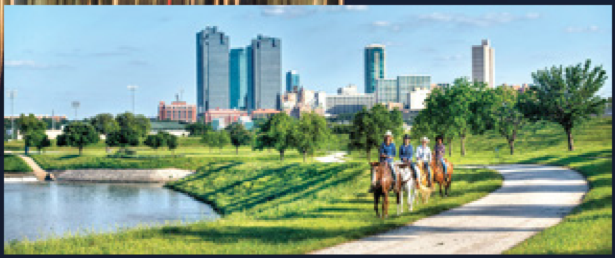
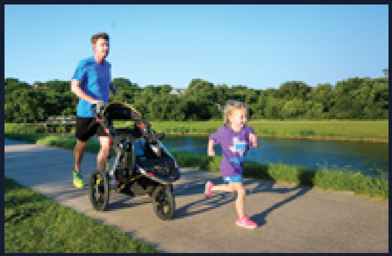
trwd Tarrant Regional Water District

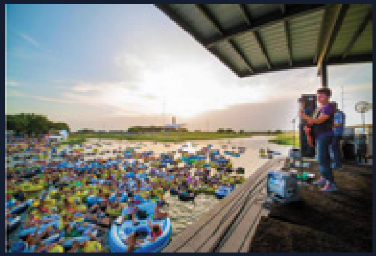
# WATER QUALITY GUIDANCE MANUAL

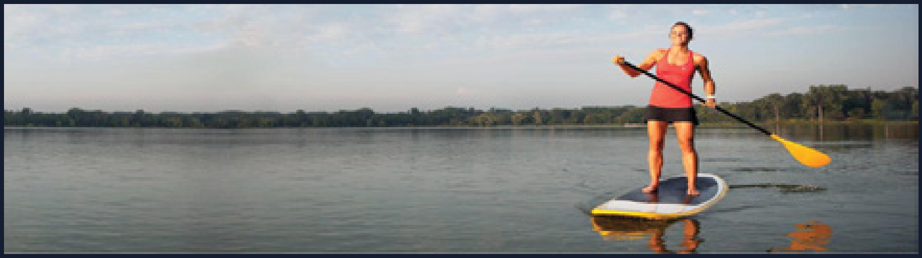
## Planning and Implementing Stormwater Quality Practices

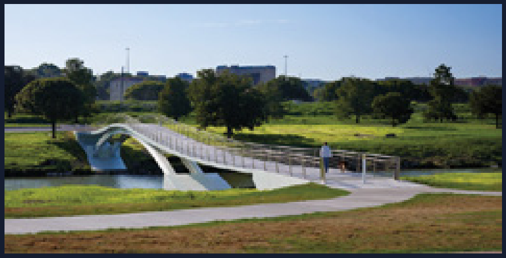
June 2018











CDM Smith

CCA LANDSCAPE ARCHITECTS Caye Cook & Associates

NCIMM National Center for Infrastructure Modeling and Management

This page intentionally left blank.

Tarrant Regional Water District

# WATER QUALITY GUIDANCE MANUAL

## Planning and Implementing Stormwater Quality Practices

June 2018


Prepared by:

CDM Smith

in association with

CCA LANDSCAPE ARCHITECTS

NCIMM
National Center for Infrastructure Modeling and Management

# ACKNOWLEDGMENTS

The project team would like to the thank the many individuals who contributed to the development of this inaugural water quality manual for the Tarrant Regional Water District to assist in implementing cost-effective storm drainage infrastructure that benefits quality as well as quantity. This manual is the result of three years of extensive study on the long-term water quality impact of untreated urban runoff on the Clear and West Forks of the Trinity.

Storm drainage infrastructure that provides water quality as well as flood protection benefits is critical to maintaining the outstanding water resource that now exists in the Trinity River as it flows through Fort Worth. These waters are enjoyed not only by Fort Worth citizens, but also by many out-of-town visitors who come to enjoy the nearly 100-miles of trails, swimming, water skiing, fishing, canoeing, kayaking, paddle-boarding, parks and nature areas, and just enjoying the aesthetics of this great resource – a resource no other major North Texas community can claim.

We would like to recognize the contributions of Dr. Bill Espey, P.E., D.WRE and Keith Moody, P.E., CFM whose many years of experience with managing water quality and implementing stormwater quality practices for developments in urban areas provided invaluable insights into real-life implementation of these practices. Similarly, the team wishes to thank Pacheco Koch's Carlo Andreani, P.E., LEED AP BD+C, for his independent review and comment on the manual.

Special thanks also to Ben Urbonas, P.E. and Dr. Charles Rowney from the National Center for Infrastructure Modeling and Management for their valuable input on hydrology, hydraulics, water quality modeling, and model integration, technical review of results.

