; therefore, 2 feet minimum media depth and slower infiltration rates (1–2 in/hr) are recommended to enhance pathogen removal (Hathaway et al. 2011; Hunt et al. 2012).

In addition to chemical and biological pollutant removal, bioretention can be designed to reduce thermal loading to waterways. Thermally enriched runoff can increase stream temperatures and have adverse impacts on stream biota and dissolved oxygen (Booth et al. 2013; USEPA 1986). Research suggests that deep media beds (generally four feet or greater) can buffer extreme temperatures and that infiltration of stormwater can decrease overall thermal loading (Hunt et al. 2012; Jones and Hunt 2009; Winston et al. 2011; Wardynski et al. 2013). Thermal mitigation can likely be enhanced by shading bioretention areas with tree canopy cover and including IWS (Hunt et al. 2012; Jones et al. 2012). The depths where typical pollutant removal occurs are shown in Figure 3-2.

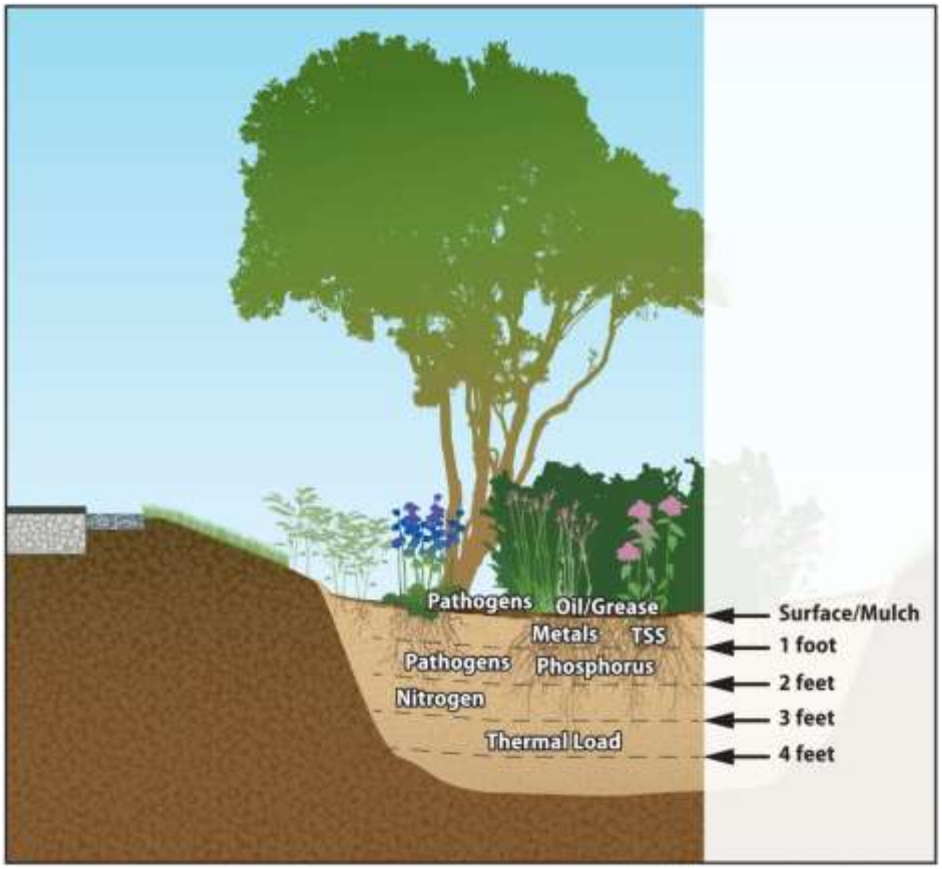

Figure 3-2. Pollutant removal depths in a bioretention area.

3.4.1.3 Applications and Configurations

Appendix B.1 outlines major design components and site considerations and describes the process for designing bioretention areas. Typical site applications and configurations are described further below.

3.4.1.4 Parking Lots

Bioretention areas can be used in parking lot islands or along the edge of the parking lot where water can be diverted into the bioretention area. Linear bioretention can also be used in the median areas between the parking spaces. Hydraulic restriction barriers should be installed and extended below adjacent pavement subgrades to protect pavement from water-induced structural issues (see Appendix B.11.6). Figure 3-3 and Figure 3-4 show examples of parking lot island bioretention areas.

Los Angeles, California   Source: Tetra Tech

Figure 3-3. Parking lot bioretention area.

Durham, North Carolina   Source: Tetra Tech

Figure 3-4. Parking lot island bioretention area.

3.4.1.5 Roads

Bioretention can also be integrated into the right-of-way of roads. Similar concepts apply to roads as parking lots. Some pretreatment is required to remove large particles and slow the runoff to non-erosive flows. Impermeable liners must be installed to protect adjacent pavement from water-induced structural issues (see Appendix B.11.7). Bioretention can be used along the edge of roads, as shown in Figure 3-5, or in medians.

Broadway Street, Witte Museum, San Antonio, Texas (rendering) Source: Bender Wells Clark Design

Figure 3-5. Roadside bioretention can be retrofit into the right-of-way to intercept street runoff through curb cuts.

Bioretention designs can be incorporated into the edge of roadways using traffic calming devices (e.g. curb extensions or "pop-outs") and the grassed strip or other areas between the edge of the roadway and the sidewalk. Figure 3-6 shows an example of bioretention incorporated into a traffic calming device.

Kansas City, Missouri   Source: Tetra Tech

Figure 3-6. Bioretention in a pop-out. A curb cut is provided at the upslope end of the pop-out to accept runoff from the gutter.

For standard traffic calming and roadway specifications, see the street design specifications in the Texas Department of Transportation Roadway Design Manual (Texas Department of Transportation 2010). For additional guidance See Appendix G. Landscaping is often required or expected in traffic calming features, which can be converted to a bioretention area to treat stormwater runoff from the paved surfaces. The maximum width of the right-of-way, minimum allowable roadway width, and required sidewalk width should be considered when optimizing bioretention implementation in the roadside environment.

Further details and design templates for bioretention areas in the right-of-way are provided in Appendix C.

3.4.1.6 Residential and Commercial Landscape

Bioretention can also be integrated into the landscape of a site in open or common areas. Runoff can be routed into the bioretention areas from rooftops, sidewalks, or impervious areas on a site. Energy dissipation is important to prevent erosion in the bioretention area and is usually accomplished in tandem with pretreatment using a stabilized forebay inlet or a vegetated filter strip. When bioretention is integrated into landscapes, it is important to consider any effects that could be made to surrounding structures from infiltration. Figure 3-7 shows a bioretention area that was integrated into a building's common area used as open space.

Buckman Heights Apartments, Portland, Oregon   Source: NCSU BAE

Figure 3-7. Bioretention in a common area.

3.4.2 Bioswales

Bioswales are shallow, narrow, vegetated channels, often referred to as linear bioretention, that are designed to treat runoff primarily by vertical filtration of runoff through soil media and infiltration into underlying soils. Bioswales can serve as conveyance for stormwater and can be used in place of traditional curbs and gutters; however, when compared to traditional vegetated swale systems, **the primary objective of bioswales is infiltration and water quality enhancement rather than conveyance (except for excessive flow)**. Bioswales significantly vary in design configuration and can be constructed with or without check dams, subsurface storage media, and underdrains. Soil media, such as that used in bioretention areas, can be added to a bioswale to improve water quality, reduce the runoff volume, and modulate the peak runoff rate, while also providing conveyance of excess runoff. Advantages and limitations of bioswales are outlined in Table 3-4.

