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LID achieves several important purposes for municipalities and developers. Restoring predevelopment hydrology and realizing associated water quality benefits are of primary importance, particularly with respect to stormwater pollution effects on aquatic life habitats. Degraded water quality will also negatively affect or restrict recreational opportunities by limiting contact with surface waters and reducing recreational fishing opportunities. Another factor to consider is that local drinking water supplies rely heavily on ground water recharge and can be impacted by poor surface water quality. For a list of the fee and credit offset benefits offered by the City of San Antonio for incorporating LID that manages the 1.18” or 1.5” storm events. See section 35-210 of The City’s Unified Development Code.

In addition to the visible, above-ground and accessible qualities of LID practices provide additional benefits when compared to traditional drainage infrastructure, including creating habitat for wildlife, improving air quality, improving aesthetics, offering recreational opportunities, and educating the public (CNT 2010). Because of its visible nature, LID offers enhanced public education opportunities, especially when signage is used to inform viewers of the features and functions of the various types of facilities.

Vegetated LID practices can provide air quality benefits, particularly those that incorporate trees. Trees absorb air pollutants, notably carbon dioxide (CO_2) but also nitrogen dioxide (NO_2), groundlevel ozone (O_3), sulfur dioxide (SO_2), and particulate matter that is 10 µm or smaller (PM-10). Green infrastructure’s ability to sequester carbon in vegetation can help to meet greenhouse gas emission goals by contributing to a carbon sink (CNT 2010).

Trees create shade that reduce indoor air temperatures and reduce the demand for energy for cooling. This yields direct cost savings to electricity consumers and, through reduced electricity demand, reduces air pollution emissions from electricity generation. Reduced emissions of air pollution benefits human health through lowered incidence and severity of respiratory ailments and reduces costs associated with air quality regulation compliance (ECONorthwest 2011).

Green infrastructure that includes trees and other vegetation can reduce the urban heat island effect, which is the phenomenon of urban area temperatures that are several degrees higher than surrounding rural land uses. The U.S. EPA (2012b) indicates that annual mean air temperature can be 1.8 °F to 5.4 °F higher in urban centers and up to 22 °F higher in the evening. Tree cover does not absorb heat like pavements do, and trees reduce temperatures through shading and evapotranspiration. Reducing urban heat islands through tree planting achieves energy reduction (reduced need for cooling, along with the ancillary benefits described above) and can reduce the incidence and severity of heat-related illnesses.

Green infrastructure that includes attractive vegetation can improve property aesthetics. This vegetation also provides habitat for urban wildlife, particularly birds and insects, even at small scales of implementation. Larger-scale facilities that include public access, such as constructed wetlands, offer recreational opportunities (e.g., fishing, bird-watching) as well as habitat for wildlife and water quality/quantity improvements.

Some evidence exists that residents’ health and well-being are improved by the presence of largerscale green space that offers recreational opportunities (Stratus Consulting 2009). Riparian area improvements that enhance stream stability can include recreational trails for walking, running, and biking. Also, creation of parks, green space, and plaza space into which green infrastructure can be integrated can create gathering spaces for local residents.

Green infrastructure can be used in concert with public safety measures to enhance walkability. Green streets that include curb bump-outs at pedestrian crossings improve pedestrian safety by slowing traffic and decreasing the distance that pedestrians must travel in the roadway.

The following components can be incorporated into BMPs to promote multiple benefits:

APPENDIX C:
Design for Multi-use Benefits

Bioretention & Bioswales

Bioretention can provide excellent ecosystem services and aesthetic value to stakeholders. In addition to enhancing biodiversity and beautifying the urban environment with native vegetation, the following components can be incorporated into bioretention to promote multi-use benefits:

- Use of native pollinator plants in bioretention areas provides multi-benefits for birds, bees, and other beneficial insects.
- Simple signage or information kiosks can educate the public on the benefits of watershed protection measures or provide a guide for native plant and wildlife identification.
- Bird and butterfly feeders can be used to attract wildlife to the bioretention area.
- Sculptures and other art can be installed in the bioretention area, and outlet structures can be painted lively colors.
- Bioretention along the roadway (bump-outs and curb extensions) can serve as a traffic calming features
- Ornamental plants can be cultivated along the perimeter and in the bed of bioretention areas (invasive plants should be avoided).
- Larger bioretention areas can be equipped with pedestrian cross-paths or benches for wildlife viewing (Figure C-1).
- Bioretention areas can function as irrigation beds for stormwater captured by other BMPs, such as rainwater harvesting or the reservoir layer of permeable pavement.
- Vegetation with canopy cover can provide shade, localized cooling, and noise dissipation.
- Volunteer groups can be organized to perform basic maintenance as an opportunity to raise public awareness.

Figure C-1. *Overflow from a rainwater cistern is discharged to a cobbled bioretention area at Mission Library, San Antonio, Texas. Source: Bender Wells Clark Design*

APPENDIX C: Design for Multi-use Benefits

Permeable Pavements

Permeable pavements inherently provide multi-use benefits because the facilities double as parking lots and transportation corridors. In addition to these benefits, permeable pavement can be enhanced by incorporating the following design elements:

- Enhanced pavement textures, colors, and patterns can calm traffic, increase aesthetic appeal, enhance pedestrian safety, and draw attention to multi-use stormwater practices.
- Stormwater reuse systems can be installed to harvest and use captured runoff for non-potable use (irrigation, ornamental water features, and such).
- Permeable pavers can be used to maintain the character of historic districts while providing stormwater management solutions.
- Educational kiosks and signage at permeable pavement areas raise public awareness of stormwater management issues.

Stormwater Bump-outs

- Can be used as traffic calming devices.
- Can reduce pedestrian travel distance.
- Use of native pollinator plants provides multi-benefits for birds, bees, and other beneficial insects.
- Can be used mid-block to incorporate shade trees.

Figure C-2. *Bioretention incorporated into a bump-out, Kansas City, Missouri. Source: Tetra Tech*

Street-side Tree Wells

- Can be used to provide shading and aesthetics along roadways, in medians, and in parking lots.

Planter Boxes

Planter boxes can fulfill similar multi-use benefits as bioretention areas, but they can be more adaptable to highly impervious, tightly confined urban landscapes.

Green Roofs

Green roofs can provide benefits to the urban environment in which they are placed. In various studies they have been shown to provide rooftop recreation and gardening opportunities, increase property values, reduce energy use, reduce heat island effect, increase roof lifespan, reduce air pollution, and enhance the health of adjacent property owners.

- Use of native pollinator plants in green roofs provides multi-benefits for birds, bees, and other beneficial insects.

Figure C-3. *Green roof that provides educational and recreational opportunities at James Madison High School Agriscience Building, San Antonio, Texas. Source: Bender Wells Clark Design*

APPENDIX C:
Design for Multi-use Benefits

Sand Filters

- Subsurface sand filters can provide multi-use benefits if they are installed below areas dedicated for parking.
- Multi-use benefits can be provided by surface sand filters by including educational signage.
- A substantial volume of stormwater can be stored to attenuate peak flows.

Stormwater Wetlands

Stormwater wetlands can provide excellent ecosystem services and aesthetic value to stakeholders. In addition to enhancing biodiversity and beautifying the urban environment with native vegetation, the following components can be incorporated into stormwater wetlands to promote multi-use benefits:

- Simple signage or information kiosks can educate the public on the benefits of watershed protection measures or provide a guide for native plant and wildlife identification.
- Boardwalks, wildlife viewing platforms, and benches can be provided to encourage interaction.
- Use of native pollinator plants in stormwater wetlands provides multi-benefits for birds, bees, and other beneficial insects.
- Volunteer groups can be organized to perform basic maintenance as an opportunity to raise public awareness.
- Wetlands can be used as outdoor classrooms for school science projects and field trips.

Extended Detention Basins

One of the primary benefits of the extended detention basin is the ability to provide combined water quality and flood control. Since some EDBs may not be considered as aesthetically pleasing as a stormwater wetland, additional features can be incorporated to generate additional uses for the extended basin. The following components can be incorporated into EDBs to promote multi-use benefits:

- Passive recreation, such as walking, biking, and wildlife observation, can be promoted by creating a multiple stage basin that will limit inundation of the passive recreation areas to one or two occurrences a year.
- Habitat for beneficial pollinators can be encouraged by creating diverse planting areas or incorporating wetlands into the EDB (note: it is important to consider potential pollutant loads from wildlife, such as indicator bacteria).
- Aesthetic appeal can be enhanced by creating flowing forms that appeared to be shaped by water, softening and varying slopes, shaping the basin bottom differently than the top, or using rocks for energy dissipation and adding them to other areas to avoid the actual energy dissipation from seeming out of place.

Cisterns

By design, rainwater harvesting practices offer multi-use benefits by providing an alternative non-potable water source while controlling runoff volume and rate. In addition to hydrologic and water quality benefits, cisterns and rain barrels can be designed for multi-use benefits by

- Providing irrigation for landscape beds and vegetated stormwater practices.
- Offsetting non-potable water supplies used for toilet flushing, car washing, swimming pools, street sweeping, and other uses (nonresidential cisterns only).
- Incorporating aesthetically pleasing colors, murals, or facades.
- Incorporating creative downspout designs for small practices (rain chains).
- Raising public awareness of stormwater issues with signage.

APPENDIX C: Design for Multi-use Benefits

Vegetated Swales

Vegetated swales can replace curb and gutter systems and storm sewers that can convey runoff. Swales require more space than curb and gutter systems but require less landscaping. Swales can double as landscaping features. Vegetated swales' use of vegetation versus hardened surfaces for conveyance can help reduce heat island impacts.

Vegetated Filter Strips

Look for areas where green space exists adjacent to roadways and sidewalks and convert the green space to vegetated filter strips.

- Can be incorporated into landscaping plans.
- Can serve as visual buffers.

Vegetated Stream Buffers

In addition to buffering streams against pollutants, reducing erosion, and reducing surface water temperatures, vegetated stream buffers can

- Enhance aquatic habitat,
- Provide wildlife habitat and travel corridors,
- Aid in groundwater recharge, and
- Aid in bank stability.

Note that human activities within constructed stream buffers should avoid soil compaction. See City of San Antonio Unified Development Code for incentives to preserve and restore riparian buffer function.

APPENDIX C: **Design for Multi-use Benefits**

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APPENDIX D: Additional Specifications

SECTION 33 41 44

Bioretention Infiltration Media

33 41 44.1 DESCRIPTION: *This item shall govern for the furnishing, placing and spreading of approved selected bioretention infiltration media, to the lines and grades, at locations shown on the plans or as directed by the Inspector and in conformity with these specifications.*

33 41 44.2 MATERIALS: Bioretention infiltration media (BIM) should achieve a long-term, in-place infiltration rate of a minimum of 1 inch per hour up to 6 inches per hour. BIM should also support plant growth while providing pollutant treatment. In order to achieve these two goals, the BIM should be a mixture of sand, fines, and organic material. BIM shall be free of roots, clods stones larger than 1-inch in the greatest dimension, pockets of coarse sand, noxious weeds, sticks, lumber, brush, and other litter. It shall not be infested with nematodes or undesirable disease-causing organisms such as insects and plant pathogens. BIM shall be friable and have sufficient structure in order to give good aeration to the soil. The following specifications should govern the bulk BIM. The following composition includes the measurements for determining the BIM by volume and weight:

BIM Composition	Sand	Fines	Maximum Organic Material
Volume	85%	10%	5%
Weight	90-92%	8-9%	0.5-1%

A. Sand: Sand should be thoroughly washed prior to delivery and free of wood, waste, and coatings such as clay, stone dust, carbonate, or any other deleterious material. All aggregate passing the No. 200 sieve size should be non-plastic. Sand for BIM should be analyzed by a qualified lab using #200, #100, #40, #30, #16, #8, #4, and 3/8-inch sieves (ASTM D422 or as approved by municipality) and meet the following gradation:

Sieve Size	Percent Passing (by weight)	
	Min.	Max.
3/8 inch	100	100
No. 4	90	100
No. 8	70	100
No. 16	40	95
No. 30	15	70
No. 40	5	55
No. 100	0	15
No. 200	0	5

Note: all sands complying with ASTM C33, Standard Specification for Concrete Aggregates for fine aggregate comply with the above gradation requirements.

B. Fines: Fines consist of a mixture of silt and clay. All fines must pass a #200 sieve.

C. Organic Material: Organic material is considered an additive to assist vegetation in initial establishment and contributes to sorption of pollutants but generally should be minimized (maximum 5 percent). Organic material can consist of aged bark fines, hardwood chips, leaf litter, or similar plant-derived organic material. Organic material should not consist of manure or animal compost.

33 41 44.3 ALTERNATIVE BIM COMPOSITION: : The composition of the BIM may be varied to accomplish a desired infiltration rate. The BIM composition specified in section 33 41 44.2 is anticipated to achieve an infiltration rate of 1 to 2 inches per hour.

A. The following composition is expected to yield an infiltration rate of approximately 1 inch per hour:

BIM Composition	Sand	Fines	Organic
Volume	83%	12%	5%
Weight	88-90%	9-11%	0.5-1%

B. The following composition is expected to yield an infiltration rate of approximately 2 inches per hour:

BIM Composition	Sand	Fines	Organic
Volume	87%	8%	5%

Weight	92-93%	6-7%	0.5-1%

C. The following composition is expected to yield an infiltration rate of approximately 4 inches per hour:

BIM Composition	Sand	Fines	Organic
Volume	90%	5%	5%
Weight	94-96%	4-5%	0.5-1%

D. The following composition is expected to yield an infiltration rate of approximately 6 inches per hour:

BIM Composition	Sand	Fines	Organic
Volume	92%	3%	5%
Weight	96-97%	2-3%	0.5-1%

33 41 44.4 SUBMITTALS: Product Data: Submit manufacturer's product data and installation instructions. Include required substrate preparation, list of materials, application rate/testing, and permeability rates.

A. Verifications: Manufacturer shall submit a letter of verification that the products meet or exceed all physical property, endurance, performance and packaging requirements.

Tests should be conducted no more than 120 days prior to the delivery date of the BIM to the project site. Batch-specific test results and certification will be required for projects installing more than 100 cubic yards of BIM.

The applicant should submit the following to the municipality for approval if requested:

1. A sample of mixed BIM.
2. Grain size analysis results of the sand component performed in accordance with American Society for Testing and Materials (ASTM) D422, Standard Test Method for Particle Size Analysis of Soils.
3. Grain size analysis results of sandy loam soil component performed in accordance with ASTM D422., Standard Test Method for Particle Size Analysis of Soils.

4. Grain size analysis results of compost component performed in accordance with ASTM D422, Standard Test Method for Particle Size Analysis of Soils.

5. Organic matter content test results of compost. Organic matter content tests should be performed in accordance with ASTM F 1647, Standard Test Methods for Organic Matter Content of Athletic Field Rootzone Mixes or Testing Methods for the Examination of Compost and Composting (TMECC) 05.07A, Loss-On-Ignition Organic Matter Method.

6. A description of the equipment and methods used to mix the sand, sandy loam, and compost to produce BIM.

7. Constant head permeability results of the mixed BIM. Constant head permeability testing in accordance with ASTM D2434, Standard Test Method for Permeability of Granular Soils (Constant Head) should be conducted on a minimum of two samples with a 6-inch mold and vacuum saturation.

8. Provide the following information about the testing laboratory(ies) including:

   a. Name of laboratory(ies)

   b. Contact person(s)

   c. Address(es)

   d. Phone contact(s)

   e. Email address(es)

   f. Qualifications of laboratory(ies), including use of ASTM and U.S. Department of Agriculture (USDA) method of standards

B. BIM Quality Testing: The final BIM should meet the following standards. Testing results from the following specifications shall be submitted for approval prior to BIM acceptance.

Parameter	Method	Requirement	Units
Organic Matter Content	ASTM F 1647 Standard Test Methods for Organic Matter Content of Athletic Field Rootzone Mixes or Testing Methods for the Examination of Compost and Composting (TMECC) 05.07A, “Loss-On-Ignition Organic Matter Method.”	0.3-0.6%	dry weight
pH	Saturation Paste	6.0–8.0	-
Carbon:Nitrogen Ratio	-	10:1–20:1	-
Cation Exchange Capacity (CEC)	-	≥ 5	meq/100 g of dry soil
Salinity (Electrical Conductivity)	Saturation Extract	0.5–3	dS/m
Boron	Saturation Extract	< 2.5	ppm
Chloride	Saturation Extract	< 150	ppm
Sodium Adsorption Rate (SAR)	-	< 3	-
Metals			
Arsenic	-	< 2	mg/kg dry weight
Cadmium		< 1	
Chromium		< 60	
Copper		< 75	
Lead		< 15	
Mercury		< 8	
Nickel		< 21	
Selenium		< 2	
Zinc		< 140	
Extractable Nutrients			
Phosphorus	Ammonium Bicarbonate/DPTA extraction method	< 15	mg/kg dry weight
Potassium		100–200	
Iron		24–35	
Manganese		0.6–6.0	
Zinc		1.0–8.0	
Copper		0.3–5.0	
Magnesium		50–150	
Sodium		0–100	
Sulfur		25–500	

Parameter	Method	Requirement	Units
Molybdenum		0.1–2.0	
Aluminum		< 3.0	
Pathogens			
Salmonella		0	MPN per 4 g
Fecal Coliform		0	MPN per 1 g
Inert Material/Physical Contaminants			
Plastic, Metal, and Glass		< 0.5%	by weight
Sharps (% > 4mm)		0%	by weight

33 41 44.5 EQUIPMENT: Provide the machinery, tools and equipment necessary for proper prosecution of the work. All machinery, tools and equipment used shall be maintained in a satisfactory and workman like manner. Compaction equipment such as vibratory compactors should not be used.

33 41 44.6 CONSTRUCTION: These guidelines should be followed to ensure proper BIM mixing and placement:

A. Erosion and sediment control practices during construction should be employed to protect the long-term functionality of the bioretention. The following practices shall be followed for this reason:

1. Provide erosion control in the contributing drainage areas to the facility and stabilize upslope areas.

2. Facilities should not be used as sediment control facilities, unless installation of all bioretention-related materials are withheld towards the end of construction, allowing the temporary use of the location as a sediment control facility, and appropriate excavation of sediment is provided prior to installation of bioretention materials.

B. Do not excavate, place soils, or amend soils during wet or saturated conditions.

C. Operate equipment adjacent to the facility. Equipment operation within the facility should be avoided to prevent soil compaction. If machinery must operate in the facility, use lightweight, low ground-contact pressure equipment.

D. If constructing an infiltrating facility, the subgrade should be ripped or scarified to a minimum depth of 9 inches on 3-foot centers to promote greater infiltration.

E. Consider the time of year and site working area when determining whether to mix BIM on-site or to import pre-mixed soil. It is recommended that the BIM should be mixed prior to being delivered to the site, and mixing is not allowed on-site during rain events. If BIM mixing occurs on-site, use an adjacent impervious area or mix BIM on plastic sheeting. (Mixing should not occur within the bioretention basin.) Protect mix stored on site from contamination.

F. Place soil in 6- to 12-inch lifts with machinery adjacent to the facility (to ensure equipment is not driven across soil). If working within the facility, to avoid over-compacting, place first lifts at far end from entrance and place backwards towards entrance.

G. Allow BIM lifts to settle naturally; lightly water to provide settlement and natural compaction between lifts. After lightly watering, allow soil to dry between lifts. Soil cannot be worked when saturated, so this method should be used with caution to ensure dry conditions. After all lifts are placed, wait at least two days to check for settlement, and add additional media as needed. No mechanical compaction is allowed.

H. The hydraulic conductivity rate immediately after installation should not be less than 2 inches per hour when tested with a double ring infiltrometer (in accordance with ASTM D3385, Standard Test Method for Infiltration Rate of Soils in Field Using Double Ring Infiltrometer), a single ring infiltrometer, a Modified Philip -Dunne Infiltrometer, or other approved methods.

I. Vehicular traffic and construction equipment shall not drive on, move onto, or disturb the BIM once placed and water-compacted.

J. Rake bioretention soil as needed to level out. Verify BIM elevations before applying mulch or installing plants.

K. Other Considerations:

1. Protect adjacent infiltration systems including swales, soils, and porous pavement from sediment.

2. Protect adjacent trees.

33 41 44.7 MEASUREMENT: Measurement of "Bioretention Infiltration Media" shall be made by the cubic yard in place and only for those areas designated on the plans, or to areas as directed by the Engineer.

33 41 44.8 PAYMENT: Bioretention infiltration media measured as specified above will be paid for at the contract unit price bid per cubic yard, which price shall be full compensation for all hauling, placing material, sprinkling the material with water, and for all labor, tools and incidentals necessary to complete the work.

33 41 44.9 BID ITEM:

Item 33 41 44.1 – Bioretention Infiltration Media – per cubic yard

SECTION 33 46 81

Impervious Liner

33 46 81.1 **DESCRIPTION:** *This section applies to all bioretention areas receiving a plastic or clay liner, unless otherwise indicated previously in the specification for that particular BMP, to provide an impermeable barrier to prevent infiltration into the subgrade. This section also includes materials and work necessary to provide a seal at each associated penetration of the liner.*

33 46 81.2 **MATERIALS:**

A. Flexible Plastic Liner. PVC liners, or approved equivalent, used for the lining of BMP areas shall meet the requirements of ASTM D-7176, Standard Specification for PVC geomembranes used in buried applications and shall conform to the requirements in Table 33 46 81.2(A).

The PVC liner should resist ultraviolet light and shall be sufficiently flexible to cover and closely conform to 90 degree edges and corners of the filter bed excavation at ambient temperatures as low as 45 degrees Fahrenheit without application of heat.

A suitable geotextile fabric shall be placed both above and below the impermeable membrane for puncture protection. The geotextile fabric (for protection of geomembrane) should be nonwoven geotextile fabric and meet the requirements in Table 33 46 81.2(B).

Table 31 46 81 2 (A)

Property	Test	Unit	PVC 30
Thickness	ASTM D-5199	in	.030" +/-
Grab Tensile Strength	ASTM D-882	kN/m (lb/in)	12.8 (73)
Tensile Elongation	ASTM D-882	%	380
Tensile Modulus	ASTM D-882	kN/m (lb/in)	5.6 (32)
Tear Strength	ASTM D-1004	N (lb)	35 (8)
Dimensional Stability	ASTM D-1204	%	3.0
Low Temp. Impact	ASTM D-1790	C	-29
Index Properties			
Specific Gravity	ASTM D-792	g/cc	1.2
Water Extraction % Loss (Max.)	ASTM D-1239	%	0.15
Avg. Plasticizer Molecular Weight	ASTM D-2124	—	400
Volatile Loss	ASTM D-1203	%	0.7
Soil Burial Break Strength	G160	%	5.0
Soil Burial Elongation	G160	%	20
Soil Burial Modulus at 100%	G160	%	20
Hydrostatic Resistance	ASTM D-751	kPa (psi)	690 (100)
Seam Strengths			
Shear Strength	ASTM D-882	kN/m (lb/in)	10 (58.4)
Peel Strength	ASTM D-882	kN/m (lb/in)	2.6 (15)

Table 33 46 81.2 (B)

Property	Test	Unit	Cushion Fabric
Weight – Typical	ASTM D-5261	g/sm (oz/sy)	271 (8)
Tensile Strength	ASTM D-4632	N (lbs)	912 (205)
Elongation @ Break	ASTM D-4632	%	50 (50)
Mullen Burst	ASTM D-3786	kPa (psi)	2413 (350)
Puncture Strength	ASTM D-4833	N (lbs)	579 (130)
CBR Puncture	ASTM D-6241	N (lbs)	2381 (535)
Trapezoidal Tear	ASTM D-4533	N (lbs)	378 (85)
Apparent Opening Size	ASTM D-4751	mm(US Sieve)	0.180 (80)
Permittivity	ASTM D-4491	Sec^{-1}	1.35
Water Flow Rate	ASTM D-4491	l/min/sm (g/min/sf)	3.657 (90)
UV Resistance @ 500 Hrs	ASTM D-4355	%	70

B. Geosynthetic Clay Liners. A geosynthetic clay liner (GCL) is a woven fabric-like material, primarily used for the lining of BMPs. Geosynthetic clay liners shall conform to the requirements in Table 33 46 81.2(C).

Table 33 46 81.2 (C) Geosynthetic Clay Liner Specifications

Property	Test Method	Unit	GCL Specification
Bentonite Mass per unit Area (min)	ASTM D-5890	g/m2	3,700
Swell index (min)	ASTM D-5891	ml/2g	24
Fluid loss (max)	ASTM D-5890	ml	18
Peel Strength (min)	ASTM D-6496	N/m	360
Index Flux (max)	ASTM D-5887	$(m^3/m^2)/s$	1×10^{-8}
Permeability (max)	ASTM D-5887	m/sec	1×10^{-8}
Tensile Strength (min)	ASTM D-6768	kN/m	4.0
Total Mass per unit Area (min)	ASTM D-5993	g/m^2	4,000

C. Compacted Clay Liner. Where plans specifically call for a compacted clay liner (CCL), the liner shall have a minimum thickness of 12 inches and conform to the requirements in Table 33 46 81.2(D).

Table 33 46 81.2 (D) Clay Liner Specifications (COA, 2004)

Property	Test Method	Unit	Specification
Permeability	ASTM D-2434	cm/sec	1×10^{-6}
Plasticity Index of Clay	ASTM D-423 & D-424	%	Not less than 15
Liquid Limit of Clay	ASTM D-2216	%	Not less than 30
Clay Particles Passing	ASTM D-422	%	Not less than 30
Clay Compaction	ASTM D-2216	%	95% of Standard Proctor Density

33 46 81.3 **EQUIPMENT:** Provide the machinery, tools and equipment necessary for proper prosecution of the work. All machinery, tools and equipment used shall be maintained in a satisfactory and workmanlike manner.

A. Field-Welded Joints. Field weld all joints for Flexible Plastic Liners in accordance with the manufacturer's recommendations. Adhesive, chemical fusion and thermal fusion welding are all acceptable. Adhesives shall be in accordance with the manufacturer's recommendations.

B. Hose Clamps. All hose clamps shall be one piece 300 series stainless steel with worm gear. The hose clamps shall be suited for water environments. Alternative clamps may be submitted to the Engineer for approval.

33 46 81.4 **CONSTRUCTION:**

A. General. Impervious Bioretention Liners that are placed within BMP areas shall be placed in accordance with the following provisions:

B. Pre-Installation Examination and Preparation. Prior to beginning work, the Contractor shall examine previous work, related work, and conditions under which this work is to be performed. This includes:

- Verifying the subgrade is at correct depths, lines, grade, and dimensions for installing the liner.

- Ensure that overly wet conditions do not exist or are anticipated to occur during installation, as they will contaminate the liner. Prior to placement, the trench must have no standing water, mud, debris or excessive moisture. No liner shall be placed on a subgrade that has become softened by water or overly dried until the subgrade has been properly reconditioned, restored and reinspected.

- Clearing of any construction debris present within the placement area which may damage the liner; work is to be sequenced to avoid construction traffic on the exposed liner at any time.

C. Flexible Plastic Liner

a. Placement. Liner shall be fit to the dimensions, cut and placed in the trench in accordance with the Plans. Trench sides and bottom shall be excavated to provide a stable, smooth surface, free of obstructions and debris.

The fabric cushions and liner shall be installed on the bottom and the side of the trench and/or on top of the permeable aggregate base and to the elevations in accordance with the plan details. To prevent lateral flow, the hydraulic restriction layer shall extend the full depth of the media to the base of the drainage layer in situations where underdrains are required. In situations where underdrains are not required, the vertical hydraulic restriction layer shall extend to a depth where saturation will not affect any adjacent load -bearing soils, as determined by a geotechnical engineer or the engineer of record. At locations where liners are not required in the vertical surfaces of the trench, the liners in the horizontal placements shall be extended and turned up minimum six inches on the vertical surfaces to provide tight layer separation.

Voids between liner and excavation sides must be prevented during construction. Removing boulders or other obstacles from the trench walls may create such voids. Natural soils should be placed in these voids during the construction to ensure liner completely and uniformly conform to the sides of the excavation.

During construction, waterproofing membrane shall be held in place by backfilling or other means without puncturing the materials. Other methods of pinning can also be used as allowed by the Engin eer.

No traffic or other equipment shall be allowed directly on the liners.

The liners shall have minimum longitudinal and vertical overlaps. unless specified otherwise, when overlaps are required between rolls, the upstream roll shall overlap the downstream roll in order to provide a shingled effect. If chemical seams are used then the panels shall overlap by 6" to 8" with a 4" wide seam. If thermal seams are used then the single track weld shall overlap 4" to 6" with a minimum 2" wide welded seam. All seams shall be made in accordance with the manufacturer's recommendation. If at all possible, seams shall not be located at low points in the subgrade unless the geometry requires seaming to be done at these locations. Field seams shall be inspected and, when ordered by the Engineer, shall be tested and pass the Vacuum Box Test.

Before covering with backfill material, the conditions of the liner including all factory seams shall be observed by the inspectors to determine that there are no holes or rips that exist in the liner and all piping or conduit penetrations are properly sealed and welded. Damaged liner material shall be repaired at Contractor's expense by placing new material that meets overlap requirements over the damaged area.

b. Pipe Penetrations and Pipe Sealant. Provide pipe penetration and Joint Sealant sealing system as shown on the Plans for all utilities and underdrain penetrations through the liner. Penetrations shall be sealed using the same plastic liner or PVC geomembrane material, flat stock and accessories as shown on the Plans and specified hereon. The field fabricated assembly shall be field welded to the main liner as shown on the Plans so as to prevent leakage. These field welds shall be in accordance with the manufacturer's recommendations. All sealed areas shall be Air Lance tested using ASTM D-4437 and verified to be leak free. Adhesive and stainless steel hose clamps shall be included as indicated on Plans.

D. Geosynthetic Clay Liners

a. Placement. Geosynthetic Clay Liners shall be installed in accordance with manufacturer recommendations.

E. Compacted Clay Liners

a. Placement. The first layer shall be placed and spread to a loose thickness that can be effectively compacted to the specified density by the available equipment. In no case shall the loose layer thickness exceed 9 inches. The moisture content of the loose soil layer shall be adjusted to the specified content.

b. Compaction. Each compacted lift shall be uniformly dense and relatively free of large depressions or dimples. Where a smooth wheel roller or other non-penetrating compaction equipment is used, the surface of each layer shall be lightly disked to achieve bonding with the subsequent overlying layer.

F. Infill. The liner shall be covered as soon as possible after being inspected, but not later than 7 calendar days after placement. Material left uncovered for more than 7 calendar days shall be inspected. If it fails inspection, it must be removed and replaced. If it passes inspection, material shall be covered as soon as possible and no later than 7 additional days. Material left uncovered for up to 14 days shall again be inspected. If it fails, it must be removed and rejected. Materials remaining uncovered after 14 days must be removed and replaced.

a. Flexible Plastic Liners. All liners shall have minimum 6 inches top soil and/or mulch covers and they shall not be exposed to any sunlight.

After placement of granular fill and bioretention soil, edges of the liner protruding at the top of the trench shall, if applicable, be anchored to concrete curb or sidewalk per plans. Excess material shall be trimmed neatly such that it is not exposed. Excess liner should not be trimmed until the site is fully stabilized.

33 46 81.5 **MEASUREMENT:** Plastic liner shall be measured for payment by the square yard of fabric placed, not including any material for overlaps and splices. Installed plastic liner shall also include cushion fabric below and above the plastic liner. Pipe penetrations and Joint Sealant shall be measured as part of the installed liner.

Geosynthetic clay liner shall be measured for payment by the square yard of material placed, not including any material for overlaps. Installed geosynthetic clay liners shall also include cushion fabric below and above the clay liner. Pipe penetrations shall be measured as part of the installed liner.

Compacted clay liners shall be measured for payment by the square yard method per thickness shown in the plans and specifications.

Measurement by the square yard is a plans quantity measurement. The quantity to be paid for is the quantity shown in the proposal unless modified by the Engineer. Additional measurements or calculations will be made if adjustments of quantities are required.

Measurement is further defined for payment by the square yard of surface area in the completed and accepted final position. The surface area of the impermeable liner is based on the width of the liner as shown on the plans.

33 46 81.6 **PAYMENT:** The payment shall include full compensation for furnishing all labor, materials, tools, equipment, testing, transportation, as well as all seams, overlaps, staking, embedment, protection measures and incidentals for doing all of the work, complete in place, as specified on the drawings, these Specifications and as directed by the Engineer.

33 46 81.7 **BID ITEM:**

Item 31 46 81.1 – Impervious Bioretention Liner (PVC) – per square yard

Item 31 46 81.1 – Impervious Bioretention Liner (GCL) – per square yard

Item 31 46 81.1 – Impervious Bioretention Liner (CCL) – per square yard

SECTION 33 46 76

Level Spreader

33 46 76.1 DESCRIPTION: *This Item shall govern the construction of level spreaders on the areas designated on the plans, to the lines and grades specified, or as directed by the Engineer.*

33 46 76.2 MATERIALS: Furnish materials that meet the requirements of the Engineer's plans and specifications.

Provide all materials necessary for the installation of a Level Spreader. Provide materials that comply with the details shown on the plans .

33 46 76.3 EQUIPMENT: Provide the machinery, tools and equipment necessary for proper execution of the work. All machinery, tools and equipment used shall be maintained in a satisfactory and workmanlike manner.

33 46 76.4 CONSTRUCTION: Prevent damage to existing pavement, vegetation, slopes, utilities, structures, and other amenities.

A. **Constructed Trench:** Contractor to excavate trench to the dimensions specified by designer. Contractor to ensure a 1-2" elevation drop from edge of pavement to top of level spreader gravel surface.
B. **Stone:** Contractor to utilize uniformly graded, clean-washed coarse aggregate (ASTM #57 Stone) in constructed trench for level spreader.
C. **Non-woven Geotextile Fabric:** Contractor to utilize non-woven geotextile fabric to line the sides and bottom of constructed trench for level spreader prior to filling with washed stone.

33 46 76.5 MAINTENANCE: Inspect the level spreader at regular intervals to ensure proper functioning.

Level spreaders require at least yearly maintenance to remove trees and shrubs that begin to grow on the level spreader or that impede flow just downslope of the level spreader. Any debris and sediment that build up in the level spreader should be removed annually and after storms greater than or equal to a 2-year storm. If possible, the vegetation immediately downslope of the level spreader lip should be mowed regularly to encourage low, dense growth and to facilitate inspection. The use of perennial, dense, low-growing ground covers downslope of the lip may help to maintain diffuse flow. These issues should be addressed immediately to restore proper function. If erosion is apparent, corrective action must be taken, such as installing erosion control matting and possibly regrading.

33 46 76.6 MEASUREMENT: Measurement of acceptable Level Spreader, complete in place, will be for linear footage of level spreader.

Measurement by the linear foot is a plans quantity measurement. The quantity to be paid for is the quantity shown in the proposal unless modified by the Engineer. Additional measurements or calculations will be made if adjustments of quantities are required.

33 46 76.7 PAYMENT: Level Spreader, measured as provided above, will be paid for at the contract unit price bid per LF of level spreader, which price shall be full compensation for furnishing, hauling and placing all materials, and for all labor, tools, equipment and incidentals necessary to complete the work.

33 46 76.8 BID ITEM:

Item 33 46 76.1– Level Spreader – per linear foot

SECTION 33 41 16.20

Structural Underdrain

33 41 16.20.1 DESCRIPTION: *This Item shall govern the furnishing and installation of all structural underdrains and associated work, including the installation of any structural underdrain cleanouts.*

33 41 16.20.2 MATERIALS:

A. Underdrain/Storage System: Structural Underdrain / storage components shall meet or exceed the following characteristics:

Property	Value
Surface Void Area	>=85%
Unit Weight	3.25 lbs/cf
Service Temperature	-14° to 167°
Unconfined Crush Strength	32.48 psi
180 Day Creep Test	
Load Applied – Initial and Sustained	11.16 psi
Creep Sustained – After 180 Days	0.20 inches
Creep Sustained – After 180 Days	1.13%
Projected Creep – 40 Years	1.72%

33 41 16.20.3 EQUIPMENT: Provide the machinery, tools and equipment necessary for proper prosecution of the work. All machinery, tools and equipment used shall be maintained in a satisfactory and workmanlike manner.

33 41 16.20.4 CONSTRUCTION: Prevent damage to vegetation, slopes, utilities, structures, and other amenities.

A. Modular structural underdrain/storage to be shipped flat and modules are to be assembled on-site prior to installation.

B. Contractor to reference underdrain manufacturer's specifications for connection to adjacent storm drain.

33 41 16.20.5 MEASUREMENT: Measurement of acceptable Structural Underdrain, complete in place, will be for each plant.

33 41 16.20.6 PAYMENT: "Structural Underdrain," measured as provided above, will be paid for at the contract unit price per fully installed structural underdrain, which price shall be full compensation for furnishing, hauling and placing all materials and for all labor, tools, equipment and incidentals necessary to complete the work.

33 41 16.20.7 BID ITEM:

Item 33 41 16.20.1 – Structural Underdrain – per each

SECTION 31 23 13.1

Subgrade Preparation (Infiltrating Soil)

31 23 13.11 DESCRIPTION: *Prepare the subgrade by scarifying, cultivating and compacting to the required density. This item applies to infiltrating soil subgrade and shall be constructed as specified herein and in conformance with the typical sections, lines and grades as shown on the plans or as established by the Engineer.*

31 23 13.12 MATERIALS: Furnish materials that meet the requirements of the Engineer's plans and specifications.

Provide all materials necessary for preparation of subgrade for infiltrating soils. Provide materials that comply with the details shown on the plans, and the requirements of this Item along with the following Item(s):

31 23 13.13 CONSTRUCTION:

A. **General:** The completed subgrade shall be uniform, free from loose or segregated areas, of uniform density and moisture content, well bound for its full depth and shall have a smooth surface.

B. **Preparation of Subgrade:** Scarifying and cultivating will be required for dry soils which are impervious to the penetration of water, for soils which contain excessive amounts of moisture which may result in unstable foundations, for soils which are nonuniform in character which may result in nonuniform relative compactions and subsequent differential settlements of finished surfaces, or when pavement is to be placed directly on the subgrade material. After rough grading has been completed, when scarifying and cultivating are required, the BMP soils shall be loosened to a depth of at least 6 inches. The loosened material shall then be worked to a finely divided condition and all rocks larger than 3 inches in diameter shall be removed. The moisture content shall be brought to minus 1 of optimum or wetter by the addition of water, by the addition and blending of dry suitable material, or by drying of existing material. The material shall then be compacted by approved equipment to the specified relative compaction and as follows:
   - The existing native subgrade material under all permeable pavement installations shall be minimally compacted and not subject to excessive construction equipment traffic prior to stone reservoir placement.
   - Compaction is acceptable if an impermeable liner is used over the subgrade.
   - If constructing an infiltrating facility, the subgrade should be ripped or scarified to a minimum depth of 9 inches on 3-foot centers to promote greater infiltration.

Uniform pervious soils that allow the immediate penetration of water or uniform impervious soils which will allow the penetration of water to a depth of at least 6 inches after the addition of a suitable wetting agent, will not require scarifying and cultivating unless a condition previously set forth in this specification requires such processing. When scarifying and cultivating are not required, the moisture content of the top 6 inches of the subgrade material shall be brought to optimum by the addition of water at the surface, and the material shall be compacted by approved equipment to the specified relative compaction.

C. **Subgrade Tolerances:** Subgrade for pavement, sidewalk, curb and gutter, driveways, or other roadway structures shall not vary more than ¼ inch from the specified grade and cross section. Subgrade for subbase or base material shall not vary more than ½ inch from the specified grade and cross section.

31 23 13.14 **MEASUREMENT:** Subgrade preparation (infiltrating soil) will be measured by the cubic yard of volume specified by the Engineer.

31 23 13.15 **PAYMENT:** The work performed and materials furnished in accordance with this Item and measured as provided under Measurement will be paid for at the unit price bid for the below bid items. This price shall be full compensation for all equipment described under this item and all associated items listed below.