Finally, the team wishes to express their gratitude to the TRWD team who worked enthusiastically with us every step of the way to help produce a tool that would be both useful for developers, appropriate to Fort Worth and its surrounds that adjoin the Trinity, and would, in end, help maintain the water quality in the Trinity. We also know that TRWD staff appreciates the cooperation and encouragement they received from City of Fort Worth in bringing this manual to fruition and looks forward to working with City staff to implement this guidance.

Robert W. Brashear, Ph.D., P.E
Associate
CDM Smith Inc.
TX PE License 80771
TX PE Firm F-3043

| **Development Team:** | | |
|---|---|---|
| *CDM Smith Inc.* | | *Tarrant Regional Water District* |
| Dr. Tina Petersen, P.E.<br>Gian Villarreal, P.E.<br>Kimberly Siemens, P.E.<br>Richard Wagner, P.E.<br>Candace Pearson, P.E. | Alan Rhames<br>Erica Wellen<br>Christine Ngan<br>Jodi Polzin,<br>Jessica Veach, | Woody Frossard<br>Darrel Andrews<br>Tina Henson<br>Brenton Dunn<br>Mark Ernst<br>Jennifer Owens |
| *National Center for Infrastructure Modeling and Management* | *Caye Cooke Landscape Architects* | *Trinity River Vision Authority* |
| Ben Urbonas, P.E<br>Dr. Charles Rowney | Caye Cook, PLA, ASLA<br>Lindsey White, PLA, ASLA | J.D. Granger<br>Jenna Brummett |

# TABLE OF CONTENTS

## List of Figures



## List of Design Criteria

# List of Tables

# Appendices

# List of Acronyms

| | |
|---|---|
| BMP | best management practice |
| CFW | City of Fort Worth |
| CGP | Construction General Permit |
| cm/s | centimeters per second |
| ft/sec | feet per second |
| GSI | green stormwater infrastructure |
| HDPE | high density polyethylene |
| iSWM™ | integrated Stormwater Management |
| lbs. | pounds |
| lbs/sq yd | pounds per square yard |
| LID | low impact development |
| NOI | notice of intent |
| NRCS | Natural Resources Conservation Service |
| O&M | operation and maintenance |
| oz/cm$^3$ | ounces per cubic centimeter |
| PCB | polychlorinated biphenyl |
| PVC | polyvinyl chloride |
| STD | standard |
| SWPPP | Storm Water Pollution Prevention Plan |
| TCEQ | Texas Commission on Environmental Quality |
| TPDES | Texas Pollutant Discharge Elimination System |
| TRWD | Tarrant Regional Water District |
| TxDOT | Texas Department of Transportation |
| USCS | Unified Soil Classification System |
| UWRI | Urban Water Resources Institute |

This page intentionally left blank.

## SECTION 1

# The TRWD Water Quality Manual

The Trinity River is one of the greatest assets of the City of Fort Worth. Management of the river is an important goal of the Tarrant Regional Water District (TRWD) to protect water supply, reduce the risk of flooding, and enhance the quality of life by creating recreation opportunities and enabling active lifestyles. Water quality protection plays an important role in this mission by ensuring water is suitable for swimming, fishing, and recreation. Part of TRWD's mission is to continually assess the current water quality conditions in the Trinity River. Because of the importance of water quality to the users of the Trinity River and the citizens of area, TRWD has spent the past three years analyzing in detail what the impact to the water quality of the river will be as the population continues to grow and land use changes (TRWD 2018). These studies have shown that without changes to how stormwater runoff is handled, the current quality of the Trinity River in Fort Worth could degrade significantly to the point contact recreation activities, such as swimming, will be impacted due to elevated amounts of bacteria. Without intervention, the aesthetics of the river will decline as well due to increasing amounts of trash in the river and unsightly algae growth from increases in nutrients which also impact aquatic life. These studies have also shown that, over time as changes occur in watersheds draining to the river, the implementation of appropriate stormwater quality infrastructure that captures and treats stormwater before discharge to waterways can mitigate much of this undesired impact to the Trinity River. Where this has been done in other locations in the country, it has often not only had the desired effect of protecting water quality, but it has also improved the aesthetic quality of the land surface, raised property values, and made communities more desirable.

The waterways of the Trinity River flowing through the City of Fort Worth are currently and will continue to be influenced by growth. This growth impacts hydrology and sediment transport in watersheds as well as the quality of receiving waters. This manual is part of a larger effort by TRWD to implement actions to protect water quality.

## 1.1 PURPOSE AND INTRODUCTION

The goal of this manual is to promote effective, useful guidance in cost-effectively planning, designing, and implementing stormwater water quality infrastructure that will protect the water quality of the Trinity River and its tributaries from the negative impacts of urban runoff.

The primary objectives of this document are to:

- Define the water quality requirements for both new and re-development projects,

- Provide planning, design, and implementation guidance for structural best management practices (BMPs) to protect water quality downstream of new development and re-development projects, and
- Outline the review process and roles and provide support materials for meeting water quality requirements for development projects.