Table 3-4. Advantages and limitations of bioswales

Advantages	Limitations
• Efficient removal of suspended solids, heavy metals, adsorbed pollutants, nitrogen, phosphorus, and pathogens • Can effectively reduce peak runoff rates for relatively frequent storms, reduce runoff volumes, and recharge ground water if soil conditions allow • Flexible to adapt to urban retrofits including bordering parking lots and linearly along impervious surfaces • Well suited for use in small areas, and multiple, distributed units can provide treatment in large drainage areas • Can be integrated naturally into landscaping to enhance aesthetics • Can reduce need/cost for more traditional, subsurface conveyance strategies • Standing water only present for 12-24 hours, so minimal vector control concerns	• Surface soil layer can clog over time (though it can be restored) • Frequent trash removal might be required, especially in high-traffic areas • Vigilance in protecting native soils from compaction during construction is essential • Single units can serve only small drainage areas • Require maintenance of plant material and mulch layer • Site slopes greater than 4% may limit application

3.4.2.1 Hydrologic Function

Bioswales share the same functions as bioretention areas in that they are vegetated and mulched or grassed (i.e., landscaped) shallow depressions that capture and temporarily store stormwater runoff but are designed to be narrow and linear to fit within certain site constraints. The captured runoff is temporarily stored on the surface then infiltrates through the bottom of the depression and a layer of soil media, approximately 2 to 4 feet deep, that has an infiltration rate capable of draining the bioretention area (to the bottom of the media) within a specified design drawdown time (usually 12 to 48 hours). The soil media provides treatment through filtration, adsorption, and biological uptake.

After the stormwater infiltrates through the soil media, it percolates into the underlying subsoil, if site conditions allow for adequate infiltration and slope protection (see Appendix B). If site conditions do not allow for adequate infiltration or slope protection, filtered water is directed toward a stormwater conveyance system or other BMP via underdrain pipes.

Bioswales are designed to capture a specified design volume and can be configured as online or offline systems. Online bioswales require an overflow system for passing larger storms. Offline bioswales do not require an overflow system but do require some freeboard (the distance from the overflow device and the point where stormwater would overflow the system).

If an underdrain is not needed because infiltration rates are adequate and slope is not a concern, the remaining stormwater passes through the soil media and percolates into the subsoil. Partial infiltration (approximately 20 to 25 percent, depending on soil conditions) can still occur when underdrains are present as long as no impermeable barrier is between the soil media and subsoil. Partial infiltration occurs in such cases because some of the stormwater bypasses the underdrain and percolates into the subsoil (Strecker et al. 2004; Hunt et al. 2006). Volume reduction can be further enhanced by including IWS and by treating the subgrade with scarification, ripping, or trenching (as discussed in Appendix B.1.2.1; Tyner et al. 2009; Brown and Hunt 2010).

Bioswales are typically planted with grasses, shrubs, and trees that can withstand short periods of saturation (12 to 72 hours) followed by longer periods of drought. Inclusion of IWS can improve soil water retention for plant survival.

3.4.2.2 Water Quality Performance

Bioswales are volume-based BMPs intended primarily for water quality treatment and, depending on site slope and soil conditions, can provide high volume reduction. Where site conditions allow, the volume-reduction capability can be enhanced for achieving additional credit toward meeting the volume-reduction requirement by omitting underdrains and providing a gravel drainage layer beneath the bioswale. Bioswales function similarly to bioretention areas and remove pollutants through physical, chemical, and biological mechanisms. Specifically, they use absorption, microbial activity, plant uptake, sedimentation, and filtration. Refer to Section 3.4.1.2 for water quality performance details.

3.4.2.3 Applications and Configurations

Appendix B.2 outlines major design components and site considerations and describes the process for designing bioswales. Typical site applications and configurations are described further below.

3.4.2.4 Parking Lots

Bioswales are especially useful along the edge of parking lots or between facing parking stalls where narrow, linear space is available for stormwater treatment. Pretreatment is important for parking lot areas to remove large sediments and to slow the runoff to non-erosive flow rates (1 in/hr for mulch and 3 in/hr for sod). Pretreatment typically consists of a gravel verge followed by turf.

3.4.2.5 Roads

Bioswales can also be integrated into the right-of-way and medians of roads. Similar concepts apply to roads as parking lots. Some pretreatment could be required to remove large particles and slow the runoff to non-erosive flows. Bioswales can be used along the edge of roads or in medians as shown in Figure 3-8.

For standard median and right-of-way specifications, see local street design standards. To allow space for bioswale implementation, new roads should be designed with the maximum right-of-way width and minimum curb-to-curb spacing.

Columbia Memorial Learning Center, Downey, California Source: Tetra Tech

Figure 3-8. Road median bioswale.

3.4.3 Permeable Pavement

Permeable pavement is a highly versatile stormwater BMP because it can effectively reduce pollutants and can be integrated into site plans with various configurations and components. Permeable pavement allows streets, parking lots, sidewalks, and other impervious covers to retain the infiltration capacity of underlying soils while maintaining the structural and functional features of the materials they replace. Permeable pavement has small voids or aggregate-filled joints that allow water to drain through to an aggregate reservoir. Stormwater stored in the reservoir layer can then infiltrate underlying soils or drain at a controlled rate via underdrains to other downstream stormwater control systems. Permeable pavement systems can be designed to operate as underground detention if the native soils do not have sufficient infiltration capacity, or if infiltration is precluded by aquifer protection, hotspots, or adjacent structures. Permeable pavement can be developed using modular paving systems (e.g., permeable interlocking concrete pavers, concrete grid pavers, or plastic grid systems) or poured in place solutions (e.g., pervious concrete or porous asphalt). Some pervious concrete systems can also be precast. In many cases, especially where space is limited, permeable pavement is a cost-effective solution relative to other practices because it doubles as both transportation infrastructure and a BMP. Advantages and limitations of permeable pavement are outlined in Table 3-5.

Table 3-5. Advantages and limitations of permeable pavement

Advantages	Limitations
• Replaces completely impervious surfaces with partially impervious surfaces • Reduces stormwater runoff rate and volume • Reduces loads of some pollutants in surface runoff by reducing the volume of stormwater leaving a site • Reduces stormwater infrastructure footprint and promotes multi-benefit uses by using treatment area for parking/driving with possible cost reductions • Increases ground water recharge • Adaptable to urban retrofits • Many options available depending on specific site needs and aesthetics • Applicable for use in recharge zones, karst, expansive clays, and hotspots when properly designed	• Potential for clogging of porous media by sediment, which could lead to reduced effectiveness without proper maintenance • Should not receive runon from adjacent pervious surfaces with high sediment/debris yield • Typically not cost effective for high-traffic areas or for use by heavy vehicles (requires increased structural design and maintenance frequency) • Permeable pavement should be installed only by contractors qualified and certified for permeable pavement installation • Typically recommended for grades of 5% or less

3.4.3.1 Hydrologic Functions

Permeable pavement systems are designed to reduce surface runoff by allowing stormwater to infiltrate the pavement surface. While the specific design can vary, most permeable pavements have a similar structure consisting of a surface course layer and an underlying stone aggregate reservoir layer. Modular storage units, chambers, and pipes can also be integrated for additional subsurface storage. Where soils permit, permeable pavement allows captured runoff to fully or partially infiltrate into underlying soils; where infiltration is restricted (such as in the Edwards Aquifer Recharge Zone, karst, or near building foundations), permeable pavement can be lined with an impermeable membrane and used as detention systems.

Volume reduction primarily depends on the drainage configuration and subsoil infiltration capacities. Systems installed without underdrains in highly permeable soils can achieve practically 100 percent volume reduction efficiency (Bean et al. 2007). Systems installed in restrictive clay soils can still give significant volume reduction (Tyner et al. 2009; Fassman and Blackbourn 2010). The volume reduction can be further enhanced by treating the subgrade with scarification, ripping, or trenching (as discussed in Appendix B.5.2; Tyner et al. 2009; Brown and Hunt 2010), by omitting underdrains (where practicable), or by incorporating an internal water storage layer by upturning underdrain inverts to create a sump (Wardynski et al. 2013). Peak flow can be also effectively attenuated by permeable pavement systems by reducing overall runoff volumes, promoting infiltration, and increasing the lag time to peak discharge (Collins et al. 2008).

3.4.3.2 Water Quality Performance

Permeable pavement systems, when designed and installed properly, consistently reduce concentrations and loads of several stormwater pollutants, including heavy metals, motor oil, sediment, and some nutrients. The aggregate subbase provides water quality improvements through filtering and chemical and biological processes, but the primary pollutant removal mechanism is typically load reduction by infiltration into subsoils.