31 23 13.16 **BID ITEM:**

31 23 13.1 – Subgrade Preparation (Infiltrating Soil) – per cubic yard

SECTION 32 93 44

Vegetation

32 93 44.1 DESCRIPTION: *This item shall govern for the furnishing and planting of vegetation on the areas designated on the plans or as directed by the Engineer or Landscape Architect. All planting shall be completed as soon as practical to avoid erosion of soil media and graded areas in advance of acceptance of the work.*

32 93 44.2 MATERIALS: For bioretention areas and bioswales to function properly as stormwater treatment and blend into the landscape, vegetation selection is crucial. Appropriate vegetation shall consist of live, growing plants secured from sources where the soil is fertile. All vegetation shall have a healthy, virile root system of dense, thickly matted roots throughout the soil. The Contractor shall not use vegetation that is thinned or has been dried out by exposure to air and sun to such an extent as to damage its ability to grow when transplanted. The vegetation shall be free from noxious weeds or other matter deleterious to its growth or which might affect its subsistence or hardiness when transplanted. Sources from which vegetation is to be obtained shall be subject to approval by the Engineer.

A. Bioretention Vegetation. Native plant species or hardy cultivars that are not invasive and do not require chemical inputs are recommended to be used to the maximum extent practicable. Only native non-invasive species will be selected in areas designated as natural open space. Plant materials must be tolerant of summer drought and extreme heat, ponding fluctuations, and saturated soil conditions for 12 hours (10 hours for bioswales) to 48 hours. Vegetation with deep and extensive root systems are more tolerant of extreme hydroperiods and can effectively transpire large volumes of soil water. It is recommended that a minimum of three tree, three shrub, and three herbaceous groundcover species be incorporated to protect against facility failure from disease and insect infestations of a single species. A list of appropriate native plants is included as an Appendix E.

1. Trees. Trees shall be of the specified height and crown to the last division of the terminal leader and diameter. The height shall be measured from the root crown. The diameter shall be measured 6 inches above the root crown. Shade trees should be free of branches for the bottom 1/3 of their total height and lines of sight must be

maintained when planting along along roadways and driving lanes within parking areas. Tree height and placement should consider overhead utilities.

2. Shrubs. Shrubs shall be of the specified type and size.

3. Herbaceous Groundcover. Groundcover shall be of the specified type and size. The plants shall be grown and remain in the flats until transplanted at the work site. If turfgrass is preferred, sod should be specified that was not grown in clay soils (or washed bare root sod should be specified).

B. Rejection of Plants. Plants with any of the following characteristics are subject to rejection:

- Disease or insect infestation, including eggs and larvae;
- Dried or damaged root system or crown;
- Excessive abrasion of the bark;
- Prematurely opened or damaged buds;
- Disfiguring knots;
- Evidence of heat, freeze, or wind burn, mold, sun scald, or similar conditions;
- Damaged, pruned, crooked, or multiple leaders, unless multiple leaders are specified or are normal for the species;
- Cut limbs over ¾ inches in diameter that have not completely callused;
- Dry, soggy, loose, cracked, broken, misshapen, or undersized root balls;
- Processed balled roots (bench balled);
- Root balls encased in impervious material;
- Overgrown or root-bound plants;
- Undersized or unsound containers;
- Stock not well established in containers;
- Containers with less than ¾ planting medium depth;
- An abnormal balance between height and spread for the species;
- Missing or broken serialized locking tags, when specified
- Any conditions that do not conform to the plans or nursery stock standards; or

- Conditions that would prevent thriving growth or cause an unacceptable appearance.

32 93 44.3 EQUIPMENT: Provide the machinery, tools and equipment necessary for proper prosecution of the work. All machinery, tools and equipment used shall be maintained in a satisfactory and workmanlike manner.

32 93 44.4 CONSTRUCTION: Prevent damage to vegetation, slopes, utilities, structures, and other amenities.

A. Plant Approval Before Delivery. Plants are subject to inspection at the nursery or location of collection. Provide and use serialized locking tags on plants selected by the Engineer as directed.

B. Plant Delivery. Notify the Engineer or Landscape Architect at least 48 hours before delivering plants to the worksite. Coordinate with the Engineer or Landscape Architect for inspection and approval of materials upon delivery. Remove rejected plants from the worksite and replace as directed.

C. Plant Inspection. All plants will be inspected prior to planting, including plants previously approved at the nursery.

D. Mark Plant Locations and Bed Outlines. Provide and install coded markings, such as wooden stakes, to mark the locations, type of plants, and the outline of planting beds. Obtain approval of the plant and bed locations before excavation begins.

Planting deep-rooting vegetation directly above buried underdrains should be avoided (although interference of plant roots with underdrains is not a common maintenance issue). For bioswales, slotted or perforated underdrain pipe must be more than 5 feet from tree locations (if space allows).

E. Plant Pit Excavation. Excavate pits for container, balled and burlapped (B&B), and fabric bag grown sock to the depth shown on the plans or at least the depth of the root ball. Excavate pits for bare root plants equal to the depth of the root system. Excavate pits on slopes using measurements shown on the plans or at least the depth of the root ball based on the uphill side of the pit. Excavate the receiving pits for mechanically transplanted plants with the same type and size equipment used to dig the plants.

Provide a minimum horizontal dimension of 12 inches between the root ball and pit walls for the following, unless otherwise shown on the plans:

- 15-gallon or larger pots,
- 14-inch or larger boxes, and
- Larger than 14-inch root balls of B&B and fabric bag grown plants.

Provide a minimum horizontal dimension of 2 times the root ball diameter across the pit for the following, unless otherwise shown on the plans:

- Less than 15-gallon pots, and
- 14-inch or smaller root balls of B&B and fabric bag grown plants.

Provide a minimum pit diameter for bare root plants that permits the roots to spread without crowding or curving around the walls of the pit.

F. Plant Installation. Install plants within 24 hours of excavating plant pits. Scarify the walls of the pits as plant installation begins. Center all plants in a pit, except those mechanically collected, backfill in lifts, each lift 1/3 of the depth of the root ball, and fill the pit with water after each lift to remove air pockets. Prune protruding roots from the root ball for mechanically collected plants, to a point even with the cutting blades. Place the plant in the pit and work soil media between the pit walls and the root ball with water until the soil media fills all the cavities. If equipment is necessary, operate equipment adjacent to the facility. Equipment operation within the facility should be avoided to prevent soil compaction. If machinery must operate in the facility, use lightweight, low ground-contact pressure equipment.

G. Watering. Coordinate the planting work to ensure that an irrigation system, when specified, operates properly to meet the watering requirements. Apply water to plants or planting areas at the rate and frequency specified for an irrigation system or for the application method shown on the plans. Keep the ground and backfill moist at least 12 inches around the entire root ball if a watering rate and frequency are not specified.

H. Plant Support Installation. Install plant supports such as staking, guying, and bracing as shown on the plans. Support and keep plants in a vertical position or as directed.

I. Plant Replacement. Remove and dispose of dead and damaged plants from the worksite as directed. Replace plants as originally specified within 10 days of notification.

32 93 44.5 MEASUREMENT: Measurement of acceptable Vegetation, complete in place will be for each plant.

32 93 44.6 PAYMENT: "Vegetation," measured as provided above, will be paid for at the contract unit price bid per plant, which price shall be full compensation for furnishing, hauling and placing all materials, for all water required and for all labor, tools, equipment and incidentals necessary to complete the work.

32 93 44.7 BID ITEM:

Item 32 93 44.1 – Vegetation (Grasses) – per square yard

Item 32 93 44.2 – Vegetation (Shrubs) – per each

Item 32 93 44.3 – Vegetation (Trees) – per each

SECTION 33 41 16.19

Underdrain Piping and Underdrain Cleanout

33 41 16.19.1 DESCRIPTION: *This Item shall govern the furnishing and installation of all underdrain piping and associated work, including the installation of any underdrain cleanouts.*

33 41 16.19.2 MATERIALS:

A. Utility Crossing PVC Plastic Pipe Cell Classification: Pipes that cross existing water lines that have a vertical clearance of less than 12” or as indicated on the plans shall have a PVC cell classification of 12454 meeting AWWA C900, CL200 meeting the requirements of DR14. No joints are permitted within 4’ of the water line crossing. All other pipes shall be made of PVC Plastic having a cell classification of 12164, as defined in ASTM D2729. The fittings shall be made of PVC plastic having a cell classification of 12454 or 13343.

B. PVC Plastic Pipe. PVC Plastic Pipe shall conform to TXDOT 2004 Standard Specifications for Construction and Maintenance of Highways, Streets and Bridges (TXDOT), as amended, Section 556.2.A.8. The underdrain PVC carrier pipes shall have minimum diameter of 6 inches and shall be sloped at a minimum of 0.5 percent. Diameter of riser pipes shall be as shown on the plans.

C. Perforated PVC Plastic Pipe. Perforated PVC Plastic Pipe shall conform to the current TXDOT Standard Specifications for Construction and Maintenance of Highways, Streets and Bridges. The underdrain PVC carrier pipes shall have minimum diameter of 6 inches and shall be sloped at a minimum of 0.5 percent. Diameter of riser pipes shall be as shown on the plans. Perforated plastic pipe shall be smooth-wall PVC plastic pipe or corrugated PVC plastic pipe with a smooth interior surface.

Perforation Requirements.	The perforation shall be:
Hole Size:	3/8” min.
Center to Center Spacing:	5” max.
Row of Holes: (holes facing down)	4 holes per each row. There shall be 2 holes on each side of the centerline of the pipe, 1 hole at 45° from the centerline of pipe and 1 hole at 80° from the centerline of the pipe as indicated on the drawings.

D. Underdrain Cleanout Lids. Underdrain cleanouts shall have watertight caps made of PVC material.

33 41 16.19.3 EQUIPMENT: Provide the tools and equipment necessary for proper prosecution of the work. All tools and equipment used shall be maintained in a satisfactory and workmanlike manner.

33 41 16.19.4 CONSTRUCTION: Underground Conduit Construction

A. General. Trenches for underdrains where perforated PVC pipes are located shall be excavated, the pipe installed and the trench backfilled with permeable material according to the dimensions and details shown on the plans. If a liner is necessary, it should be placed per Section 33 46 81, "Impervious Liner". When underdrains are installed in trenches outside the subgrade area, the top 6" (150 mm) of the trench shall be backfilled, as shown on the plans.

When feasible, the contractor shall locate underdrain systems at or above the invert of adjacent storm water systems. Watertight joints shall be required when working in the presence of high groundwater tables and highly erodible soils.

To prevent clogging of underdrain from construction sediments, the associated stormwater facilities shall be excavated to rough grade. After the contributing drainage area is stabilized, underdrains and the stormwater facilities shall be constructed to achieve the final elevation.

Multiple underdrains are necessary for bioretention or permeable pavement areas wider than 40 feet, and each underdrain shall be located no more than 20 feet from the next pipe or the edge of the storage layer (for long and narrow applications, a single underdrain running the length of the bioretention is sufficient).

All bioretention or permeable pavement applications shall include at least one observation well and/or cleanout pipe. The observation wells may be tied into any of the tees in the underdrain system and shall extend upward to the biore tention cell or permeable pavement surface.

B. Pipe Installation. The solid and perforated PVC pipe shall be installed per TXDOT Standard Specifications Section 566.

The perforated PVC pipe shall be placed such that the perforations are pointed downward. The drainage stone shall be placed and compacted so that it is firm and unyielding prior to placing the pipe. Subsequent backfill shall be in lifts no greater than 8" and compacted to be firm and unyielding. The underdrain shall be encased in a layer of clean, double washed ASTM D448 No.57 or smaller (No. 68, 8, or 89) stone. The underdrain must be sized so that the bioretention or permeable pavement BMP fully drains within 72 hours or less.

Underdrain systems shall be designed to discharge freely to an acceptable discharge point. The underdrain can be connected to a downstream open conveyance (vegetated swale), to another BMP as part of a connected treatment system, daylight to a vegetated dispersion area using an effective flow dispersion device, stored for reuse, or to a storm water conveyance system (catch basin or existing pipe).

Pipe underdrains shall be placed at grades equal to or steeper than 0.5 percent.

Unless internal water storage is planned, the underdrain shall be elevated from the bottom of the excavation by 6 inches within the gravel blanket to create a fluctuating anaerobic/aerobic zone below the drain pipe.

The depth of the underdrain shall depend on the permeability of the soil, the elevation of the water table, and the amount of drawdown needed to ensure stability. Additionally, consideration shall be given to the depth and proximity of storm drains. Typically, the underdrain shall be placed at a depth sufficient to keep the underdrain above the existing storm drain infrastructure.

C. Clean Out Installation. An underdrain clean out is made by bringing the PVC pipe to ground level on a 45 degree angle as shown on the plans. A terminal cleanout is required at the upper and lower end of the underdrain. Intermediate inspection wells are required at maximum 300-foot intervals or at any bend that exceeds 15 degrees. The diameter of the cleanout shall be at least the diameter of the conduit. Cleanouts shall be installed with the top at least 3 inches above the high water level.

D. Jointing. Jointing of solid PVC pipe shall be securely made in accordance with TXDOT Standard Specification Section 556.2.A.8. As indicated on the plans, where there is less than 12” of vertical clearance between the underdrain and the existing water line, then no joints shall be within 10’ of either side of the existing water line.

Perforated PVC pipe shall be connected with belled ends, or with sleeve-type joints under AASHTO M 278. Solvent cementing of joints is not required.

33 41 16.19.5 MEASUREMENT: Underdrain pipe shall be measured along the pipe centerline and parallel with the slope line. The quantity shall include provision for all fittings, risers, connectors, connections, termination caps, or plugs.

Measurement of acceptable Underdrain cleanouts complete in place will be for each cleanout.

33 41 16.19.6 PAYMENT: Pipe underdrain is measured along the centerline of the pipe and parallel with the slope line. The payment quantity includes the length of elbows, outlets, risers, tees, wyes and other branches to the point of intersection.

Payment for Underdrain Pipe shall include all costs for furnishing all materials, labor, tools, equipment and incidentals (including pipe risers, caps, and fittings) to complete the work. The unit of measurement will be linear feet. Price and payment shall be full compensation for all the work, including all materials and all excavation except the volume included in the items for the grading work.

Payment for underdrain cleanout will be made at the Contract unit price per each which will include excavation, shoring, backfill, compaction, installation of cleanout including wye and jointing, pipe riser, gaskets, screw cap, concrete encasement, and all labor, materials, tools, equipment and incidentals needed to complete work specified.

33 41 16.19.7 BID ITEM:

Item 33 41 16.19.1 – Underdrain Piping – per Linear Foot

Item 33 41 16.19.2 – Underdrain Cleanout – Subsidiary to piping

APPENDIX E: **Plant List**

The following plant list was created to guide users of this manual in general selection of appropriate plants for the region. However, plant species commonly grown in landscape areas in San Antonio will grow differently in BMP applications, especially where amended or engineered soils are used. Please see individual BMP design guidance before selecting plants. Plant selection and care is also dependent upon other factors such as microclimate, soil, rainfall, season, placement (e.g., North side of building), density, efficiency, and use. A knowledgeable landscape architect, horticulturalist, botanist, ecologist or arborist, preferably with experience in the San Antonio area, should be consulted for final plant selection. In addition, local tree preservation and landscaping regulations may limit the use of certain species.

Detailed information about native plants is available from the Native Plant Information Network (NPIN) at **www.wildflower.org/explore**. To find a plant's county-by-county distribution, please search the USDA's Plants Database at: **plants.usda.gov**. To find native plant suppliers in your area, visit **www.wildflower.org/suppliers**.

APPENDIX E: **Plant List**

Common name	*Scientific name*	Native to SARB[1]	Size		Evergreen (E) Deciduous (D) or Semi (S)	Lifespan / Duration (Annual [A], Perennial [P], Biennial [B])	Light			Soil Moisture				Comments
			Height	Spread			Sun	Part sun/shade	Shade	Dry	Moist	Wet	Shallow water	
SHADE TREES														
American elm	*Ulmus americana*	✓	72'-90'	50'-70'	D	200+ yrs	✓	✓						
American sycamore	*Platanus occidentalis*	✓	75'-100'	50'-70'	D	200+ yrs	✓	✓	✓					
Anaqua	*Ehretia anacua*	✓	20'-45'	20'-45'	E	60+ yrs	✓	✓						Showy flowers & fruit. Attracts pollinators, birds
Arizona ash	*Fraxinus velutina*		36'-72'	45'-60'	D	30+ yrs	✓							Fast-growing
Bald cypress	*Taxodium distichum*	✓	50'-75'	30-60'	D	600+ yrs	✓	✓						
Black walnut	*Juglans nigra*	✓	72'-100'	72'-100'	D	100+ yrs	✓	✓						Certain plants sensitive to tannins from walnut husks
Black willow	*Salix nigra*	✓	36'-72'	36'-72'	D	65+ yrs	✓	✓	✓					Fast-growing, stabilizes soil
Box elder	*Acer Negundo*	✓	35'-50'	30'-40'	D	75+ yrs	✓	✓						Fast-growing, susceptible to breakage
Bur oak	*Quercus macrocarpa*		36'-100'	36'-100'	D	200+ yrs	✓	✓	✓					
Monterrey Oak	*Quercus polymorpha*		36'-72'	20'-35'	S		✓	✓						
Cedar elm	*Ulmus crassifolia*	✓	50'-70'	40'-60'	D	100+ yrs		✓						Fast growing, long-living
Cottonwood	*Populus deltoides*	✓	12'-36'	12'-30'	D	100+ yrs	✓	✓	✓					Fast-growing, susceptible to breakage
Honey mesquite	*Prosopis glandulosa*	✓	12'-36'	12'-36'	D	75+ yrs	✓							Thorny, Attracts pollinators

APPENDIX E: **Plant List**

Common name	*Scientific name*	Native to SARB[1]	Size: Height	Size: Spread	Evergreen (E) Deciduous (D) or Semi (S)	Lifespan / Duration (Annual [A], Perennial [P], Biennial [B])	Light: Sun	Light: Part sun/shade	Light: Shade	Soil Moisture: Dry	Soil Moisture: Moist	Soil Moisture: Wet	Soil Moisture: Shallow water	Comments
Mexican sycamore	*Platanus mexicana*		40'-50'	30'-35'	D	70+ yrs	✓	✓						Benefits from occasional deep soakings
Montezuma cypress	*Taxodium mucronatum*		36'-72'	30-60'	E	700+ yrs		✓						Deciduous in colder climates
Pecan	*Carya illinoinensis*	✓	70'-100'	50'-70'	D	200+ yrs	✓							Edible fruit, prune to maintain strong branching
Sugarberry/ Hackberry	*Celtis laevigata*	✓	60'-80'	60'-70'	D	60+ yrs		✓						Bird Habitat
UNDERSTORY & SMALL TREES														
Guajillo	*Senegalia berlandieri*	✓	3'-15'	3'-15'	D	15+ yrs	✓	✓						Showy flowers, Attracts pollinators, birds
Huisache	*Vachellia farnesiana*	✓	15'-25'	15'-25'	D	30+ yrs	✓							Thorny, forms dense thickets through suckers, Attracts pollinators
Mexican buckeye	*Ungnadia speciosa*	✓	20'-30'	15'-20'	D	60+ yrs		✓						Seeds toxic if eaten
Mexican plum	*Prunus mexicana*	✓	15'-35'	15'-35'	D	25+ yrs	✓	✓						Attracts pollinators, birds, edible fruit
Red mulberry	*Morus rubra*	✓	12'-36'	10'-30'		50+ yrs	✓	✓	✓					Attracts birds, ripened fruit edible, toxic: leaves, stems, unripened fruit
Retama	*Parkinsonia aculeata*	✓	12'-36'	15'-40'	D	15+ yrs	✓							Thorny, self-seeds aggressively in moist soils, Attracts pollinators, birds
Texas redbud	*Cercis canadensis* var. *texensis*	✓	10'-20'	10'-20'	D	20+ yrs	✓	✓						Showy flowers

APPENDIX E: **Plant List**

Common name	*Scientific name*	Native to SARB[1]	Size		Evergreen (E) Deciduous (D) or Semi (S)	Lifespan / Duration (Annual [A], Perennial [P], Biennial [B])	Light			Soil Moisture				Comments
			Height	Spread			Sun	Part sun/shade	Shade	Dry	Moist	Wet	Shallow water	
Texas persimmon	*Diospyros texana*	✓	15'-35'	15'-35'	D, S	50+ yrs	✓	✓						Edible fruit, Attracts pollinators, birds
SHRUBS														
American beautyberry	*Callicarpa americana*	✓	3'-5'	3'-5'	D	P		✓						Showy berries, Attracts birds
Blackbrush acacia	*Vachellia rigidula*	✓	5'-15'	5'-15'	D	P	✓	✓						Thorny, suckers readily, often used for erosion control, Attracts pollinators
Buttonbush	*Cephalanthus occidentalis*	✓	6'-12'	6'-10'	D	P		✓	✓					Showy flowers, Attracts pollinators
Chile pequin	*Capsicum annuum*	✓	1'-2'	1'-2'	D	P	✓	✓	✓					Edible fruit (hot pepper), Attracts birds
Common elderberry	*Sambucus nigra ssp. Canadensis*	✓	6'-12'	6'-12'	D	P		✓						Showy flowers & fruit, Attracts pollinators, birds, ripened fruit edible, toxic parts: leaves, stems, unripened fruit
Dwarf palmetto	*Sabal minor*	✓	5-'10'	5-'10'	E	P	✓	✓	✓					Showy fruits
False willow	*Baccharis neglecta*	✓	6'-12'	6'-12'	S	P		✓						Attracts Pollinators
Illinois bundleflower	*Desmanthus illinoensis*	✓	2'-3'	1'-2'	D	P	✓							Attracts pollinators
Indigo spires salvia	*Salvia 'Indigo Spires'*		3.5'	3.5'	D	P	✓							Showy flowers
Narrow-leaf water primrose	*Ludwigia octovalvis*	✓	3'-6'	2'-4'	D	P	✓	✓						Fast-growing, reseeds readily
River fern	*Thelypteris kunthii*	✓	2.5'	1'	E	P		✓	✓					

APPENDIX E: **Plant List**

Common name	*Scientific name*	Native to SARB[1]	Size		Evergreen (E) Deciduous (D) or Semi (S)	Lifespan / Duration (Annual [A], Perennial [P], Biennial [B])	Light			Soil Moisture				Comments
			Height	Spread			Sun	Part sun/shade	Shade	Dry	Moist	Wet	Shallow water	
Rock rose	*Pavonia lasiopetala*	✓	4'	4'	D	P	✓	✓						Showy flowers, Attracts pollinators
Texas lantana	*Lantana urticoides (L. horrida)*	✓	2'-6'	2'-6'	E	P	✓	✓						Showy flowers, Attracts pollinators , stems become thorny with age
Texas sage	*Leucophyllum frutescens*	✓	2'-8'	2'-8'	E	P	✓	✓						Showy flowers, pollinators
Texas star hibiscus	*Hibiscus coccineus*		3'-6'	3'-6'	D	P	✓							Showy flowers
Turk's cap	*Malvaviscus arboreus* var. *drummondii*	✓	3'-5'	3'-5'	E	P		✓	✓					Showy flowers & fruits, Attracts pollinators
GRASSES & GRASS-LIKE FORBS														
Big bluestem	*Andropogon gerardii*	✓	4'-8'	1'-3'	E*	P	✓	✓						Bunchgrass, droops with high soil moisture
Buffalograss	*Bouteloua dactyloides*	✓	6"-12"	spreads	S	P	✓							Spreads by rhizomes
Bushy bluestem	*Andropogon glomeratus*	✓	2'-5'	spreads	E*	P	✓							Showy seedheads
Canada wildrye	*Elymus canadensis*	✓	2'-4'	spreads	E*	P	✓	✓						Showy seedheads , establishes quickly
Cane bluestem	*Bothriochloa barbinodis*	✓	1'-3'	spreads	E*	P	✓							
Eastern gamagrass	*Tripsacum dactyloides*	✓	3'-6'	3'-4'	E	P		✓						Soil stabilizer

APPENDIX E: **Plant List**

Common name	*Scientific name*	Native to SARB[1]	Size		Evergreen (E) Deciduous (D) or Semi (S)	Lifespan / Duration (Annual [A], Perennial [P], Biennial [B])	Light			Soil Moisture				Comments
			Height	Spread			Sun	Part sun/shade	Shade	Dry	Moist	Wet	Shallow water	
Fringed windmillgrass	*Chloris ciliata*	✓	1'-3'	spreads	E*	P		✓						
Green sprangletop	*Leptochloa dubia*	✓	2'-3'	spreads	E*	P	✓	✓						
Gulf Coast muhly	*Muhlenbergia capillaris*	✓	1.5'-3'	1.5'-3'	E*	P	✓							Showy seedheads
Hairy grama	*Bouteloua hirsuta*	✓	6"-18"	spreads	E*	P		✓						
Hooded windmillgrass	*Chloris cucullata*	✓	6"-24"	spreads	E*	P		✓						
Indiangrass	*Sorghastrum nutans*	✓	3'-6'	1'-3'	E*	P	✓	✓						Showy seedheads
Inland sea oats	*Chasmanthium latifolium*	✓	2'-4'	spreads	E*	P		✓	✓					Showy seedheads , spreads aggressively, erosion control
Horsetail (Scouring rush)	*Equisetum hyemale* var. *affine*	✓	2'-4'	spreads	E	P	✓	✓						Spreads aggressively
Lindheimer's muhly	*Muhlenbergia lindheimeri*	✓	2'-5'	2'-5'	E	P	✓							Semi-evergreen
Liriope	*Liriope muscari 'Big Blue'*		12"-18"	12"-18"	E	P		✓	✓					
Little bluestem	*Schizachyrium scoparium*	✓	1.5'-2'	spreads	E*	P	✓	✓						Showy Seedheads
Needle spikerush	*Eleocharis acicularis*	✓	6"	spreads	E*	A	✓							
Plains bristlegrass	*Setaria leucopila*	✓	3'-6'	spreads	E*	P	✓							
Purple threeawn	*Aristida purpurea*	✓	12"-18"	spreads	E*	A	✓							Good for erosion control
Purpletop	*Tridens flavus*	✓	2'-6'	spreads	E*	P	✓	✓						
Sand lovegrass	*Eragrostis trichodes*	✓	1'-3'	spreads	E*	P		✓						Adapts to heavier soils

APPENDIX E: **Plant List**

Common name	*Scientific name*	Native to SARB[1]	Size: Height	Size: Spread	Evergreen (E) Deciduous (D) or Semi (S)	Lifespan / Duration (Annual [A], Perennial [P], Biennial [B])	Light: Sun	Light: Part sun/shade	Light: Shade	Soil Moisture: Dry	Soil Moisture: Moist	Soil Moisture: Wet	Soil Moisture: Shallow water	Comments
Seep muhly	*Muhlenbergia reverchonii*	✓	1'-3.5'	1'-3.5'	E	P	✓			■	■			
Sideoats grama	*Bouteloua curtipendula*	✓	1'-3'	spreads	E*	P	✓	✓		■	■			Showy Seedheads , state grass of Texas
Slender spikerush	*Eleocharis tenuis*	✓	1'-3'	spreads	E*	P	✓				■	■		
Softstem bulrush	*Schoenoplectus tabernaemontani*	✓	3'-6'	spreads	E*	P	✓					■		Good for habitat reconstruction
Squarestem spikerush	*Eleocharis quadrangulata*	✓	1.5'-4'	spreads	E*	P	✓					■	■	
Switchgrass	*Panicum virgatum*	✓	3'-6'	3'-5'	E*	P	✓	✓		■	■	■		Showy Seedheads, soil stabilizer
Texas cupgrass	*Eriochloa sericea*	✓	1'-2'	1'-2'	E*	P	✓	✓		■	■			Attracts birds
Texas grama	*Bouteloua rigidiseta*	✓	6"-12"	spreads	E*	P	✓			■				
Vine mesquite	*Panicum obtusum*	✓	1'-2'	spreads	E*	P		✓		■	■			
Western wheatgrass	*Pascopyrum smithii*	✓	1'-2.5'	spreads	E*	P	✓	✓		■	■			Turf grass, can crowd out other grasses
VINES														
Alamo vine	*Merremia dissecta*	✓	6'-12'	4'-10'	D	P	✓	✓		■	■			Showy flowers, twining climber, can be aggressive
Carolina snailseed	*Cocculus carolinus*	✓	3'-15'	3'-15'	D	P		✓			■			Showy fruits, spreads vigorously, fast-growing
Mustang grape	*Vitis mustangensis*	✓	36'-72'	36'-72'	D	P		✓		■				Twining climber, showy fruit, edible fruit, Attracts birds
Old man's beard	*Clematis drummondii*	✓	20'-25'	3'-6'	D	P		✓		■	■			Showy seedheads, aggressive

APPENDIX E: **Plant List**

Common name	*Scientific name*	Native to SARB[1]	Size		Evergreen (E) Deciduous (D) or Semi (S)	Lifespan / Duration (Annual [A], Perennial [P], Biennial [B])	Light			Soil Moisture				Comments
			Height	Spread			Sun	Part sun/shade	Shade	Dry	Moist	Wet	Shallow water	
Passionflower	*Passiflora foetida*	✓	15'-20'	3'-6'	D	A	✓	✓						Twining climber, edible fruit, suckers vigorously
Peppervine	*Ampelopsis arborea*	✓	30'-40'	30'-40'	S	P	✓	✓						Showy fruits, aggressive, climbing and/or trailing
Trumpet creeper	*Campsis Radicans*	✓	25'-35'	6'-8'	D	P	✓							Showy flowers, climbs by aerial rootlets, aggressive
Virginia creeper	*Parthenocissus quinquefolia*	✓	12'-36'	12'-36'	D	P	✓	✓	✓					Fall color, high climbing or trailing with tendrils, toxic berries
SMALL FORBS & GROUNDCOVER														
American basketflower	*Centaurea americana*	✓	2'-5'	2'-5'	D	A	✓							Showy flowers, pollinators
American water-willow	*Justicia americana*	✓	1'-3'	1'-3'	D	P	✓	✓	✓					
Annual sunflower	*Helianthus annuus*	✓	2'-8'	1'-2'	D	A	✓	✓						Showy flowers, Attracts pollinators, birds, spreads rapidly by seed
Autumn sage (salvia)	*Salvia gregii*	✓	2.5'	2.5'	E	P	✓							Showy flowers, Attracts pollinators, stems brittle -
Bee blossom	*Gaura suffulta*	✓	1'-3'	1'-2'	D	A	✓							Showy flowers, Attracts pollinators
Black-eyed Susan	*Rudbeckia hirta*	✓	1'-3'	1.5'-2'	D	A	✓	✓						Showy flowers, Attracts pollinators
Blackfoot daisy	*Melampodium leucanthum*	✓	6"-12"	1'-2'	D	P	✓	✓						Showy flowers, Attracts pollinators

APPENDIX E: **Plant List**

Common name	*Scientific name*	Native to SARB[1]	Size: Height	Size: Spread	Evergreen (E) Deciduous (D) or Semi (S)	Lifespan / Duration (Annual [A], Perennial [P], Biennial [B])	Light: Sun	Light: Part sun/shade	Light: Shade	Soil Moisture: Dry	Soil Moisture: Moist	Soil Moisture: Wet	Soil Moisture: Shallow water	Comments
Blue curls	*Phacelia congesta*	✓	1'-3'	2'-3'	D	A	✓	✓	✓					Showy flowers, Attracts pollinators , best if sheltered from west sun, stem is brittle
Bulbine	*Bulbine frutescens*		1'-2'	2'-3'	E	P	✓	✓						
Bush sunflower	*Simsia calva*	✓	1'-3'	1'-3'	D	P	✓							
Butterflyweed	*Asclepias tuberosa*	✓	1'-2'	1'-2'	D	P	✓	✓						Showy flowers, Attracts pollinators, roots and plant sap are toxic
Clasping leaf coneflower	*Dracopis amplexicaulis*	✓	1'-2'	1'-2'	D	A	✓	✓						Showy flowers, Attracts pollinators
Cowpen daisy	*Verbesina encelioides*	✓	1'-3'	1'-2'	D	A	✓							Showy flowers, Attracts pollinators
Delta arrowhead	*Sagittaria platyphylla*	✓	1'-3'	1'-3'	D	P	✓	✓						
Drummond phlox	*Phlox drummondii*	✓	6"-18"	6"-18"	D	A	✓	✓						Showy flowers, Attracts pollinators
Drummond's woodsorrel	*Oxalis drummondii*	✓	6"-12"	6"-12"	D	P	✓	✓						Showy flowers, Attracts pollinators
Engelmann's daisy	*Engelmannia peristenia*	✓	1.5'-2'	1'-3'	E	P		✓	✓					Showy flowers, Attracts pollinators
Foxglove	*Penstemon cobaea*	✓	1'-2'	1'-2'	D	P	✓	✓						Showy flowers, Attracts pollinators , may go dormant during summer
Frogfruit	*Phyla nodiflora*	✓	3"-6"	3"-6"	S	P	✓	✓	✓					Attracts pollinators, tolerates drought and flooding

APPENDIX E: **Plant List**

Common name	*Scientific name*	Native to SARB[1]	Size: Height	Size: Spread	Evergreen (E) Deciduous (D) or Semi (S)	Lifespan / Duration (Annual [A], Perennial [P], Biennial [B])	Light: Sun	Light: Part sun/shade	Light: Shade	Soil Moisture: Dry	Soil Moisture: Moist	Soil Moisture: Wet	Soil Moisture: Shallow water	Comments
Gayfeather	*Liatris mucronata*	✓	1'-3'	1'-2'	D	P	✓	✓						Showy flowers, Attracts pollinators
Golden wave	*Coreopsis basilis*	✓	6"-18"	6"-18"	D	A	✓	✓						Showy flowers, Attracts pollinators
Greenthread	*Thelesperma filifolium*	✓	1'-3'	1'-2'	D	A	✓							Showy flowers, Attracts pollinators
Hill Country rain lily	*Cooperia pedunculata*	✓	6"-12"	3"-6"	D	P	✓							Blooms after rain
Horsemint	*Monarda citriodora*	✓	1'-2'	1'-2'	D	A	✓	✓						Showy flowers, Attracts pollinators
Huisache daisy	*Amblyolepis setigera*	✓	6"-15"	6"-15"	D	A	✓	✓						Showy flowers, Attracts pollinators
Indian blanket	*Gaillardia pulchella*	✓	12"-18"	12"-18"	D	A	✓	✓						Showy flowers, Attracts pollinators
Indian paintbrush	*Castilleja indivisa*	✓	6"-16"	6"-9"	D	A	✓							Showy flowers, Attracts pollinators
Lanceleaf coreopsis	*Coreopsis lanceolata*		1'-2.5'	1'-2'	E	P	✓	✓	✓					Showy flowers, Attracts pollinators not reliably perennial, but self-sows readily
Lindheimers senna	*Senna lindheimeriana*	✓	1'-3'	3'-6'	D	P	✓	✓						Showy flowers, Attracts pollinators
Maximilian sunflower	*Helianthus maximiliani*	✓	4'-6'	3'-6'	D	P	✓	✓						Showy flowers, pollinators, soil stabilizer
Mealy blue sage	*Salvia farinacea*	✓	2'-3'	1'-2'	D	P	✓	✓						Showy flowers, Attracts pollinators, birds

APPENDIX E: **Plant List**

Common name	*Scientific name*	Native to SARB[1]	Size: Height	Size: Spread	Evergreen (E) Deciduous (D) or Semi (S)	Lifespan / Duration (Annual [A], Perennial [P], Biennial [B])	Light: Sun	Light: Part sun/shade	Light: Shade	Soil Moisture: Dry	Soil Moisture: Moist	Soil Moisture: Wet	Soil Moisture: Shallow water	Comments
Money plant, Water pennywort	*Hydrocotyle umbellata*		3"-10"	3"-10"	D	P	✓	✓	✓		■	■		Can absorb pollutants
Obedient plant	*Physostegia intermedia*	✓	1'-5'	1'-3'	D	P	✓	✓	✓		■	■	■	Showy flowers, Attracts pollinators
Partridge pea	*Chamaecrista fasciculata*	✓	1'-3'	1'-3'	D	A	✓	✓		■	■	■		Showy flowers, Attracts pollinators
Pickerelweed	*Pontederia cordata*	✓	3'-4'	2'-3'		P	✓	✓				■	■	Showy flowers, Attracts pollinators
Pigeonberry	*Rivina humilis*	✓	6"-18"	2'-3'	D	P		✓			■			Showy flowers & fruits toxic if ingested
Pink evening primrose	*Oenothera speciosa*	✓	1'-2'	1'-2'	S	P	✓	✓		■	■			Showy flowers, Attracts pollinators
Pitcher sage	*Salvia azurea*	✓	2-'4'	1-'3'	D	P	✓	✓		■	■			Showy flowers, Attracts pollinators
Plains coreopsis	*Coreopsis tinctoria*	✓	1'-2'	6"-12"	D	A	✓	✓			■			Showy flowers, Attracts pollinators
Prairie verbena	*Glandularia bipinnatifida*	✓	6"-12"	6"-12"	D	P	✓	✓		■	■			Showy flowers, Attracts pollinators
Purple coneflower	*Echinacea purpurea*		2'-4'	2'-4'	D	P	✓	✓		■				Showy flowers, Attracts pollinators
Upright prairie coneflower	*Ratibida columnifera*	✓	1'-3'	1'-2'	D	P	✓	✓		■	■			Showy flowers, Attracts pollinators Can be aggressive
Purple prairie clover	*Dalea purpurea*	✓	1'-3'	1'-2'	D	P	✓			■	■			Showy flowers, Attracts pollinators

APPENDIX E: **Plant List**

Common name	*Scientific name*	Native to SARB[1]	Size		Evergreen (E) Deciduous (D) or Semi (S)	Lifespan / Duration (Annual [A], Perennial [P], Biennial [B])	Light			Soil Moisture				Comments
			Height	Spread			Sun	Part sun/shade	Shade	Dry	Moist	Wet	Shallow water	
River primrose	*Oenothera jamesii*	✓	3'-6'	3'-6'	D	B	✓							Showy flowers, Attracts pollinators
Scarlet sage	*Salvia coccinea*	✓	6"-24"	6"-24"	S	P	✓	✓						Showy flowers, Attracts pollinators
Scrambled eggs	*Corydalis curvisiliqua*	✓	6"-12"	9"-24"	D	A		✓						Showy flowers
Standing cypress	*Ipomopsis rubra*	✓	2'-4'	1'-2'	D	B	✓	✓						Showy flowers, pollinators, birds
Straggler daisy	*Calyptocarpus vialis*	✓	6"-12"	2'-3'	S	P	✓	✓	✓					Pollinators
Texas betony	*Stachys coccinea*		2.5'	2.5'	D	P		✓						Showy flowers, Attracts pollinators
Texas bluebonnet	*Lupinus texensis*	✓	6"-18"	6"-18"	D	A	✓							Showy flowers, pollinators, state flower of Texas
Texas vervain	*Verbena halei*	✓	1'-3'	15"	D	P	✓							Showy flowers, Attracts pollinators
Water hyssop	*Bacopa monnieri*	✓	6"-12"	6"-12"	D	P	✓	✓						
White gaura	*Oenothera lindheimeri*		2'-5'	1'-3'	D	P	✓	✓						Showy flowers, Attracts pollinators
White prairie clover	*Dalea candida*	✓	1'-2'	1'-2'	D	P	✓							
White pricklypoppy	*Argemone albiflora*	✓	2'-4'	2'-4'	D	A	✓	✓						Showy flowers, Attracts pollinators toxic foliage, can absorb pollutants
Widow's tears	*Commelina erecta*	✓	6"-18"	6"-18"	D	P		✓						
Wild petunia	*Ruellia nudiflora*	✓	1'-2'	1'-2'	D	P	✓	✓	✓					

Common name	*Scientific name*	Native to SARB[1]	Size		Evergreen (E) Deciduous (D) or Semi (S)	Lifespan / Duration (Annual [A], Perennial [P], Biennial [B])	Light			Soil Moisture				Comments
			Height	Spread			Sun	Part sun/shade	Shade	Dry	Moist	Wet	Shallow water	
Winecup	*Callirhoe involucrata*	✓	6"-12"	1'-2'	S	P	✓	✓						Showy flowers, Attracts pollinators
Zigzag iris	*Iris brevicaulis*		1'-2'	1'-2'	D	P		✓	✓					Showy flowers

*Year-round leaf retention, but foliage loses color during dormancy

[1] Designates species native to the San Antonio River Basin (SARB) based on the United States Department of Agriculture PLANTS Database. All other species listed are native to at least one county in the State of Texas except: Bulbine, Indigo spires salvia, Liriope muscari 'Big Blue', Mexican sycamore, and Texas Star Hibiscus.