Four zones are designated within the region shown in Figure 1.1 (additional maps with more detail are provided in Appendix F). BMP requirements vary based on the zone in which development or re-development occurs. This manual focuses on the requirements for Zone 2 (the requirements are discussed in Section 1.5).

The BMPs and designs identified in this manual are intended to foster the use of beneficial green stormwater infrastructure (GSI) features and provide mitigation of the water quality impacts of development and redevelopment activities. The BMPs may also provide flood control management, (e.g., extended (dry) detention basins); however, this manual is focused on mitigating water quality impacts of land draining to the Trinity River. Seven types of structural BMPs are discussed in this manual that if designed, constructed, and maintained as described in this manual and with proper documentation (see Section 1.6), meet the required level of water quality treatment. These are:

- Bioretention basin
- Constructed wetland
- Sand or media filter
- Wet (pond) basin
- Extended (dry) detention basin
- Retention and irrigation basin
- Permeable or porous pavers (Note that there are limitations to the drainage areas that can be treated using pavers).

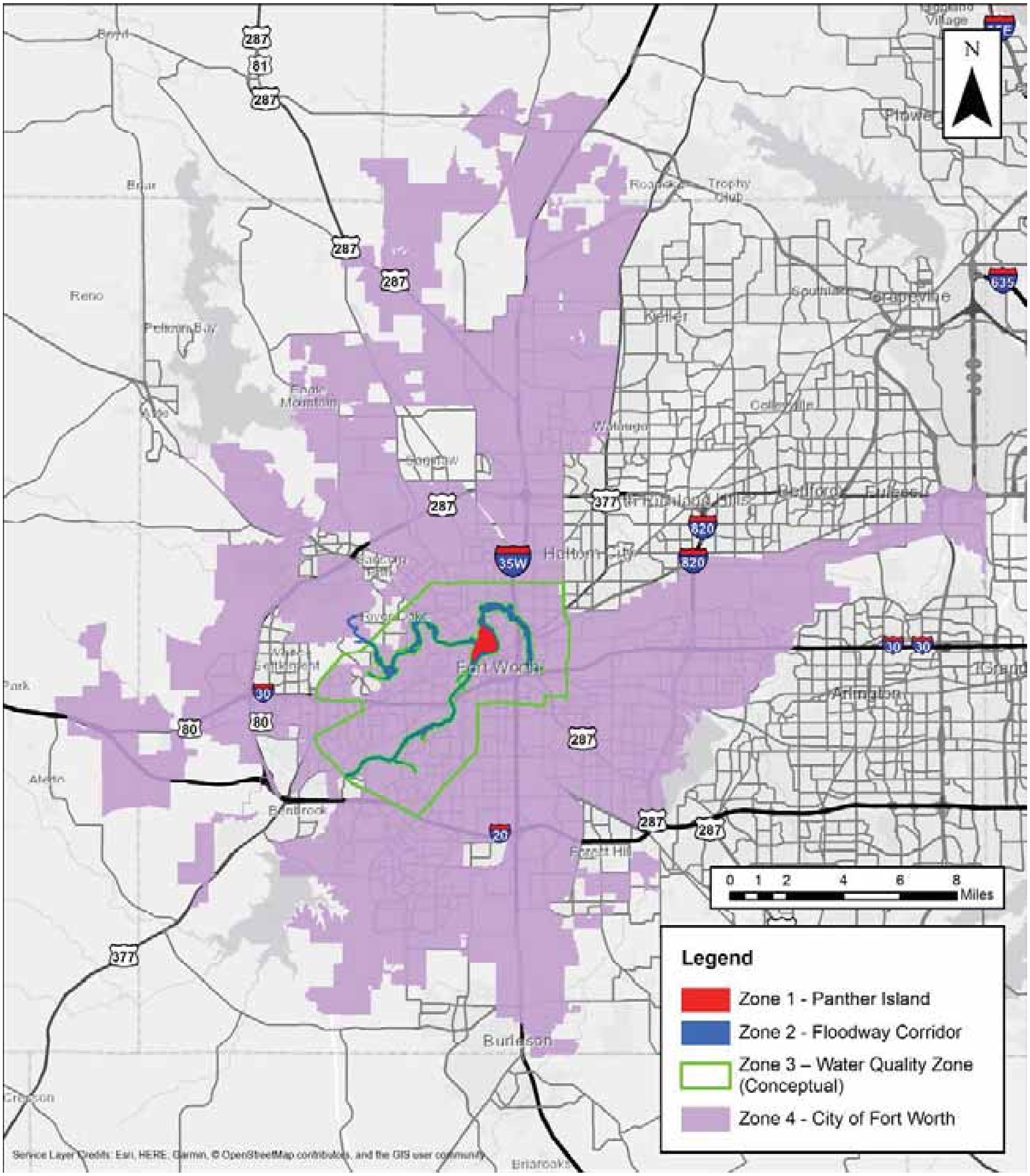
In addition to these seven types of BMPs, there are two BMPs described in this manual that can be used for small drainage areas, where appropriate, to reduce the overall required treatment volume for a site or in conjunction with the seven BMPs listed above. These BMPs are:

- Vegetative filter strip and
- Grass swale

Some of the BMPs listed above are commonly referred to as low impact development (LID) or green stormwater infrastructure (GSI) facilities.