Pollutant-removal efficiencies for permeable pavements have been well studied. Permeable pavement systems consistently reduce sediment concentrations and loads; however, high loadings of TSS significantly reduce the functional life of permeable pavement systems because of clogging in the void space. TSS reductions have been shown to range from 32 to 96 percent, with average removal efficiency of 81 percent (MWCOG 1983; Schueler 1987; Pagotto et al. 2000; Rushton 2001; Gilbert and Clausen 2006; Bean et al. 2007; CWP 2007; Toronto and Region Conservation Authority 2007; Roseen et al. 2009, 2011; Fassman and Blackbourn 2011). TSS can be practically eliminated (100 percent reduction) when systems fully infiltrate captured runoff. Because phosphorus tends to be associated with sediment particles, total phosphorus reduction is fairly consistent, and removal efficiencies range from 20 to 78 percent (MWCOG 1983; Schueler 1987; Rushton 2001; Gilbert and Clausen 2006; Bean et al. 2007; CWP 2007; Toronto and Region Conservation Authority 2007; Roseen et al. 2009, 2011; Yong et al. 2011). As with phosphorus, sediment-bound metals are also reliably reduced; average removal efficiencies for cadmium, lead, zinc, and copper range from 65 to 84 percent (MWCOG 1983; Schueler 1987; Pagotto et al. 2000; Rushton 2001; Dierkes et al. 2002; Brattebo and Booth 2003; Gilbert and Clausen 2006; Bean et al. 2007; Toronto and Region Conservation Authority 2007; CWP 2007; Roseen et al. 2009, 2011; Fassman and Blackbourn 2011).

Nitrogen removal is more variable because permeable pavement does not typically provide the mechanisms for denitrification. Total nitrogen removal efficiency has been shown to range from –40 to 88 percent (MWCOG 1983; Schueler 1987; CWP 2007; Collins et al. 2010). High removal efficiencies have been reported for hydrocarbons (92–99 percent; Roseen et al. 2009, 2011). Permeable pavement has demonstrated mixed performance for reducing indicator bacteria counts from effluent (Myers et al. 2009; Tota-Maharaj and Scholz 2010); however, infiltrating systems could effectively reduce pathogen counts by filtering runoff through underlying soils and reducing the overall stormwater volume.

Similar to bioretention, research indicates that permeable pavement can be used to mitigate thermal loading to waterways by buffering extreme temperatures within the aggregate profile and by infiltrating runoff into subsoils (Wardynski et al. 2013).

3.4.3.3 Applications and Configurations

Appendix B.3 outlines major design components and site considerations and describes the process for designing permeable pavement. Typical site applications and configurations are described further below.

Parking Lots

Permeable pavement is typically used in a parking lot to provide a pervious alternative to a typically impervious area. The entire lot or only portions can be permeable; typically the parking stalls will be permeable and the driving lanes consist of standard paving. If a high level of traffic is anticipated regularly (such as in a drive-through) or heavy vehicles must pass through (such as garbage trucks) it may be cost effective to design the travel lane with standard paving materials and slope them toward the permeable parking stalls; however, permeable pavements can be designed for heavy traffic loading by using abrasion resistant materials and by increasing the structural base layer depth. Figure 3-9 shows an example of the entire parking lot being permeable pavement, and Figure 3-10 shows only the parking stalls being permeable.

Cottonwood Park, Encinitas, California
Source: Tetra Tech

Figure 3-9. Pervious concrete parking lot.

Oaks Business Park, San Antonio, Texas
Source: Bender Wells Clark Design

Figure 3-10. PICP parking stalls.

Sidewalks and Pedestrian Plazas

Permeable pavement can also be effective for pedestrian uses, and most types of permeable surface courses are ADA compliant. Sidewalks can be constructed of pervious pavement materials to reduce runoff in highly impervious areas. This can be effective in malls, plazas, promenades, and other outdoor hardscapes with low sediment loads. Care should be taken during site layout to allow for ease of maintenance (for details on maintaining permeable sidewalks, see Section 4.3.5). An example of permeable pavement in a pedestrian plaza is shown in Figure 3-11.

James Madison High School Agriscience Building, San Antonio, Texas Source: Bender Wells Clark Design

Figure 3-11. Permeable pavement pedestrian plaza.

Access Roads and Shoulders

Permeable pavement can also be used in areas that receive little traffic, such as fire lanes, shown in Figure 3-12, or vegetated shoulders for temporary parking. Most pavers are rated for loading of heavy vehicles such as fire trucks as long as sufficient structural base layers are provided.

San Diego, California Source: Tetra Tech

Figure 3-12. Permeable pavement fire access lane.

3.5 Filtration BMPs

Filtration BMPs have been used widely because of their relatively small footprint and moderate physical requirements (FHWA 2002). Because of their versatility, filtration BMPs can be incorporated into a wide range of landscapes including roadway corridors, rights-of-way, sidewalks, and areas with limited space; certain filtration BMPs (e.g., sand filters) can also be implemented underground. Most filtration BMPs are designed to treat only a portion of a storm event, usually based on volume- or flow-based designs. Stormwater quality management is primarily provided by filtration, sedimentation, straining, and sorption as stormwater passes through small pore spaces. Filtration BMPs are not intended to infiltrate runoff into subsoils.

3.5.1 Planter Boxes

A planter box is a concrete box containing soil media and vegetation that functions similarly to a small bioretention area but is completely lined and must have an underdrain. Planter boxes have been implemented around paved streets, parking lots, and buildings to provide initial stormwater detention and treatment of runoff. Such applications offer an ideal opportunity to minimize directly connected impervious areas in highly urbanized areas. In addition to stormwater management benefits, planter boxes provide on-site stormwater treatment options, green space, and natural aesthetics in tightly confined urban environments. The vegetation and soil media in the planter box provide functions similar to bioretention area. Advantages and limitations of planter boxes are outlined below in Table 3-6.

Table 3-6. Advantages and limitations of planter boxes

Advantages	Limitations
• Efficient removal of suspended solids, heavy metals, adsorbed pollutants, nitrogen, phosphorus, and pathogens • Can effectively reduce peak runoff rates for the water quality design storm and reduce runoff volumes through evapotranspiration • Flexible to adapt to urban retrofits and are well suited for small, highly impervious, areas • Can be integrated naturally into landscaping to enhance aesthetics and provide multi-benefit use • Does not require a setback from structural foundations • No geotechnical limitations—can be used where infiltration is restricted (e.g., Edwards Aquifer Recharge Zone, clay soils)	• Surface soil layer could clog over time (though it can be restored) • Frequent trash removal could be required, especially in high-traffic areas • Single units can serve only small drainage areas • Requires maintenance of plant material and mulch layer • Does not promote deep infiltration to supplement ground water recharge

3.5.1.1 Hydrologic Functions

Planter boxes are vegetated and mulched or grassed (i.e., landscaped), shallow depressions that capture, temporarily store, and filter stormwater runoff before directing the filtered stormwater toward a stormwater conveyance system or other BMP via underdrain pipes. The captured runoff infiltrates through the bottom of the depression and a soil media layer approximately 2 to 4 feet deep that has an infiltration rate capable of draining the planter box (to the bottom of the soil media) within a specified design drawdown time (usually 12 to 48 hours; Davis et al 2009; Hunt and Lord 2006). The soil media provides treatment through filtration, adsorption, and biological uptake. Some volume reduction is possible through evapotranspiration and storage in the soil media. Planter boxes are typically planted with grasses, shrubs, and trees that can withstand short periods of saturation (12 to 24 hours; Davis et al 2009; Hunt and Lord 2006) followed by longer periods of drought.

3.5.1.2 Water Quality Performance

Planter boxes are volume-based BMPs intended, primarily, for water quality treatment that can provide limited peak-flow reduction for the water quality or design storm and volume reduction. Planter boxes should be used only in place of bioretention areas where geotechnical conditions do not allow for infiltration. Although planter boxes do not allow for infiltration into the subsoils, they still provide functions considered fundamental for LID practices. Research has shown that runoff volume can be reduced by as much as 15 to 20 percent by systems that are lined or completely contained (Hunt et al. 2006) through evapotranspiration. They are considered only as a last resort to provide some water quality treatment in areas where infiltration is not recommended.