Notes:

APPENDIX F: **Critical Construction Considerations**

Essential functions of permanent LID BMPs can be deteriorated by common construction practices, such as compacted soils from heavy equipment, erosion and sediment build-up, or work performed in saturated conditions. Construction observation and inspections by a qualified inspector familiar with the functions of structural BMPs are recommended for quality control and assurance. As part of construction oversight, inspectors should ensure that the proper temporary erosion control practices are implemented in accordance with federal, state, and local regulations. Construction specifications might include the following measures to protect the permanent LID BMP while construction operations are underway:

- Establish a protective zone around valued natural areas and trees that will be preserved.
- Minimize the use of heavy equipment, especially in areas where infiltration BMPs will be.
- Minimize soil disturbance and unprotected exposure of disturbed soils.
- Expose only as much area as needed for immediate construction.
- As areas are cleared and graded, apply appropriate erosion controls to minimize soil erosion.
- Protect stormwater infiltration BMPs from unwanted sedimentation during the construction phase.
- Provide a temporary outlet to convey runoff down slope with sediment traps at outlets and inlets.
- Minimize the movement of soil into the drainage system.
- Use sediment and erosion protection practices early in the site clearing and grading process to reduce the sediment-laden runoff reaching soils intended for future infiltration.
- Protect future infiltration BMPs from sediment from adjacent properties.

Proper Construction Sequencing

For moreinformation on practice-specific construction best practices, see below.

Proper construction sequencing can reduce the risk of clogging by excessive accumulation of fine particles in the soil media layers. Designers should specify proper construction sequencing to minimize potential disturbance to LID structures. During construction, the extent of disturbed, exposed soils should be limited to reduce the risk of erosion by specifying the timing and extent of permanent vegetation establishment. Imported soil media should not be incorporated into BMPs until the drainage area has been stabilized. Soil media should not be installed until at least the first course of pavement has been set for roads and parking lots, which minimizes the amount of fines washed from the bedding layers into the BMP. In addition to proper construction sequencing, wrapping features in geotextile fabric may be beneficial in protecting features from accumulated sedementation and fines during the construction process. However,a geotextile liner might not be sufficient to prevent fines from migrating into and clogging the soil media layer; for that reason, proper construction sequencing is crucial.

Bioretention

Construction technique and sequencing are critical to bioretention cell performance. Failure of improperly constructed systems can be easily avoided by effective communication with the contractor and by inspection during key steps. Emphasizing the following points will help ensure successful installation of bioretention cells.

Minimize and Mitigate Compaction by Scarifying Subsoil Surface

Compaction of underlying soils (an inherent consequence of construction) can decrease infiltration rates and result in poor drainage, extended periods of standing water, plant die-off, and, in some cases, leaching of previously captured pollutants. Construction effects on underlying soils can be mitigated by excavating the last 12 inches of cut with a toothed excavator bucket. This method breaks up compacted layers and prevents smearing, which can seal the subsoil surface *(Brown and Hunt 2010)*. Infiltration can also be significantly enhanced by ripping or trenching the subsoils to a depth of 9–12 inches *(Tyner et al. 2009)*. Ripped furrows (on 3-foot centers) should be filled with a clean sand to maintain free-flowing conditions. Trenches are typically constructed 12 inches wide on 6-foot centers and are filled with pea gravel.

Inspect Soil Media Before Placement

It is important to ensure that the soil media is consistent with specifications before installation—media that is too sandy will not provide adequate treatment, whereas media that is too fine might not drain in adequate time *(Carpenter and Hallam 2010)*. To field-verify the texture of soil media, moisten the soil and form into a 1-inch ball. Drop the ball from 1 foot onto the open palm of the hand. The ball should break apart on impact, indicating that it is a sandy soil. When rubbed between the fingers, the moist soil should also leave a thin layer of mud residue on the skin, indicating that fines are present in the mix.

Soil media should also contain a small amount of plant-based organic matter evenly distributed throughout the mix—the organic matter should not smell like manure. Note: These inspection techniques are intended for field verification and do not substitute for laboratory soil test results.

Verify that Average Ponding Depth is Provided

It is important to verify that the intended design volume of runoff can be captured by the bioretention cell. Contractors who are unfamiliar with construction of bioretention may try to minimize surface ponding by installing the outlet elevation too low. Cells that do not provide their intended capacity of surface storage will overflow more often than intended and discharge untreated runoff to waterways *(Brown and Hunt 2011b; Luell et al. 2011)*. Therefore, it is critical to check that the average surface ponding depth has been provided and that the bed of the cell has been uniformly graded—this can be performed by simply verifying the overflow/bypass elevation of the system relative to the average elevation of the mulch bed surface. An average depth must be measured because the height of the outlet structure relative to adjacent ground surface is not a reliable indicator of average ponding depth *(Wardynski and Hunt 2012)*. Excessive mulch (deeper than 4 inches) can also displace surface storage volume and should be avoided.

Bioswales

Construction technique and sequencing are critical to bioretention cell performance. For construction and implementation notes, see bioretention.

Permeable Pavement

Notes on construction plans should specify that tracked vehicles (versus wheeled vehicles) be used whenever practicable to minimize compaction of subsoils. Construction specifications should also include notes requiring the testing of subgrade infiltration rates before installing aggregate (for infiltrating systems). This step ensures that captured water will draw down in the required duration. If subgrade infiltration rates are drastically lower than design values, the subgrade should be treated by scarifying, ripping, or trenching according to the recommendations in bioretention. If infiltration rates remain lower than required, the profile depth must be changed to provide additional storage or the drainage configuration must be altered to regulate the drawdown.

Careful inspection of several construction steps can prevent costly errors. Construction of permeable pavement systems should be performed only by a contractor with experience in permeable pavement installation and that is certified by the Interlocking Concrete Pavement Institute or the National Ready Mix Concrete Association. Lists of certified contactors are at **www.icpi.org** or **www.nrmca.org**. The following practices should be completed by the designer or a trained inspector.

Inspect Aggregate Upon Delivery

Stone aggregate bedding, base, and subbase courses should be thoroughly washed to prevent fines from clogging the subsoil interface or underdrains *(Fassman and Blackbourne 2010)*. Before placement, the furnished aggregate should appear free of fines and leave no substantial dust on the skin when handled. Unwashed aggregate should be replaced or washed onsite using proper construction site sediment control practices.

Inspect Elevations

Elevation discrepancies during grading or placing pipe inverts can result in undersized (and underperforming) systems. Verifying the average subgrade elevation and the elevation of the outlet invert will help ensure that the specified reservoir storage volume has been provided.

Test Actual Subgrade Infiltration Rate

After excavation and before installing aggregate, the actual in situ infiltration rate should be measured using the methods in Common Design Elements. This is a critical step to determine the level of compaction experienced during construction so that adequate mitigation practices can be recommended.

Mitigate Soil Compaction to Enhance Exfiltration

If exfiltration rates (as determined in previous step) are substantially lower than design values, the subgrade should be treated according to Table F-1 to mitigate compaction. If subgrade exfiltration rates are substantially lower than original design rates, it may be necessary to provide additional aggregate reservoir depth to accommodate storage and exfiltration of subsequent rainfall events.

TABLE F-1. SUBGRADE TREATMENTS FOR INFILTRATION ENHANCEMENT

Subgrade compaction	Minimum subgrade treatment	Specification
Low	Scarification	Loosen the top 6 to 9 inches of subgrade using the teeth of an excavator bucket (or comparable). This can be achieved by excavating the final 1 foot using a toothed bucket.
Low-Medium	Ripping	Using a subsoil ripper or metal bar, rip the subgrade to a depth of 9 to 12 inches, every 3 feet (on center). When operating in silty, loamy, or clay soils, fill ripped areas with coarse sand to maintain free-flowing trenches.
High	Trenching	Excavate 1-foot-deep by 1-foot wide trenches into the subgrade, every 6 feet (on center). Fill the bottom of the trench with one-half inch of coarse sand, and top off trench with washed aggregate (No. 57 stone or comparable).

Inspect Surface Course Placement and Curing

Poured in place surface courses should be inspected during placement to ensure proper mix characteristics. After screeding and compaction, inspectors should ensure that the surface of pervious concrete is not smeared (particularly when placing plastic over the surface for curing).

Planter Boxes

The same construction considerations for bioretention should be employed in constructing planter boxes, except subgrade compaction does not require mitigation. In fact, depending on the weight of the planter box, aboveground systems might require a gravel or concrete footer to distribute the load (see foundation requirements in Cisterns).

Green Roofs

Green roofs inhabit a unique location in the urban landscape that results in designers facing construction considerations that are not applicable to landscape-based BMPs.

Provide Access for Installation, Inspection, and Maintenance

During construction, green roof materials must be transported to the rooftop. This can be done via ladder lifts, elevators, or human physical labor; the most efficient method is typically using a crane. Media can be pneumatically blown onto the roof surface. Adequate areas must be available at the building perimeter for material and equipment staging. To accommodate regular inspection, a physical access method should be provided to the rooftop. Designated pathways across the green roof surface should be provided to prevent damage to plants and compaction of media during maintenance activities.

Consider Supplemental Irrigation during Plant Establishment

In the plant establishment phase, supplemental irrigation might be necessary to ensure plant survival and full roof coverage of roofing materials.

Visitor Safety

Where public access is provided to the green roof for recreation or other purposes, consider barriers to mitigate fall risk. If vegetation includes grasses or other species that results in significant dead vegetation matter, incorporate fire prevention into maintenance plans or public signage.

Sand Filters

Construction considerations for sand filters are similar to those for bioretention. For subsurface sand filters, care should be taken to verify elevations of all structures and allow for ease of access for maintenance.

Stormwater Wetlands

Provide Maintenance Access

To maintain stormwater wetlands, maintenance crews and equipment must occasionally access wetland components. Wetland design should incorporate a dedicated access easement from a public road to the wetland and an appropriate maintenance staging area. The grading plan for the wetland should incorporate access paths as appropriate for maintenance equipment to reach critical maintenance points including, for example, the forebay and outlet. The site geotechnical analysis will determine whether the access path must be stabilized to support heavy equipment.

Incorporate Nuisance Wildlife Deterrents

Improperly maintained stormwater treatment wetlands provide ideal habitat for urban waterfowl and other nuisance wildlife. Some species such as snakes might be perceived as distasteful to nearby citizens but do not negatively affect the function of the wetland itself. Other species such as geese and nutria might negatively affect the wetland including grazing wetland plants, disturbing bottom sediments, and contributing pollutants through fecal matter. Burrowing animals may also compromise the geotechnical stability of embankments. Various methods can be used to deter or remove nuisance species from the wetland. Each method should be considered in the context of project objectives, local laws, and stakeholder perception of the nuisance. The most effective method control of nuisance waterfowl is to maintain tall vegetation around the entire perimeter of the wetland because waterfowl tend to be wary of tall vegetation for fear of hidden predators. Abundant, diverse vegetation can also provide favorable habitat for dragonflies and other mosquito predators, whereas monocultures of vegetation (such as Typha. spp. or Phragmites spp.) can harbor mosquito larvae in dense mats of roots and detritus *(Hunt et al. 2005)*. Where advanced vector control is required, *(Barrett 2005)* recommends introducing Gambusia affinis (mosquito fish) at a density of 200 fish per acre of permanent pool. Several references are available for appropriate methods of nuisance wildlife control:

- Managing Waterfowl in Stormwater Ponds: https://www.clemson.edu/extension/water/stormwater-ponds/problem-solving/nuisance-wildlife/waterfowl/index.html
- Goose Control Best Management Practices to Prevent Pollution of Ponds, Streams, and Rivers: http://www.pittsfieldtwp.org/NRC_Goose_Control
- Nuisance Wildlife Repellent Handbook: http://files.dnr.state.mn.us/assistance/backyard/livingwith_wildlife/repellent_handbook.pdf

APPENDIX F: Critical Construction Considerations

Extended Detention Basins

Construction Plan Notes

To ensure that the EDB is constructed properly it is essential that the final construction documents include detailed notes in either the plans or specifications as appropriate. These notes should include items such as maximum allowable slopes (typically 3:1), pretreatment and erosion protection at all water entry points, planting schedules, specifications for all structures or proprietary devices, and any traffic and safety plans that may be necessary.

Site Preparation

Prior to beginning construction, the areas to be disturbed by construction or to be used as borrow locations must be cleared of trees, vegetation, roots, and any other materials. Soil stockpile locations must be graded to provide proper drainage and stabilized by seeding. Natural steep slopes such as those near channel banks should be re-graded to 1:1 or less. All trees within 15 feet of the embankment toe should be removed.

All soils that are used for the embankments and core trenches must either be approved by a geotechnical engineer or conform to GC, SC, CH, or CL by the Unified Soil Classification and have 30% passing the #200 sieve.

Structures and Propriety Devices

All structures and pre-fabricated devices must be installed to designer specifications. It is especially critical that orifices and overflow inverts are placed at the correct elevations. Trash racks must be properly installed so that no gap larger than the bar spacing is created between the outflow structure and the rack. Orifice screens should be installed so that the screen begins at the bottom of the micropool. This allows water to continue to enter the orifice plate even if clogging occurs due to floating debris.

Embankments

Embankments should be constructed per design specifications with a maximum allowable slope of 3:1. Areas with fill placement should be scarified prior to placing the fill lifts to improve adhesion. Fill should be placed in 8-12 inch lifts with each lift compacted with appropriate equipment prior to placement of the next lift.

Basin Geometry

All flow path lengthening features such as internal baffles must be constructed per the design to ensure that the basin flow length to width ratio is 2:1 or greater. The longitudinal slope of the low flow or trickle channel should be 0.4-1.0%.

Erosion Protection

Rip rap shall be placed below the outfall pipes and near the inflow point if necessary. Longitudinal slopes along the basin bottom shall not exceed 1%. Following construction, all exposed soils should be stabilized by hydroseeding or seeding under straw. Seeded areas must be tended until plants have established and reseeded if necessary.

Stormwater Pollution and Prevention Plan

During construction the extended detention basin must remain offline. Care should be given to design proper sedimentation precaution on-site during construction.

Provide Maintenance Access

To maintain EDBs, maintenance crews and equipment must occasionally access the forebay and micropool. The EDB design should incorporate a dedicated access easement from a public road to the basin and an appropriate maintenance staging area. The grading plan for the basin should incorporate access paths as appropriate for maintenance equipment to reach critical maintenance points including, for example, the forebay and outlet. The site geotechnical analysis will determine whether the access path must be stabilized to support heavy equipment.

APPENDIX F: **Critical Construction Considerations**

Cisterns

Cisterns and rain barrels can present safety hazards if improperly designed. Engineers should direct contractors to implement appropriate OSHA health and safety protocol when installing cisterns. Elevated rain barrels and tall cisterns should be securely anchored to prevent toppling and subsequent injury.

Vegetated Swales

Accurate fine grading of vegetated swales is important to prevent nuisance ponding and subsequent vector issues. Care should be taken to ensure positive drainage by providing slopes of 0-5% or steeper. Proper erosion control procedures are also important to protect swales during vegetation establishment. Temporary erosion control blankets, mats, and/or mulch should be applied per the recommendations in *(Barrett 2005)*. Turf reinforcement matting may be necessary for high flow areas.

Vegetated Filter Strips

The primary mechanism of failure for filter strips is the development of concentrated flow, which results in erosion and the formation of rills. Vegetated filter strips should thus be carefully graded to prevent concentration of flow and level spreaders (if used) should be completely level.

REFERENCES

Barrett, M.E. 2005. Complying with the Edwards Aquifer Rules. Technical Guidance on Best Management Practices. RG-348. Prepared for Texas Commission on Environmental Quality, Field Operations Division, Austin, TX.

Brown, R.A., and W. F. Hunt. 2010. Impacts of construction activity on bioretention performance. Journal of Hydrologic Engineering 15(6):386–394.

Brown, R.A., and W. F. Hunt. 2011b. Impacts of media depth on effluent water quality and hydrologic performance of under-sized bioretention cells. Journal of Irrigation and Drainage Engineering 137(3):132–143.

Carpenter, D.D., and L. Hallam. 2010. Influence of planting soil mix characteristics on bioretention cell design and performance. Journal of Hydrologic Engineering 15(6):404–416.

Fassman, E.A., and S.D. Blackbourn. 2010. Urban runoff mitigation by a permeable pavement system over impermeable soils. Journal of Hydrologic Engineering 15(6):475–485.

Hunt, W.F., C.S. Apperson, and W.G. Lord. 2005. Mosquito Control for Stormwater Facilities. Urban Waterways.

Luell, S.K., W.F. Hunt, and, R.J. Winston. 2011. Evaluation of undersized bioretention stormwater control measures (SCMs) for treatment of highway bridge deck runoff. Water Science and Technology 64(4):974–979.

Tyner, J.S., W.C. Wright, and P.A. Dobbs. 2009. Increasing exfiltration from pervious concrete and temperature monitoring. Journal of Environmental Management 90:2636–2641.

Wardynski, B.J., and W.F. Hunt. 2012. Are bioretention cells being installed per design standards in North Carolina: A field assessment. Journal of Environmental Engineering 138(12):1210–1217.

APPENDIX G: Operations & Maintenance

Proper maintenance is crucial for continued BMP performance. If BMPs are constructed over the Edwards Aquifer Recharge Zone, refer to Complying with the Edwards Aquifer Rules: Technical Guidance on Best Management Practices for maintenance guidance. Otherwise, see the text and subsequent tables G-1 through G-10 below for operations and maintenance guidance.

Bioretention & Bumpouts

Bioretention areas require regular plant, soil, and mulch layer maintenance to ensure optimum infiltration, storage, and pollutant-removal capabilities. Table G-1 (page 257) provides a detailed list of maintenance activities.

1. **Erosion control:** Inspect flow entrances, ponding area, and surface overflow areas periodically during the rainy season, and replace soil, plant material, or mulch layer in areas if erosion has occurred. Properly designed facilities with appropriate flow velocities should not have erosion problems except perhaps in extreme events. If erosion problems occur, the following must be reassessed: (1) flow velocities and gradients within the cell, and (2) flow dissipation and erosion protection strategies in the pretreatment area and flow entrance. If sediment is deposited in the bioretention area, immediately determine the source within the contributing area, stabilize, and remove excess surface deposits. Any exposed soil in the catchment should be permanently stabilized with grass, rock, or other erosion-resistant materials *(per TxDOT 2011)*.
2. **Inlet:** The inlet of the bioretention area should be inspected after the first storm of the season, then weekly during the rainy season to check for sediment accumulation and erosion. Sediment can accumulate especially at inlets where curb cuts or bypass structures are used and should be inspected regularly. Any accumulated sediment that impedes flow into the bioretention area should be removed and properly disposed of. The inlet of street-side bioretention and bumpouts should be inspected regularly for trash debris that may impede flows.
3. **Overflow and underdrains:** Sediment accumulation in the overflow device or underdrain system can cause prolonged ponding and potential flooding. Excess ponding can have adverse effects on vegetation and vector control. Overflow and underdrain systems should be inspected after the first storm of the season, then weekly during the rainy season to remove sediment and prevent mulch accumulation around the overflow. The underdrain system should be designed so that it can be flushed and cleaned as needed. If water is ponded in the bioretention area for more than 72 hours, the underdrain system should be flushed with clean water until proper infiltration is restored. Street-side bioretention and bumpouts should be inspected regularly for trash debris that may impede flow of the system and cause prolonged ponding.
4. **Plant material:** Depending on aesthetic requirements, occasional pruning and removing dead plant material might be necessary. Replace all dead plants, and if specific plants have a high mortality rate, assess the cause and, if necessary, replace with more appropriate species. Periodic weeding is necessary until plants are established. The weeding schedule can become less frequent if the appropriate plant species and planting density have been used and, as a result, undesirable plants are excluded.
5. **Nutrient and pesticides:** The soil mix and plants are selected for optimum fertility, plant establishment, and growth. Nutrient and pesticide inputs should not be required and can degrade the pollutant processing capability of the bioretention area and contribute pollutant loads to receiving waters. By design, bioretention areas are located in areas where phosphorous and nitrogen levels are often elevated. If in question, have the soil analyzed for fertility.
6. **Mulch:** Replace mulch annually in bioretention areas where heavy metal deposition is likely (e.g., contributing areas that include industrial and auto dealer/repair parking lots and roads). In areas where metal deposition is not a concern, add mulch as needed to maintain a 2- to 3-inch depth. Mulch should be replaced every 2 to 3 years.
7. **Soil:** Soil mixes for bioretention areas are designed to maintain long-term fertility and pollutant processing capability. Estimates from metal attenuation research suggest that metal accumulation should not present an environmental concern for at least 20 years in bioretention systems. Replacing mulch in bioretention areas where heavy metal deposition is likely provides an additional level of protection for prolonged performance. If in question, have the soil analyzed for fertility and pollutant levels and consult local regulations for disposal protocol.
8. **Watering:** Plants must be selected to be drought tolerant and not require watering after establishment (3 years). Watering could be required during prolonged dry periods after plants are established.

REFERENCES:

TxDOT (Texas Department of Transportation). 2011. Chapter 13, Section 2. Soil Erosion Control Considerations. Hydraulic Design Manual. Austin, TX.

APPENDIX G: **Operations & Maintenance**

Bioswales

Bioswales, similar to bioretention areas, require regular plant, soil, and mulch layer maintenance to ensure optimum infiltration, storage, and pollutant-removal capabilities. Table G-1 (next page) lists maintenance tasks for bioswales.

1. **Erosion control:** Inspect flow entrances, ponding area, and surface overflow areas periodically during the rainy season, and replace soil, plant material, or mulch layer in areas if erosion has occurred. Properly designed facilities with appropriate flow velocities will not have erosion problems except perhaps in extreme events. If erosion problems occur, the following must be reassessed: (1) flow velocities and gradients within the cell, and (2) flow dissipation and erosion protection strategies in the pretreatment area and flow entrance. If sediment is deposited in the bioswale, immediately determine the source in the contributing area, stabilize, and remove excess surface deposits. Any exposed soil in the catchment should be permanently stabilized with grass, rock, or other erosion-resistant materials *(per TxDOT 2011)*.

2. **Inlet:** The inlet area should be inspected after the first storm of the season, then weekly during the rainy season to check for sediment accumulation and erosion. Sediment can accumulate especially at inlets where curb cuts or bypass structures are used and should be inspected regularly. Any accumulated sediment that impedes flow into the bioswale should be removed and properly disposed of.

3. **Overflow and underdrains:** Sediment accumulation in the overflow device or underdrain system can cause prolonged ponding and potential flooding. Excess ponding can have adverse effects on vegetation and vector control. Overflow and underdrain systems should be inspected after the first storm of the season, then weekly during the rainy season to remove sediment and prevent mulch accumulation around the overflow. The underdrain systems should be designed so that it can be flushed and cleaned as needed. If water is ponded in the bioswale for more than 72 hours, the underdrain system should be flushed with clean water until proper infiltration is restored.

4. **Plant material:** Depending on aesthetic requirements, occasional pruning and removing of dead plant material might be necessary. Replace all dead plants, and if specific plants have a high mortality rate, assess the cause and, if necessary, replace with more appropriate species. Periodic weeding is necessary until plants are established. The weeding schedule could become less frequent if the appropriate plant species and planting density have been used and, as a result, undesirable plants are excluded.

5. **Nutrient and pesticides:** The soil mix and plants are selected for optimum fertility, plant establishment, and growth. Nutrient and pesticide inputs should not be required and can degrade the pollutant processing capability of the bioswale, and contribute pollutant loads to receiving waters. By design, bioswales are located in areas where phosphorous and nitrogen levels are often elevated, and those should not be limiting nutrients. If in question, have the soil analyzed for fertility.

6. **Mulch:** Replace mulch annually where heavy metal deposition is likely (e.g., contributing areas that include industrial and auto dealer/repair parking lots and roads). In areas where metal deposition is not a concern, add mulch as needed to maintain a 2- to 3-inch depth. Mulch should be replaced every 2 to 3 years.

7. **Soil:** Soil mixes are designed to maintain long-term fertility and pollutant processing capability. Estimates from metal attenuation research suggest that metal accumulation should not present an environmental concern for at least 20 years. Replacing mulch where heavy metal deposition is likely provides an additional level of protection for prolonged performance. If in question, have soil analyzed for fertility and pollutant levels and check local regulations for disposal protocol.

8. **Watering:** Drought-tolerant plants should be selected to reduce watering after establishment (2 to 3 years). Watering might be required during prolonged dry periods after plants are established.

REFERENCES:

TxDOT (Texas Department of Transportation). 2011. Chapter 13, Section 2. Soil Erosion Control Considerations. Hydraulic Design Manual. Austin, TX.

APPENDIX G: Operations & Maintenance

Bioretention, Street-side Bioretention, Bioswales, Bump-outs, & Planter Boxes Table G-1

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Catchment inspection	Weekly with routine property maintenance; before and after significant storm events	Excessive sediment, trash, or debris accumulation on the surface of bioswale, etc.	Permanently stabilize any exposed soil and remove any accumulated sediment. Adjacent pervious areas might need to be re-graded.
Inlet inspection	Weekly with routine property maintenance	Internal erosion or excessive sediment, trash, or debris accumulation	Check for sediment accumulation to ensure that flow into the bioretention is as designed. Remove any accumulated sediment.
Litter and leaf litter removal	Weekly with routine property maintenance	Accumulation of litter and leafy debris in the bioswale area	Litter and leaves should be removed to reduce the risk of outlet clogging, reduce nutrient inputs to the bioretention area and to improve aesthetics.
Pruning	1-2 times per year or as needed	Overgrown vegetation that interferes with access, lines of sight, or safety	Nutrients in runoff often cause bioretention vegetation to flourish and grow quicker and larger than anticipated.
Weeding	Weekly with routine property maintenance	Appearance of undesirable plant material	Control weeds using Integrated Pest Management strategies. Avoid treatment with herbicides preferred. Some features will be naturally more prone to infestations due to location and the surrounding environment.
Mowing	2-12 times per year	Overgrown vegetation	Frequency depends on location, desired aesthetic appearance, and type of vegetation.
Mulch removal and replacement	Once every 2-3 years	Less than 3 inches of mulch remains, or mulch has become matted reducing moisture and oxygen infiltration.	Removing matted, decomposed mulch increases moisture and oxygen infiltration rate. Remove matted layer and replace with fresh mulch to a total depth of no more than 3 inches.
Temporary irrigation	Once every 2-3 days for the first 1-2 months then less frequently, depending on plant material and environmental conditions, until established	Dull leaf color and plant wilting	Watering after plant establishment during periods of drought or for aesthetics may be required.
Remove and replace dead plants	As needed	Dead or missing plants	Plant die-off tends to be highest during the first year. Maintaining complete plantings helps to reduce weed encroachment and improve feature functionality.
Outlet inspection	Weekly with routine property maintenance	Debris and/or erosion at outlet	Remove any accumulated mulch or sediment and repair any erosion.
Miscellaneous	Weekly with routine property maintenance	Tasks may include trash collection, plant health observations, spot weeding, and removing mulch and debris from overflow devices. Look for evidence of erosion or rutting, vehicular damage, vandalism, etc.	

Note: Not all maintenance tasks will apply to all BMPs (e.g. Planter Boxes are not mowed).

Permeable Pavement

Maintenance of permeable pavement systems is critical to the overall and continued success of the system. Specific maintenance activities are listed in Table G-2. Key maintenance procedures consist of the following:

1. Adjacent areas that drain to the permeable pavement area should be permanently stabilized and maintained to limit the sediment load to the system.
2. Vacuum sweeping should be typically performed a minimum of twice a year. Adjust the frequency according to the intensity of use and deposition rate on the permeable pavement surface.
3. Any weeds that grow in the permeable pavement should be sprayed with pesticide immediately. Weeds should not be pulled, because doing so can damage the fill media.
4. Mowing and trimming turf grass used with permeable pavers and plastic grid systems must be performed regularly according to site conditions. Grass should be mowed at least once a month in the growing season. All vegetated areas must be inspected at least annually for erosion and scour.

Permeable Pavement
Table G-2

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Catchment inspection	Weekly with routine property maintenance	Sediment accumulation on adjacent impervious surfaces or in voids/joints of permeable pavement	Stabilize any exposed soil and remove any accumulated sediment. Adjacent pervious areas might need to be graded to drain away from the pavement.
Standard maintenance	Weekly with routine property maintenance	Trash, leaves, weeds, or other debris accumulated on permeable pavement surface	Remove debris to prevent migration into permeable pavement voids. Identify the source of the debris to mitigate or plan for future maintenance needs.
Preventive vacuum/ regenerative air street sweeping	Twice a year	N/A	Pavement should be swept with a vacuum power or regenerative air sweeper at least twice per year to maintain infiltration rates.
Restorative maintenance	As needed	Surface infiltration test indicates poor performance or water is ponding on pavement surface during rain events	Pavement should be swept with a vacuum power or regenerative air street sweeper to restore infiltration rates. Sidewalk should be blown or swept away from the permeable pavement system.
Replace fill materials	As needed	For paver systems, whenever void space between joints becomes apparent or after vacuum sweeping	Replace bedding fill material to keep fill level with the paver surface and prevent shifting.

Green Roofs

Inspection and maintenance are critical to ensuring safe and effective functioning of green roofs. Table G-3 provides specific inspection and maintenance tasks.

Green Roofs
Table G-3

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Media inspection	2 times per year Coordinate with other roof inspections	Internal erosion of media from runoff or wind scour, exposed underlayment components	Replace eroded media and vegetation. Adopt additional erosion prevention practices as appropriate.
Liner inspection		Liner is exposed or tenants have experienced leaks	Evaluate liner for cause of leaks. Repair or replace as necessary.
Outlet inspection		Accumulation of litter and debris around the roof drain or scupper, or standing water in adjacent areas.	Litter, leaves, and debris should be removed to reduce the risk of outlet clogging. If sediment has accumulated in the gravel drain buffers, remove and replace the gravel.
Vegetation inspection		Dead plants or excessive open areas on green roof	Within the first year, 10% of plants can die. Survival rates increase with time.
Invasive vegetation		Presence of unwanted or undesirable species	Remove undesired vegetation. Evaluate green roof for signs of excessive water retention.
Temporary watering	Once every 2-3 days for the first 1-2 months then less frequently, depending on plant material and environmental conditions, until established	Dull leaf color and plant wilting	Watering after plant establishment during periods of drought or for aesthetics may be required.

APPENDIX G: **Operations & Maintenance**

Sand Filters

Sand filters require regular, frequent maintenance of the media layer and pretreatment devices to ensure optimum infiltration, storage, and pollutant removal capabilities. Key activities are described below:

1. **Erosion control:** Inspect flow entrances, ponding area, and surface overflow areas periodically during the rainy season, and replace vegetation or erosion control materials if erosion has occurred. Properly designed facilities with appropriate flow velocities will not have erosion problems except perhaps in extreme events. If erosion problems occur, the following must be reassessed: (1) flow velocities and gradients within the filter, and (2) flow dissipation and erosion protection strategies in the pretreatment area and flow entrance. If sediment other than the designed soil media is deposited in the media chamber, immediately determine the source in the contributing area, stabilize, and remove excess surface deposits.
2. **Inlet:** The inlet should be inspected after the first storm of the season, then monthly during the rainy season to check for sediment accumulation and erosion. Sediment can accumulate, especially at inlets where bypass structures are used, and should be inspected regularly. Any accumulated sediment that impedes flow into the sand filter should be removed and properly disposed of. Flow spreaders should be cleaned and reset as needed to maintain diffuse flows.
3. **Overflow and underdrains:** Sediment accumulation in the overflow device or underdrain system can cause prolonged ponding and potential flooding. Overflow and underdrain systems should be inspected after the first storm of the season, then monthly during the rainy season to remove sediment accumulation around the overflow. The underdrain system should be designed so that it can be flushed and cleaned as needed. If water is ponding over the filter media for more than 72 hours, the underdrain system should be flushed with clean water until proper infiltration is restored. Flow spreaders should be checked to maintain diffuse flow.
4. **Sand media:** If in question, have the soil analyzed for pollutant levels. A sediment depth indicator may be installed in the sedimentation chamber to indicate the depth of sediment accumulation as an indication that maintenance is required *(according to Barrett 2005)*.
5. **General maintenance:** Trash and debris should be removed from the sand filter as needed. Any visual evidence of contamination from pollutants such as oil and grease should be removed as needed.

REFERENCES

Barrett, M.E. 2005. Complying with the Edwards Aquifer Rules. Technical Guidance on Best Management Practices. RG-348. Prepared for Texas Commission on Environmental Quality, Field Operations Division, Austin, TX.

Sand Filters

Table G-4

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Catchment inspection	Weekly with routine property maintenance	Excessive sediment, trash, or debris accumulation on the surface of sand filter	Permanently stabilize any exposed soil and remove any accumulated sediment. Adjacent pervious areas might need to be re-graded.
Inlet inspection	Once after first major storm event of the season, then monthly	Debris or sediment has blocked inlets	Remove any accumulated material.
Sedimentation chamber/forebay inspection	Once a month	Sediment has reached 6 inches deep (install a fixed vertical sediment depth marker) or litter and debris has clogged weirs between sedimentation chamber and sand filter chamber (for subsurface filters)	Remove accumulated material from sedimentation chamber. Remove and replace top 2 to 3 inches of sand filter if necessary.
Sand filter surface infiltration inspection	After major storm events or biannually	Surface ponding draws down in more than 48 hours	Remove and replace top 2 to 3 inches of sand filter, or as needed to restore infiltration capacity. Inspect watershed for sediment sources.
Outlet inspection	Once after first major storm event of the season, then monthly	Erosion or sediment deposition at outlet	Check for erosion at the outlet and remove any accumulated sediment.
Miscellaneous maintenance	Once a month	Tasks include trash collection, spot weeding, replacing soil media, and removing visual contamination.	

Stormwater Wetlands

Inspection and maintenance area key to ensure the proper function and aesthetics of stormwater wetlands. Table G-5 lists specific operation and maintenance tasks.

Stormwater Wetlands
Table G-5

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Forebay inspection	Weekly with routine property maintenance	Internal erosion or excessive sediment, trash, or debris accumulation	Check for sediment accumulation to ensure that forebay capacity is as designed. Remove any accumulated sediment.
Basin inspection	Annually	Excessive sediment, trash, and/or debris accumulation in the wetland	Remove any accumulated sediment and debris and trash. Adjacent pervious areas might need to be re-graded to help control sedimentation.
Outlet inspection	Weekly with routine property maintenance	Accumulation of litter and debris in wetland area, large debris around outlet, internal erosion.	Remove litter, leaves, and debris to reduce the risk of outlet clogging and to improve facility aesthetics. Erosion should be repaired and stabilized.
Mowing	2-12 times per year	Overgrown vegetation on embankment or adjacent areas	Need and frequency depends on vegetation, location, and desired aesthetic appearance.
Embankment inspection	Annually	Erosion at embankment	Repair eroded areas and revegetate.
Plant replacement	Annually	Dead plants or excessive open areas in wetland	Plant die-off tends to be highest during the first year. Survival rates increase with time.
Temporary irrigation	Once every 2-3 days for the first 1-2 months then less frequently, depending on plant material and environmental conditions, until established	Dull leaf color and plant wilting	Watering after the initial establishment may be required under drought conditions.
Nuisance wildlife management	Weekly as needed	Animals, feces, or burrows evident in or around wetland	Maintain diverse vegetated shelf around entire basin. Eliminate monocultures and replace with diverse vegetation. Employ qualified wildlife management professionals if needed.

Extended Detention Basins

Inspection and maintenance are key to ensure the proper function and aesthetics of EDBs. Table G-6 lists specific operation and maintenance tasks.

Extended Detention Basin

Table G-6

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Forebay inspection	Weekly with routine property maintenance	Internal erosion or excessive sediment, trash, or debris accumulation	Check for sediment accumulation to ensure that forebay capacity is as designed. Remove any accumulated sediment, trash, and debris and repair erosion and stabilize.
Basin inspection	Annually	Cracked, eroded, or broken structural components	Repair basin inlets, outlets, forebays, low flow channel liners, and energy dissipaters when damage is discovered.
Outlet inspection	Weekly with routine property maintenance	Accumulation of litter and debris in basin area, large debris around outlet, internal erosion	Remove litter, leaves, and debris to reduce the risk of clogging and to improve facility aesthetics. Erosion should be repaired and stabilized.
Mowing	Twice a year if needed	Overgrown vegetation on embankment or adjacent areas	Frequency depends on vegetation, location, and desired aesthetic appearance.
Embankment inspection	Annually	Erosion at embankment	Repair eroded areas and revegetate to stabilize.
Vegetation	Annually	Dead plants, woody growth on embankments	Plant die-off tends to be highest during the first year. Survival rates increase with time. Remove trees that encroach embankment toe, top, and buffer area.
Temporary irrigation	Once every 2-3 days for the first 1-2 months then less frequently, depending on plant material and environmental conditions, until established	Dull leaf color and plant wilting	Watering after the initial establishment may be required under drought conditions.
Nuisance control	Weekly as needed	Animals, feces, or burrows evident in or around EDB; Odor	Employ qualified wildlife management professionals if needed. Remove conditions that create odors.

Stormwater Cistern
Table G-7

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Gutter and rooftop inspection	Biannually and before heavy rain events are expected	Stormwater does not enter cistern	Clean gutters and roof of debris that have accumulated, check for leaks
Inlet filter inspection	Monthly and/or after rain events	Stormwater does not enter cistern	Filter is clogged with debris or scum layer has formed on the screen.
First flush diverter	Monthly and/or after rain events	Diverter does not empty after rain event	The orifice on a passive outlet is often very small. Check that the orifice is not clogged, and the first flush diverter can drain properly.
Check for organic accumulation	Monthly	The water will have a bad odor, a sulfur or rotten egg smell	The odor will occur when organic material, such as pollen or leaves, builds up in the cistern. Shock chlorination or a monthly chlorination maintenance routine can be used to address the odor.
Vector control	Monthly	Presence of mosquitos	Check screens on all the inlets and outlets. Add mosquito dunks (Bti) to the tank if necessary.
Structure inspection	Biannually	Cistern is leaning or soils are slumping or eroding around the foundation	Check the cistern for stability and anchor if necessary. Stabilize/repair minor slumping or erosion.
Structure inspection	Biannually	Leaks	Check pipe, valve connections, and cistern structure for leaks. Overflow outlet should be free of debris and free flowing.
Add ballast	Before any major wind-related storms	Tall, high profile tank less than half full	Add water to half full.
Miscellaneous	Annually	Make sure cistern access port is operational and secure. Check for sediment accumulation in the bottom of the tank. Sediment accumulations which inhibit the cistern's outlet or are in excess of 6 inches should be removed.	

Vegetated Swales

1. Inspect vegetated swales for erosion or damage to vegetation at least twice annually for offline swales, preferably at the beginning and end of the wet season. Additional inspection during the wet season(s) and after periods of heavy runoff is recommended. Each swale should be checked for debris and litter and areas of sediment accumulation.
2. Inspect inlets for erosion and sediment accumulation twice annually. Remove sediment if it is blocking the entry of stormwater. After sediment is removed, vegetation replanting or reseeding might be required. Repair erosion immediately and stabilize.
3. Side slopes should be maintained to prevent erosion. Slopes should be stabilized and planted using appropriate vegetation when native soil is exposed or erosion is observed.
4. Swales should drain within 48 hours. If a gravel drainage layer is incorporated underneath the swale to promote infiltration, the layer should drain within 72 hours of the end of the storm. Till the swale if compaction or clogging occurs. The perforated underdrain pipe, if present, should be cleaned if necessary.
5. Vegetation should be healthy and dense enough for filtration while protecting underlying soils from erosion. Specific maintenance items for vegetation are listed in Table G-8 and consist of the following:
   - Vegetation, large shrubs, or trees that interfere with landscape swale operation should be pruned.
   - Fallen leaves and debris from deciduous plant foliage should be removed.
   - Grassy swales should be mowed to keep grass at least 4 to 6 inches minimum height. Grass clippings should be removed, and mowing should be performed perpendicular to the direction of flow such that no preferential flow paths are created by ruts.
   - Invasive vegetation must be removed and replaced with noninvasive species.
   - Dead vegetation should be removed if it composes more than 10 percent of the area covered or when swale function is impaired. Vegetation should be replaced and established before the wet season to maintain cover density and control erosion where soils are exposed.
6. Check dams (if present) should control and distribute flow across the swale. Identify causes for altered water flow and channelization, and clear obstructions. If damaged, repair check dams. The vegetated swale should be well maintained; trash and debris, sediment, visual contamination (e.g. oils), and noxious or nuisance weeds should be removed.