Compliance requires the proper sizing, design, site layout, construction and appropriate maintenance for the BMP(s) chosen for any given site.

**Figure 1.1 Water Quality Zones for the Trinity River**




Note: new developments and re-developments in or across Zone 2 will be required to incorporate water quality BMPs to treat the water quality protection volume as described in this manual.

## 1.2 HOW TO USE THIS MANUAL

The intended audience for the TRWD Water Quality Manual includes developers, engineers, landscape architects, designers, and reviewers for governing authorities. An understanding of the local ordinances, BMPs, and design alternatives will be beneficial to all. This manual is intended to be a living document. The relevant items in the manual for each of the intended audiences is outlined below.

- Developers – This manual summarizes requirements and siting considerations (Section 2) and includes BMP descriptions and fact sheets (Appendix B). These sections are intended to provide the information relevant to developers to meet water quality requirements.
- Engineers, Landscape Architects, and Designers – This manual provides sizing information and guidance (Sections 3 and 4) for BMPs for professionals performing the calculations and design for BMPs. In addition, several other sections provide relevant information, including planting palettes (Appendix C), and BMP spreadsheets (Appendix E).
- TRWD and Adjacent Jurisdictions – This manual provides an outline of the key jurisdictions and responsibilities (Section 2) and provides design review resources (Appendix A) as well as inspection and maintenance resources (Appendix D).

The manual contains the following sections:

**Section 1 – The Water Quality Manual** – Provides an introduction to the manual, including the objectives, the intended users, and background information.

**Section 2 – BMP Process and Plan Development** – Describes the initial steps of evaluating the need and options for BMPs at a site. It provides information about locating BMP devices and estimating the water quality protection volume to be treated. This section provides an overview of the TRWD review process for BMPs and highlights major steps in the process. Section 2 provides a description of the items required for submittal for review and graphical examples and templates that can be used by the developer and TRWD.

**Section 3 – Post-Construction BMP Practices** – Provides an introduction to the BMPs covered in the manual and a description of each BMP, graphical examples, the benefits of each BMP, and inspection and maintenance requirements.

**Section 4 – Post-Construction BMP Practice Design Components** – Provides an explanation of the design elements that can be integrated into each BMP. The design components are the fundamental elements required for a BMP to function adequately. Section 4 provides details and specifications for components, including inlets, pretreatment, energy dissipation, area protection, storage media, media barriers, planting media, landscaping, and outlets/piping.

**Section 5 – Water Quality Requirements Specific to Panther Island (Zone 1)** – The application of this manual varies somewhat for Zone 1 (Panther Island). For consistency with the Panther Island Form-Based Code, to leverage the associated Public Improvement District planned for Panther Island, and to allow redevelopment the maximum amount of footprint to work with, Zone 1 is restricted smaller set of available practices and they will be predominantly sited in the public right of way. This greatly increases the efficiency and lowers the cost of stormwater quality management for developers.

**APPENDICES**

**Appendix A – Design Review Resources** – Provides tools to develop and review project submittals, a summary of the required design details to be provided with submittals, and checklists the reviewer can use to evaluate the submittals. Appendix A should be filled out and submitted to TRWD with the other required project submittals.

**Appendix B – BMP Fact Sheets** – Provides a quick overview of the BMPs discussed in this manual and include:

1. Introduction and applicability
2. Major design elements
3. Operation and maintenance (O&M)
4. Constructability
5. Basic sizing guidelines
6. Submittal requirements

**Appendix C – Planting Palettes** – Provides an overview of the plants that should be used for BMP projects.

**Appendix D – Design Component Inspection and Maintenance** – Provides guidance for inspection and maintenance of BMP design components.

**Appendix E – BMP Spreadsheets** – Provides spreadsheet tools that can be used to help design and review BMPs.

**Appendix F –Zone Maps**

## 1.3 WATER QUALITY IMPACTS FROM DEVELOPMENT

Increasing urbanization in watersheds draining to the Trinity River in Fort Worth threatens to reduce or eliminate the ability of the river to support contact recreation activities and other designated uses. Development has significant impacts on hydrology and stormwater runoff. Development also can lead to alteration of hydrology, hydraulics, and sediment transport.