Planter boxes remove pollutants through physical, chemical, and biological mechanisms. Specifically, they use absorption, microbial activity, plant uptake, sedimentation, and filtration, similar to bioretention areas. Planter boxes are capable of consistent and high pollutant removal for sediment, metals, and organic pollutants (e.g., hydrocarbons). Current research shows that pollutant removal is possible with underdrains through the function provided at the surface and by the soil media. Most of the sediment removal occurs in the top mulch layer, while metals removal commonly occurs in the first 18 inches of the soil media (Hseih and Davis 2005; Hunt and Lord 2006).

3.5.1.3 Applications and Configurations

Appendix B.4 outlines major design components and site considerations and describes the process for designing planter boxes. Typical site applications and configurations are shown below. Figure 3-13 shows how a planter box can be incorporated next to a building, and Figure 3-14 shows a planter box in an ultra-urban area.

San Diego, California Source: Tetra Tech

Figure 3-13. Planter boxes near a building.

Philadelphia, Pennsylvania Source: Tetra Tech

Figure 3-14. Planter box in an ultra-urban setting.

3.5.2 Green Roofs

Green roofs reduce runoff volume and rates by intercepting rainfall in a layer of rooftop growing media. Rainwater captured in rooftop media then evaporates or is transpired by plants back into the atmosphere. Rainwater in excess of the media capacity is detained in a drainage layer before flowing to roof drains and downspouts. Green roofs are highly effective at reducing or eliminating rooftop runoff from small to medium storm events, which can reduce downstream pollutant loads; however, green roofs do not typically improve the quality of captured rainwater. In addition to stormwater volume reduction, green roofs offer an array of benefits, including extended roof lifespan (due to additional sealing, liners, and insulation), improved building insulation and energy use, reduction of urban heat island effects, opportunities for recreation and rooftop gardening, noise attenuation, air quality improvement, bird and insect habitat, and aesthetics (Tolderlund 2010; Berndtsson 2010; Getter and Rowe 2006). Green roofs can be designed as extensive, shallow-media systems or intensive, deep-media systems depending on the design goals, roof structural capacity, and available funding. Extensive green roofs in the San Antonio region may require drip irrigation to sustain vegetation through hot summer months, but air conditioner condensate or harvested rainwater can be used for this purpose. To improve vegetation resistance and resilience, a biodiverse, locally-adapted plant palette should be used. Even with careful plant selection, many “green” roofs will remain brown during much of the year. *Blue roofs* are another form of rooftop runoff management also known as *rooftop ponding areas* or *rooftop detention* that can be effective for volume and flow control. Brown roofs are another form of rooftop runoff management focused on grasses or other “brown” vegetation rather than succulents, although this manual focuses on vegetated roofs because of their multi-use benefits. Additional information and design recommendations for blue roofs and brown roofs can be found in *Guidelines for the Design and Construction of Stormwater Management Systems* from the New York City Department of Environmental Protection and New York City Department of Buildings. Table 3-7 describes the advantages and limitations of green roofs.

Table 3-7. Advantages and limitations of green roofs

Advantages	Limitations
• Reduces stormwater volume and peak flow through evapotranspiration • Independent of site soils and geological setting • Can be used to reduce size of downstream BMPs • Improve building energy use and reduce energy costs • Enhance roof lifespan • Provide rooftop recreation and gardening opportunities • Reduce noise and air pollution • Provide urban bird and insect habitat • Improve aesthetics and increase property values (if visible)	• Structural constraints could preclude use • Installation can be challenging in certain locations • Tend to be costly compared to other stormwater volume reduction practices • Although total stormwater volume is reduced, tend to export high nutrient concentrations and possibly pathogens (Berndtsson 2010) • Roof slopes steeper than 45° tend to require special design • May require irrigation for maintenance of vegetation during summer months (depends on plant selection and design goals)

3.5.2.1 Hydrologic Functions

The main benefits of green roofs are from significant rainfall volume retention, evapotranspiration, and reduced peak discharge from rooftops. While hydrologic performance of green roofs varies with media and material type, roof pitch, vegetation, climate, and season, green roofs tend to retain (on average) between 45 and 75 percent of annual rainfall (Berndtsson 2010). Vegetation has been shown to significantly enhance rooftop rainwater retention when compared with unplanted soil media, especially in the summer and in arid environments, although the majority of water retention and evaporation occurs in the soil media (Wolf and Lundholm 2008; Berndtsson 2010; Schroll et al. 2011). High runoff retention mimics evapotranspiration and canopy interception of natural systems, which shifts the urban water balance more toward predevelopment hydrology conditions.

3.5.2.2 Water Quality Performance

The body of knowledge surrounding green roof effluent quality is limited, but in general, green roofs are expected to export higher phosphorus and nitrogen concentrations than measured in rainfall (Berndtsson 2010). This is mainly from decomposition and release of nutrients from organic matter in the green roof soil media. Nevertheless, overall nutrient loads can be reduced when water volume reduction is considered (Kohler et al. 2002). Green roofs also tend to reduce heavy metal loads relative to incoming loads from precipitation (Berndtsson 2010).

3.5.2.3 Applications and Configurations

Appendix B.5 outlines major design components and site considerations and describes the process for designing green roofs. Green roofs are typically differentiated into two categories (intensive and extensive) based on desired function and structural capacity of the roof. Some examples of each type are provided below.

Extensive Green Roof

Green roofs with shallow, lightweight media are generally known as extensive. Media depths typically range from 4 to 6 inches to minimize loading on structures. Extensive green roofs are typically implemented solely for stormwater management, although alternative benefits are often realized (including reduced energy costs, improved roof lifespan, and pollinator habitat). An example of an extensive green roof is provided in Figure 3-15.

Live Roof System, Hipolito F. Garcia Federal Building, San Antonio, Texas Source: Joss Growers

Figure 3-15. Extensive green roofs reduce stormwater runoff while providing cooling effects, habitat for pollinators, and aesthetic value.

Intensive Green Roof

Roof gardens and rooftop parks with media deeper than 6 inches are commonly known as intensive green roofs. Unlike extensive green roofs, intensive green roofs are typically installed primarily for recreational and aesthetic purposes and provide stormwater benefits as an auxiliary function. Because deep media depth exerts high loads on underlying structures, implementation of intensive green roofs is common on the top level of parking decks, high-rise buildings, and other structures specifically designed for extreme loading. Example of an intensive green roof is shown in Figure 3-16.

James Madison High School Agriscience Building, San Antonio, Texas Source: Bender Wells Clark Design

Figure 3-16. Intensive green roofs provide recreational, aesthetic, and educational opportunities in addition to stormwater benefits.

3.5.3 Sand Filter

A sand filter is a treatment system used to remove particulates and solids from stormwater runoff by facilitating physical filtration. It is a flow-through system designed to improve water quality from impervious drainage areas by slowly filtering runoff through sedimentation and filtration chambers. With increased detention time, the sedimentation chamber allows larger particles to settle in the chamber. The filtration chamber removes pollutants and enhances water quality as the stormwater is strained through a layer of sand. The treated effluent is collected by underdrain piping and discharged to the existing stormwater collection system or another BMP. Advantages and limitations of sand filters are outlined below in Table 3-8.

Table 3-8. Advantages and limitations of sand filters

Advantages	Limitations
• Efficient removal of suspended solids, heavy metals, oil and grease, particle-bound nutrients, and pathogens • Can effectively reduce peak runoff rates for relatively frequent storms, reduce runoff volumes, and recharge ground water if soil conditions allow • Flexible to adapt to urban retrofits • Can incorporate deeper ponding depths and require less space • Can be placed underground in areas where space is limited • Can have high infiltration rates	• Surface layer can clog over time (though it can be restored) • Frequent trash removal might be required, especially in high-traffic areas • Vigilance in protecting native soils from compaction during construction might be necessary (for infiltrating systems) • Can be unattractive in some areas • Standing water in sedimentation/grit chambers can provide vector breeding habitat • Higher overall cost for implementation

3.5.3.1 Hydrologic Functions

Sand filters are filtering BMPs that remove trash and pollutants by passing stormwater vertically through a sand media. Sand filters are generally applied to land uses with a large fraction of impervious surfaces and ultra-urban locations. Although an individual sand filter can handle only a small contributing drainage area, multiple units can be dispersed throughout a large site. Two strategies are available for incorporating sand filters into the site design. One option is the open basin or above ground design that allows sunlight penetration to enhance pathogen removal. The second option is a closed basin or below ground design that requires very little space in a site but has reduced pollutant-removal capabilities. Because sand filters can be implemented underground, they can also be used in areas with limited surface space.