Vegetated Filter Strips

The primary maintenance requirement of a vegetated filter strip is managing vegetation in the filter strip. As a result, specialized equipment and training of maintenance crews is typically not necessary. Maintenance activities for vegetated filter strips are listed in Table G-8 and include the following:

- Regular mowing to maintain visual aesthetics. Grass height should be maintained at a minimum of 4 inches high. Clippings should be removed so flow is not impeded. Mowing should be performed perpendicular to the direction of flow to prevent preferential flow paths caused by wheel ruts.
- Remove accumulated sediment from the inlet lip of the vegetated filter strip when accumulation is obvious (monthly during seasons of heavy rainfall).
- Weeds and other vegetation should be removed as needed being careful not to cause pits or exposed soil that could lead to increased erosion.

Vegetated Swales and Vegetated Filter Strips

Table G-8

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Inlet inspection	Twice annually or after storm event	Ponding occurring at inlet	Check for sediment accumulation and/or uneven flow spreader.
Outlet inspection	Twice annually or after storm event	Ponding occurring in feature	Check for debris or trash accumulation and/or erosion at outlet.
Mowing	2-12 times a year	Overgrown vegetation	Frequency depends on location, desired aesthetic appearance, and type of vegetation. 4” minimum grass height preferred.
Weeding	Monthly as needed	Appearance of undesirable or invasive plant material	Control weeds using Integrated Pest Management strategies. Avoid treatment with herbicides preferred. Some features will be naturally more prone to infestations due to location and the surrounding environment.
Remove and replace dead plants	As needed	Bare space, exposed soil	Plant die-off tends to be highest during the first year. Maintaining complete plantings helps to reduce weed encroachment and is necessary to prevent erosion.
Temporary irrigation	Once every 2-3 days for the first 1-2 months then less frequently, depending on plant material and environmental conditions, until established	Dull leaf color and plant wilting	Watering after plant establishment during periods of drought or for aesthetics may be required.
Inspect check dams	Once before the wet season(s) and monthly during the wet season(s)		Check for sediment accumulation and erosion around or underneath the dam materials.
Miscellaneous	Monthly	Trash collection and erosion and/or rut repairs	

Vegetated Stream Buffer
Table G-9

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Pruning	1-2 times per year or as needed	Overgrown vegetation that interferes with lines of sight or safety	Nutrients in runoff often cause vegetation to flourish and grow quicker and larger than anticipated.
Weeding	Weekly with routine property maintenance	Appearance of undesirable or invasive plant material	Control weeds using Integrated Pest Management strategies. Avoid treatment with herbicides preferred. Some features will be naturally more prone to infestations due to location and the surrounding environment.
Plant replacement	1-2 times per year or as needed	Bare or sparsely covered areas	Expanding canopy growth over time may limit the amount of light reaching understory plantings requiring a transition to more shade tolerant species.
Temporary irrigation	Once every 2-3 days for the first 1-2 months then less frequently, depending on plant material and environmental conditions, until established	Dull leaf color and plant wilting	Watering after plant establishment during periods of drought or for aesthetics may be required.
Embankment inspection	Annually and after storm events	Erosion at embankment	Repair eroded areas and revegetate.
Nuisance wildlife management	Weekly as needed	Animals, slides, or burrows evident in embankments	Employ qualified wildlife management professionals if needed.
Miscellaneous	Weekly with routine property maintenance	Trash and debris cleanup, look for evidence of erosion or vandalism, ect.	

Note: Some of these tasks may not be applicable to naturally occurring streams.

Batch Detention
Table G-10

Task	Frequency	Indicator maintenance is needed	Maintenance notes
Forebay inspection	Weekly; following storm events	Internal erosion or excessive sediment, trash, or debris accumulation	Check for sediment accumulation to ensure that forebay capacity is as designed. Remove any accumulated sediment, trash, and debris and repair erosion and stabilize.
Basin inspection	Annually	Cracked, eroded, or broken structural components	Repair basin inlets, outlets, forebays, low flow channel liners, and energy dissipaters when damage is discovered.
Outlet inspection	Weekly; following storm events	Accumulation of litter and debris in basin area, large debris around outlet, internal erosion	Remove litter, leaves, and debris to reduce the risk of clogging and to improve facility aesthetics. Erosion should be repaired and stabilized.
Automatic controller and valve	Twice a year	Target detention time of 12 hours and drawdown time of no more than 48 hours is deficient or exceeded	One inspection during wet weather to determine if the basin is meeting the target detention and drawdown time; another inspection between storm events to manually verify proper operation of the valve and controller.
Mowing	Twice a year if needed	Overgrown vegetation on embankment or adjacent areas	Frequency depends on vegetation, location, and desired aesthetic appearance.
Embankment inspection	Annually	Erosion at embankment	Repair eroded areas and revegetate to stabilize.
Vegetation	Annually	Dead plants, woody growth on embankments	Plant die-off tends to be highest during the first year. Survival rates increase with time. Remove trees that encroach embankment toe, top, and buffer area.
Temporary irrigation	Once every 2-3 days for the first 1-2 months then less frequently, depending on plant material and environmental conditions, until established	Dull leaf color and plant wilting	Watering after the initial establishment during drought or for aesthetics may be required.
Nuisance control	Weekly as needed	Animals, feces, or burrows evident in or around batch detention; Odor	Employ qualified wildlife management professionals if needed. Remove conditions that create odors.

Proprietary Systems

See manufacturer's guidance for maintenance tasks, frquency, and need indicators.

APPENDIX H: **ADA Requirements**

BMPs typically require surfaces with little to no slope, therefore, Americans with Disabilities Act (ADA) requirements are rarely an issue. However, in areas with high levels of pedestrian traffic, some effort should be made to delineate the BMP. Several options—including low-level and decorative fencing, such as the one shown in Figure H-1, or a low-profile curb, as shown in Figure H-2, can often be used to delineate the space around the BMP and alert pedestrians of the change in grade.

Coordinate with the local municipality regarding sheet flow over pathways.

Figure H-1 (left) *Low-level fencing, San Antoino, TX. Source: San Antonio RIver Authority*
Figure H-2 (right) *Low-profile curbing, Greensboro, NC. Soucre: Tetra Tech*

REFERENCES

Barrett, M.E. 2005. Complying with the Edwards Aquifer Rules. Technical Guidance on Best Management Practices. RG-348. Prepared for Texas Commission on Environmental Quality, Field Operations Division, Austin, TX.

Fassman, E.A. and S. Blackbourn. 2010. Urban runoff mitigation by a permeable pavement system over impermeable soils. Journal of Hydrologic Engineering 15(6):475-485.

TxDOT (Texas Department of Transportation). 2011. Chapter 13, Section 2. Soil Erosion Control Considerations. Hydraulic Design Manual. Austin, TX.

UDFCD (Urban Drainage and Flood Control District). 2010. T-12 Outlet Structures. Urban Storm Drainage Criteria Manual, Volume 3 – Best Management Practices. Denver, CO. http://www.udfcd.org/downloads/down_critmanual_volIII.htm.

Notes:

APPENDIX I: **San Antonio River Authority District Maps**

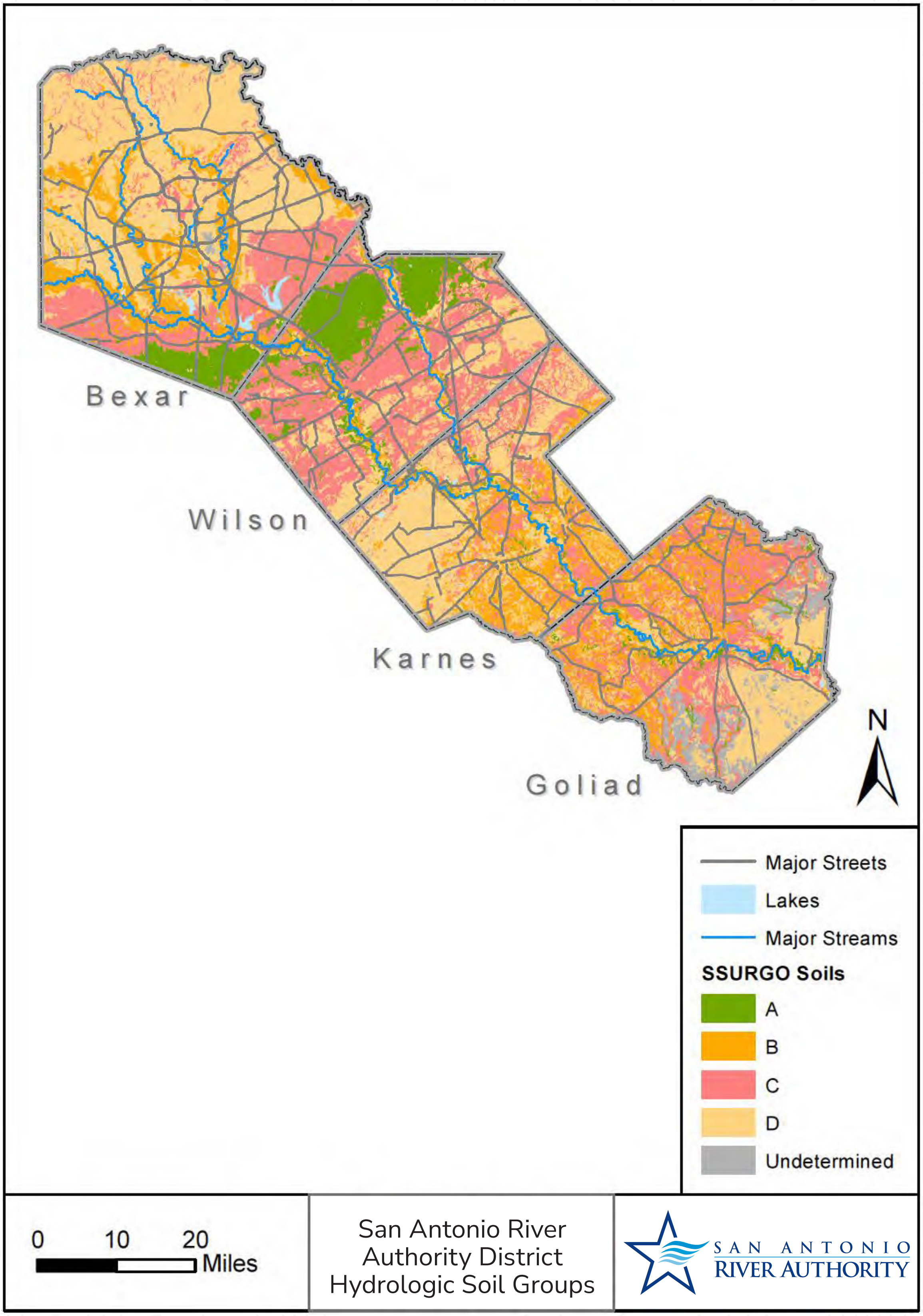


Figure 2-1. Hydrologic soil groups for San Antonio River Authority District

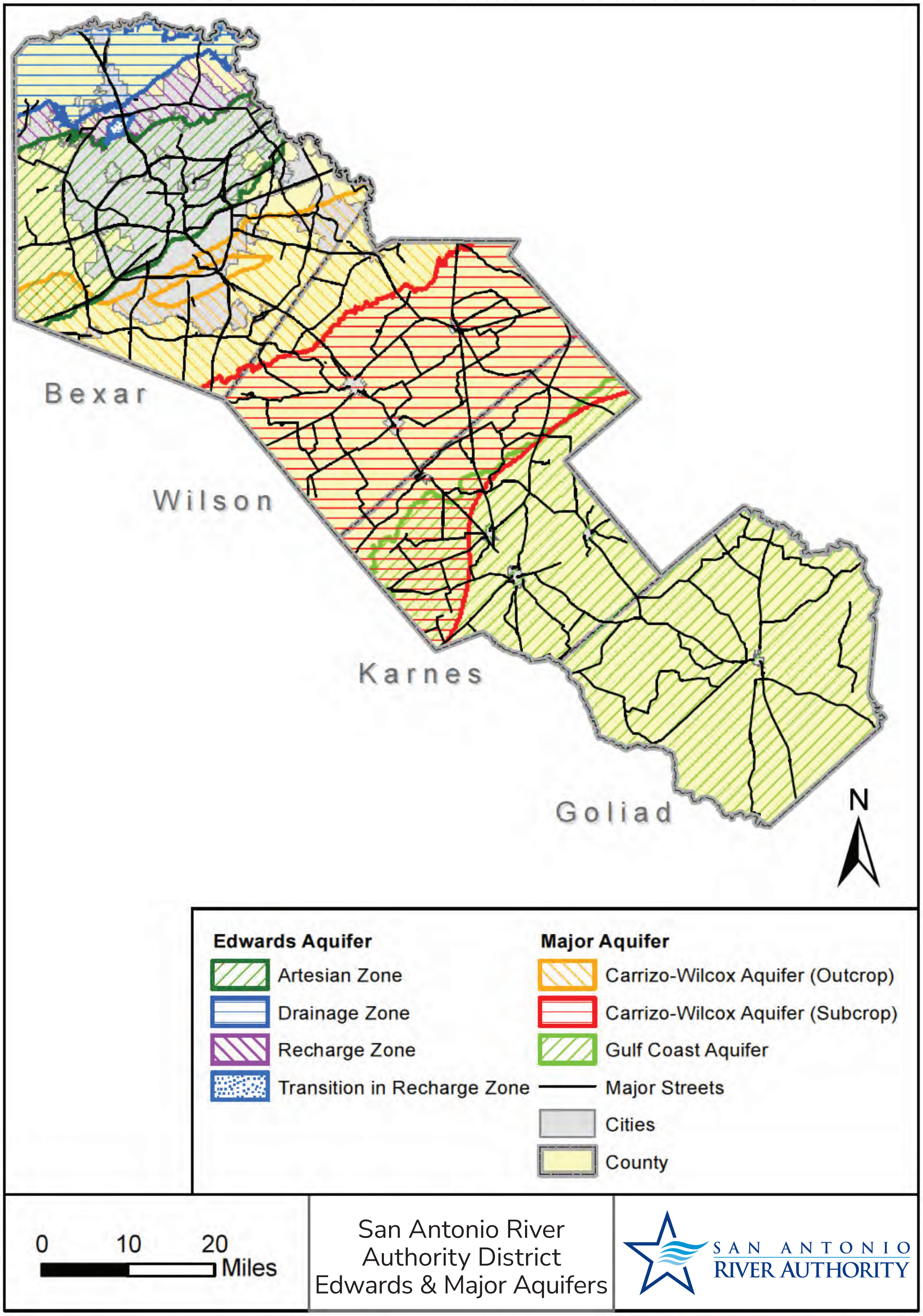


Figure 2-2.
Artesian, drainage, recharge, and transition zones of the San Antonio River Authority District

APPENDIX I: **San Antonio River Authority District Maps**

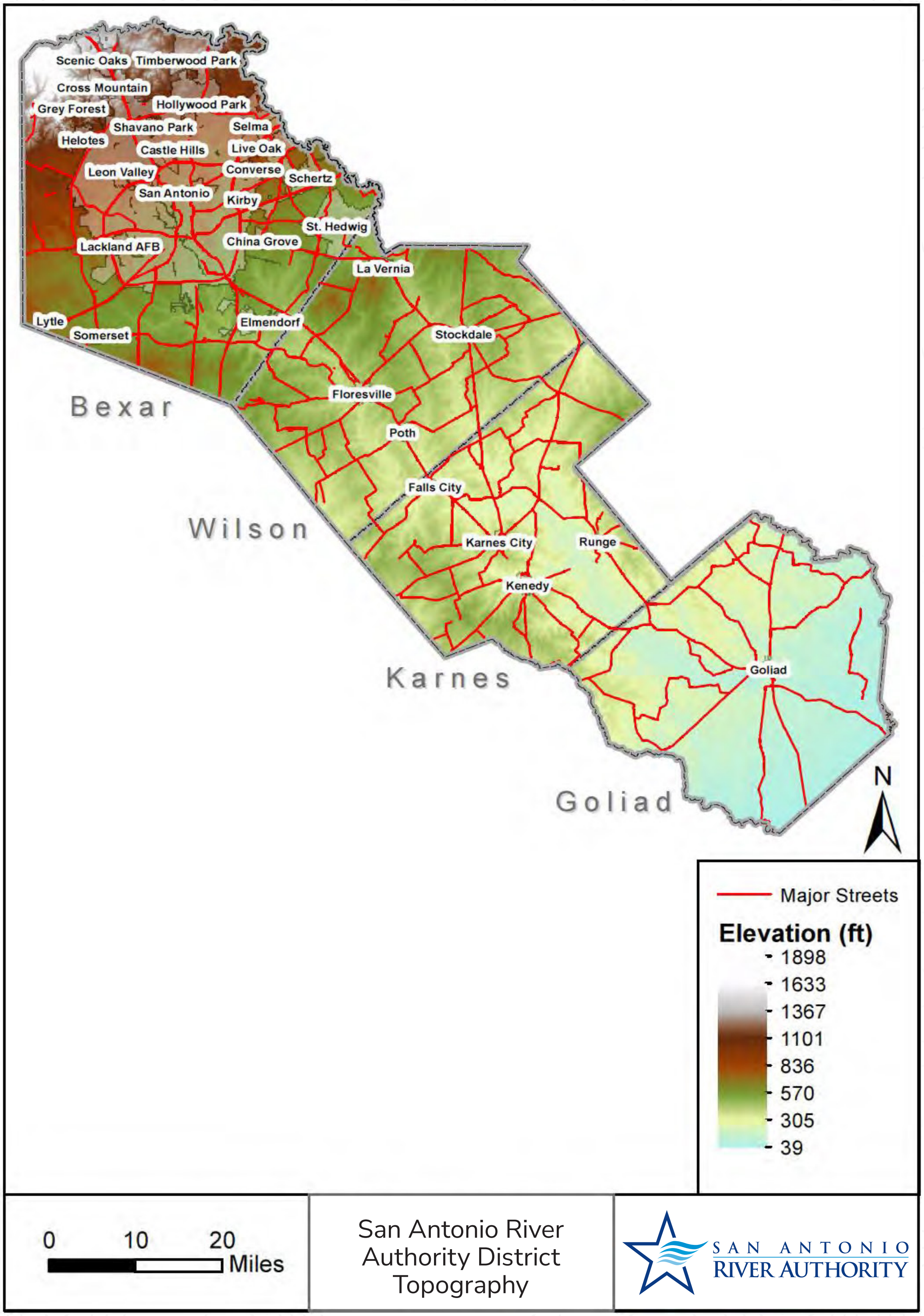


Figure 2-3. Topography of the San Antonio River Authority District

Notes:

APPENDIX J: **BMP Sizing & Performance Curves**

PERFORMANCE CURVE DEVELOPMENT

Process-based continuous simulation models were used to generate the BMP performance curves. The watershed runoff response was simulated using the Hydrologic Simulation Program in FORTRAN (HSPF), while BMP responses were simulated using the System for Urban Stormwater Analysis and INtegration (SUSTAIN). Both HSPF and SUSTAIN estimate runoff volume and pollutant fate and transport at a high temporal resolution (i.e. hourly or sub-hourly). Although not used in this analysis, anther model commonly used for rainfall/runoff and storage/transport simulation is the StormWater Management Model (SWMM). One advantage of continuous simulation is its ability to show varied storm responses as a function of antecedent conditions. For example, a storm occurring in the spring immediately after another rainfall event will have a notably different response than an isolated storm of the same size occurring in the summer. Not only would runoff and pollutant loads differ, but also BMP performance would differ. The modeling approach used to generate the BMP performance curves considers all of those interactions when estimating BMP performance. In fact, it is the aggregations of those interactions that make BMP performance vary in a non-linear way as a function of BMP size.

Runoff hydrograph and pollutograph boundary conditions for the BMP performance curves presented here were generated using the HSPF models provided to Tetra Tech by SARA. The two major drainage basins represented by these models were Salado Creek and the Upper San Antonio River in Bexar County, Texas. The impervious land (IMPLND) blocks from those existing HSPF models served as the basis for generating runoff boundary conditions as input to SUSTAIN. The IMPLND block produces runoff volume and associated pollutant loadings, which represent BMP inflow for SUSTAIN. Figure J-1 is a schematic illustrating the various HSPF and SUSTAIN processes as well as the linkage between the two models.

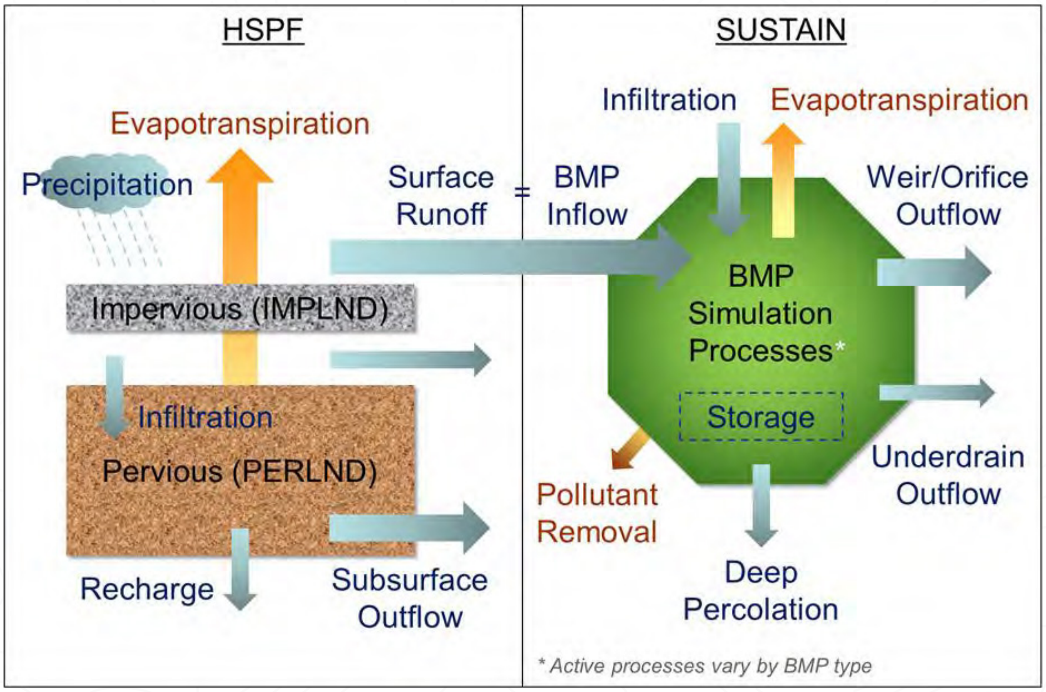


Figure J-1. *Schematic of simulated HSPF and SUSTAIN processes and surface runoff linkage.*

APPENDIX J: **BMP Sizing & Performance Curves**

Model evaluation revealed that there were two unique groups of IMPLND runoff boundary conditions represented in the HSPF models, as summarized in Table J-1. Meteorological data from Station #12921 in the HSPF Watershed Data Management (WDM) file for calendar year 2007 were used to generate runoff hydrographs and pollutographs. That selected rainfall gage (12921) was evaluated against long-term National Climatic Data Center (NCDC) observed rainfall at San Antonio International Airport, as summarized in Figure J-2. Among calendar years-in-common, 2007 was selected for this analysis because it had both the highest annual precipitation volume and the highest number of days with rainfall than any other year available in the HSPF WDM file.

TABLE J-1. SUMMARY OF LAND USE TYPES FROM THE SALADO AND USAR HSPF MODELS

Land Use Group	Land Use Type	Hspf Classification
Residential	Dispersed	Residential Dispersed
	Low	Residential Low
	Medium	Residential Medium
	High	Residential High
	Multi-Family	Residential Multi-Family
Other Urban	Commercial	Commercial
	Industrial	Industrial
		Services Mixed-Use
		Services Utilities
	Transportation	Transportation
	Open Space	Open Space Easements
Water	Water (Not Considered Here)	Water

Use local municipality's definition of low, medium, high, etc.

APPENDIX J: **BMP Sizing & Performance Curves**

Input parameters for the SUSTAIN model runs for all BMPs are available from the San Antonio River Authority upon request. BMPs were modeled for a range of site conditions, defined by hydrologic soil groups A, B, C, and D. An underdrain option was available for certain BMP types, as outlined in Table J-2 below. As shown in Table J-2, eight responses were modeled for every type of BMP. For bacteria, two different responses were modeled because the HSPF runoff loads from non-residential land use types were 50 percent lower than those from residential (as shown in Figure J-3 below). With the exception of Open Space Easements and Water, which are not relevant for runoff inputs for this BMP analysis, all other modeled HSPF boundary condition outputs were identical for all land use types.

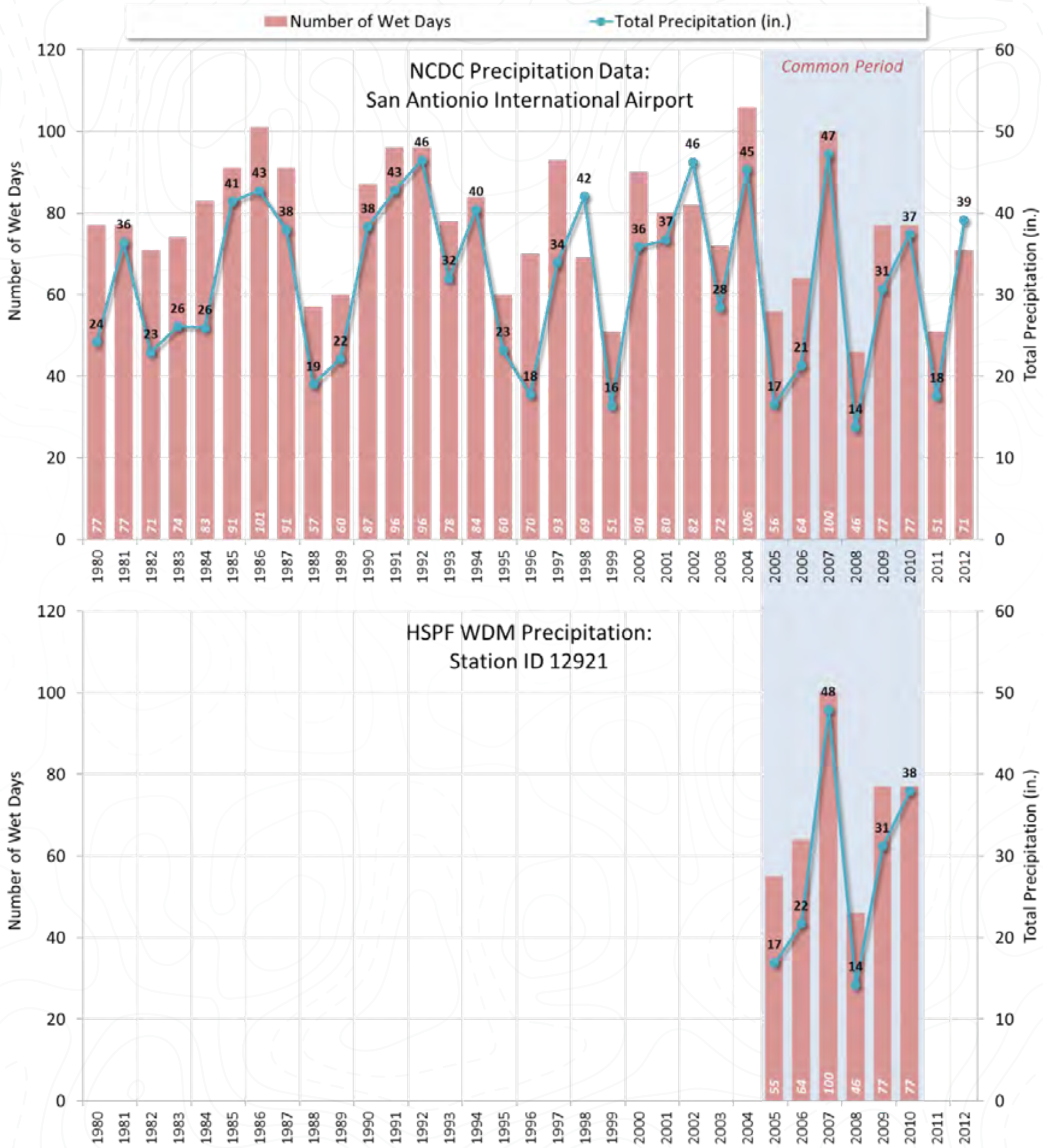


Figure J-2. *Comparison of WDM precipitation at 12921 with corresponding NCDC long-term observed precipitation data.*

APPENDIX J: **BMP Sizing & Performance Curves**

TABLE J-2. MATRIX OF BMP MODEL RESPONSES BY SITE CONDITION AND BMP TYPE

Site Conditions	BMP Type	Model Responses
A & B soils, no underdrain option A & B soils, with underdrain option C & D soils, with underdrain option	Bioretention basin	1) Flow volume 2) Bacteria a) Residential b) Com/Ind/Trans 3) CBOD 4) Sediment 5) Total-N 6) Total-P 7) Total-Pb 8) Total-Zn
	Bioswale	
	Permeable pavement	
A, B, C, and D soils (underdrain option is not applicable)	Stormwater wetland	
	Vegetated filter strip (VFS)	
Site-specific BMPs (native soil type is not applicable)	Cistern	
	Green Roof	
	Rain Barrel	
	Sand Filter	

Figure J-3. *HSPF modeled annual average bacteria export by impervious land use category.*

For each of the unique modeled responses, there are six graphs: (1) bioretention basin, (2) bioswale, (3) permeable pavement, (4) stormwater wetland, (5) VFS, and (6) other site-specific BMPs. Each graph has multiple curves corresponding to the various applicable site conditions. There is only one graph for each of the five site-specific BMP types since they do not depend on the infiltration rate of the native soil. The last graph of each set of modeled responses presents results for all five sitespecific BMP types. As previously noted, there are two different sets of modeled responses for bacteria because of land use differences in the HSPF boundary condition (i.e., Residential and Commercial/Industrial/Transportation).

Figure J-4 presents example performance curves showing flow volume reduction as a function of bioretention basin size. Annual percent reduction is for the modeled calendar year 2007. The x-axis represents BMP size and is interpreted as the equivalent runoff depth or rainfall depth captured from one acre of impervious area. This depth is equal to the rainfall depth if one assumes that flow abstractions along the impervious surface upstream of the BMP are negligible. Figure J-5 presents two examples for how to use the curves to assist in BMP designs. The curves can be used either to estimate the benefit of sizing a BMP to a given size or to estimate the required size to achieve a desired level of performance. The first example (1 → 2 → 3) is for a bioretention basin with underdrain to be built in an area with native C-soils. For this example, the light-blue curve is used.

If the BMP is being sized to capture 1.5 inches of runoff, equivalent to a rainfall depth of 1-5 inches, it is expected to reduce annual average runoff by 50 percent (for selected the 2007 wet year). The second example (4 → 5 → 6) is for a BMP to be built in an area with native B-soils, with no underdrain. For this example, the green curve is used. This time, the desire is to control 75 percent of annual runoff (for 2007); therefore, the BMP must be sized to capture 2.2 inches of runoff, equivalent to a rain fall depth of 2.2 inches. The runoff or rainfall depths determined in the performance curves included in this Appendix are then applied to the methods presented in the BMP Sizing section below to determine the water quality volume.

BMP Sizing

Volume-based Method 1

Two runoff volume calculation methods are used throughout the region and are adopted in this analysis. These are the Rational Method application for runoff volume estimation described in Section 6 of Complying with the Edwards Aquifer Rules—Technical Guidance on Best Management Practices (TCEQ 2005), and the Natural Resources Conservation Service (NRCS) hydrologic method described in the San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling (SARA undated). As the Rational Method is recommended for watersheds less than 200 acres in area, that is the approach that is evaluated here. Local regulations may require the use of the NRCS or other rainfall-runoff analysis methods to calculate volumes or flow rates. In those cases, standard hydrologic software such as HEC-HMS can be utilized.

The Rational Method is implemented as follows:

$$WQV = C * \left(\frac{P_x}{12}\right) * A \qquad \text{[Equation 1]}$$

Where:

WQV = BMP water quality storage volume (ft3),

C = runoff coefficient,

P_x = rainfall depth (determined in Section A-2 or alternative from A-1),

A = watershed area draining to the BMP (ft2), and

$$C = C_i * (\%Imp) + C_p * (1 - \%Imp) \qquad \text{[Equation 2]}$$

The value of C_i can be set to 0.95 to 1.0 depending on slope and roughness or may be calculated as a composite value for watersheds with multiple impervious cover types. Lower values would be appropriate for flat asphalt parking lots and higher values for metal, sloped roof buildings. The parameter C_p (pervious areas) will vary by hydrologic soil group (HSG) and land use type. In developed areas, the primary pervious areas are either undisturbed woods/brush or maintained lawns. Table J–3 lists runoff coefficients by HSG that are appropriate for use in the San Antonio River Basin and can be translated to curve numbers when evaluating BMP practices in watersheds over 200 acres.

TABLE J-3. RUNOFF COEFFICIENTS FOR OPEN SPACE AREAS BY HYDROLOGIC SOIL GROUP

Hydrologic Soil Group	Woods, No Grazing	Pasture (lawns)
A	0.06	0.10
B	0.13	0.20
C	0.16	0.25
D	0.20	0.30

Volume-based Method 2

Volume-based method 2 is described in Section 3.3 of the TGM (TCEQ 2005) and was developed to achieve TSS reduction targets by treating a percent of the annual rainfall volume. The calculationapproach is applicable to LID design since it results in a capture volume based on watershed area.

The method is implemented as:

$$\text{WQV} = \text{Rainfall Depth (in)} * \frac{\textit{Runoff Coefficient}}{12} * \text{Area (ft}^2\text{)} * 1.2 \qquad \textit{[Equation 3]}$$

The runoff coefficient is estimated from Figure J–4 or calculated from

$$\text{Runoff Coefficient} = 1.72 * \%\text{Imp}^3 - 1.97 * \%\text{Imp}^2 + 1.23 * \%\text{Imp} + 0.02 \qquad \textit{[Equation 4]}$$

the rainfall depth is determined from Table J–4, and the area is the total watershed draining to the BMP in square feet. The storage factor 1.2 is provided to account for stored sediment that would reduce volume in between maintenance cycles.

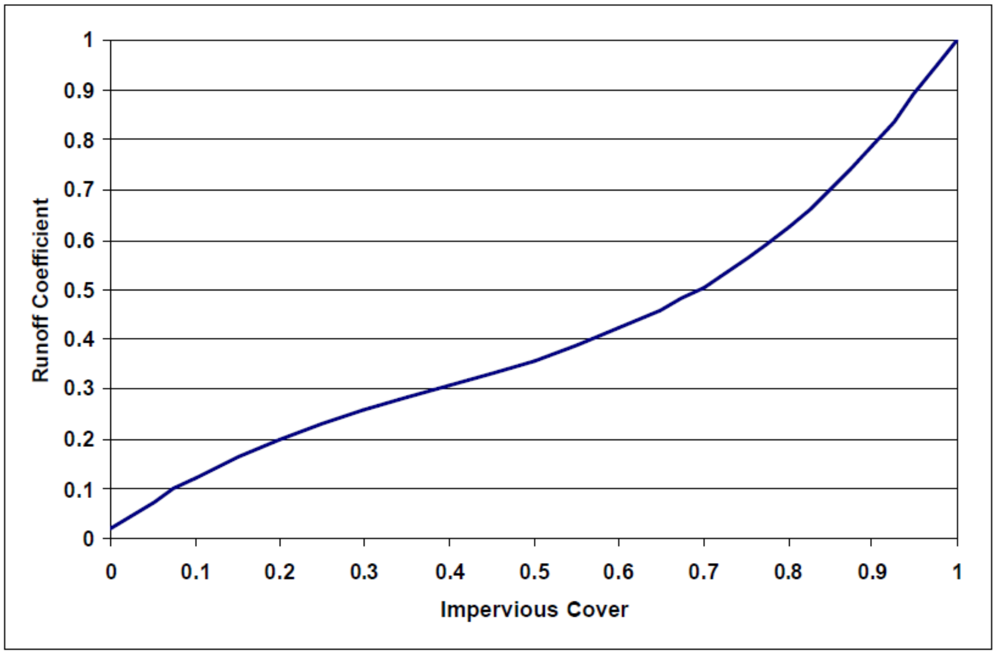


Figure J-4. *Relationship between runoff coefficient and impervious cover (Figure 3-12 from TCEQ 2005)*

TABLE J-4.
RELATIONSHIP BETWEEN FRACTION OF ANNUAL RAINFALL & RAINFALL DEPTH (IN)

F	Rainfall Depth	F	Rainfall Depth	F	Rainfall Depth	F	Rainfall Depth
1.00	4.00	0.80	1.08	0.60	0.58	0. 40	0. 29
0. 99	3.66	0. 79	1.04	0. 59	0. 56	0. 39	0. 28
0. 98	3.33	0. 78	1.00	0. 58	0. 54	0. 38	0. 27
0. 97	3.00	0. 77	0. 97	0. 57	0. 52	0. 37	0. 25
0. 96	2.80	0. 76	0. 94	0. 56	0. 50	0. 36	0. 24
0. 95	2.60	0. 75	0. 92	0. 55	0. 49	0. 35	0. 23
0. 94	2.40	0. 74	0. 89	0. 54	0. 47	0. 34	0. 23
0. 93	2.20	0. 73	0. 86	0. 53	0. 46	0. 33	0. 22
0. 92	2.00	0. 72	0. 83	0. 52	0. 45	0. 32	0. 21
0. 91	1.80	0. 71	0. 80	0. 51	0. 44	0. 31	0. 20
0. 90	1.70	0. 70	0. 78	0. 50	0. 42	0. 30	0. 19
0. 89	1.60	0. 69	0. 75	0. 49	0. 41	0. 29	0. 18
0. 88	1-50	0. 68	0. 73	0. 48	0. 40	0. 28	0. 18
0. 87	1.44	0. 67	0. 71	0. 47	0. 38	0. 27	0. 17
0. 86	1.38	0. 66	0. 69	0. 46	0. 37	0. 26	0. 16
0. 85	1.32	0. 65	0. 67	0. 45	0. 36	0. 25	0. 15
0. 84	1.26	0. 64	0. 66	0. 44	0. 34		
0. 83	1.20	0. 63	0. 64	0. 43	0. 33		
0. 82	1.16	0. 62	0. 62	0. 42	0. 32		
0. 81	1.12	0. 61	0. 60	0. 41	0. 31		
0. 80	1.08	0. 60	0. 58	0. 40	0. 29		

Flow-Based Control Practices

Similar to the volume based control methods, two regionally appropriate methods are available to calculate flow-based sizing criteria for infiltrating, filtering, or treating:

1. The maximum flow rate of runoff produced from a rainfall intensity of 1.1 inch of rainfall per hour for each hour of a storm event (TCEQ 2005). Local rainfall analysis by TCEQ indicates 90 percent of the annual rainfall occurs at intensities below this level:

   or

2. The maximum flow rate of runoff produced by the regulatory percentile hourly rainfall intensity, as determined from the local historical rainfall record, multiplied by a factor of two.

Both methods describe how to apply the design rainfall intensity for flow-based control practices (i.e., applying a uniform 1.1 inches per hour intensity or applying the regulatory percentile hourly rainfall intensity after multiplying by 2 as a safety factor).

Flow-based Method 1

The water quality flow (WQF, cfs) is calculated as:

$$WQF = C * 1.1 * A, \qquad \text{[Equation 5]}$$

where C is the rational method coefficient, as described above, 1.1 in/hour is the rainfall intensity from the TCEQ's Edwards Aquifer compliance design manual, and A is the drainage area in square feet.

Flow-based Method 2

Flow-based method 2 is similar to method 1, except that the flow is based on the regulatory percentile peak intensity value from a local rainfall analysis (i), multiplied by a safety factor:

$$WQF = C * (i * 2) * A \qquad \text{[Equation 6]}$$

The intensity should be calculated from rainfall data that covers at least 30 years of automated 5 to 15 minute automated recording gage data. Alternatively, hourly rainfall estimates could be used for areas with sparse gage data.

Performance Curves

Immediately below is an example performace curve showing the flow volume reduction versus bioretention basin size. Following that example are performance curves for flow volume; bacteria, residential; bacteria, commercial/industrial/transportation; CBOD; sediment; Total-N; Total P; Total-Pb; and Total-Zn for the BMPs presented in this manual.