The manual is intended to reference, build off of, and be consistent with extensive studies and resources on the effect of new development and re-development on this important water resource for TRWD, the City of Fort Worth, and other adjacent municipalities, specifically with regard to water quality.

The primary water quality parameters of concern for the Trinity River and its tributaries are:

- Bacterial indicators
- Nutrients
- Sediment
- Floatables

## 1.4 APPLICABLE WATER QUALITY PROTECTION ZONES

TRWD provides protection to the Trinity River. Figure 1.1 shows four water quality zones defined by TRWD where water quality requirements are being adopted or recommended. These are:

- Zone 1 Panther Island
- Zone 2 Floodway Corridor
- Zone 3 Water Quality Zone
- Zone 4 City of Fort Worth (outside of Zones 1-3)

**New developments and re-developments in or across Zones 1 and 2 will be required to incorporate water quality BMPs to treat the water quality protection volume as described in this manual.** The specifics of requirements for development in Zone 1 are described in Section 5 – Water Quality Requirements Specific to Panther Island (Zone 1).

## 1.5 AUTHORITIES AND JURISDICTIONS

This section discusses the authorities and jurisdictions that are involved with the water quality program. For new developments and re-developments in or across Zone 1 and Zone 2, TRWD will review water quality BMPs associated with the project. The required submittals are outlined in Section 2.5 of this manual.

For activities within the City of Fort Worth, the City of Fort Worth will review the water quality impacts and plans. The City of Forth Worth has flood control, drainage, tree preservation and other requirements which are not discussed in this manual. These requirements must be followed. Any conflicts between guidance in this manual with City of Fort Worth requirements should be discussed with TRWD. More information about the requirements for projects within the City of Fort Worth is provided in the City of Fort Worth's Stormwater Criteria manual (2015 or the most recent adopted version of the manual). If the project is in another city within the drainage area of the Clear Fork or West Fork Trinity rivers, the guidance in this document may be applicable; TRWD should be contacted for clarification on requirements in other cities.

All applicable state and federal regulatory requirements must be met. Compliance with this manual does not imply compliance with state and federal requirements. These may include National Pollutant Discharge Elimination System (NPDES) and Texas Pollutant Discharge Elimination System (TPDES) permit requirements or coverage under the Construction General Permit (CGP) authorized by the Texas Commission on Environmental Quality (TCEQ).

## 1.6 BMP SUBMITTAL REQUIREMENTS

The BMP requirements outlined in this manual must be followed for new developments and re-developments in or across Zones 1and 2 with Zone 1 (Panther Island) having specific requirements discussed in Section 5. The BMP must be certified as meeting the water quality performance specifications and must be submitted to TRWD for review. The BMP submittals will need to be certified by a Professional Engineer licensed in the State of Texas.

**The applicant must submit the following for review**:

1) **The plans and details for all water quality BMPs. These and any variances must be certified by a licensed Professional Engineer to verify they meet the water quality goals of the guidance manual (*see design submittal requirements checklists in Section 4 for more detail by component*),**
2) **Calculation summary sheets for WQv and for BMP structures (*see Section 4 for detail on the necessary calculations for different components and Appendix E for design spreadsheets*),**
3) **Supporting information, including test results, manufacturer information or specific details and assumptions where there is variation from the guidance manual, and**
4) **Facility maintenance plan with guarantee that the maintenance will occur.**

**After construction of the BMP, Certification from the Design Engineer or other Professional Engineer licensed in the State of Texas must be submitted to TRWD to verify that the BMP was built in accordance with the submitted plan information.**

Drainage and BMP reviews are required at several stages of the overall development review process. However, some of the specifics of the review depend on the types of development activities proposed and the location of the project. The contractor or developer should provide advance notice to TRWD of pre-construction meetings for new and re-development.

As noted above, the developer must provide a certificate of completion that states that the BMP was installed in accordance with the design submittals and BMP construction requirements. In addition, as-builts must be submitted that are signed by a Professional Engineer licensed in the State of Texas. The as-builts must show that the BMPs were built in accordance with the design submittals and the Zone 2 requirements.

For developments within the City of Fort Worth, the engineer shall provide the City information as per their requirements. For projects in or across Zone 2, the calculations must also be consistent with the Water Quality Volume estimation guidance provided in Section 2.3 of this manual.

The BMP should be identified, and relevant information provided in required submittals, that may include grading plans, concept plans, and platting. The drainage calculations should be provided in the drainage study of the existing, proposed, and fully developed conditions required to be submitted to the city. The water quality features of the site plan and temporary and post-construction water quality BMPs should be detailed in the documents.

Proper maintenance of the BMP is critical to maintain effective stormwater treatment. To ensure that maintenance will be performed as necessary, a maintenance plan and agreement must be submitted as part of the required BMP documentation using the *Stormwater Facility Maintenance Agreement – Water Quality Devices* (available through the City of Forth Worth). The agreement must outline the actions that will be taken to maintain the facility (including frequency and schedule) and the repercussions if the facility is not maintained.