Sand filters are designed primarily for water quality enhancement; however, surface sand filters can store a substantial volume of water and be used for peak flow attenuation. Sand filters typically employ underdrain systems to collect and discharge treated stormwater but can also be designed as infiltration-type systems when in soils with sufficient permeability or infiltration rates. Infiltration further enhances a sand filter’s ability to mitigate flood flows and reduces the erosive potential of urban runoff.

3.5.3.2 Water Quality Performance

Sand filters are capable of removing a wide variety of pollutant concentrations in stormwater via settling, filtering, and adsorption processes. Sand filters have been a proven technology for drinking water treatment for many years and are capable of removing many particulate-bound urban stormwater pollutants including TSS, particulate-bound nutrients, and metals (Barrett 2008). Sand filters are volume-based BMPs intended primarily for treating the water quality design volume. In many cases, sand filters are contained within enclosed concrete or block structures with underdrains; therefore, only minimal volume reduction occurs via evaporation as stormwater percolates through the filter to the underdrain.

Because sand filters rely on filtration as the primary function for pollutant reduction, infiltration rates could be higher than what is recommended for a bioretention area, allowing a greater volume to pass through the media in a short time. That requires less surface area of the BMP to treat the same volume with a lower performance for some pollutants. Sand filters generally have high removal rates for sediment, BOD, and fecal coliform bacteria (USEPA 1999). Effluent concentrations of sediment and sediment-bound pollutants tend to be relatively independent of influent concentrations, indicating sand filters can be expected to discharge constant effluent quality regardless of influent concentrations (Barrett 2008). TSS removal rates range from 74 to 95 percent, with a typical efficiency of 90 percent (Bell et al. 1995; Horner and Horner 1995; Barrett 2003, 2008, 2010). TSS effluent concentrations ranged from 13 to 25 mg/L for five study sites in Texas (compared to influent concentrations of 69 to 304 mg/L; Barrett 2010).

Barrett (2010) reported the following pollutant removal rates (percent reductions in event mean concentration from inlet to outlet) for five sand filter study sites in Texas:

- Total phosphorus: –14 percent (export) to 69 percent (reduction)
- BOD: –27 percent (export) to 55 percent (reduction)
- Zinc: 35 to 87 percent reduction
- Copper: 14 to 59 percent reduction
- Lead: 61 to 86 percent reduction
- Fecal coliform: –70 percent (export) to 54 percent (reduction)
- Fecal streptococcus: 11 to 68 percent reduction

In another study, Barrett (2008) reported that total nitrogen is modestly removed, with an average efficiency of approximately 20 percent, while removal of total metals ranges from 50 to 87 percent, with lower removal of dissolved metals.

3.5.3.3 Applications and Configurations

Appendix B.6 outlines major design components and site considerations and describes the process for designing sand filters. Typical site applications and configurations are described below.

Surface

Surface sand filters require some method of pretreatment, such as a filter strip or swale, to remove large solids and reduce the velocity of stormwater entering the BMP. Surface sand filters can be integrated into the site plan as recreational facilities such as volleyball courts or open space as shown in Figure 3-17.

Parman Library, San Antonio, Texas Source: Bender Wells Clark Design

Figure 3-17. Surface sand filter.

Subsurface

Subsurface sand filters require very little space and are easily incorporated belowground into the edge of parking lots and roadways. Subsurface sand filters require a pretreatment sedimentation chamber that is a minimum of 1.5 feet wide to allow for settling of large solids. An example of a subsurface sand filter with a sedimentation chamber is shown in Figure 3-18.

Raleigh, North Carolina Source: Tetra Tech

Figure 3-18. Subsurface sand filter.

3.6 Volume-Storage and Reuse BMPs

Stormwater wetlands can be effectively implemented in open space areas to temporarily capture and store runoff where infiltration is limited or not feasible. Using BMPs around buildings is intended to maximize rainfall interception and minimize pollutant introduction into stormwater. Cisterns and rain barrels are examples of volume-storage and reuse BMPs that reduce runoff washed from buildings. With the goal of reducing the total runoff volume washed into the traditional stormwater conveyance system (MS4), stormwater wetlands, cisterns, and rain barrels are especially effective in capturing volumes from smaller storm events. Once captured, the stormwater is slowly released between storm events and can used for irrigation. The controlled release from cisterns reduces peak storm volumes and, therefore, reduces runoff and erosion potential.

3.6.1 Stormwater Wetlands

Stormwater wetlands are engineered, shallow-water ecosystems designed to treat stormwater runoff. Commonly implemented in low-lying areas, stormwater wetlands are well suited to areas along river corridors where water tables are higher. Sediment and nutrients are efficiently reduced by stormwater wetlands by means of sedimentation, chemical and biological conversions, and uptake. Stormwater wetlands provide flood control benefits by storing water and slowly releasing it over 2 to 5 days. In addition to stormwater management, stormwater wetlands provide excellent plant and wildlife habitat and can often be designed as public amenities. Research has indicated that a home located next to stormwater wetlands can have a 20 to 30 percent higher selling price (Russell et al. 2012). Advantages and limitations of stormwater wetlands are outlined in Table 3-9.

Table 3-9. Advantages and limitations of stormwater wetlands

Advantages	Limitations
• Excellent sediment and nutrient reduction • Useful in low-lying areas, areas with high water tables, or where infiltration is otherwise restricted/discouraged • Construction and design techniques similar to conventional detention ponds • Provide multi-benefit uses by enhancing biodiversity and providing recreational/educational opportunities • Typically require fewer vector control efforts than unvegetated ponds because properly maintained habitat supports mosquito predators (dragonflies and fish)	• Limited use in semi-arid climates where supplemental water would be required to maintain water level(a site-specific water balance must be performed to justify implementation)

3.6.1.1 Hydrologic Functions

Runoff enters stormwater wetlands and is stilled in a forebay where large solids and debris are captured. The design volume then fills the wetland to a depth of 12 inches or less and drains over 2 to 5 days through a drawdown orifice installed at the elevation of the permanent pool. Runoff in excess of the design volume can bypass to the downstream stormwater network or can be detained using a riser structure or weir. Although stormwater wetlands can mitigate peak discharge, they are not designed for volume reduction—in fact, infiltration is discouraged to ensure that permanent pools are maintained for plant survival and aesthetic purposes (more information in Appendix B.7).

3.6.1.2 Water Quality Performance

Similar to natural wetlands, water quality improvement is effectively achieved in constructed wetlands through physicochemical and biological processes as water is temporarily stored. Specific unit processes include sedimentation, denitrification, and uptake. Consequently, the flow path through the wetland should be maximized to increase residence time and contact with vegetation, soil, and microbes. Very high sediment removal efficiencies have been reported for properly sized stormwater wetlands (50 to 80 percent reduction), with average effluent concentrations near 9 mg/L (Hathaway and Hunt 2010; Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. 2012). Subsequently, particle-bound metals are thought to be reduced as sediment falls out of suspension, and significant reduction of total copper, total cadmium, total lead, and total zinc is expected (although metals can dissociate from sediment and organic matter into solution under anaerobic conditions; Newman and Pietro 2001; Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. 2012).