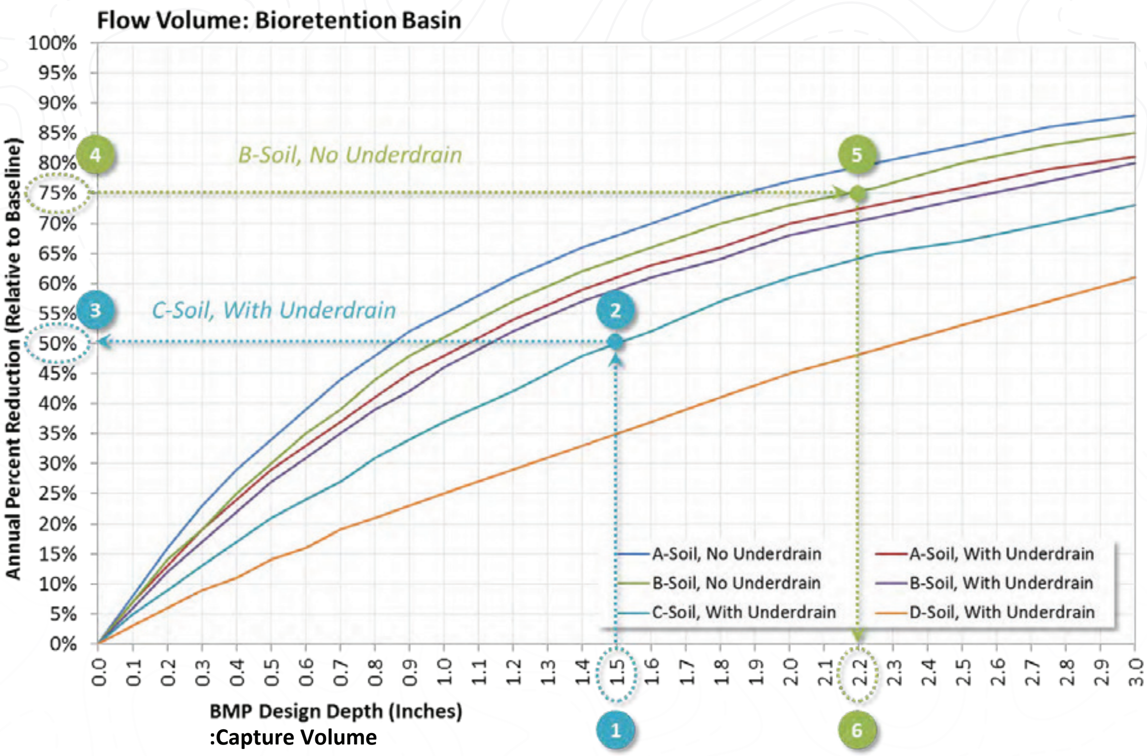
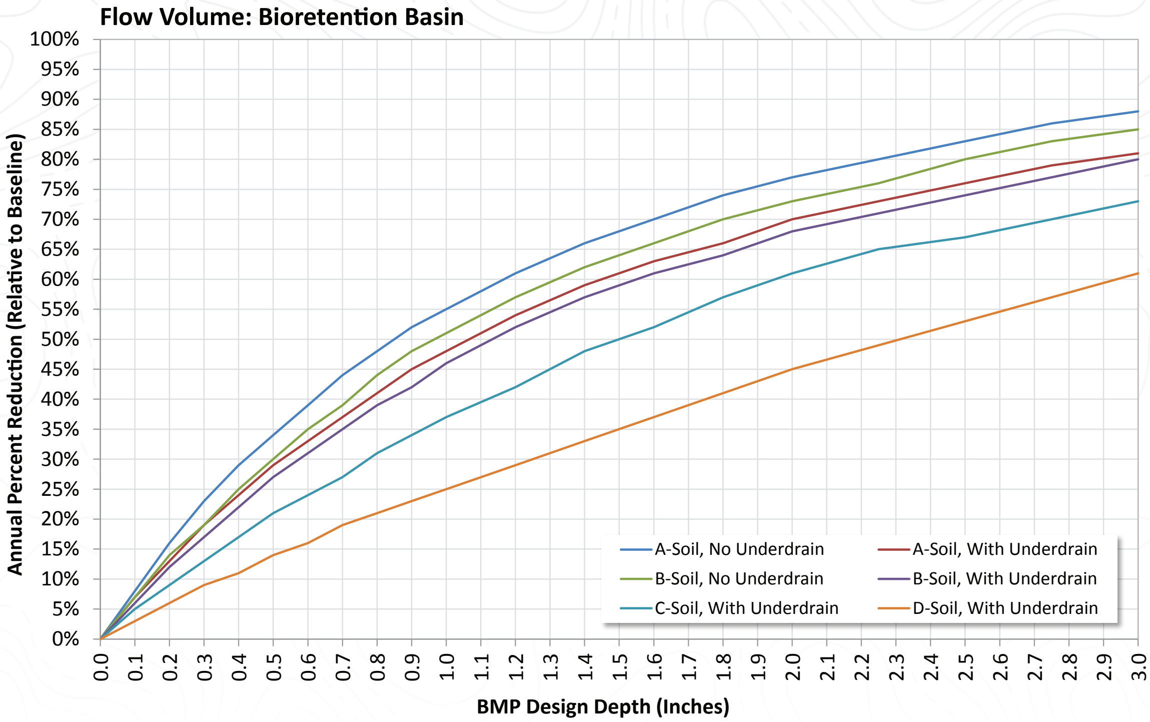
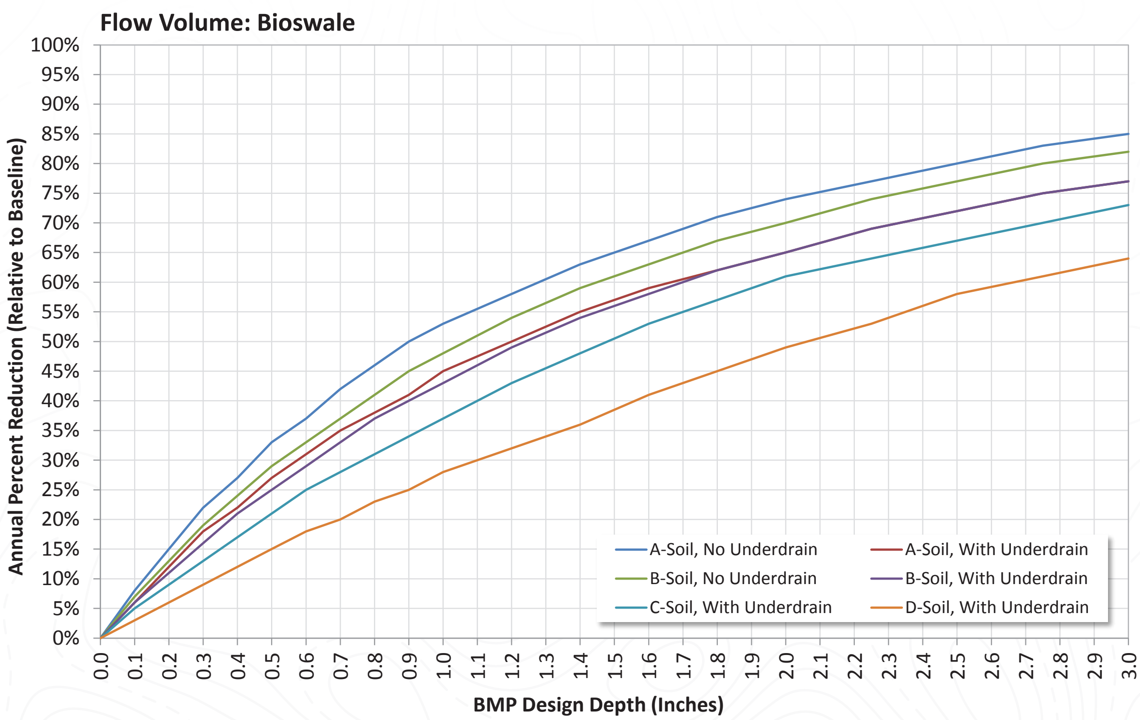


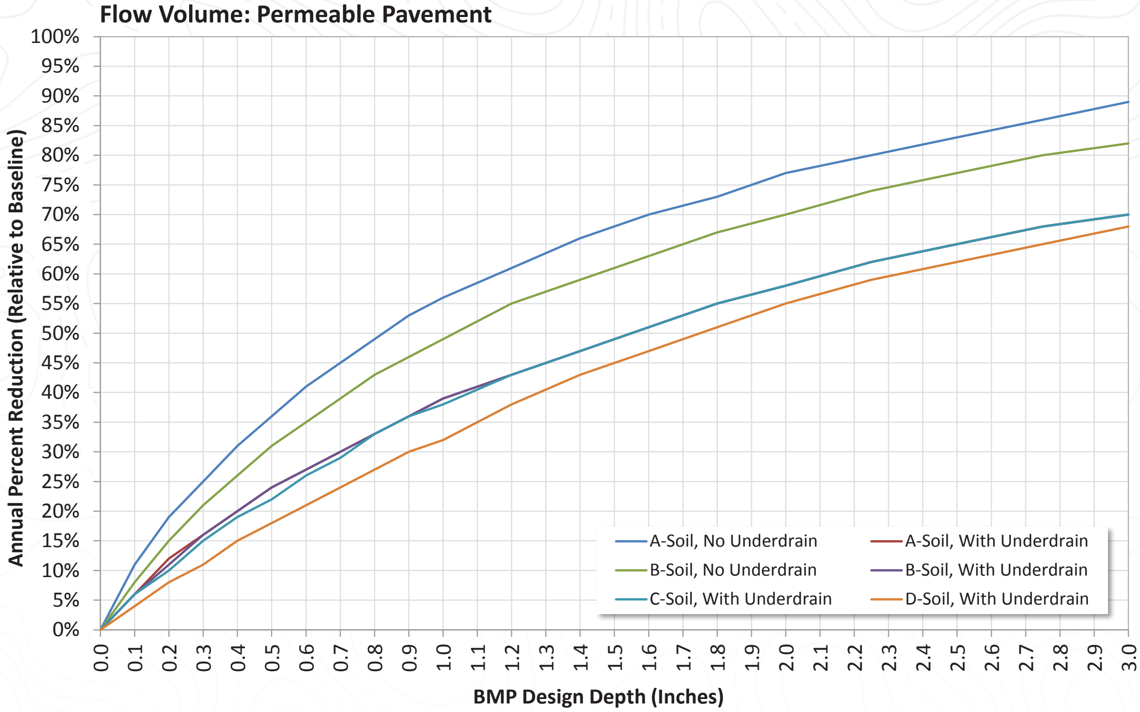
Figure J-5. Example performance curves showing flow volume reduction versus bioretention basin size.

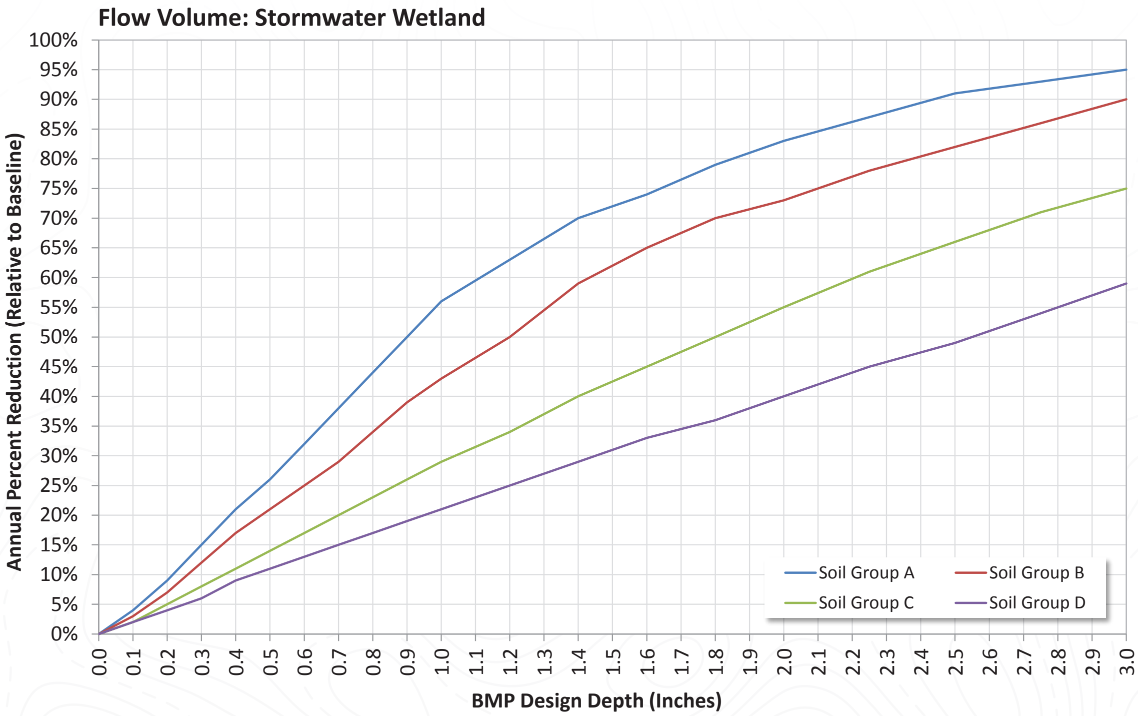
APPENDIX J: **BMP Sizing & Performance Curves**

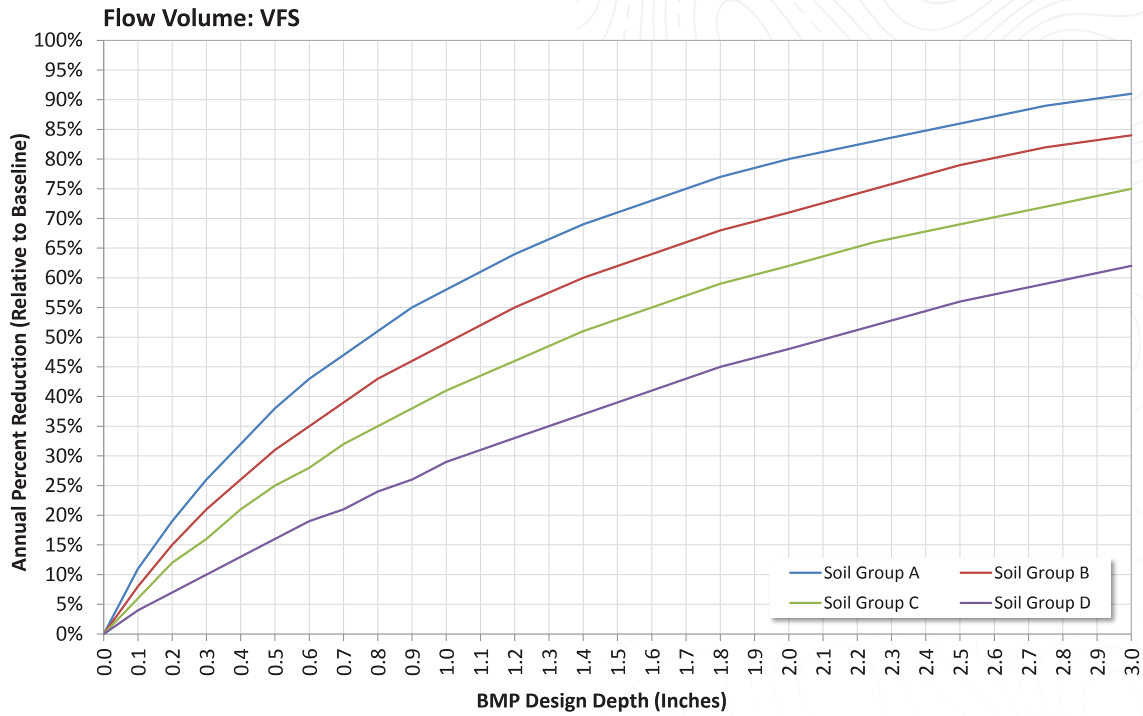




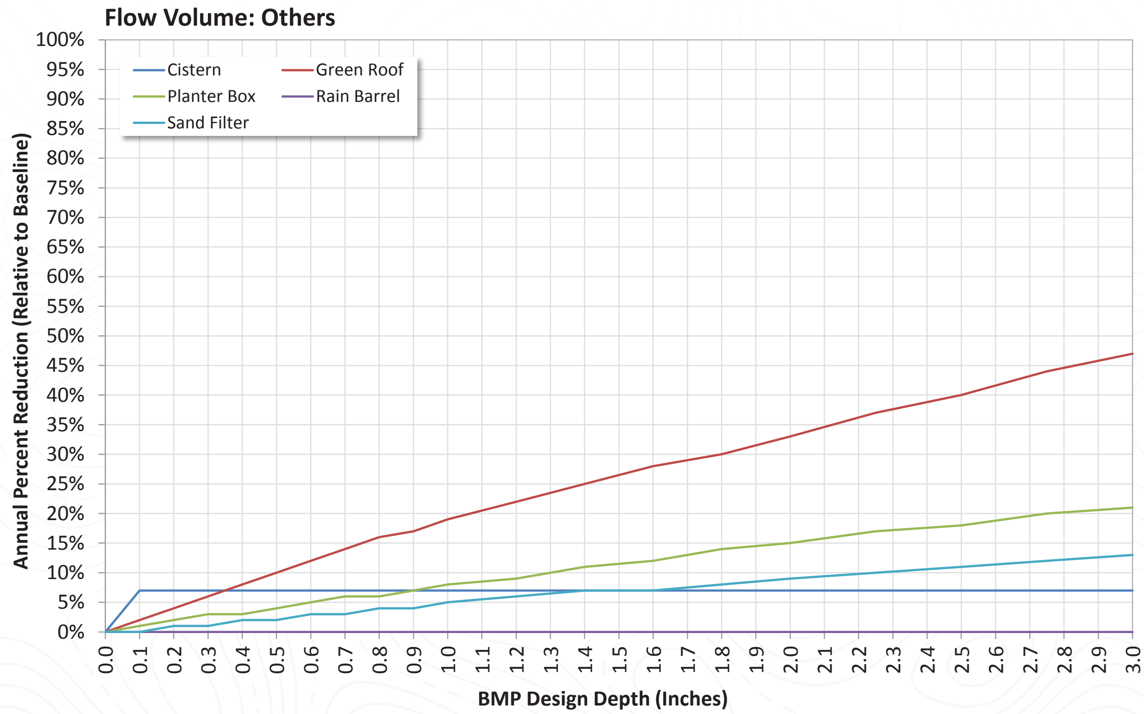
APPENDIX J: **BMP Sizing & Performance Curves**





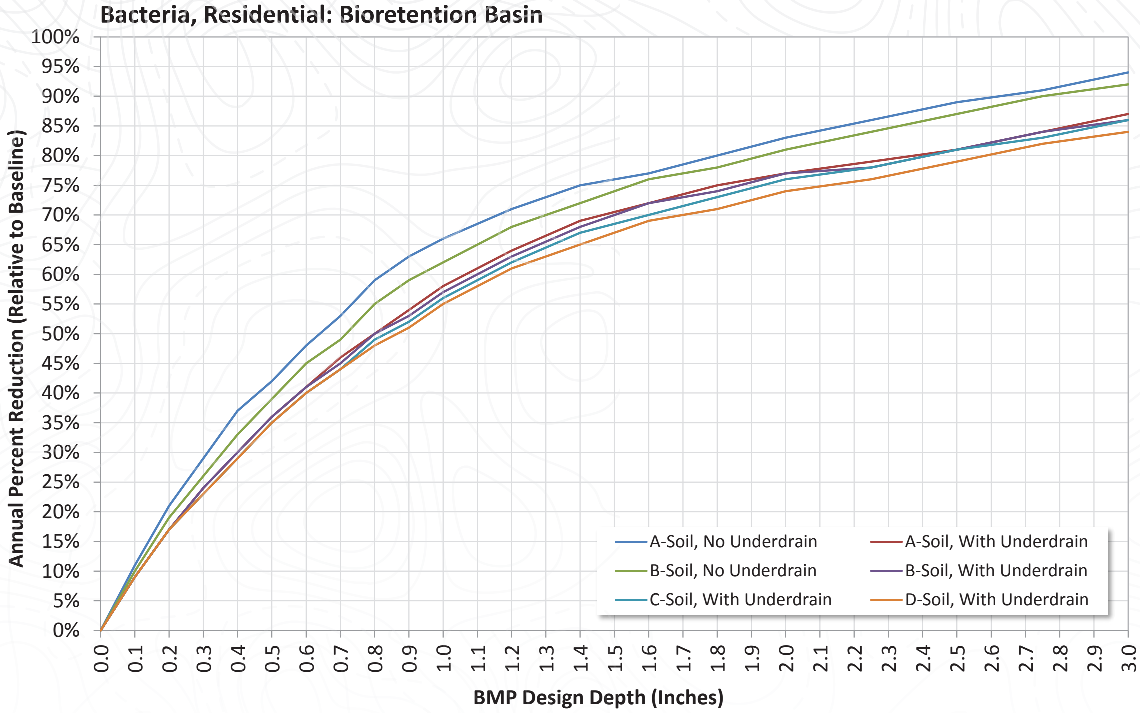


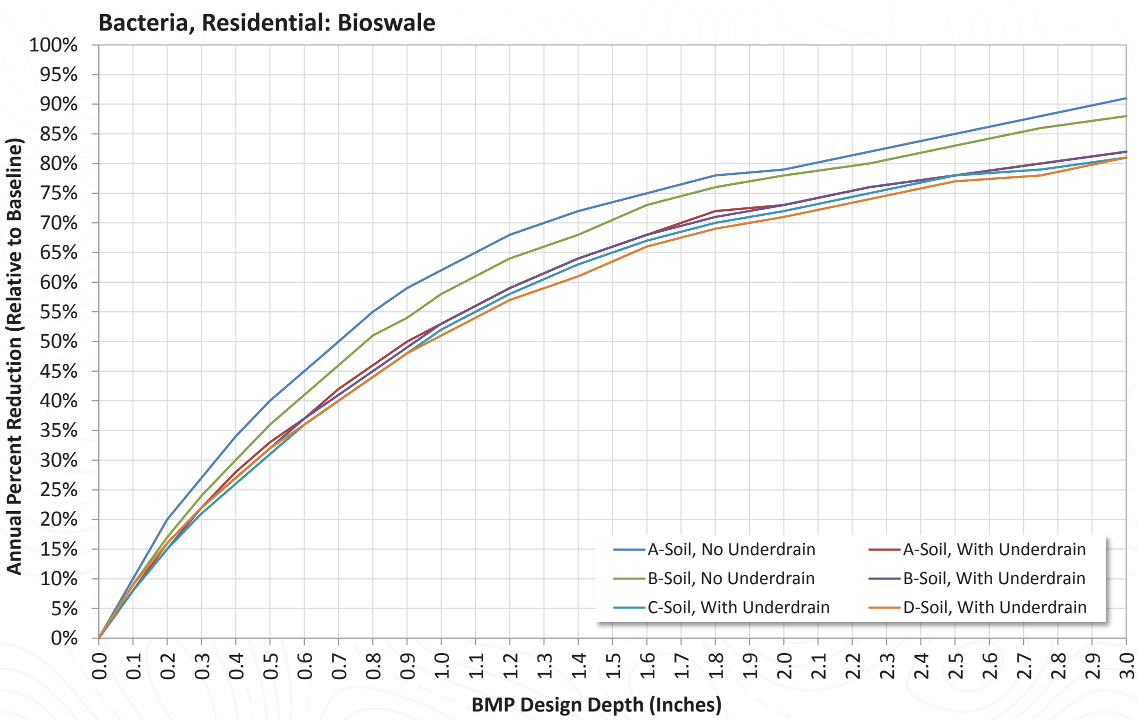
Flow Volume: VFS
Annual Percent Reduction (Relative to Baseline)
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9 3.0
BMP Design Depth (Inches)
Soil Group A
Soil Group B
Soil Group C
Soil Group D

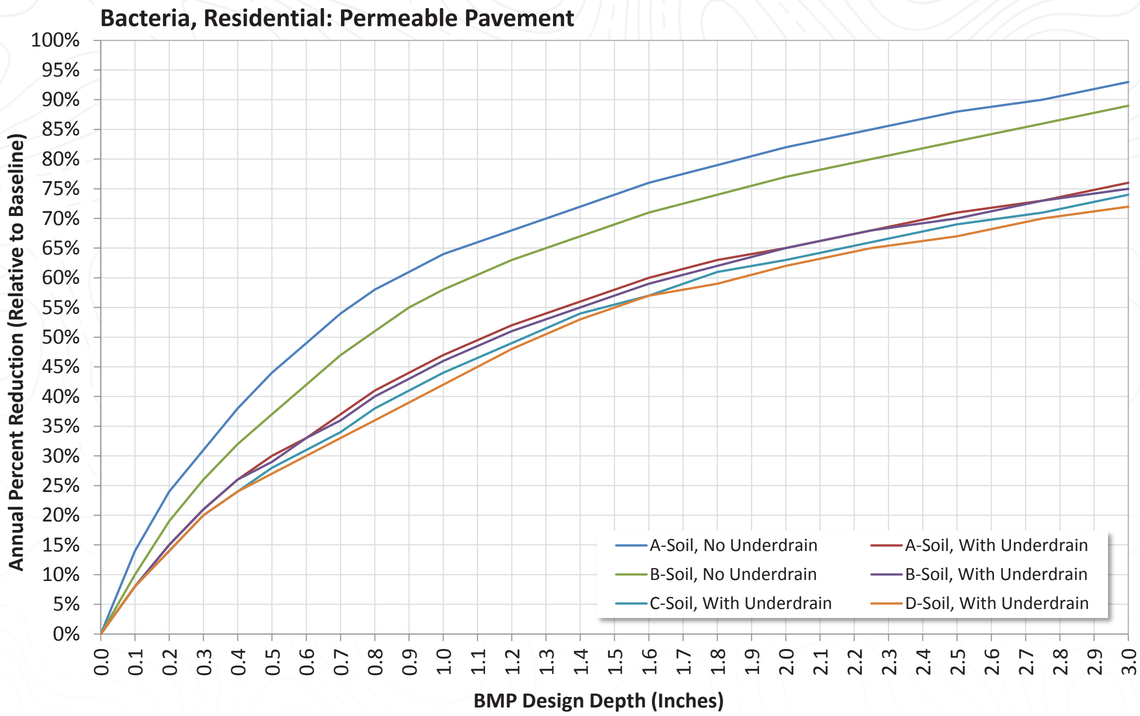


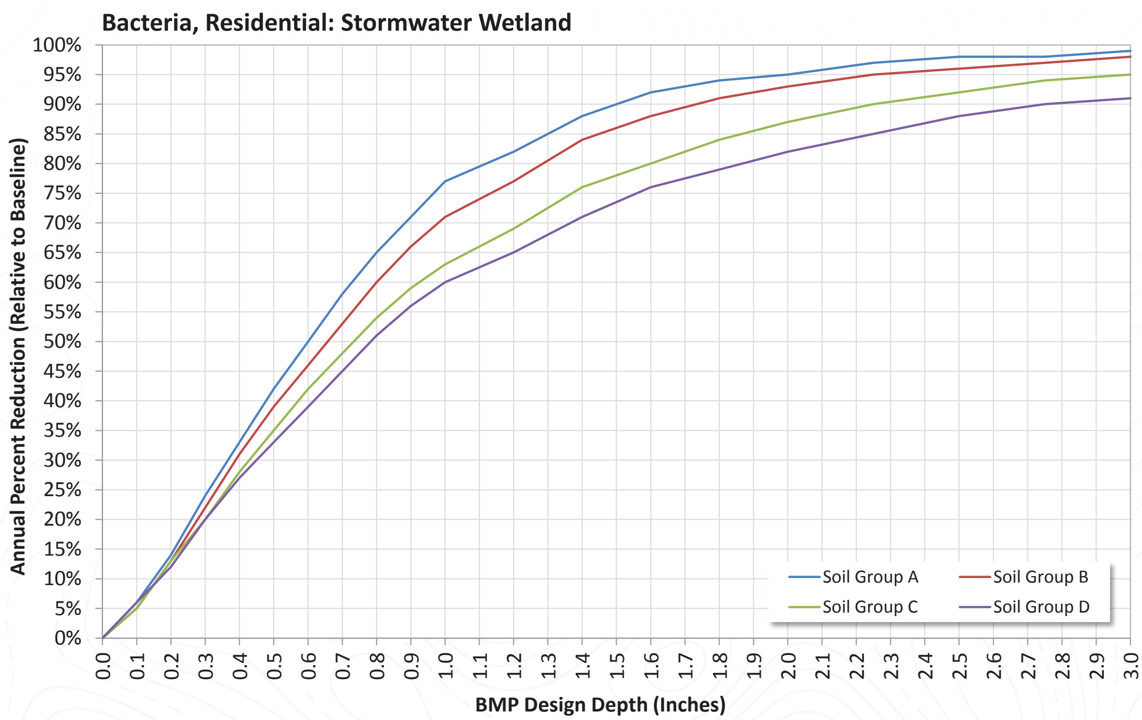
Flow Volume: Others
Annual Percent Reduction (Relative to Baseline)
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9 3.0
BMP Design Depth (Inches)
Cistern
Green Roof
Planter Box
Rain Barrel
Sand Filter

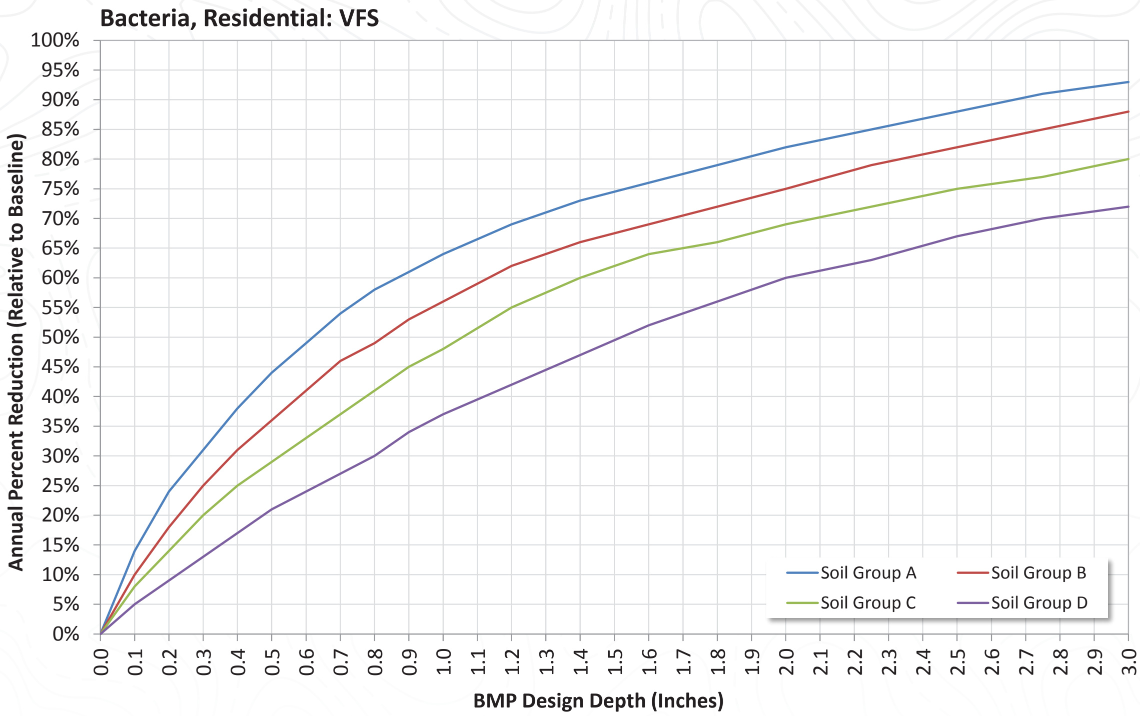
APPENDIX J: **BMP Sizing & Performance Curves**

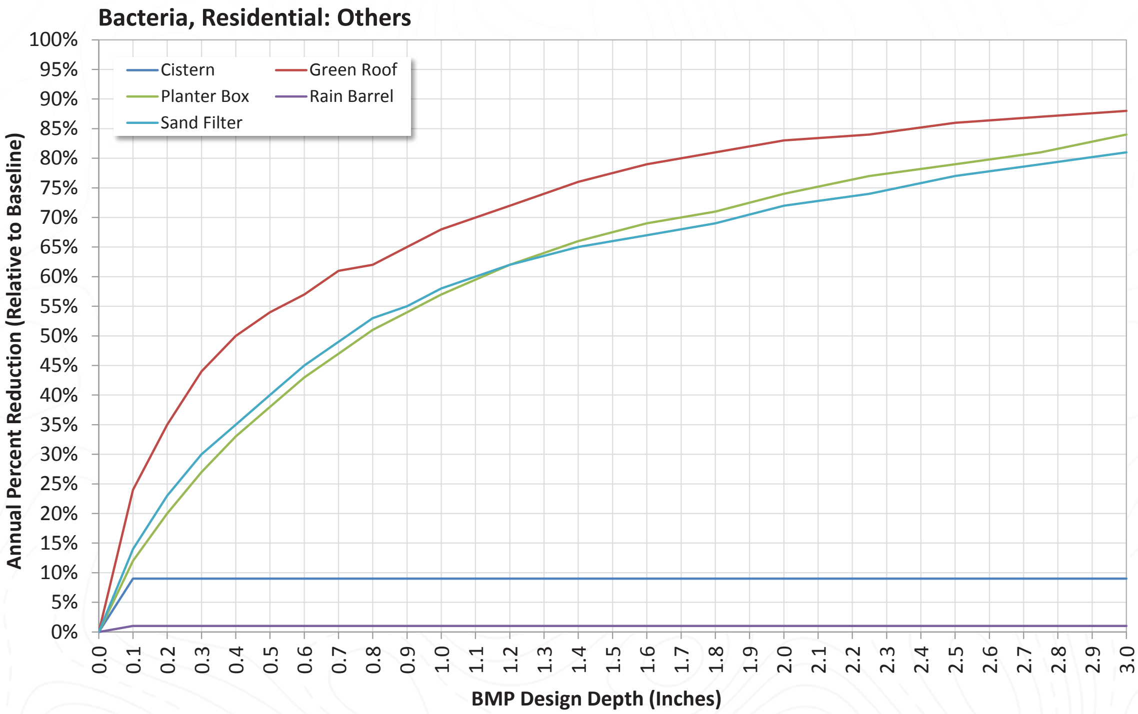


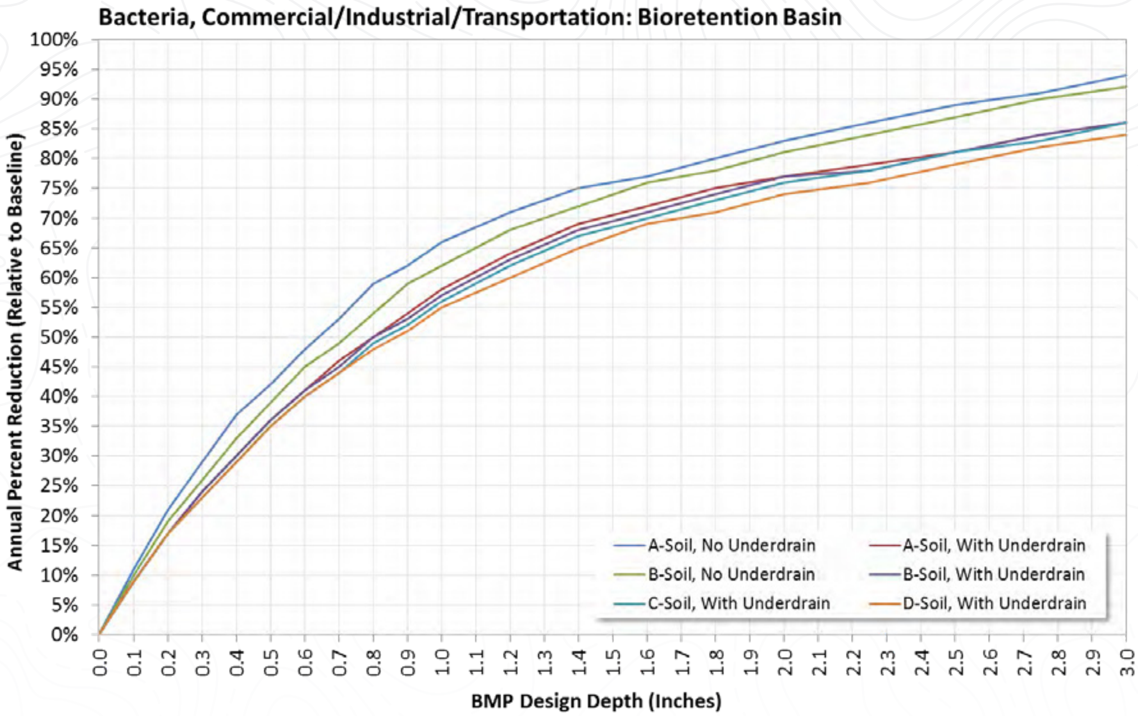


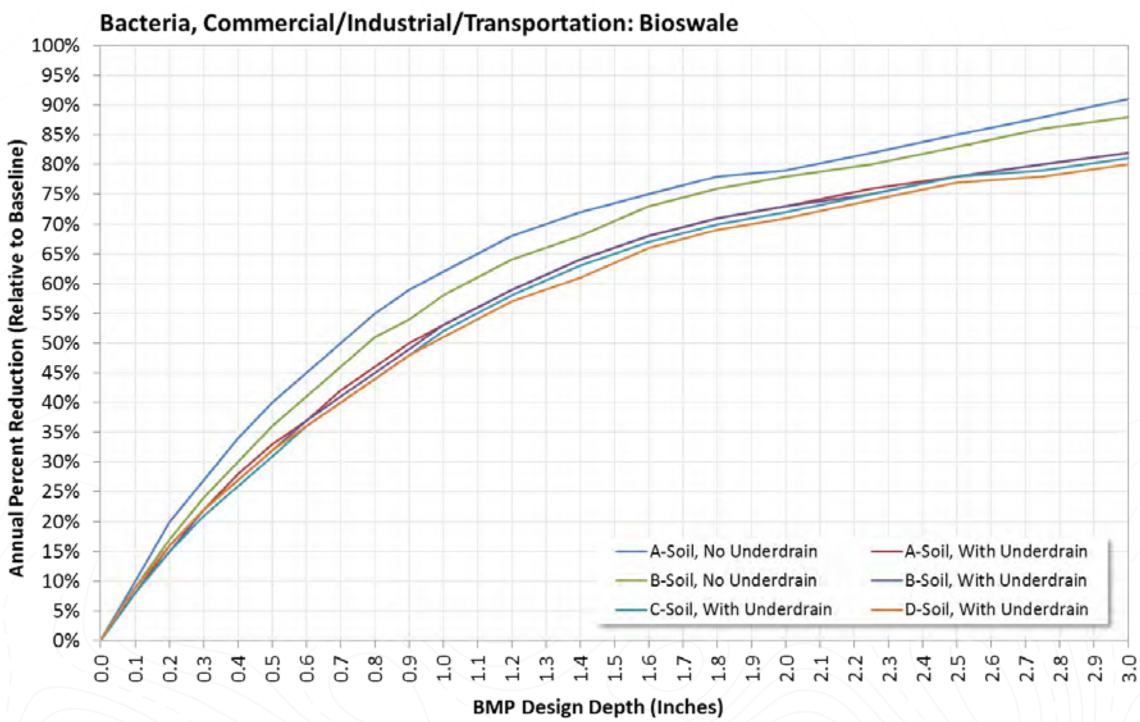

Bacteria, Residential: Permeable Pavement
Annual Percent Reduction (Relative to Baseline)
BMP Design Depth (Inches)
A-Soil, No Underdrain
A-Soil, With Underdrain
B-Soil, No Underdrain
B-Soil, With Underdrain
C-Soil, With Underdrain
D-Soil, With Underdrain