## 1.7 ALTERNATIVE APPROACHES

The applicant may propose alternative approaches to achieving compliance. N*ote that TRWD will NOT entertain requests to use alternatives approaches based solely because the applicant considers it more convenient to do so or to avoid the stormwater pollutant reduction goals intended in this manual.*

Should an applicant desire TRWD to consider one or more alternative approaches to compliance with requirements in this manual or a variance from full compliance from requirements, the following steps must be taken:

1) Apply the processes as set forth in this manual and a currently registered Professional Engineer in the State of Texas (Texas PE) shall document the results including results that show one or more compelling reasons why alternatives should be considered.
2) Submit this documentation along with a request in writing to TRWD, notifying the District of the applicant's desire to request one or more alternatives for compliance.
3) After review and discussion with applicant, TRWD will issue a determination that compelling reasons either do or do not exist to consider deviations to the processes outlined in this manual.
5) If TRWD determines that compelling reasons do not exist, applicant will be notified in writing and applicant should continue their submittals to TRWD based on the processes outlined in this manual.
6) If TRWD determines that compelling reasons do exist for deviating from the processes outlined in this manual, applicant should submit alternative approaches and technologies applied to their property under the seal of a Texas PE to TRWD for review and approval. As a part of this submittal applicant must document that these alternatives can meet the pollutant reduction goals established in step 6. TRWD will then approve, reject, or request revision and resubmittal of alternative approaches.

## 1.8 PROJECT REVIEW PROCESS

As part of the review process for the local municipality, TRWD will review compliance with water quality requirements for projects within their jurisdiction. TRWD will review compliance with the process established by TRWD and outlined in this manual, the required submittals, and with water quality goals. The review process will include verification that the applicant is following this manual, including the WQv estimates, design criteria, details, and specifications.

The applicant must follow the process established for submittal and review of development by the local jurisdiction.

As an administrative procedures toolkit to the review process, this manual includes a submittal checklist (see Appendix A) and the digital spreadsheet for calculation and review comparison (see Appendix E).

### REFERENCES

TRWD, "Hydrodynamic and Water Quality Modeling of The Trinity River and Its Watersheds Through Downtown Fort Worth – Model Documentation, developed and prepared by CDM Smith, Tarrant Regional Water District, Fort Worth, Texas, March 2018

## ADDITIONAL RESOURCES

[1] City of Fort Worth. December 20, 2012. Standard Construction Specification Documents.

[2] Federal Interagency Stream Restoration Working Group (FISRWG). 1998. Stream Corridor Restoration: Principles, Processes, and Practices. GPO Item No. 0120-A; SuDocs No. A 57.6/2:EN 3/PT.653. ISBN-0-934213-59-3.

[3] North Central Texas Council of Governments (NCTCOG). September 2014. "iSWM Technical Manual: Water Quality: 1.0 Water Quality Protection Volume and Peak Flow", Arlington, Texas, April 2010, Revised September 2014, http://iswm.nctcog.org/Documents/technical_manual/Water%20Quality_9-2014.pdf

[4] Texas Commission on Environmental Quality (TCEQ). November 2015. Rules and Regulations for Public Water Systems.

[5] Urban Watershed Research Institute (UWRI). October 5, 2015. Comparison of Water Quality Capture Volume Needs for Ft. Worth, TX Region to Capture of 85th Percentile Runoff Volume and Runoff Events

[6] U.S. Environmental Protection Agency (EPA). 2005. National Management Measures to Control Nonpoint Source Pollution from Urban Areas., http://water.epa.gov/polwaste/nps/urban/index.cfm. Accessed June 20, 2013.

This page intentionally left blank.

# SECTION 2

## BMP Process and Plan Development

Proper planning for development projects and implementation of BMPs is important for the mitigation of impacts to water quality and protection of receiving water bodies. Implementing a plan that considers the existing hydrology of the site and protects pervious areas and existing vegetation can help minimize both the cost and the footprint of structural drainage practices.

This section provides a brief overview of the BMP planning processes and outlines the plan submittal requirements for new development and re-development projects. This includes a discussion to support integration of water quality BMPs into site development and recommendations to help determine the type and layout of BMPs for a specific site layout. Additional detail is provided in Sections 3 and 4.

### 2.1 BMP AND SITE PLANNING

Proper BMP planning includes consideration of site layout and BMP placement early in the process. These steps can help to provide important water quality benefits. The recommended steps for the planning of the site and BMPs are:

1. Identify protected and sensitive features and opportunities to protect these. This may include development of a setback for impervious areas from creeks, wetlands, riparian areas, and dense and / or desirable vegetation. Other planning practices include:
    - Locate the development in less sensitive areas of the site
    - Fit the design to the terrain
2. Define the areas that are most suitable for development, areas to be landscaped, and areas to be conserved. Conform site layout along natural landforms and avoid excessive grading and soil disturbance. Avoid construction on steep slopes, in floodplains, and on erodible soils.
3. Assess opportunities to minimize overall impervious coverage on the site.
4. Locate BMPs with consideration for capturing stormwater runoff from areas with a high potential for pollutant loading, such as parking lots.