High phosphorus removal rates have been observed in stormwater wetlands, but, similar to metals, phosphorus can desorb from sediments under anaerobic conditions (Hathaway and Hunt 2010). Stormwater wetlands typically perform well for nitrate removal because the anaerobic conditions and organic material in wetland sediment create an ideal environment for denitrification (converting nitrate into nitrogen gas). Significant nitrate reduction is commonly observed in stormwater wetlands, but total nitrogen reduction depends on the species and concentration of incoming nitrogen (Hathaway and Hunt 2010; Moore et al. 2011; Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. 2012). Pathogen removal in stormwater wetlands is expected because of predation, solar radiation, and sedimentation (Davies and Bavor 2000; Struck et al. 2008; Geosyntec Consultants, Inc. and Wright Water Engineers, Inc. 2012); furthermore, wetlands tend to reduce bacteria more than do traditional wet detention ponds (Davies and Bavor 2000).

3.6.1.3 Applications and Configurations

Appendix B.7 outlines major design components and site considerations and describes the process for designing stormwater wetlands. In general, stormwater wetlands are particularly well suited to low-lying sites with large drainage areas. The configuration of the stormwater wetland will vary by site and can be adapted to the available space and desired functions. Long, linear wetlands can be installed along the perimeter of sites, smaller pocket wetlands can be distributed throughout a development, or larger wetlands can be installed at the downstream end of a catchment. Figure 3-19 and Figure 3-20 illustrate examples of stormwater wetlands.

Lenoir, North Carolina Source: Tetra Tech

Figure 3-19. A large linear stormwater wetland.

Wilmington, North Carolina Source: Tetra Tech

Figure 3-20. Small wetlands along the perimeter of a neighborhood.

3.6.2 Rainwater Harvesting

Cisterns or their smaller counterpart, rain barrels, are containers that capture runoff and store it for future use. With control of the timing and volume, the captured stormwater can be more effectively released for irrigation or alternative grey water uses between storm events. Rain barrels tend to be smaller systems, less than 100 gallons. Cisterns are larger systems that can be self-contained aboveground or belowground systems generally larger than 100 gallons. Belowground systems often require a pump for water removal. For San Antonio and surrounding areas, cisterns and rain barrels primarily provide control of stormwater volume; however, water quality improvements can be achieved when cisterns and rain barrels are used in a treatment train with BMPs such as bioretention areas. Water in cisterns or rain barrels can be controlled by permanently open outlets or operable valves depending on project specifications. Cisterns and rain barrels can be a useful method of reducing stormwater runoff volumes in urban areas where site constraints limit the use of other BMPs. Advantages and limitations of rainwater harvesting are outlined in Table 3-10.

Table 3-10. Advantages and limitations of rainwater harvesting

Advantages	Limitations
• Provides peak flow mitigation for frequent and infrequent storm events • Aids in infiltration by delaying runoff • Variable configurations to meet site constraints • Can reduce the size of infiltration BMPs • Can be designed for high visibility to raise stormwater awareness or can be hidden from view • Effective where underground utilities or other constraints preclude use of surface/subsurface storage BMPs • Can be designed to supplement or replace nonpotable water supplies (for nonresidential uses) or for irrigation (residential or nonresidential) • Rainwater harvesting equipment is exempt from sales tax under Texas Tax Code 151.355	• Requires regular maintenance of inlet filters and mosquito control screens • Can require structural support • Reuse systems may require filtration and disinfection per intended use and local plumbing codes

3.6.2.1 Hydrologic Functions

Cisterns are typically placed near roof downspouts such that flows from existing downspouts can be easily diverted into the cistern. Runoff enters the cistern near the top and is filtered to remove large sediment and debris. Collected water exits the cistern from the bottom or can be pumped to areas more conducive for infiltration. Cisterns can be used as a reservoir for temporary storage or as a flow-through system for peak flow control. Cisterns are fitted with a valve that can hold the stormwater for reuse, or they release the stormwater from the cistern at a rate below the design storm rate. Regardless of the intent of the storage, an overflow must be provided if the capacity of the cistern is exceeded. The overflow system should route the runoff to a BMP for treatment or safely pass the flow into the stormwater drainage system. The overflow should be conveyed away from structures. The volume of the cistern should be allowed to slowly release, preferably into a BMP for treatment or into a landscaped area where infiltration has been enhanced.

Cisterns have been used for millennia to capture and store water. Droughts in recent years have prompted a resurgence of rainwater harvesting technology as a means of offsetting potable water use. Studies have shown that adequately designed and used systems reduce the demand for potable water and can provide important hydrologic benefits (Vialle et al. 2012; DeBusk et al. 2012). Hydrologic performance of rainwater harvesting practices varies with design and use; systems must be drained between rain events to reduce the frequency of overflow (Jones and Hunt 2010). When a passive drawdown system is included (e.g., an orifice that slowly bleeds water from the cistern into an adjacent vegetation bed or infiltrating practice), significant runoff and peak flow reduction can be achieved (DeBusk et al. 2012; AECOM Technical Service, Inc. 2011).

3.6.2.2 Water Quality Performance

Because most rainwater harvesting systems collect rooftop runoff, the water quality of runoff harvested in cisterns is largely determined by surrounding environmental conditions (overhanging vegetation, bird and wildlife activity, atmospheric deposition, and such), roof material, and cistern material (Thomas and Greene 1993; Despins et al. 2009; Lee et al. 2012). Rooftop runoff tends to be relatively clean regarding physical and chemical pollutants, but elevated microbial counts are typical (Thomas and Greene 1993; Lye 2009; Gikas and Tsihrintzis 2012; Lee et al. 2012). Physicochemical contaminants can be further reduced by implementing a first-flush diverter (discussed later); however, first-flush diverters can have little impact on reducing microbial counts (Lee et al. 2012; Gikas and Tsihrintzis 2012).

Pine Knoll Shores, North Carolina   Source: Tetra Tech

Figure 3-21. Typical plastic cistern.

The pollutant reduction mechanisms of cisterns are not yet well understood, but it is thought that water quality improvement can be achieved by sedimentation and biochemical transformations (given adequate residence time). Despite limited data describing reduction in stormwater contaminant concentrations in cisterns, rainwater harvesting can greatly reduce pollutant loads to waterways if stored rainwater is infiltrated into surrounding soils using a low-flow drawdown configuration or when it is used for alternative purposes such as toilet flushing or vehicle washing (Khastagir and Jayasuriya 2010). Rainwater harvesting systems can also be equipped with filters to further improve water quality.

3.6.2.3 Applications and Configurations

Appendix B.8 outlines major design components and site considerations and describes the process for designing rainwater harvesting systems that are in compliance with the San Antonio plumbing code (City of San Antonio 2009). Additional Texas-specific resources are provided in TCEQ (2011), Texas Water Development Board (2005), and Texas A&M AgriLife Extension Services (2013). Typical site applications and configurations are described below.

A cistern typically holds several hundred to several thousand gallons of rainwater that can be used in a variety of settings in residential, commercial, governmental, and industrial applications. Cisterns provide non-potable water for irrigation, toilet flushing, cooling system makeup, and equipment and vehicle washing and come in a variety of shapes, colors, and configurations. Figure 3-21 shows a typical above ground plastic cistern and Figure 3-22 shows the same cistern with a wooden wrap. Cisterns can also be decorative such as the one shown in Figure 3-23 at the Children's Museum in Santa Fe, NM or below ground as shown in Figure 3-24.

Pine Knoll Shores,, North Carolina Source: Tetra Tech

Figure 3-22. Wood wrapped cistern.

Source: Santa Fe, New Mexico, Children's Museum

Figure 3-23. Decorative cistern.

Fayetteville, North Carolina Source: Tetra Tech

Figure 3-24. Below ground cistern.

Smaller cisterns (less than 100 gallons), commonly referred to as rain barrels, are mostly used on a residential scale (Figure 3-25). Rain barrels are much less complicated to install because of their size and have similar components as cisterns. Rain barrels require an inlet connection to the downspout, an outlet, and an overflow. Water that is collected can be used to supplement municipal water for nonpotable uses, primarily irrigation. Although useful for raising public awareness and for meeting basic irrigation needs, rain barrels do not typically provide substantial hydrologic benefits because they tend to be undersized relative to their contributing drainage area. Nevertheless, modeling has suggested that the cumulative effects of watershed-wide rain barrel implementation in the San Antonio region (particularly when paired with rain gardens) can have significant impacts on 100-yr peak flow and annual volume reduction (AECOM Technical Services, Inc. 2011). Figure 3-26 shows rain barrels adequately sized for the contributing roof area.