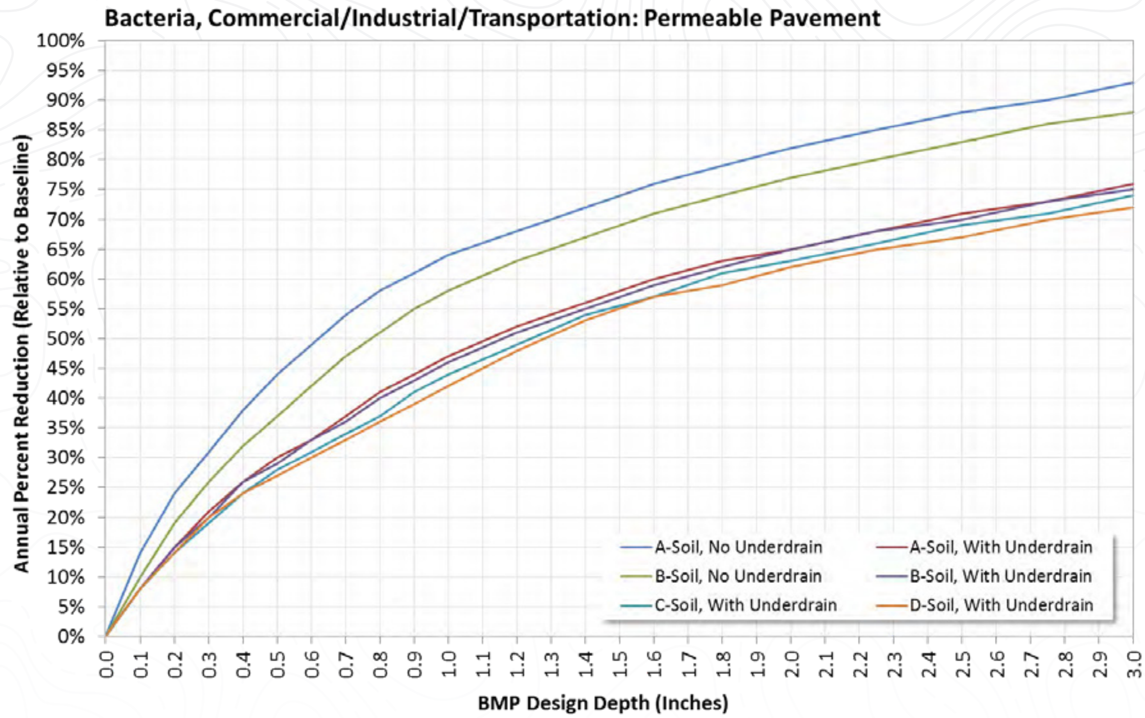

Bacteria, Residential: Stormwater Wetland
Annual Percent Reduction (Relative to Baseline)
BMP Design Depth (Inches)
Soil Group A
Soil Group B
Soil Group C
Soil Group D

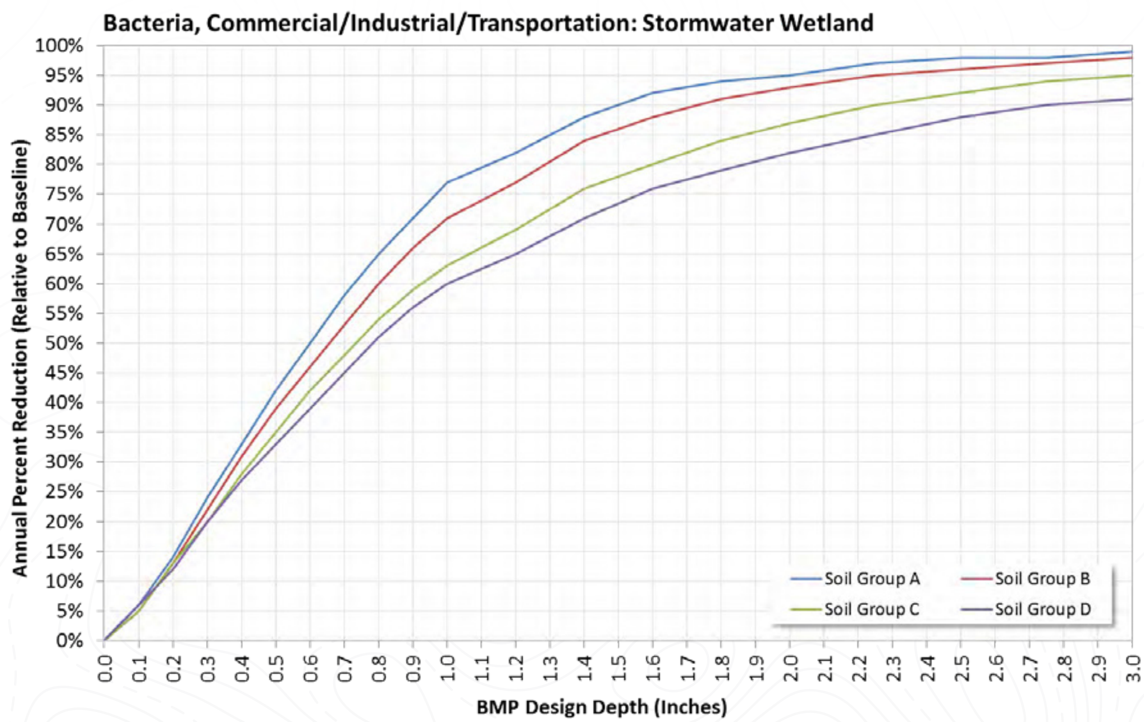

Bacteria, Residential: VFS
Annual Percent Reduction (Relative to Baseline)
BMP Design Depth (Inches)
Soil Group A
Soil Group B
Soil Group C
Soil Group D


Bacteria, Residential: Others
Annual Percent Reduction (Relative to Baseline)
BMP Design Depth (Inches)
Cistern
Green Roof
Planter Box
Rain Barrel
Sand Filter

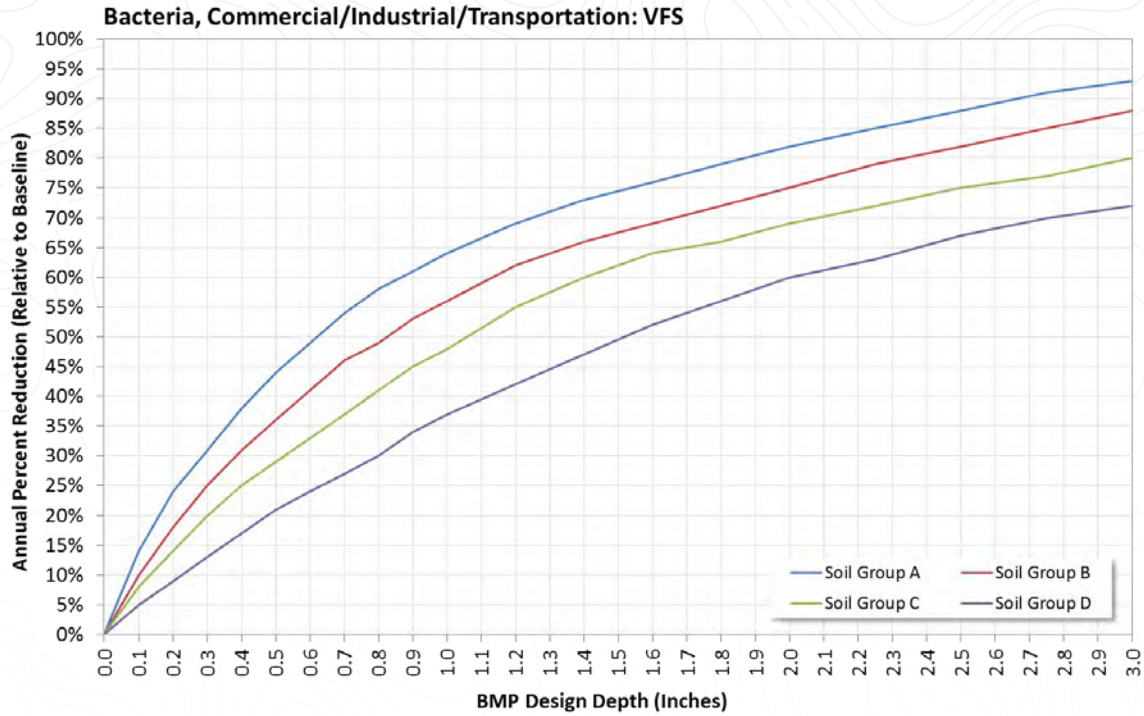

Bacteria, Commercial/Industrial/Transportation: Bioretention Basin
Annual Percent Reduction (Relative to Baseline)
BMP Design Depth (Inches)
A-Soil, No Underdrain
A-Soil, With Underdrain
B-Soil, No Underdrain
B-Soil, With Underdrain
C-Soil, With Underdrain
D-Soil, With Underdrain

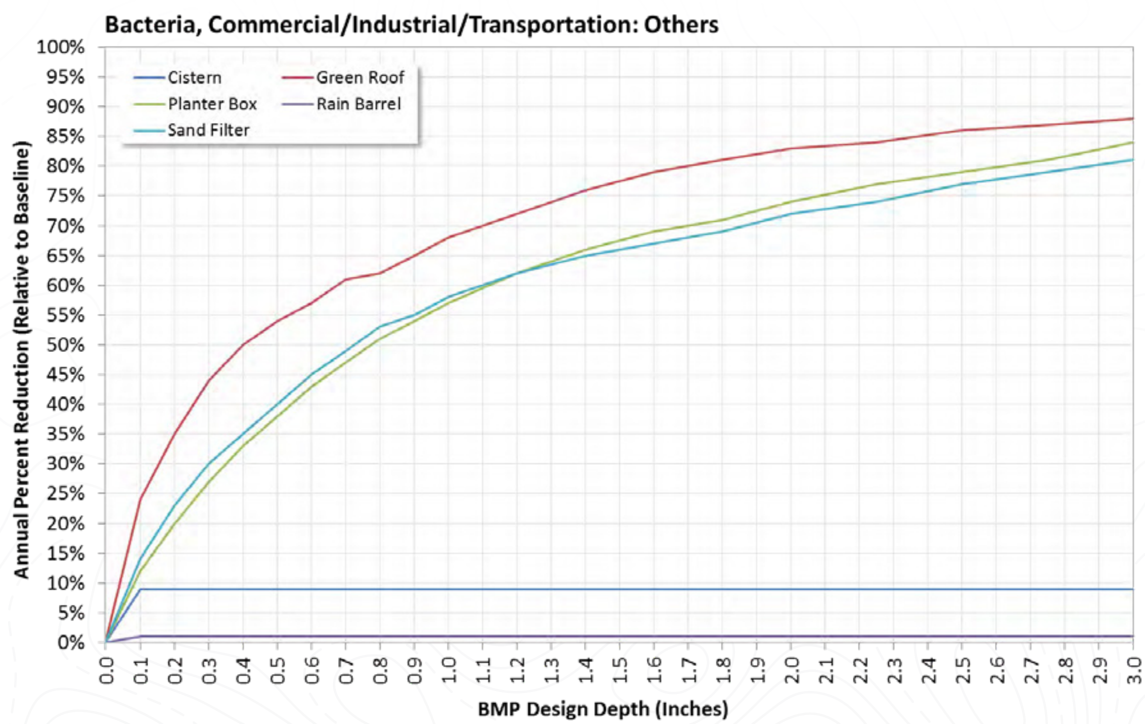

Bacteria, Commercial/Industrial/Transportation: Bioswale
Annual Percent Reduction (Relative to Baseline)
BMP Design Depth (Inches)
A-Soil, No Underdrain
A-Soil, With Underdrain
B-Soil, No Underdrain
B-Soil, With Underdrain
C-Soil, With Underdrain
D-Soil, With Underdrain

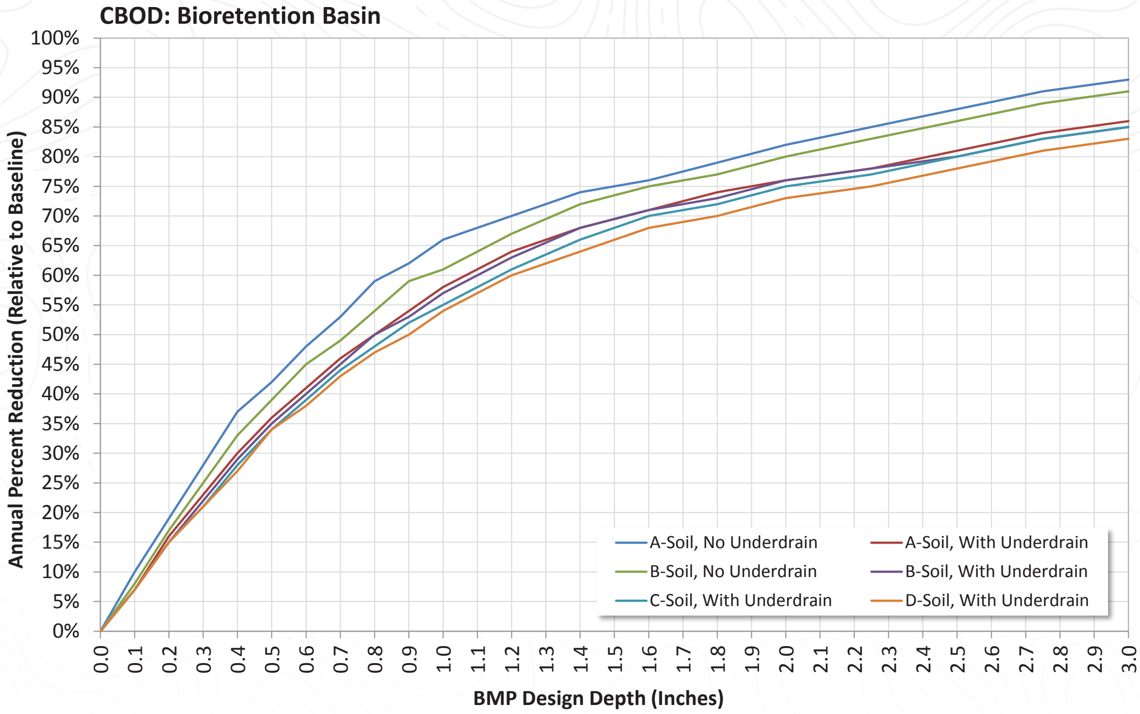

Bacteria, Commercial/Industrial/Transportation: Permeable Pavement
Annual Percent Reduction (Relative to Baseline)
BMP Design Depth (Inches)
A-Soil, No Underdrain
A-Soil, With Underdrain
B-Soil, No Underdrain
B-Soil, With Underdrain
C-Soil, With Underdrain
D-Soil, With Underdrain


Bacteria, Commercial/Industrial/Transportation: Stormwater Wetland
Annual Percent Reduction (Relative to Baseline)
BMP Design Depth (Inches)
Soil Group A
Soil Group B
Soil Group C
Soil Group D

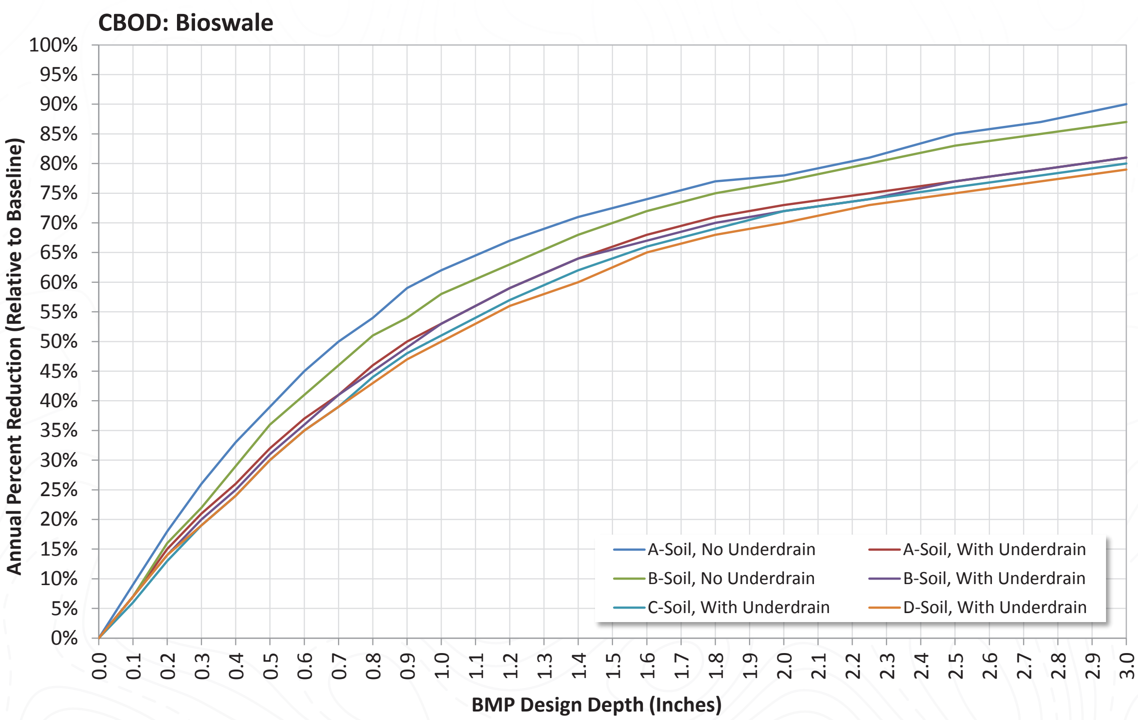
APPENDIX J: **BMP Sizing & Performance Curves**





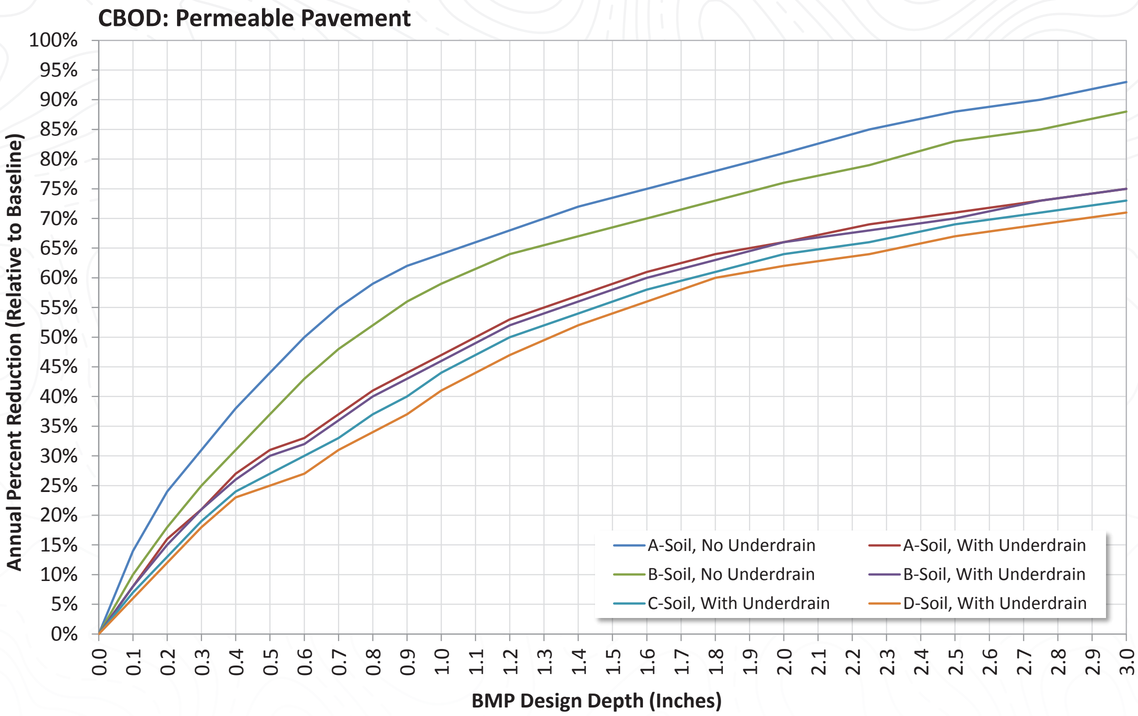


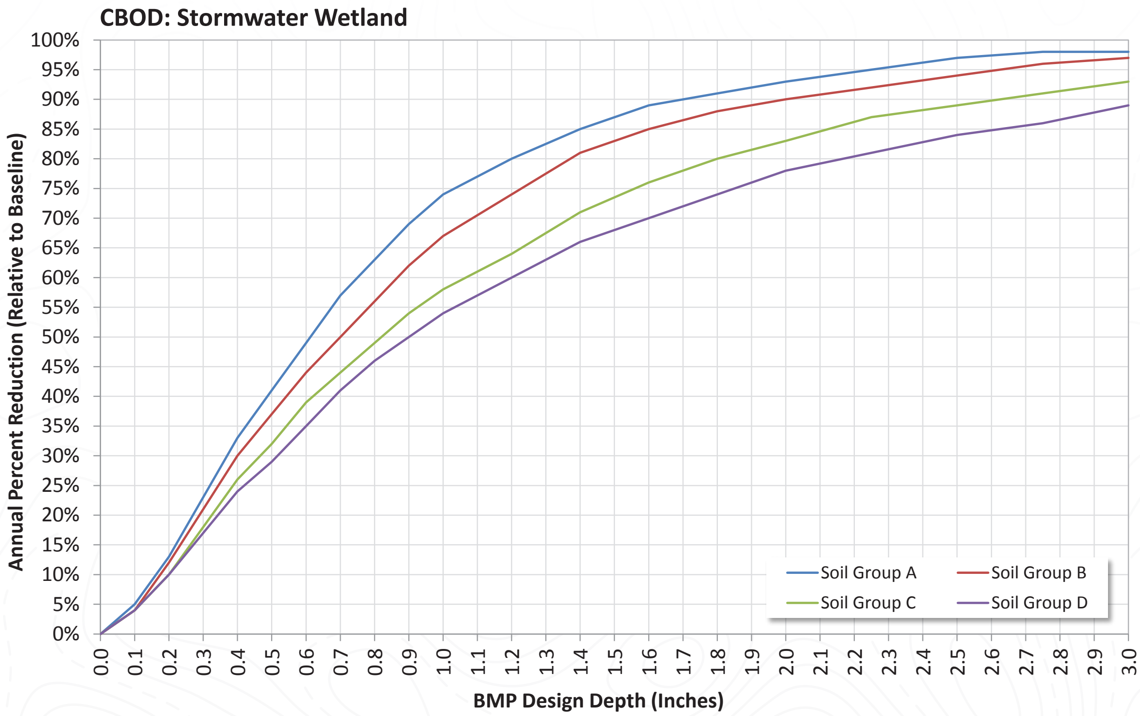
CBOD: Bioretention Basin
Annual Percent Reduction (Relative to Baseline)
BMP Design Depth (Inches)
A-Soil, No Underdrain
A-Soil, With Underdrain
B-Soil, No Underdrain
B-Soil, With Underdrain
C-Soil, With Underdrain
D-Soil, With Underdrain



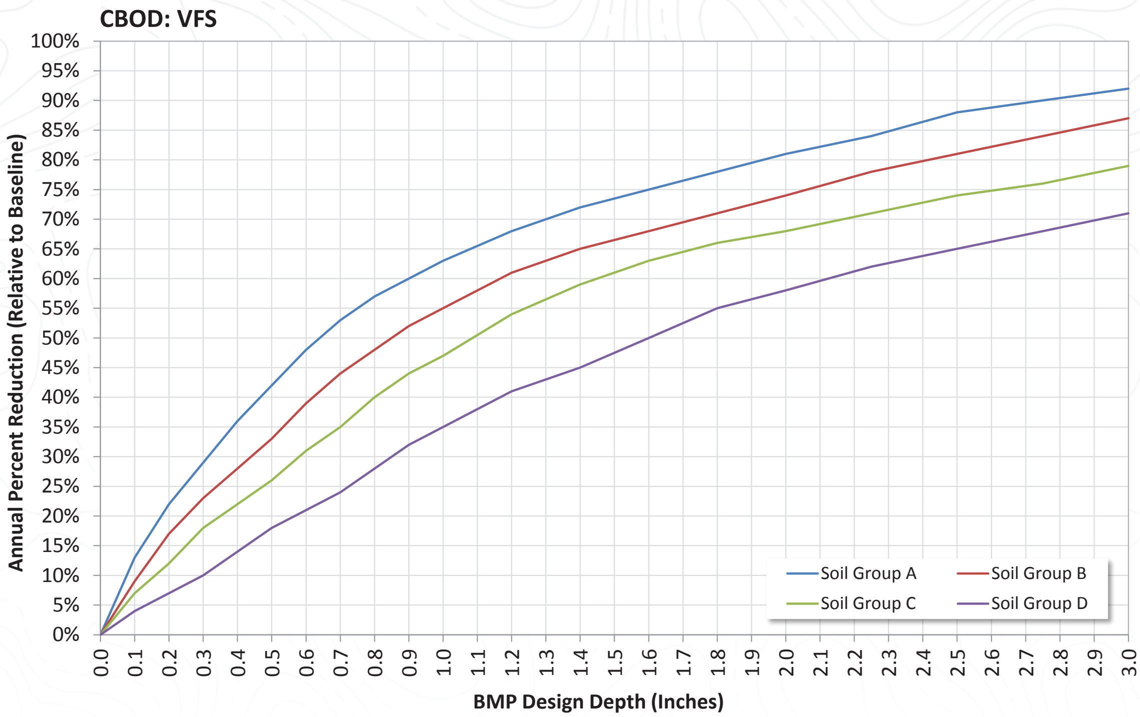
CBOD: Bioswale
Annual Percent Reduction (Relative to Baseline)
BMP Design Depth (Inches)
A-Soil, No Underdrain
A-Soil, With Underdrain
B-Soil, No Underdrain
B-Soil, With Underdrain
C-Soil, With Underdrain
D-Soil, With Underdrain

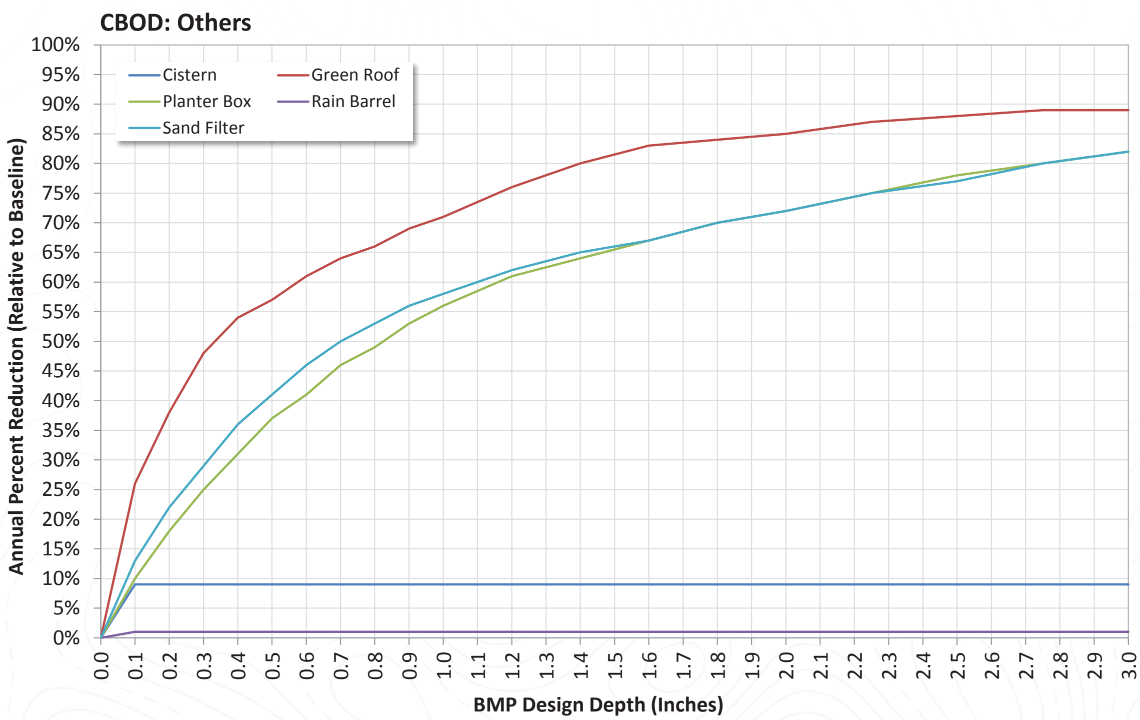
APPENDIX J: **BMP Sizing & Performance Curves**



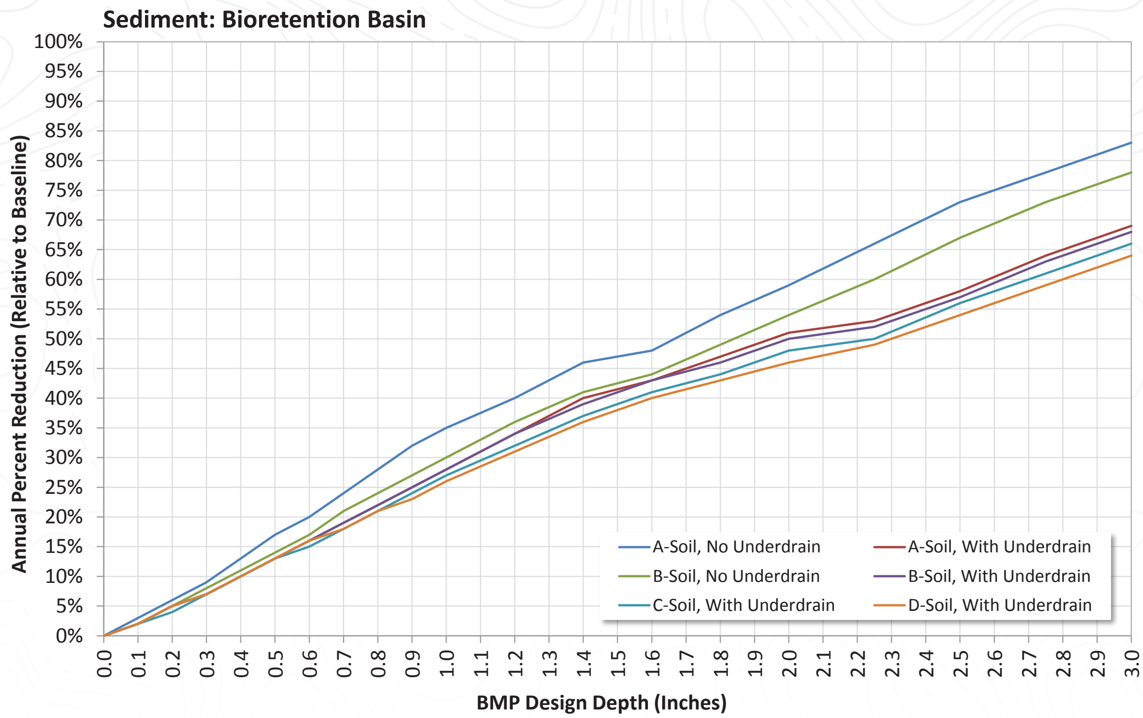


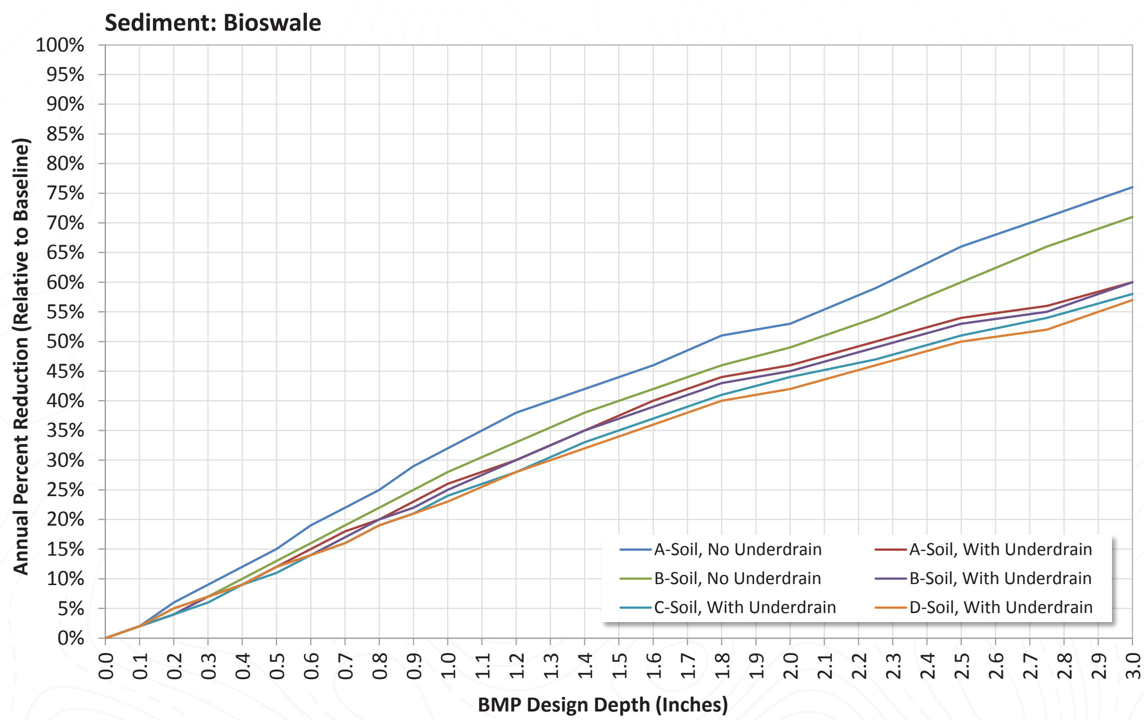
APPENDIX J: **BMP Sizing & Performance Curves**



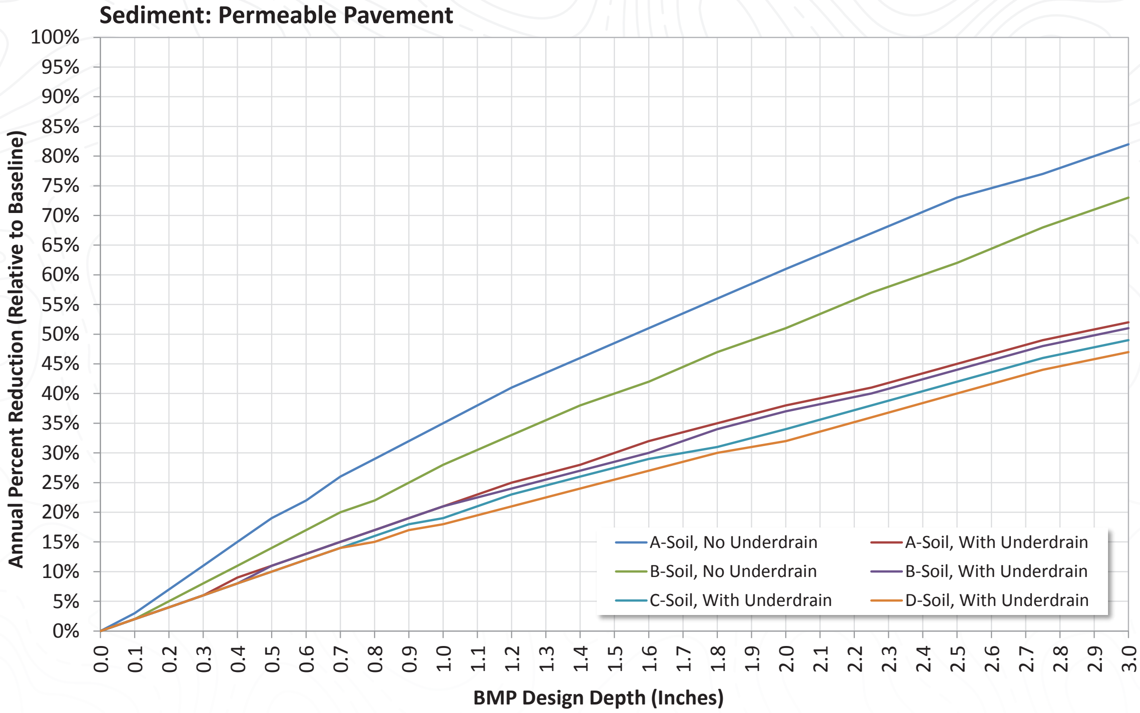


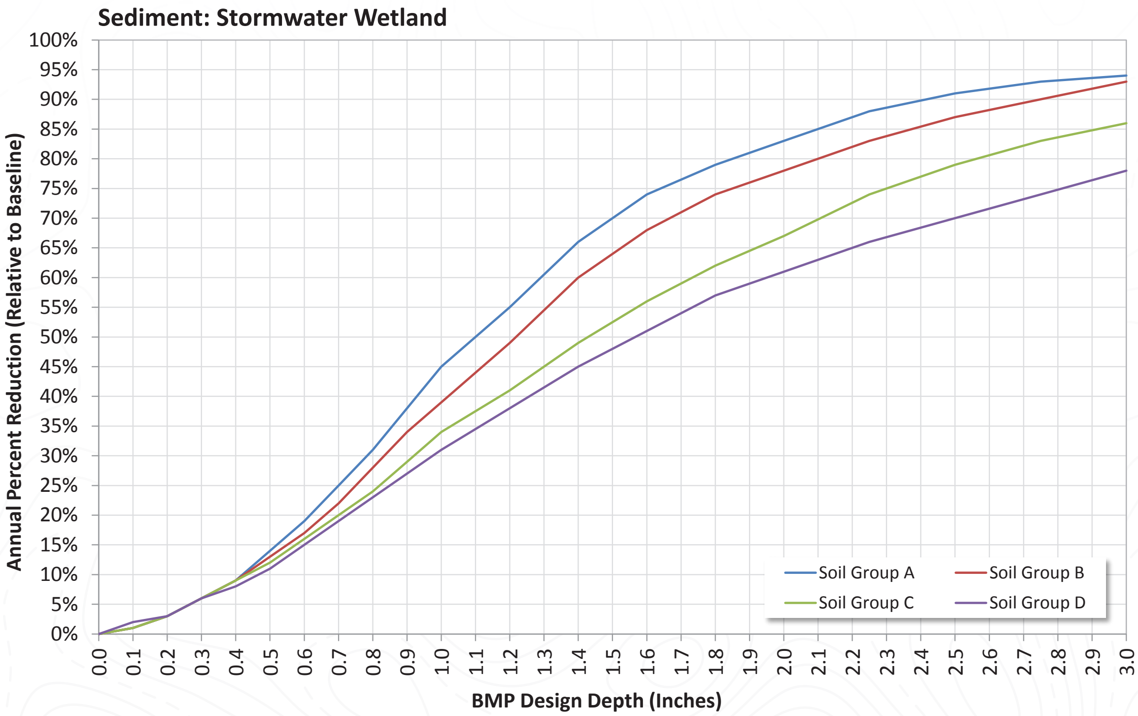
APPENDIX J: **BMP Sizing & Performance Curves**

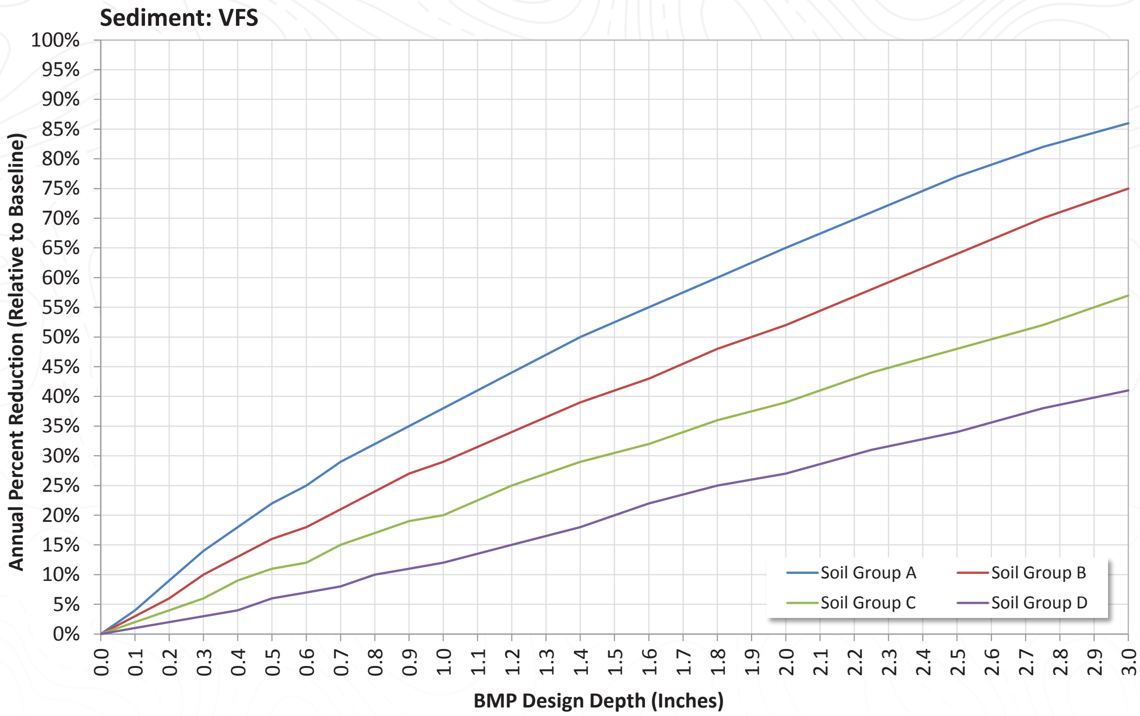




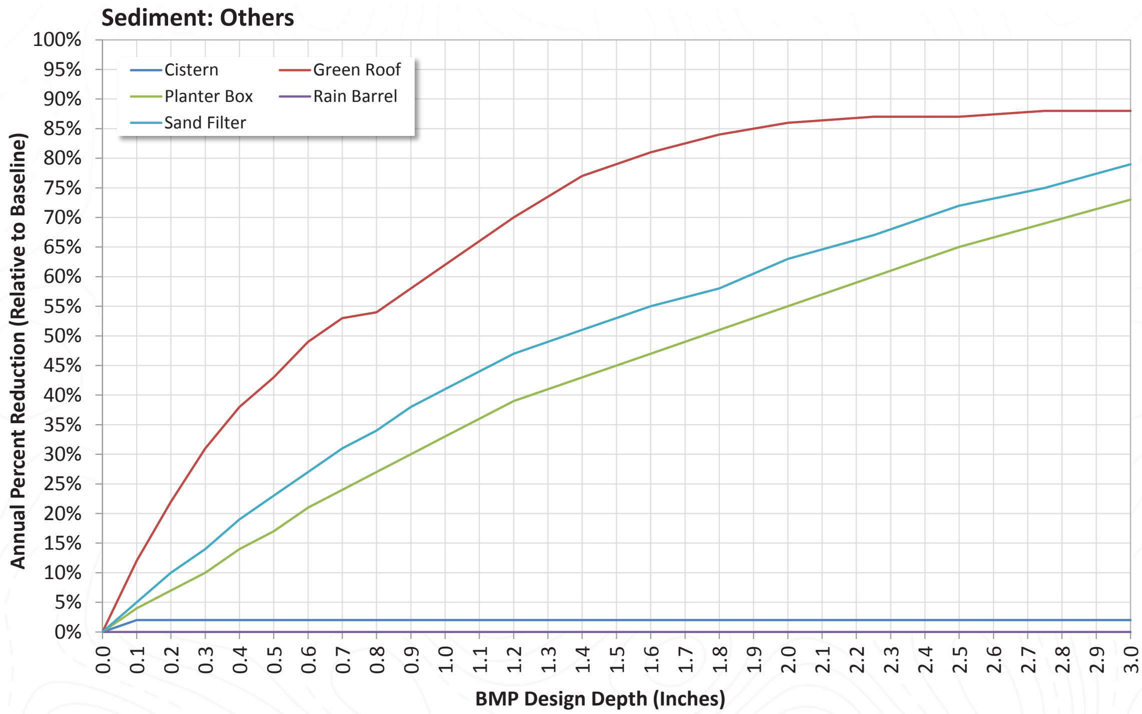
APPENDIX J: **BMP Sizing & Performance Curves**