#### 2.1.1 SITE LAYOUT

Careful consideration of the site layout can help mitigate the water quality impact of the development and, as a result, reduce the water quality volume (WQV) that must be treated and the required BMP footprint.

The existing site conditions that serve important hydrologic functions such as reducing runoff or pollutant loads downstream should be identified for protection early in the site assessment process. Natural and sensitive features that should be protected include:

- Bodies of water such as streams, rivers, ponds, and lakes
- Natural drainage paths
- Riparian areas
- Floodplains
- Wetlands
- Aquifer recharge areas
- Steep slopes
- Erodible soils
- Areas of dense vegetation
- Areas with seasonal high groundwater
- Other site-specific features that may impact hydrology

The developer should take steps during planning and construction to protect these features. It is important to consider that the disturbance of soil during construction can enable large quantities of sediment to be mobilized during stormwater events. These sediment loads can harm natural features and clog or otherwise damage BMPs. Temporary construction controls should be implemented as per City of Fort Worth and TCEQ requirements to prevent erosion and sediment transport.

### 2.1.2 IMPERVIOUS SURFACES

The developer should minimize the amount of impervious cover in the site design where possible to help reduce the size and cost of structural BMPs. $WQ_V$ and BMP size are calculated based on the impervious cover for new and re-development sites. Therefore, reducing the amount of impervious cover can reduce the volume, cost, and land required for BMPs. Approaches might include using more vertical construction (reducing building footprints), utilizing pervious pavement, and designing the site for efficient vehicle circulation, reducing pavement area.

Disconnecting impervious surfaces can also be an effective way to reduce the required $WQ_V$ treated by structural BMPs. This can be performed at an individual lot level and at the larger development site level. At an individual lot or property, impervious surfaces can be disconnected by directing gutter downspouts to pervious areas, installing rain gardens, and implementing other small scale BMPs or pre-treatment devices. Similar strategies can be implemented at the larger development scale by draining runoff to pervious areas. Other examples of this may include using stable grass swales instead of curb and gutters and natural channel paths instead of storm sewers. Both of these alternatives could function as pre-treatment based on compliance with the design standards outlined in this manual.

### 2.1.3 SITING BMPS

The developer should consider potential sources of high pollutant loading and locate BMPs to capture stormwater runoff from these areas. Roof runoff and parking lots will require pre-treatment before treatment by approved BMPs. Section 4 of this manual outlines the options for pre-treatment.

## 2.2 BMP SELECTION

The planning for the types and locations of BMPs to be implemented on a site should be performed with consideration of the pollutants of concern, available right-of-way, existing soil types and infiltration rates, pollutants of concern, and the development goals that impact aesthetics of the development. Table 2.1 summarizes the level of treatment that each type of BMP provides for pollutants of concern.

**Table 2.1 Pollutant Reductions by BMP**

| | Sand and Media Filters* | Bioretention Basins* | Constructed Wetlands | Wet Basins | Retention and Irrigation Basin | Detention Basin | Vegetated Filter Strips/ Grass Swales* | Permeable Surfaces |
|---|---|---|---|---|---|---|---|---|
| **Sediment** | High | High | High | High | High | Moderate | Moderate to High | High |
| **Nutrients** | Low to Moderate | Moderate | Moderate to High** | Moderate to High** | Moderate to High | Low to Moderate | Low to Moderate | Low |
| **Trash** | High | High | High | High | High | High | Low to Moderate | High |
| **Metals** | Moderate to High | Moderate to High | Moderate | Moderate | High | Moderate | Low to Moderate | Moderate |
| **Bacteria** | Moderate to High | High | High** | High** | High | Moderate to High | Low | High |
| **Oil and Grease** | High | High | High | High | No Data | No Data | Moderate to High | Moderate |
| **Organics** | Moderate to High | Moderate | High** | High** | No Data | Low | Moderate to High | Low |

*Source: SARA, 2013; NCTCOG, 2014; TCEQ, 2005; ISWBD, 2017*

** Removal effectiveness varies dependent on infiltration capacity and design*

*** Wetlands, Wet Basins, and other BMPs with wildlife habitat can have high internal loads of bacterial indicators, nutrients, and organics*

Section 3 of this manual outlines the requirements and benefits of the post-construction BMPs that can be implemented to comply with the water quality requirements for areas covered in this manual. The fact sheets (Appendix B) summarize the effectiveness of the BMPs for removal of different pollutants.