Wilmington, North Carolina   Source: Tetra Tech

Figure 3-25. Residential rain barrel.

Asheville, North Carolina   Source: Tetra Tech

Figure 3-26. Rain barrels adequately sized for contributing roof area.

3.7 Conveyance and Pretreatment BMPs

3.7.1 Vegetated Swales

Vegetated swales are shallow, open grass channels that are LID alternatives to traditional curbs and gutters. Swales are designed to convey runoff while providing limited pollutant removal by sedimentation and horizontal filtration through vegetation. Swales are effective for pretreatment of concentrated flows before discharge to a downstream BMP. **Vegetated swales should not be confused with bioswales, which rely on vertical filtration of runoff through subsurface bioretention media**. Compared with other LID practices, vegetated swales have a relatively low construction cost, a moderate maintenance burden, and require only a moderate amount of surface area.

Advantages and limitations of vegetated swales are outlined in Table 3-11.

Table 3-11. Advantages and limitations of vegetated swales

Advantages	Limitations
• Combines limited stormwater treatment with runoff conveyance • Often less expensive than curb and gutter • Provides limited peak flow reduction • Can be installed in narrow, marginal spaces along roadways and parking lots to convey runoff to downstream BMPs	• Higher maintenance than curb and gutter • Impractical in areas with very flat grades or steep topography (can cause nuisance standing water and vector issues) • Not as effective for high flow volumes/velocities • Not effective for volume reduction

3.7.1.1 Hydrologic Functions

Vegetated swales are flow-based BMPs intended primarily for water quality treatment. Depending on site slope and soil conditions, swales provide minimal volume reduction. Vegetated swales are not intended to be a primary BMP for meeting stormwater volume and quality goals, although they can help reduce the peak flow rate by increasing the site's T_C and providing marginal volume reduction through infiltration.

3.7.1.2 Water Quality Performance

Vegetated swales can remove sediment and particulate-bound pollutants by sedimentation and filtration (Deletic and Fletcher 2006). Particle removal performance primarily depends on flow-rate, particle setting velocity, and flow length (Deletic and Fletcher 2006; Yu et al. 2001; Bäckström 2003; Bäckström 2006). In some cases, swales can export metals and pathogens (Bäckström 2003; USEPA 2012). The effectiveness of vegetated swales can be enhanced by adding check dams at approximately 50-foot increments along their length (depending on slope). The dams maximize the retention time in the swale, decrease flow velocities, and promote particulate settling. Incorporating vegetated filter strips parallel to the top of the channel banks can help to treat sheet flows entering the swale (Barrett et al. 1998).

3.7.1.3 Applications and Configurations

Appendix B.9 outlines major design components and site considerations and describes the process for designing vegetated swales. Although it might be difficult to use vegetated swales to receive stormwater runoff in urban areas because of space constraints, they can be used to receive stormwater on a wide variety of development sites in rural and suburban areas, including residential, commercial, industrial, and institutional development sites. Figure 3-27 shows a vegetated swale at James Madison High School

Agriscience in San Antonio. Vegetated swales also are well suited for use in the right-of-way of linear transportation corridors; Figure 3-28 shows a vegetated swale along a roadside.

James Madison High School Agriscience Building, San Antonio, Texas
Source: Bender Wells Clark Design

Figure 3-27. Vegetated swale in an institutional setting.

San Antonio, Texas Source: Tetra Tech

Figure 3-28. Roadside vegetated swale.

3.7.2 Vegetated Filter Strips

Vegetated filter strips are bands of dense, permanent vegetation with a uniform slope, designed to provide pretreatment of runoff generated from impervious areas before flowing into another BMP as part of a treatment train. Vegetated filter strips on highly permeable soils can also provide infiltration, improving volume reduction. Increased infiltration can decrease the necessary horizontal length. Such characteristics make it ideal to use vegetated filter strips as a BMP around roadside shoulders or safety zones.

Vegetated filter strips are implemented for improving stormwater quality and reducing runoff flow velocity. As water sheet flows across the vegetated filter strip, the vegetation filters out and settles the particulates and constituents, especially in the initial flow of stormwater. Removal efficiency often depends on the slope, length, gradient, and biophysical condition of the vegetation in the system. Advantages and limitations of filter strips are outlined in Table 3-12.

Table 3-12. Advantages and limitations of filter strips

Advantages	Limitations
• Good pretreatment BMP • Simple to install (often requiring only minimal earthwork and planting) • Simple, aesthetically pleasing landscaping • Low cost/maintenance	• Must be sited next to impervious surfaces • Might not be suitable for industrial sites or large drainage areas • May require large footprint for sufficient treatment • Requires sheet flow across vegetated area • Application in arid areas is limited because of the need for thick vegetation • Does not provide attenuation of peak flows

3.7.2.1 Hydrologic Functions

Filter strips are often used as pretreatment devices for other, larger-capacity BMPs such as bioretention areas and assist by filtering sediment and associated pollutants before they enter the larger-capacity BMP, preventing clogging and reducing the maintenance requirements for larger-capacity BMPs. Filter strips provide an attractive and inexpensive vegetative BMP that can be easily incorporated into the landscape design of a site. Filter strips are commonly used in the landscape designs of residential, commercial, industrial, institutional, and roadway applications. They must be adjacent to the impervious areas they are intended to treat. Vegetated filter strips are flow-based BMPs intended for achieving water quality treatment. Depending on site slope and soil conditions, they can provide some volume reduction and can increase a site's time of concentration (T_c). However, vegetated filter strips are not intended to act as a standalone, primary BMP for meeting volume-reduction objectives.

3.7.2.2 Water Quality Performance

Vegetated filter strips are well suited for treating runoff from roads, highways, driveways, roof downspouts, small parking lots, and other impervious surfaces. They can also be used along streams or open vegetated waterways to treat runoff from adjacent riparian areas. In such applications, they are commonly referred to as buffer strips. Because of their limited ability to provide peak attenuation and their ability to decrease sediment loads, vegetated filter strips are often used as a pretreatment for other BMPs such as bioretention or permeable pavement. They have not been widely accepted as primary BMPs because of the wide range of pollutant removal efficiencies (Schueler et al. 1992; Young et al. 1996).

Whereas some assimilation of dissolved constituents can occur, filter strips are generally more effective in trapping sediment and particulate-bound metals and nutrients (in the absence of erosion; Knight et al. 2013; Winston et al. 2011). Nutrients that bind to sediment include phosphorus and ammonium; soluble nutrients include nitrate. Biological and chemical processes could help break down pesticides, uptake metals, and use nutrients that are trapped in the filter. Vegetated filter strips also exhibit good removal of litter and other debris when the water depth flowing across the strip is below the vegetation height.

3.7.2.3 Applications and Configurations

Appendix B.10 outlines major design components and site considerations and describes the process for designing filter strips. Figure 3-29 and Figure 3-30 show vegetated filter strips between impervious areas and bioretention facilities. Figure 3-31 shows a filter strip next to a parking lot.

Apex, North Carolina Source: Tetra Tech

Figure 3-29. Vegetated filter strip that pretreats roadway runoff.

Raleigh, North Carolina Source: Tetra Tech

Figure 3-30. Vegetated filter strip surrounding a bioretention area in a parking lot.

San Antonio, Texas Source: Tetra Tech

Figure 3-31. Vegetated filter strip next to a parking lot.

3.8 BMP Selection Matrix

Table 3-13 is a tool to help select practices according to site characteristics and constraints when considering LID stormwater management practices. Existing or expected site characteristics can be used to determine individual practices or a suite of practices that might be appropriate in site design. Vegetated swales and filter strips are not included in the table because this manual considers these practices appropriate for pretreatment and not as standalone water quality BMPs. In addition, relative cost considerations can assist in specific BMP selection, particularly between two or more BMPs that achieve the project's goal. As such, the table lists dollar signs as qualitative costs for a relative comparison between types of BMPs rather than actual values. BMP costs can vary widely and overlap between BMP types depending on the complexity of the BMP configuration required. Costs should be used as a relative guide with emphasis on the water quality performance and the site conditions and configuration in selecting the BMP type.