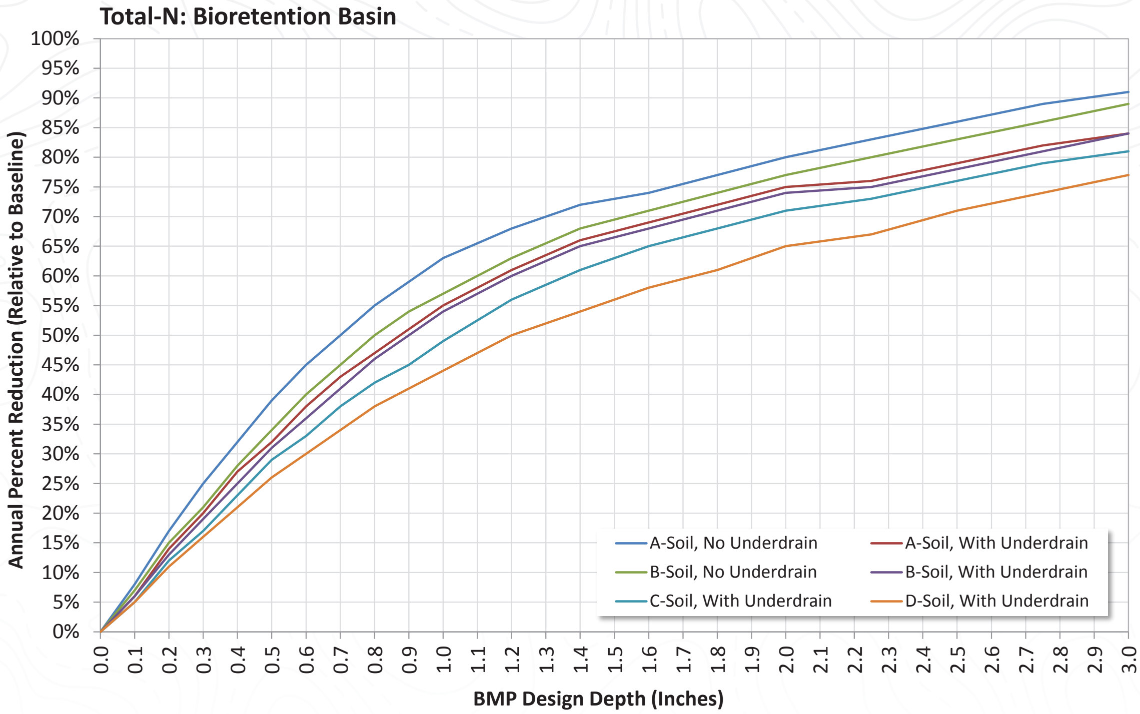


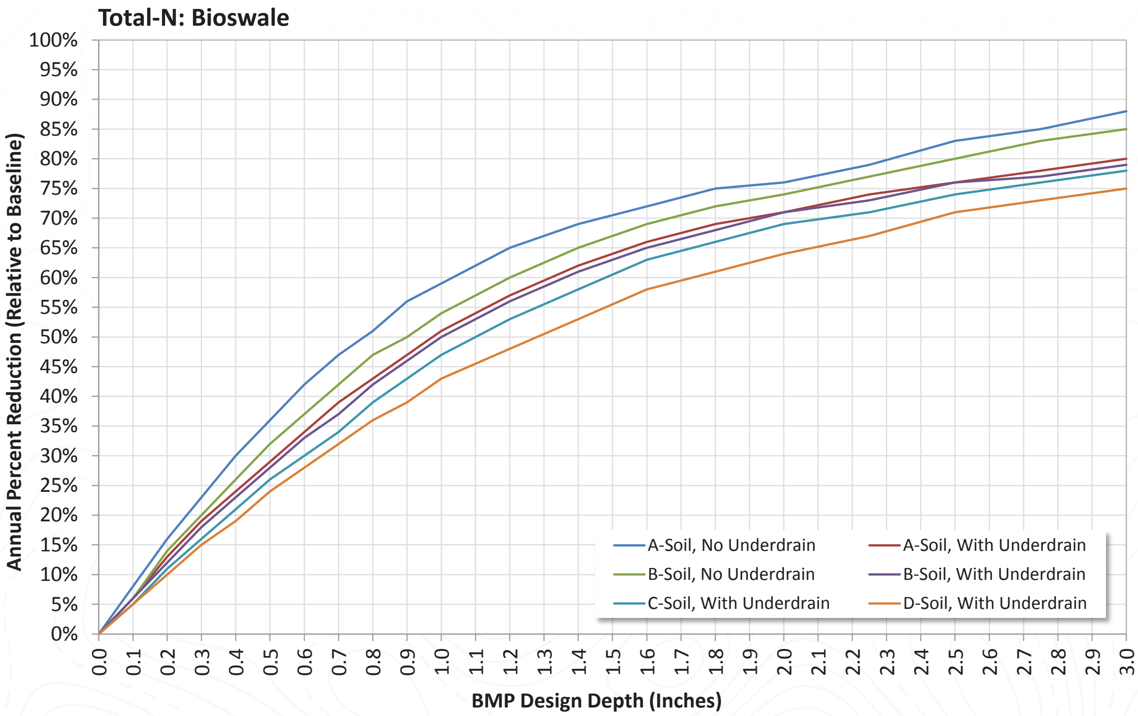


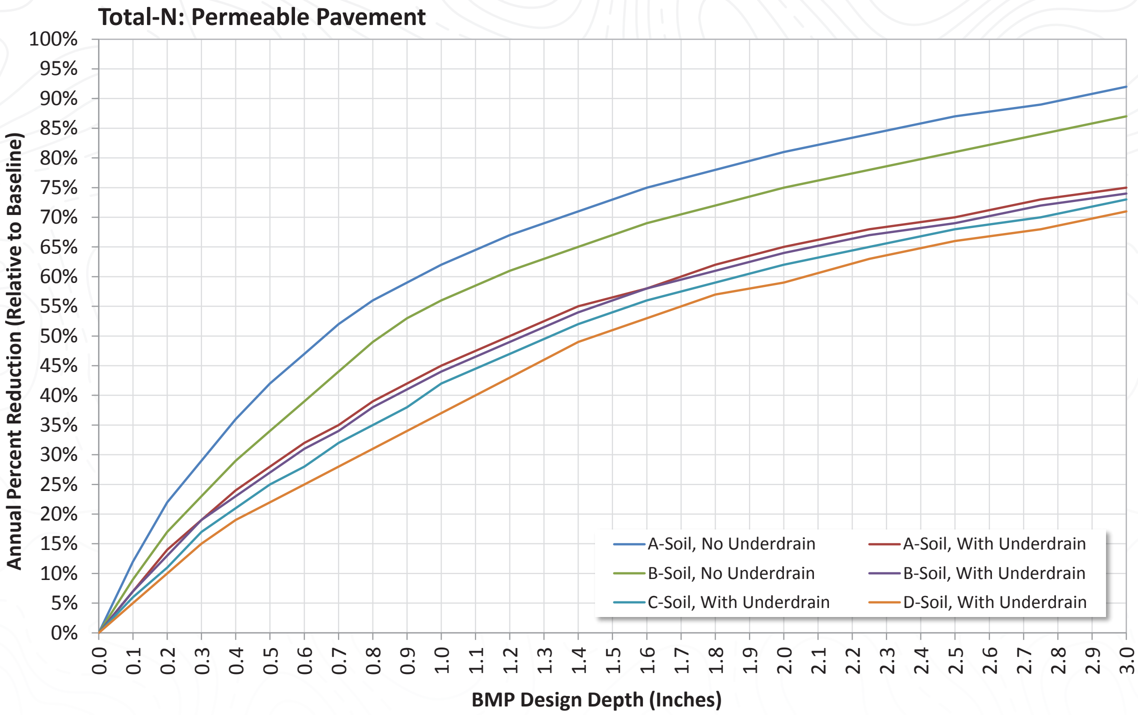
Sediment: VFS
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Annual Percent Reduction (Relative to Baseline)
Soil Group A
Soil Group B
Soil Group C
Soil Group D
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9 3.0
BMP Design Depth (Inches)



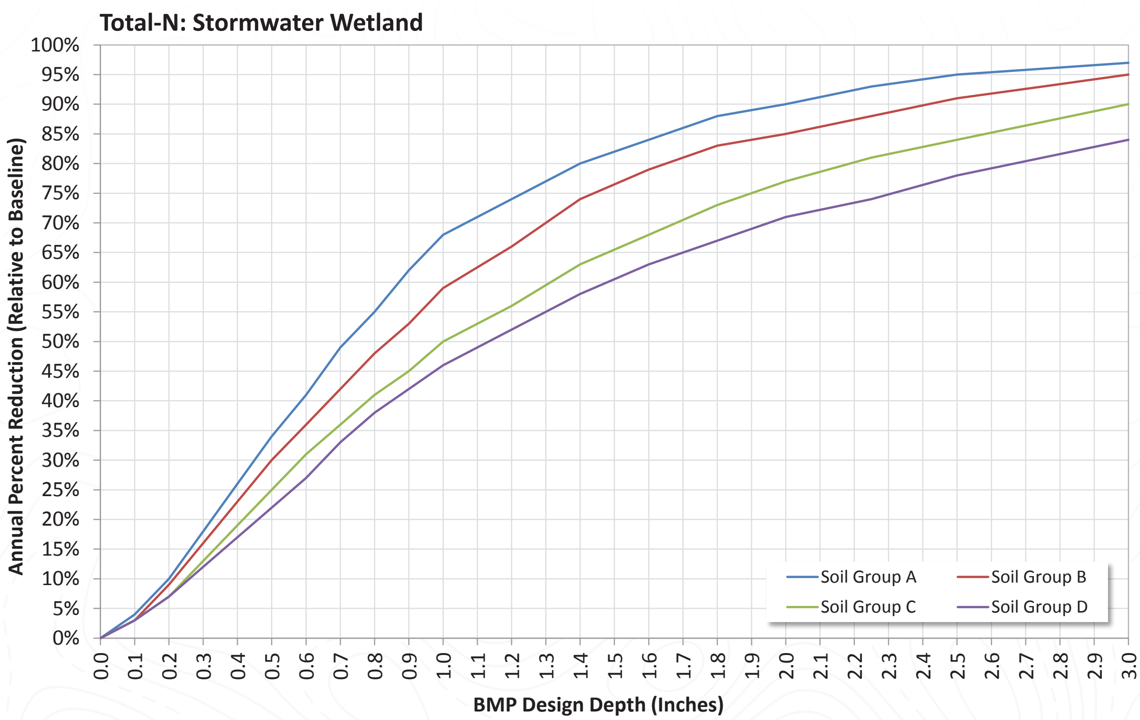
Sediment: Others
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Annual Percent Reduction (Relative to Baseline)
Cistern
Green Roof
Planter Box
Rain Barrel
Sand Filter
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9 3.0
BMP Design Depth (Inches)


Total-N: Bioretention Basin
Annual Percent Reduction (Relative to Baseline)
BMP Design Depth (Inches)
A-Soil, No Underdrain
A-Soil, With Underdrain
B-Soil, No Underdrain
B-Soil, With Underdrain
C-Soil, With Underdrain
D-Soil, With Underdrain


Total-N: Bioswale
Annual Percent Reduction (Relative to Baseline)
BMP Design Depth (Inches)
A-Soil, No Underdrain
A-Soil, With Underdrain
B-Soil, No Underdrain
B-Soil, With Underdrain
C-Soil, With Underdrain
D-Soil, With Underdrain

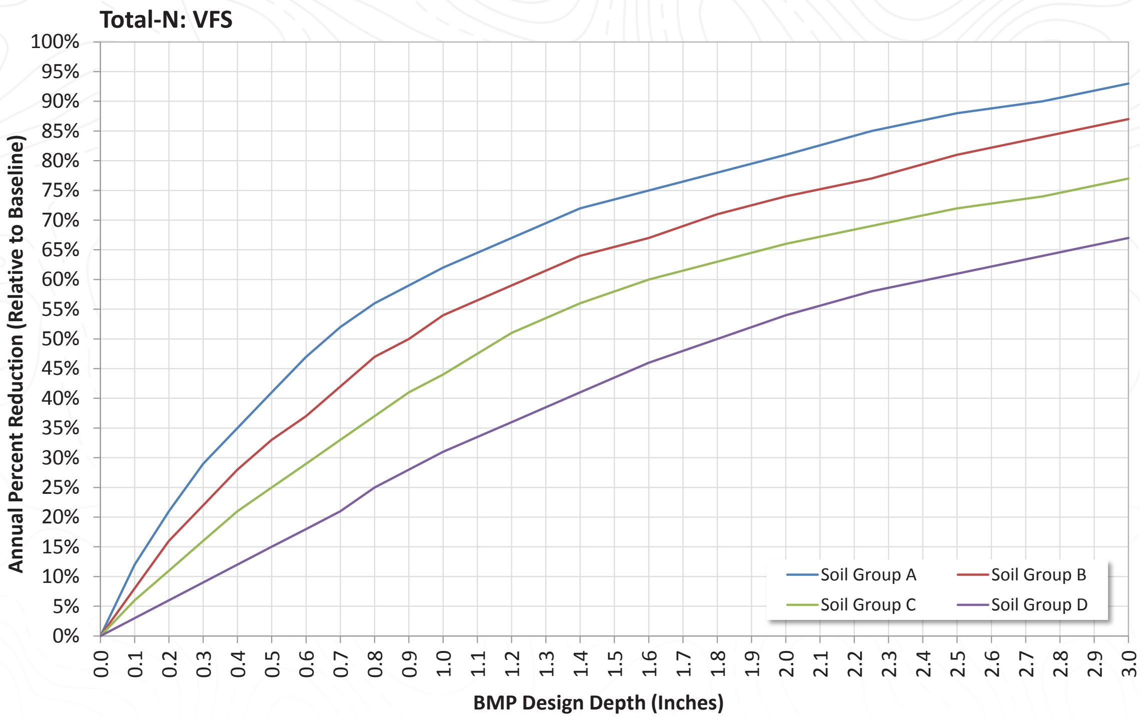


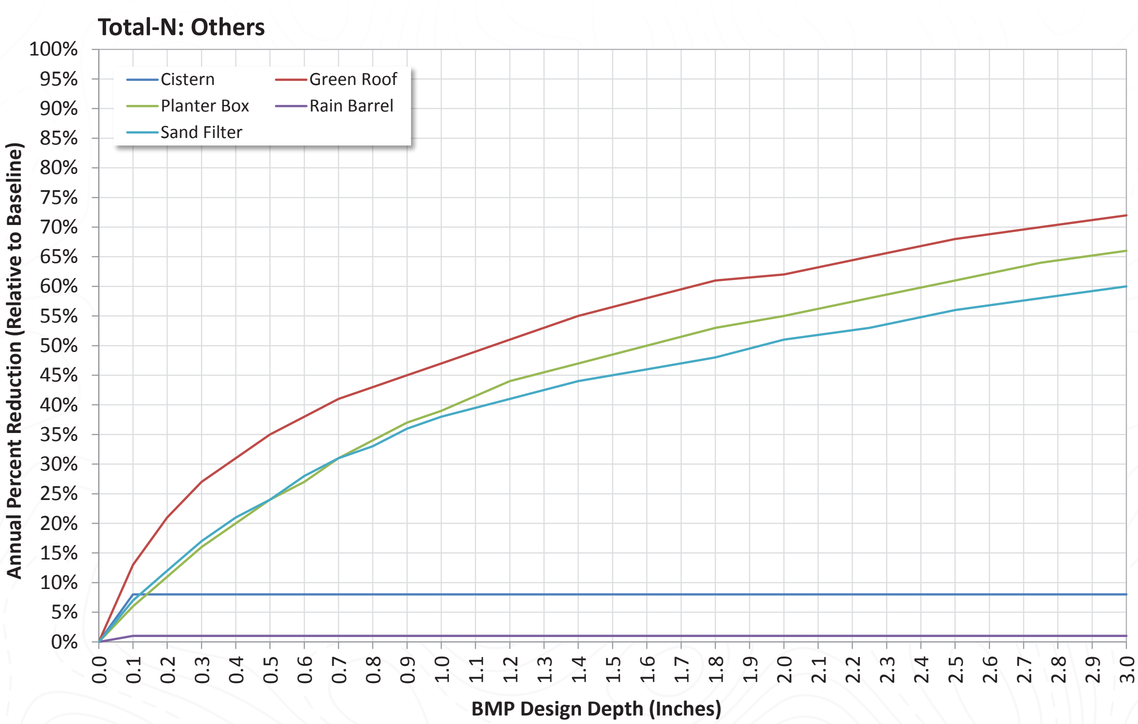
Total-N: Permeable Pavement
Annual Percent Reduction (Relative to Baseline)
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9 3.0
BMP Design Depth (Inches)
A-Soil, No Underdrain
A-Soil, With Underdrain
B-Soil, No Underdrain
B-Soil, With Underdrain
C-Soil, With Underdrain
D-Soil, With Underdrain



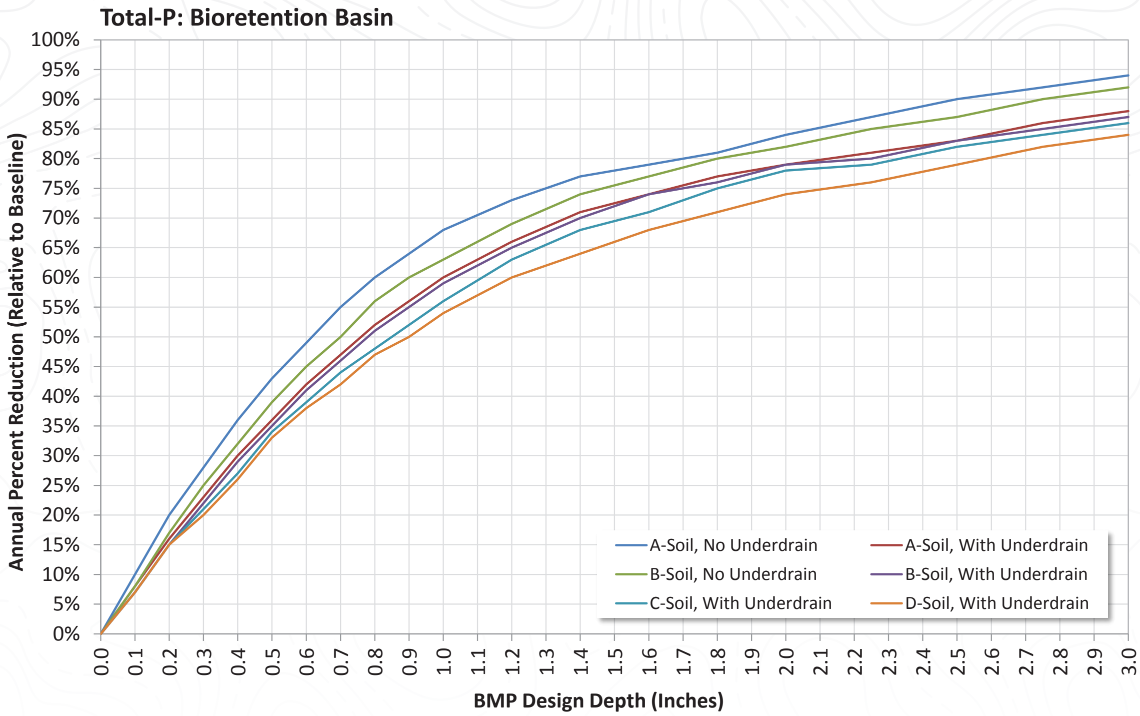
Total-N: Stormwater Wetland
Annual Percent Reduction (Relative to Baseline)
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9 3.0
BMP Design Depth (Inches)
Soil Group A
Soil Group B
Soil Group C
Soil Group D

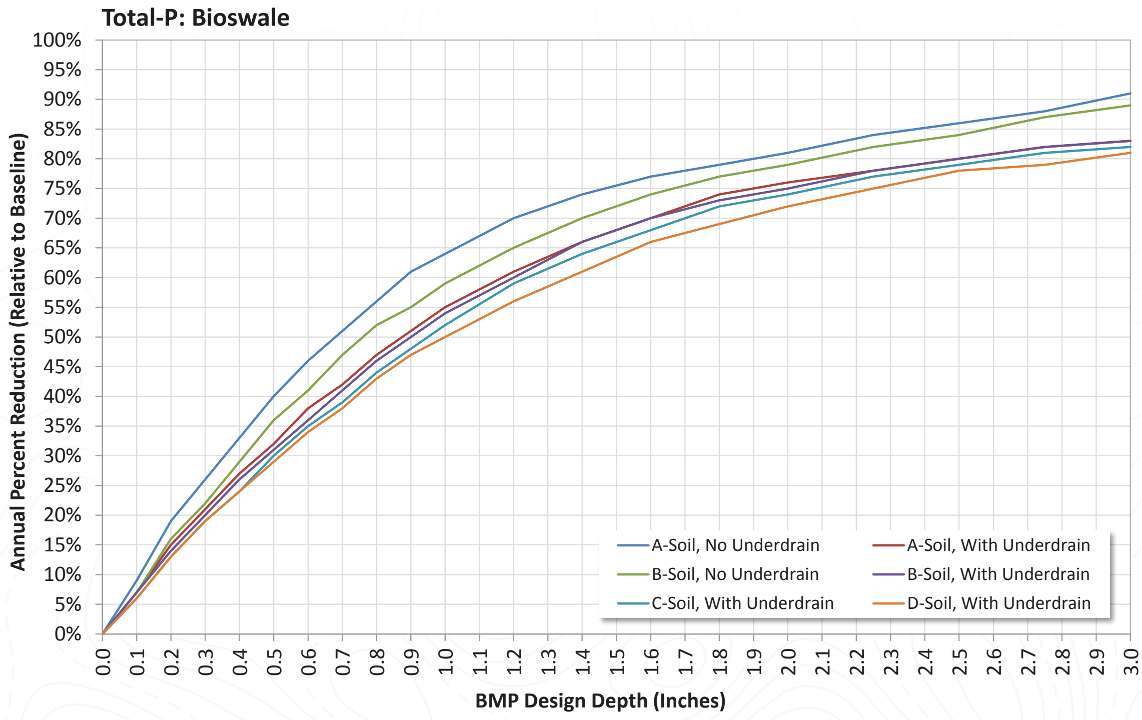
APPENDIX J: **BMP Sizing & Performance Curves**





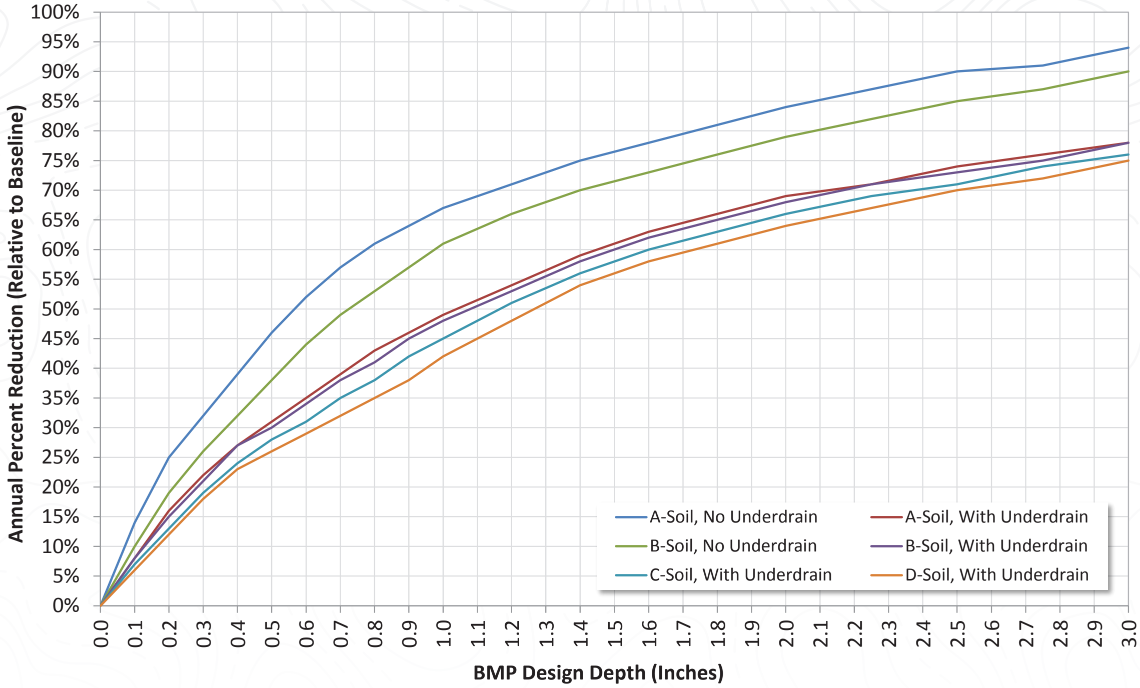
APPENDIX J: **BMP Sizing & Performance Curves**



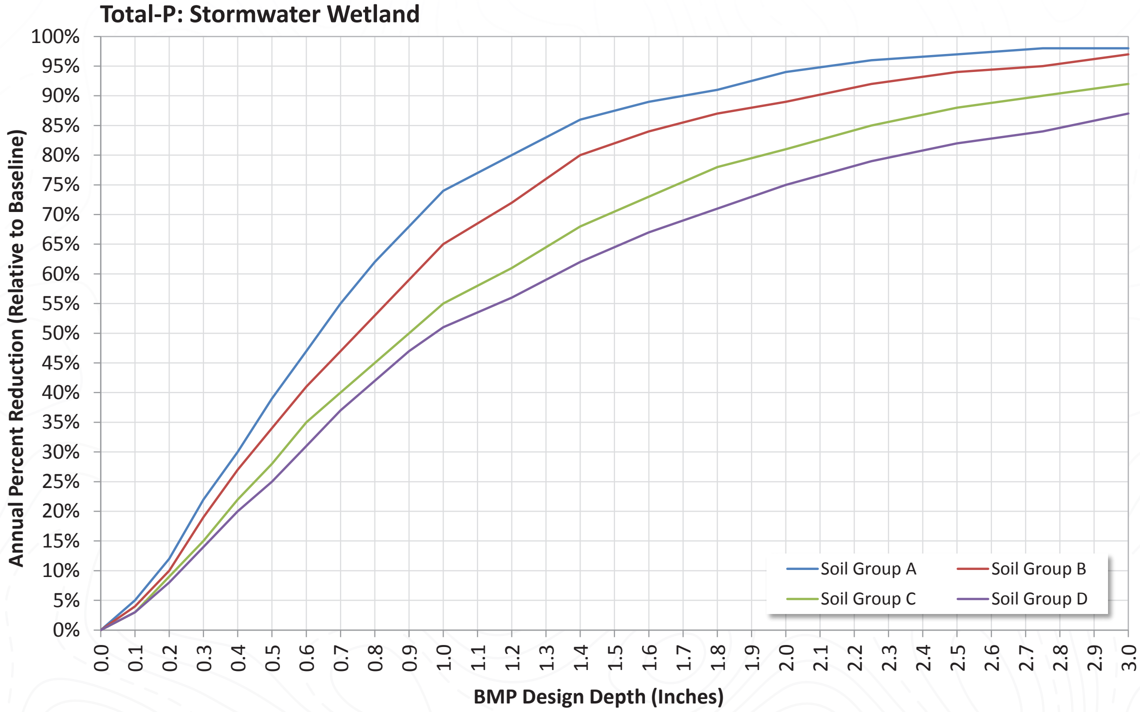


APPENDIX J: **BMP Sizing & Performance Curves**

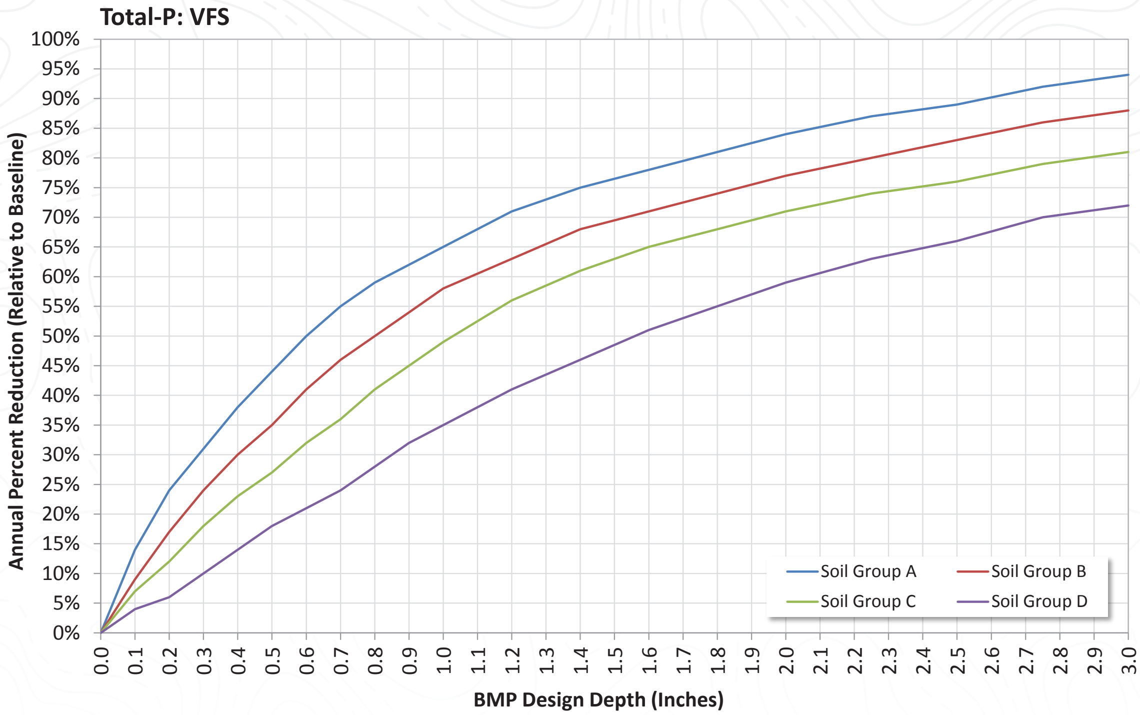
Total-P: Permeable Pavement

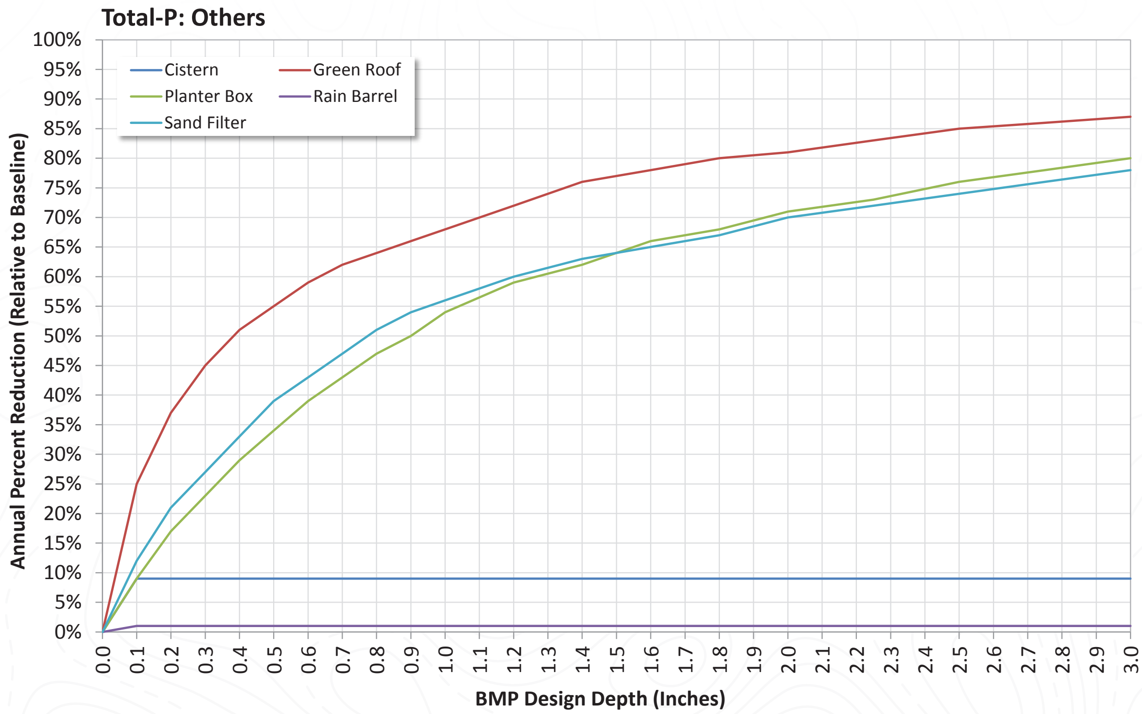


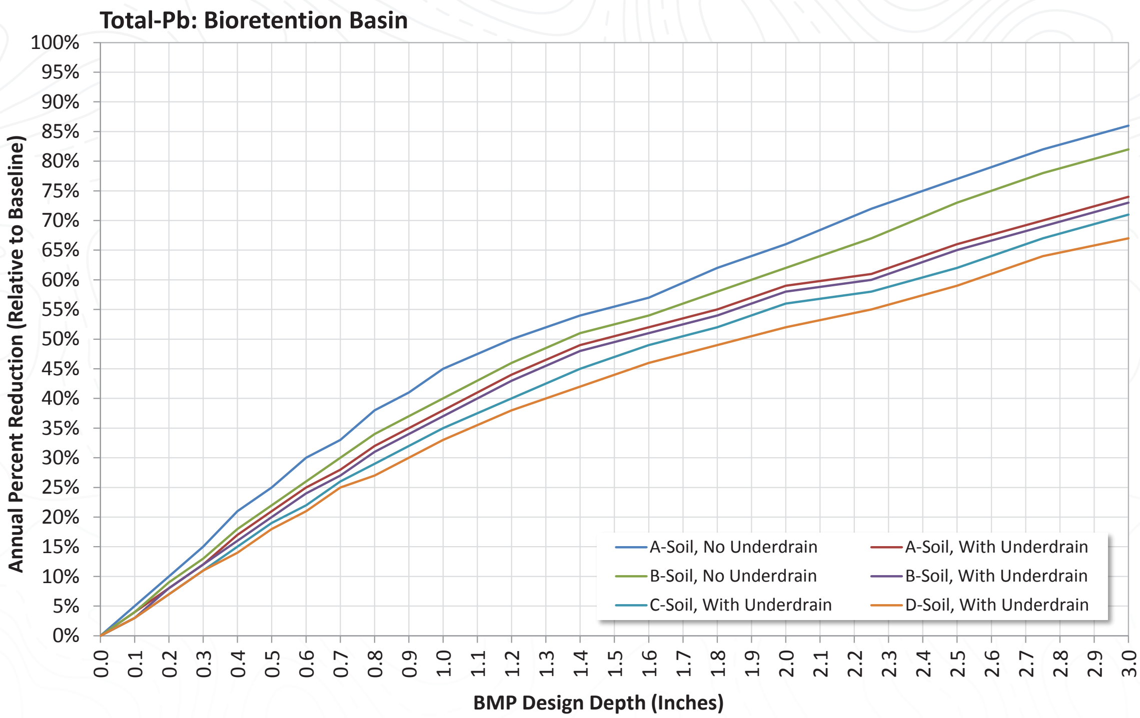
Total-P: Stormwater Wetland

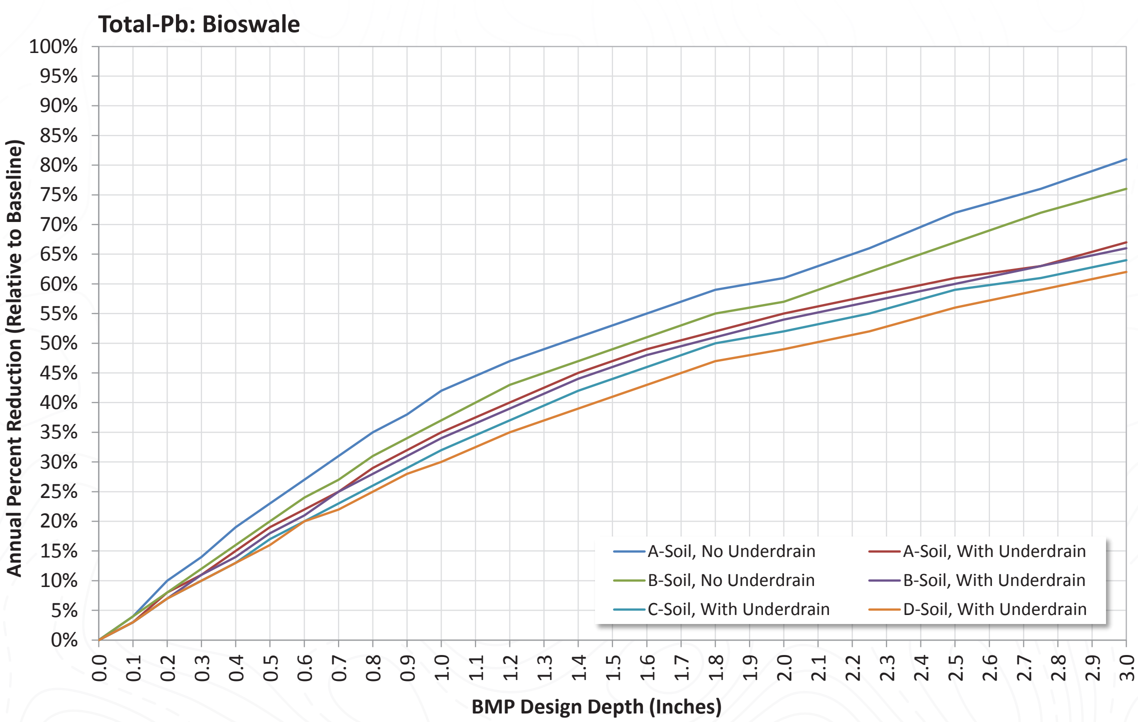


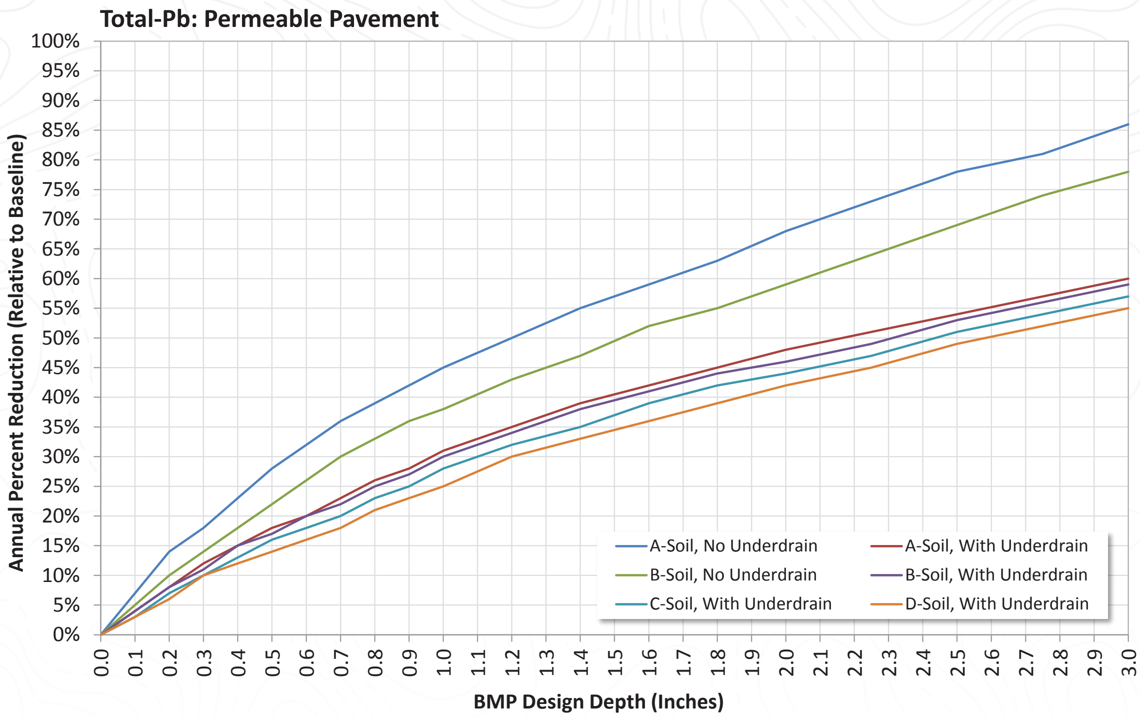
APPENDIX J: **BMP Sizing & Performance Curves**

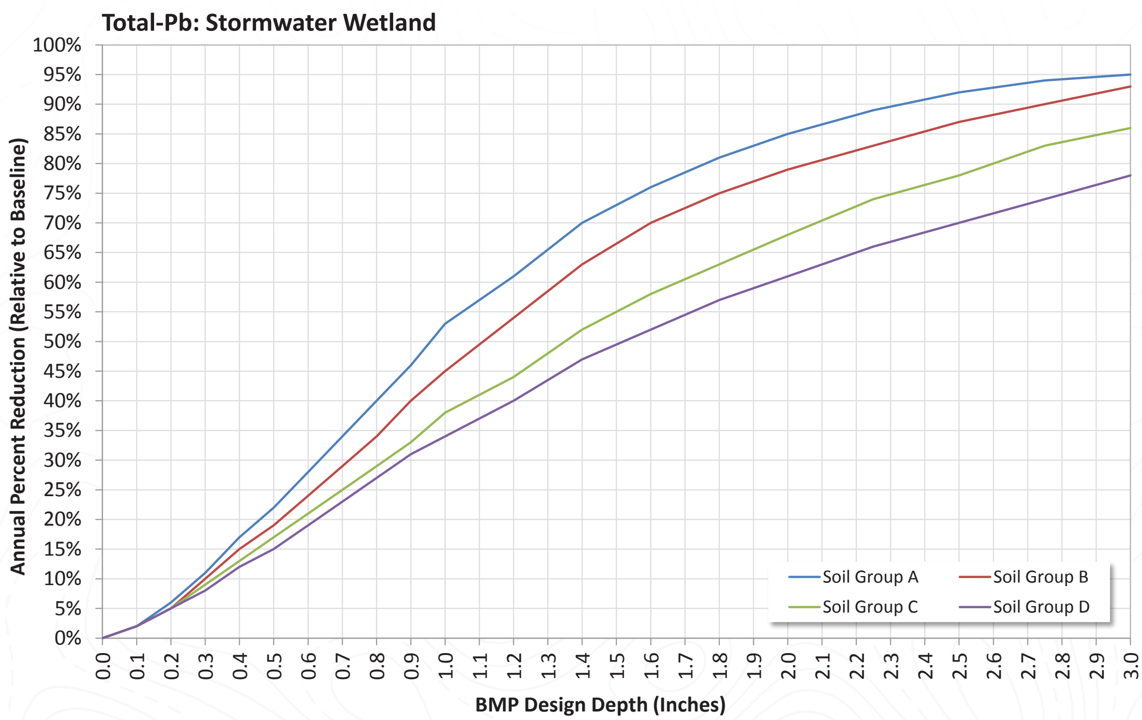




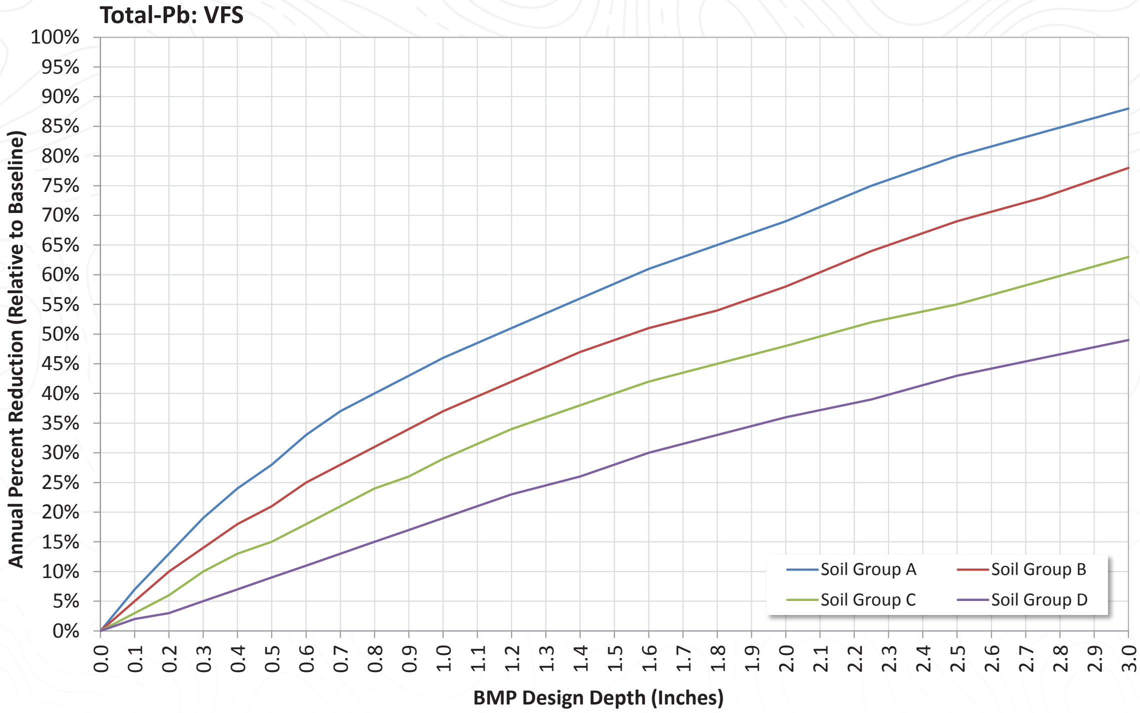

Total-Pb: Bioretention Basin
Annual Percent Reduction (Relative to Baseline)
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9 3.0
BMP Design Depth (Inches)
A-Soil, No Underdrain
A-Soil, With Underdrain
B-Soil, No Underdrain
B-Soil, With Underdrain
C-Soil, With Underdrain
D-Soil, With Underdrain

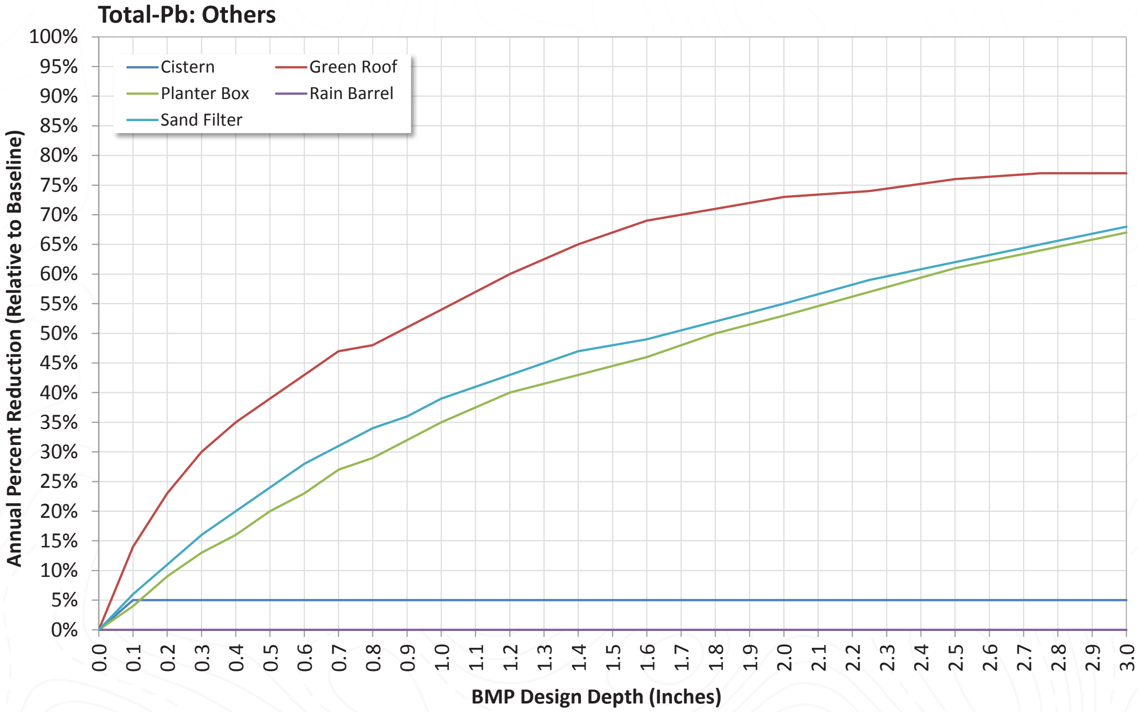

Total-Pb: Bioswale
Annual Percent Reduction (Relative to Baseline)
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9 3.0
BMP Design Depth (Inches)
A-Soil, No Underdrain
A-Soil, With Underdrain
B-Soil, No Underdrain
B-Soil, With Underdrain
C-Soil, With Underdrain
D-Soil, With Underdrain

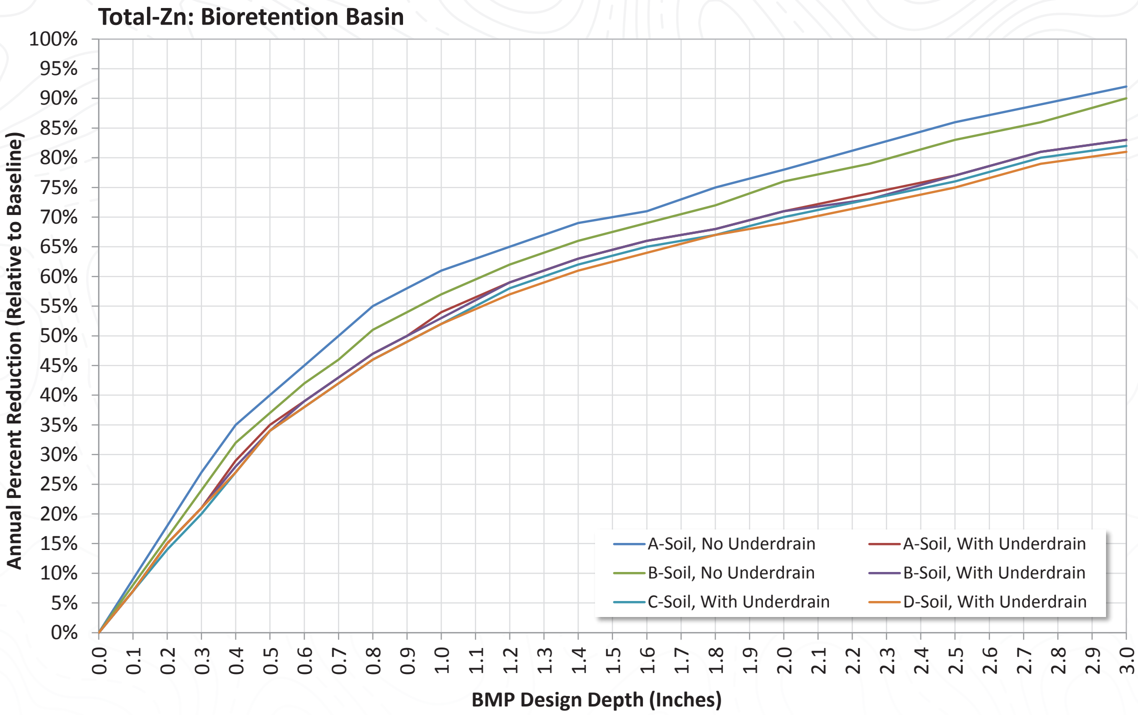

Total-Pb: Permeable Pavement
Annual Percent Reduction (Relative to Baseline)
BMP Design Depth (Inches)
A-Soil, No Underdrain
A-Soil, With Underdrain
B-Soil, No Underdrain
B-Soil, With Underdrain
C-Soil, With Underdrain
D-Soil, With Underdrain

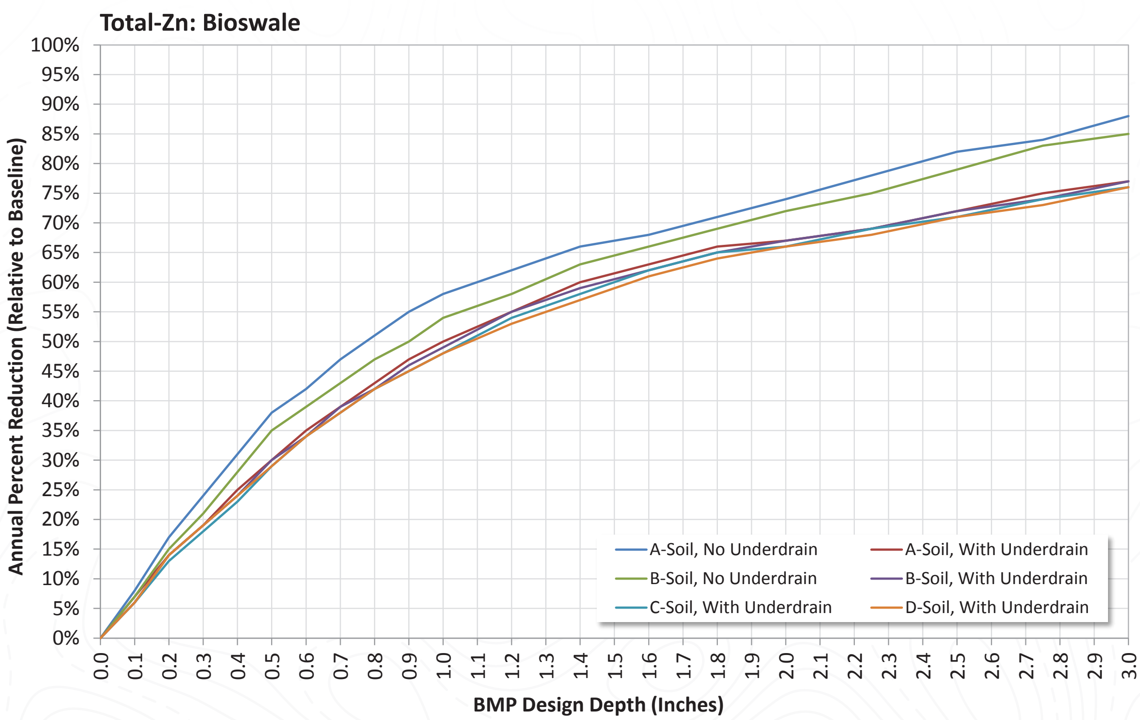

Total-Pb: Stormwater Wetland
Annual Percent Reduction (Relative to Baseline)
BMP Design Depth (Inches)
Soil Group A
Soil Group B
Soil Group C
Soil Group D

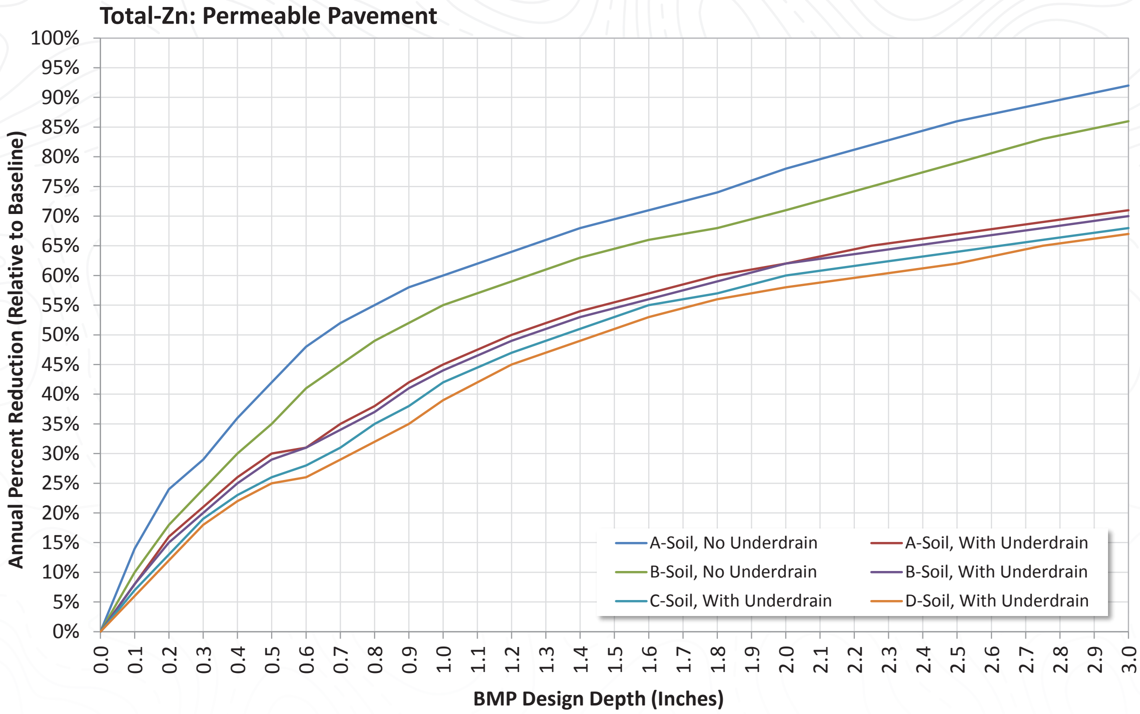
APPENDIX J: **BMP Sizing & Performance Curves**

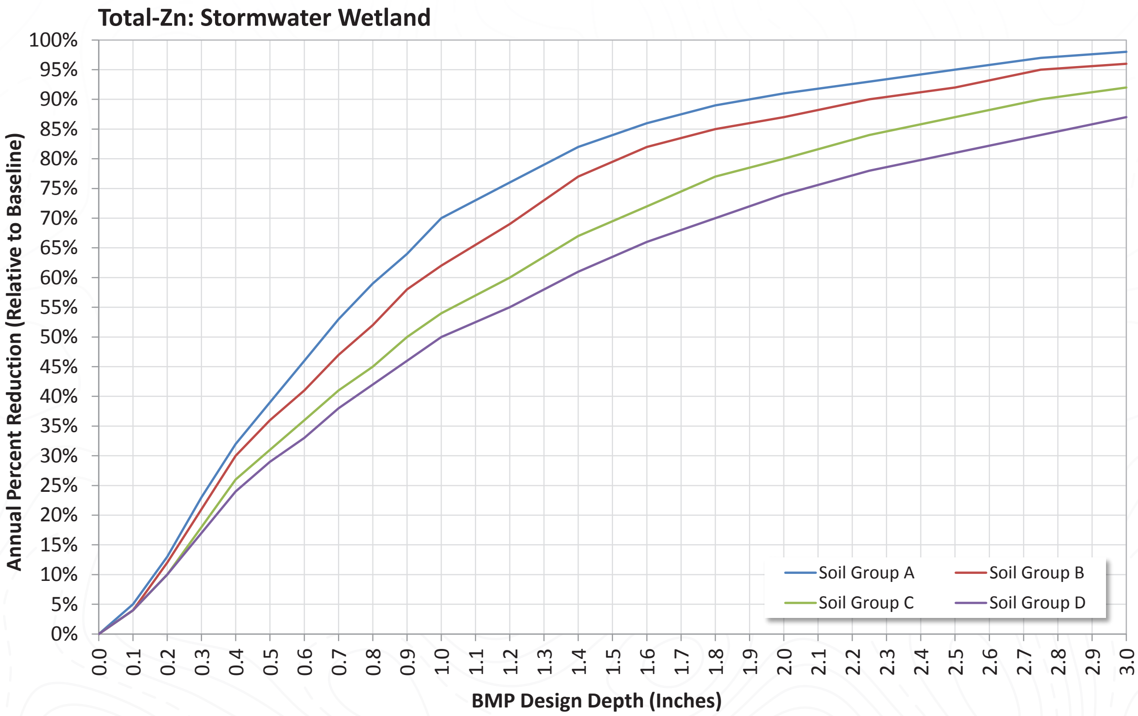


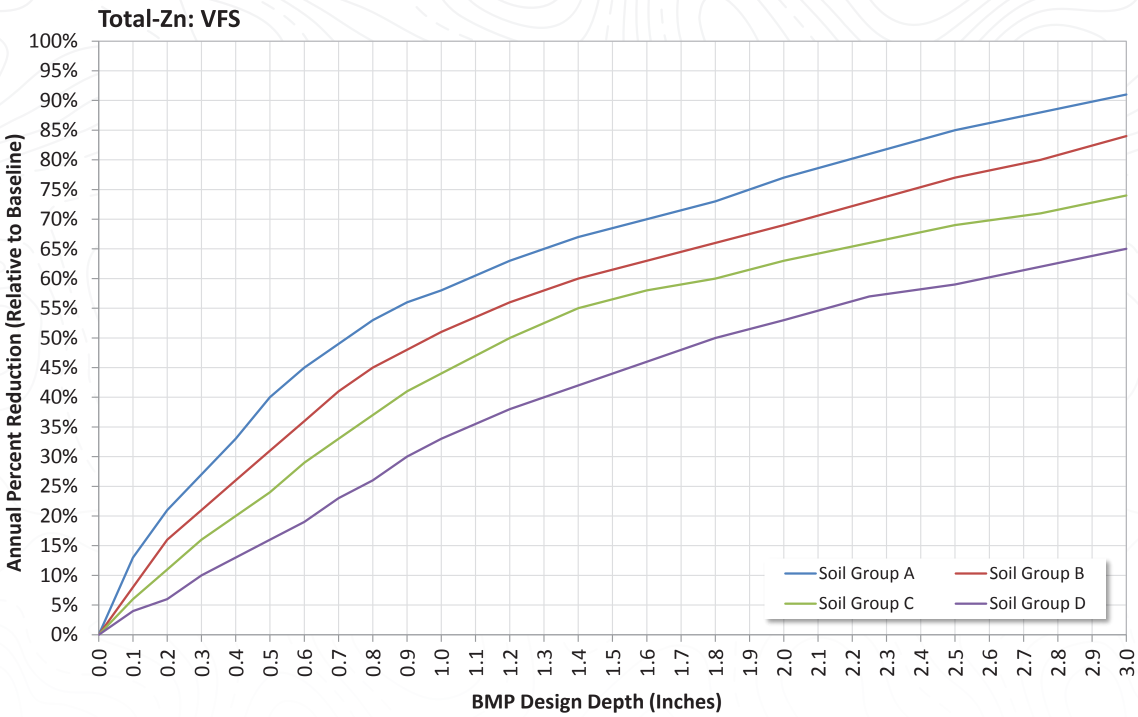


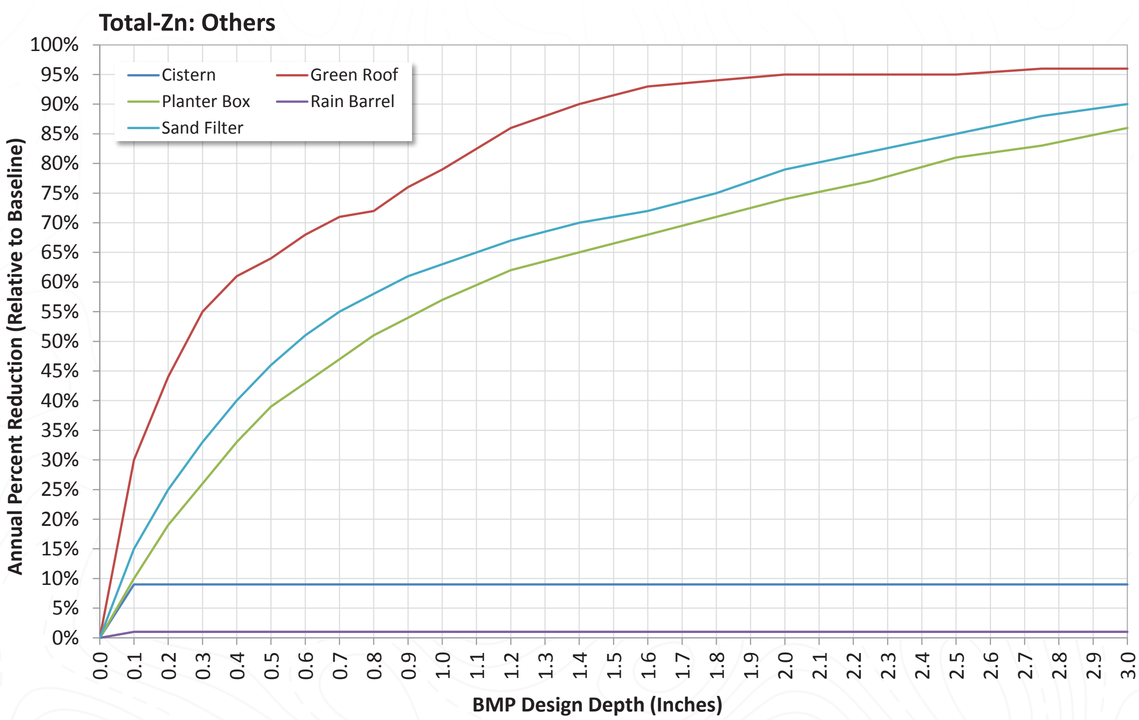

Total-Zn: Bioretention Basin
Annual Percent Reduction (Relative to Baseline)
BMP Design Depth (Inches)
A-Soil, No Underdrain
A-Soil, With Underdrain
B-Soil, No Underdrain
B-Soil, With Underdrain
C-Soil, With Underdrain
D-Soil, With Underdrain


Total-Zn: Bioswale
Annual Percent Reduction (Relative to Baseline)
BMP Design Depth (Inches)
A-Soil, No Underdrain
A-Soil, With Underdrain
B-Soil, No Underdrain
B-Soil, With Underdrain
C-Soil, With Underdrain
D-Soil, With Underdrain


Total-Zn: Permeable Pavement
Annual Percent Reduction (Relative to Baseline)
BMP Design Depth (Inches)
A-Soil, No Underdrain
A-Soil, With Underdrain
B-Soil, No Underdrain
B-Soil, With Underdrain
C-Soil, With Underdrain
D-Soil, With Underdrain


Total-Zn: Stormwater Wetland
Annual Percent Reduction (Relative to Baseline)
BMP Design Depth (Inches)
Soil Group A
Soil Group B
Soil Group C
Soil Group D


Total-Zn: VFS
Annual Percent Reduction (Relative to Baseline)
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9 3.0
BMP Design Depth (Inches)
Soil Group A
Soil Group B
Soil Group C
Soil Group D


Total-Zn: Others
Annual Percent Reduction (Relative to Baseline)
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9 3.0
BMP Design Depth (Inches)
Cistern
Green Roof
Planter Box
Rain Barrel
Sand Filter

APPENDIX J: **BMP Sizing & Performance Curves**

REFERENCES

San Antonio River Authority. Undated. San Antonio River Basin Regional Modeling Standards for Hydrology and Hydraulic Modeling.

TCEQ (Texas Commission on Environmental Quality). 2005. Complying with the Edwards Aquifer Rules—Technical Guidance on Best Management Practices. RG-348 (Revised) with Addendum. Texas Commission on Environmental Quality, Austin, TX http://www.tceq.texas.gov/field/eapp.

Notes:

LID Calculation Sheets

Project Name: ____________________

Date Prepared: ____________________

Place cursor over cells with a triangle in the upper right corner for additional information.

Characters shown in blue (bold) are data entry fields.

Characters shown in black (bold) are calculated fields and should not be edited.

BMP Area #1

Type of Development	Redevelopment	
Total project area included in BMP area	1	acres
Pre-development impervious cover	0	acres
Post-development impervious cover	0.6	acres
New impervious cover	0.6	acres
Design treatment rainfall depth	1.18	inches
BMP #1 Target Water Quality Volume:	2570.0	CF

BMP Type	Treatment Volume Provided (CF)
Bioswale / Bioretention	1312
Permeable Pavement	710
Tree Well / Planter Box	137
Green Roof	240
Sand Filter	0
Cistern	0.0
Batch Detention	0
Stormwater Wetland	0
Vegetated Swale	0
Vegetated Filter Strip	0
Vegetated Stream Buffer	0
Miscellaneous	0
Total WQV	2399

Results	
% WQV Target Met	93%
60% WQV Met?	Yes
Rainfall Treated (in.)	1.1

BMP Area #2

Type of Development	Redevelopment	
Total project area included in BMP area	1	acres
Pre-development impervious cover	0.2	acres
Post-development impervious cover	0.75	acres
New impervious cover	0.55	acres
Design treatment rainfall depth	1.18	inches
BMP #1 Target Water Quality Volume:	3212.6	CF

BMP Type	Treatment Volume Provided (CF)
Bioswale / Bioretention	0
Permeable Pavement	0
Tree Well / Planter Box	0
Green Roof	1500
Sand Filter	0
Cistern	0
Batch Detention	0
Stormwater Wetland	0
Vegetated Swale	0
Vegetated Filter Strip	0
Vegetated Stream Buffer	0
Miscellaneous	0
Total WQV	1500

Results	
% WQV Target Met	47%
60% WQV Met?	No
Rainfall Treated (in.)	0.6

BMP Area #3

Type of Development	Redevelopment	
Total project area included in BMP area	1	acres
Pre-development impervious cover	0.2	acres
Post-development impervious cover	0.75	acres
New impervious cover	0.55	acres
Design treatment rainfall depth	1.18	inches
BMP #1 Target Water Quality Volume:	3212.6	CF

BMP Type	Treatment Volume Provided (CF)
Bioswale / Bioretention	820
Permeable Pavement	0
Tree Well / Planter Box	0
Green Roof	0
Sand Filter	0
Cistern	141
Batch Detention	0
Stormwater Wetland	0
Vegetated Swale	0
Vegetated Filter Strip	0
Vegetated Stream Buffer	1000
Miscellaneous	0
Total WQV	1961.371669

Results	
% WQV Target Met	61%
60% WQV Met?	Yes
Rainfall Treated (in.)	0.7

BMP Area #4

Type of Development	Redevelopment	
Total project area included in BMP area	1	acres
Pre-development impervious cover	0.2	acres
Post-development impervious cover	0.75	acres
New impervious cover	0.55	acres
Design treatment rainfall depth	1.18	inches
BMP #1 Target Water Quality Volume:	3212.6	CF

BMP Type	Treatment Volume Provided (CF)
Bioswale / Bioretention	0
Permeable Pavement	0
Tree Well / Planter Box	0
Green Roof	0
Sand Filter	0
Cistern	0
Batch Detention	0
Stormwater Wetland	0
Vegetated Swale	0
Vegetated Filter Strip	600
Vegetated Stream Buffer	0
Miscellaneous	1500
Total WQV	2100

Results	
% WQV Target Met	65%
60% WQV Met?	Yes
Rainfall Treated (in.)	0.8

BMP Area #5

Type of Development	Redevelopment	
Total project area included in BMP area	1	acres
Pre-development impervious cover	0.2	acres
Post-development impervious cover	0.75	acres
New impervious cover	0.55	acres
Design treatment rainfall depth	1.18	inches
BMP #1 Target Water Quality Volume:	3212.6	CF

BMP Type	Treatment Volume Provided (CF)
Bioswale / Bioretention	0
Permeable Pavement	0
Tree Well / Planter Box	0
Green Roof	0
Sand Filter	904
Cistern	0
Batch Detention	0
Stormwater Wetland	0
Vegetated Swale	49.5
Vegetated Filter Strip	120
Vegetated Stream Buffer	120
Miscellaneous	0
Total WQV	1193.5

Results	
% WQV Target Met	37%
60% WQV Met?	No
Rainfall Treated (in.)	0.4

Bioswale & Bioretention Volume Calculations						
BMP Area #	Total Bioswale /Bioretention Area (SF)	Ponding Depth (ft)	Bioretention Media (Mulch+Engineered Soil +Sand) Depth (ft)*	Gravel Storage (#8 & #57 Stone) Depth (ft)*	Total Equivalent Storage Depth (ft)	Proposed Treatment WQV ** (CF)
1	800	0.75	2	1.5	**2.05**	**1312**
2	0	0	0	0	**0**	**0**
3	500	0.75	2	1.5	**2.05**	**820**
4	0	0	0	0	**0**	**0**
5	0	0	0	0	**0**	**0**

*The corresponding calculations utilize an average porosity value, n, of 0.35 for the Bioretention Media layers and 0.40 for the Bioretention Gravel layers

** The proposed treatment volume accounts for 20% of designed volume as sediment accumulation.

	A	B	C	D	E	F	G	H
1								
2								
3								
4								
5								
6								
7		**Permeable Pavement Volume Calculations**						
8		BMP Area #	Total Permeable Pavement Area (SF)	Gravel Storage (#8 & #57 Stone) Depth (ft)*	Sand Depth (ft)*	Total Equivalent Storage Depth (ft)	Proposed Treatment WQV (CF)	
9		1	800	2	0.25	**0.8875**	**710**	
10		2	0	0	0	**0**	**0**	
11		3	0	0	0	**0**	**0**	
12		4	0	0	0	**0**	**0**	
13		5	0	0	0	**0**	**0**	
14		*The corresponding calculations utilize an average porosity						
15		value, n, of 0.40 for the Gravel layers and 0.35 for sand layers.						
16								
17								

Tree Well and Planter Box Volume Calculations						
BMP Area #	Total Tree Well/Planter Area (SF)	Ponding Depth (ft)	Bioretention Media (Mulch+Engineered Soil +Sand) Depth (ft)*	Gravel Storage (#8 & #57 Stone) Depth (ft)*	Total Equivalent Storage Depth (ft)	Proposed Treatment WQV** (CF)
1	80	0.75	2.25	1.5	**2.1375**	**136.8**
2	0	0	0	0	**0**	**0**
3	0	0	0	0	**0**	**0**
4	0	0	0	0	**0**	**0**
5	0	0	0	0	**0**	**0**

*The corresponding calculations utilize an average porosity value, n, of
0.35 for the Bioretention Media layers and 0.40 for the Bioretention Gravel layers
0.35 for the Bioretention Media layers and 0.40 for the Bioretention Gravel layers
** The proposed treatment volume accounts for 20% of designed volume as sediment accumulation.

Green Roof Volume Calculations

BMP Area #	Total Green Roof Area (SF)	Ponding Depth (ft)	Drainage Layer Porosity*	Drainage Layer Depth (ft)	Total Equivalent Storage Depth (ft)	Proposed Treatment WQV (CF)
1	800	0.125	0.35	0.5	0.175	240
2	5000	0.125	0.35	0.5	0.175	1500
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0

* Ponding depth is the distance from the top of the designed green roof elevation to the invert of the overflow.

**Drainage Layer Porosity, n, is usually equal to 0.35 for most engineered soils and 0.40 for most stone layers.

Sand Filter Volume Calculations

BMP Area #	Sand Filter Area (SF)	Ponding Depth (ft)	Sand Depth (ft)*	Gravel Storage (#57 Stone) Depth (ft)*	Total Equivalent Storage Depth (ft)	Proposed Treatment WQV** (CF)
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	400	2	1.5	0.75	2.825	904

*The corresponding calculations utilize an average porosity value, n, of 0.35 for the sand layers and 0.40 for the gravel storage layer.
0.35 for the Bioretention Media layers and 0.40 for the Bioretention Gravel layers
** The proposed treatment volume accounts for 20% of designed volume as sediment accumulation.

Cistern Volume Calculations			
BMP Area #	Cistern Diameter (ft)	Working Cistern Height (ft)	Working Cistern Volume (CF)
1	0	0	**0.0**
2	0	0	**0.0**
3	6	5	**141.4**
4	0	0	**0.0**
5	0	0	**0.0**

Batch Detention Volume Calculations			
BMP Area #	Batch Detention Top Area (SF)	Average Ponding Depth (ft)	Proposed Treatment WQV* (CF)
1	0	0	**0**
2	0	0	**0**
3	0	0	**0**
4	0	0	**0**
5	0	0	**0**

* The proposed treatment volume accounts for 20% of designed volume as sediment accumulation.

Extended Detention Volume Calculations			
BMP Area #	Extended Detention Top Area (SF)	Average Ponding Depth (ft)	Proposed Treatment WQV* (CF)
1	0	0	**0**
2	0	0	**0**
3	0	0	**0**
4	0	0	**0**
5	0	0	**0**

* The proposed treatment volume accounts for 20% of designed volume as sediment accumulation.

Stormwater Wetland Volume Calculations

BMP Area #	Stormwater Wetland Top Area (SF)	Average Ponding Depth (ft)	Proposed Treatment WQV* (CF)
1	0	0	**0**
2	0	0	**0**
3	0	0	**0**
4	0	0	**0**
5	0	0	**0**

* The proposed treatment volume accounts for 20% of designed volume as sediment accumulation.

LID Calculation Sheets

Vegetated Swale Calculations			
BMP Area #	Vegetated Swale Area* (SF)	Water Quality Volume Depth (FT)	Proposed Treatment WQV** (CF)
1	0	0.33	0
2	0	0.33	0
3	0	0.33	0
4	0	0.33	0
5	150	0.33	49.5

*Area of channel 4" above the bottom of channel depth and lower

** Channel velocity must be <= 1 FT/s to use swale as WQV

Vegetated Filter Strip Calculations			
BMP Area #	Vegetated Filter Strip Area (SF)*	Soil Type	Proposed Treatment WQV** (CF)
1	**0**	**C-D w/ Soil Amendment**	**0**
2	**0**	**C-D**	**0**
3	**0**	**C-D**	**0**
4	**20000**	**C-D**	**600**
5	**2000**	**A-B**	**120**

* Maximum slope =5% for credit, must be sheet flow onto filter strip for credit

**Soil type will determine level of credit for filter strip (A-B = $6ft^3/100ft^2$, C-D = $3ft^3/100ft^2$, C-D w/ Soil Amendment = $6ft^3/100ft^{2)}$

Vegetated Stream Buffer Calculations			
BMP Area #	Vegetated Stream Buffer Area (SF)*	Soil Type	Proposed Treatment WQV** (CF)
1	**0**	**C-D**	**0**
2	**0**	**C-D**	**0**
3	**25000**	**C-D**	**1000**
4	**0**	**C-D**	**0**
5	**2000**	**C-D w/ Soil Amendment**	**120**

* Must be sheet flow onto vegetated stream buffer for credit

**Soil type will determine level of credit for filter strip (A-B = $9ft^3/100ft^2$, C-D = $4ft^3/100ft^2$, C-D w/ Soil Amendment = $6ft^3/100ft^{2)}$

Miscellaneous Volume Calculations		
BMP Area #	Type of BMP	Proposed Treatment WQV* (CF)
1	-	**0**
2	-	**0**
3	-	**0**
4	**Jellyfish Filter System**	**1500**
5	-	**0**

* Attach supporting calculations from proprietary systems, i.e. cartridge systems, settling tanks, high-flow systems, etc.

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