Estimated costs in this table and in Appendix B cover all components of construction and operation and maintenance for various-sized projects but do not cover other conveyance needs that might be applicable. Cost estimates are based on the design standards recommended in Appendix B and can vary widely by the necessary configuration of the BMP and site constraints. These cost numbers are estimates and intended for planning purposes only. The project manager must refine these numbers throughout the phases of design to prepare a more accurate project construction estimate for bidding purposes. Cost estimates, particularly the maintenance costs, do not account for cost savings accompanied with integrated practices, such as incorporating BMP retrofits into CIP projects or integrating bioretention areas into landscaping where the routine maintenance could be included in the budget for typical landscape maintenance. The inclusion of various sizes of projects in the maintenance costs attempts to include those costs in which an economy of scale has been observed. The sizes selected for this analysis were as follows:

- Large BMP system = 4,000 ft^2
- Medium BMP system = 2,000 ft^2
- Small BMP system = 500 ft^2

These categories are based on typically sized BMPs and are intended to account for the varying degrees of economy of scale. Cost estimates for small BMPs could be used for the projects where the only maintenance required for the project will be for the BMPs. Estimates for the large systems could be used for projects where maintenance for landscaping as well as the BMPs will be accounted for providing an economy of scale. Fixed costs for maintenance, such as equipment, mobilization, and disposal, can be dispersed more effectively for larger more complex project resulting in a lower unit cost. As a BMP area represents a system, the area can include the application of multiple BMPs. Appendix G also provides more detailed information on costs, including actual cost numbers, that are based on the frequency and type of maintenance required, such as routine maintenance (costs associated with maintenance required monthly up to every 2 years), intermediate maintenance (costs associated with maintenance required every 6 to 10 years) and replacement maintenance (costs associated with replacement of the system; estimated as a service life of 20 years). Table 3-13 does not include the more detailed frequency costs.

Once individual or groups of BMPs have been selected using this matrix, consult Appendix B to develop detailed designs and Appendix G to develop a more detailed cost estimate.

Table 3-13. LID management practice selection matrix according to site characteristics

Attribute	Bioretention		Bioswale		Permeable pavement		Planter boxes	Green roofs	Sand filter		Rainwater harvesting	Stormwater wetlands
	Infiltrating	Lined	Infiltrating	Lined	Infiltrating	Lined			Infiltrating	Lined		
Edwards Aquifer Zone Allowed (see Section 2.2)	Artesian	All	Artesian	Artesian	Artesian, Contributing	All	All	All	Artesian	All	All	All
Typical contributing drainage area (acres)	< 5		< 2		0[a]		< 0.35	Rooftop	< 5		Rooftop	> 5
Min. elevation difference between inlet and outlet (ft)	3.5 (2.5 if using IWS)		3.5 (2.5 if using IWS)		1 to 2 (depends on design)		2.5	N/A	2.5 (2 if using IWS)		N/A	2
Separation of subgrade from bedrock and seasonal high water table (ft)	≥ 3		≥ 3		≥ 3		Above water table	N/A	≥ 3		Above water table and bedrock[b]	At or below permanent pool elevation
Practice slope	< 2%		< 2%		< 2%		N/A	N/A	< 6%	< 6%	< 5%	< 5%
Underdrain required?	If soil infiltration < 0.5 in/hr	Yes	If soil infiltration < 0.5 in/hr	Yes	If soil infiltration < 0.5 in/hr	Yes	Yes	N/A	If soil infiltration < 0.5 in/hr	Yes	N/A	N/A
Pollutant removal[e]: Sediments	High		High		High		High	Typically water quality is not improved by green roofs (although stormwater volume reduction can reduce total pollutant loads)	High		Pollutant removal provided by downstream BMP, refer to specific BMP for removal efficiency	High
Pollutant removal[e]: Nutrients	Medium		Medium		Low		Medium		Low			High
Pollutant removal[e]: Trash	High		High		High		High		High			High
Pollutant removal[e]: Metals	High		High		High		High		Low			High
Pollutant removal[e]: Bacteria	High		High		Medium		High		Medium			High
Pollutant removal[e]: Oil and grease	High		High		Medium		High		Medium			High
Pollutant removal[e]: Organics	High		High		Low		High		Medium			High
Runoff volume reduction	High	Low	High	Low	High	Low	Low	High	Low	Low	Varies based on cistern size and water demand	None
Peak flow control	Medium		Medium		Medium		Low	Medium	Medium	Medium		High
Setbacks (ft): Structures	> 10		> 10		> 10		N/A	N/A	> 10		> 5	> 10
Setbacks (ft): Steep slopes	> 50		> 50		> 50		> 50	N/A	> 50		> 50	> 50
Costs[c]: Construction	$–$$		$–$$		$$–$$$		$$	$$$	$–$$		$–$$	$
Costs[c]: O & M (small)	$$–$$$		$$–$$$		$$–$$$		$$	$–$$	$$–$$$		$$	$–$$
Costs[c]: O & M (med.)	$–$$[d]		$–$$		$$		$–$$	$–$$	$$		$–$$	$–$$
Costs[c]: O & M (large)	$–$$[d]		$–$$		$–$$		$–$$	$–$$	$–$$		$–$$	$–$$

a. Typically permeable pavements are designed to treat direct rainfall, but, if located outside the Edwards Aquifer Recharge, Contributing, or Transition Zones, a 1:1 drainage area to permeable pavement area ratio can be accommodated with adequate maintenance. b. For tank outlet and overflow. c. Costs are relative, can vary project to project, and are generalized; for more specific cost information, see Appendix G. d. Based on necessary regular landscape maintenance already required. e. Pollutant removal performance is based on facilities constructed per design specifications in Appendix B.

3.9 Maximizing Multiple Benefits of BMPs

The targets for treating stormwater runoff in the San Antonio River Basin can be expressed as either volume- or flow-based criteria. The volume-based requirement for an LID facility is to capture and treat the entire runoff volume from the volume-based design storm event. The flow-based requirement for a BMP facility is to treat the design runoff rate by applying the rainfall intensity-based water quality design storm. Methods for determining treatment volume and flow rates are provided in Appendix A for a range of design criteria.

LID BMPs can provide excellent ecosystem services and aesthetic value to stakeholders (see Section 1.7 for an expanded discussion of the multiple benefits of LID). Bioretention areas can also enhance biodiversity and beautifying the urban environment with native vegetation. Permeable pavements inherently provide multi-use benefits because the facilities double as parking lots and transportation corridors and rainwater harvesting allows for the provision of an alternative non-potable water source. The following components can be incorporated into BMPs to promote multi-use benefits:

- Simple signage or information kiosks to raising public awareness of stormwater issues and educate the public on the benefits of watershed protection measures or provide a guide for native plant and wildlife identification
- Volunteer groups can be organized to perform basic maintenance as an opportunity to raise public awareness
- Larger BMPs can be equipped with pedestrian cross-paths or benches for wildlife viewing
- Sculptures and other art can be installed within the BMP and outlet structures incorporating aesthetically-pleasing colors, murals, or facades
- Vegetation with canopy cover can provide shade, localized cooling (heat island mitigation), and noise dissipation
- Enhanced pavement textures, colors, and patterns and other “complete streets” components can calm traffic, increase aesthetic appeal, enhance pedestrian safety, and draw attention to multi-use stormwater practices
- Bird and butterfly feeders can be used to attract wildlife to the BMPs
- Ornamental plants can be cultivated along the perimeter and in the bed of vegetated BMPs (invasive plants should be avoided)
- BMPs can function as irrigation beds for stormwater captured by other BMPs, such as rainwater harvesting or the reservoir layer of permeable pavement
- Reuse of captured runoff offsetting non-potable water supplies used for toilet flushing, car washing, swimming pools, street sweeping, and other uses
- Permeable pavers can be selected to maintain the character of historic districts while providing stormwater management solutions
- Incorporating creative downspout designs for small practices (rain chains)

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