## 2.3 CALCULATION OF WATER QUALITY VOLUME

The required $WQ_V$ to be treated is calculated based on the runoff volume from the 85th percentile runoff event. A continuous hydrologic simulation model assessment was performed to define the $WQ_V$. The model assessment considered routing through the capture basin, infiltration in the tributary drainage area, and the recapture of infiltration and other losses during dry periods in the Trinity River watershed.

For a development within Zones 1 and 2, the water quality volume can be estimated using Figure 2.1 or Table 2.2. The process to estimate is also summarized in the callout on this page.

### How to Estimate $WQ_V$

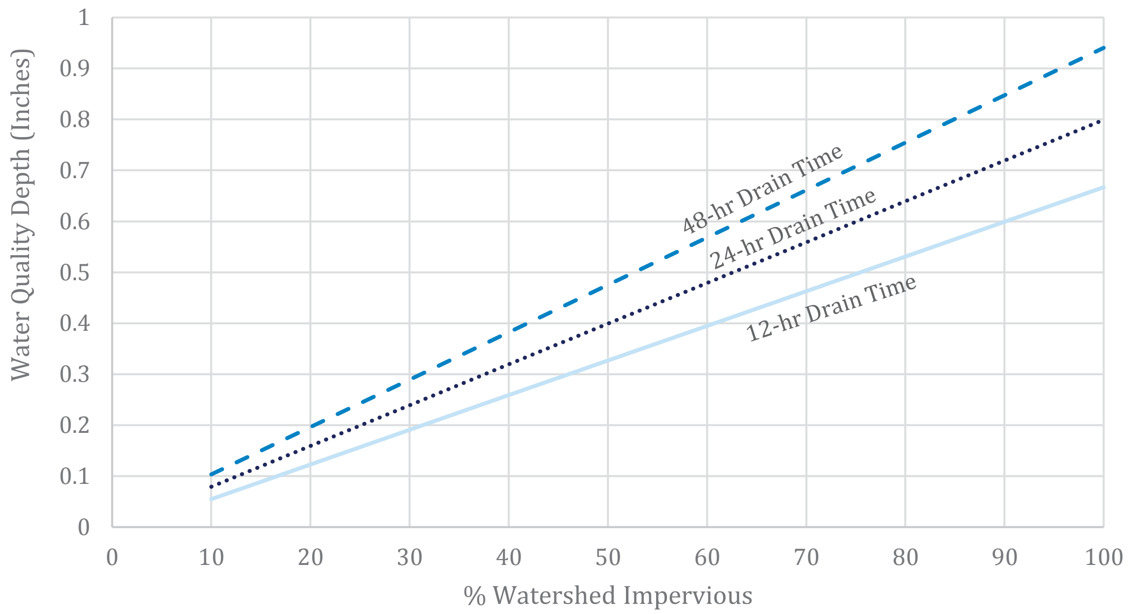
1. Define the drainage areas within the project site
2. Calculate the impervious cover % for drainage area = final impervious cover for drainage area / drainage site area X 100%
3. Identify BMP(s) to be used to treat stormwater on-site
4. Estimate required drain time for BMP
5. Use Figure 2.1 or Table 2.1 to estimate the $WQ_D$ for the drainage area based on the Impervious % and BMP Drain Time
6. Multiply $WQ_D$ by drainage area to estimate total $WQ_V$ for project

First, the developer should define the drainage areas within the project site and calculate the size of each of the drainage areas (step 1). Note that the project area may have more than one drainage area, and one or more BMPs should be used for each drainage area where there will be new impervious or redevelopment. Only the portion of each drainage area within the site boundaries will need to be treated.

Next, the developer should estimate the amount of impervious cover and the percentage of impervious cover within each drainage area (step 2). This should be done for each drainage area within the site. The developer should then identify the BMP type(s) that may be used to treat stormwater runoff on the site and evaluate the drainage time and components for the BMP(s) (step 3 and step 4).

Figure 2.1 provides a graphical representation of the Water Quality Depth ($WQ_D$) expressed in inches as a function of the percent impervious area of a development and the design drain time for the selected BMPs. Equations to estimate the $WQ_D$ are also provided in Table 2.2. To calculate the total water quality volume for each drainage area within the project site, use the percent impervious for that drainage area and the drain time for the selected BMP to estimate the $WQ_D$ (step 5). Multiply the $WQ_D$ by the drainage area to calculate the total $WQ_V$ for that drainage area (step 6). The $WQ_D$ and $WQ_V$ should be estimated for each drainage area separately.

**Figure 2.1 Water Quality Depth (in watershed inches) for the 85th Percentile Capture of Runoff Volume**




As noted, the equations provided in Table 2.2 can also be used to calculate the $WQ_D$ for BMPs based on the amount of impervious in the drainage area and the drain time of the BMP. As described for Figure 2.1, multiply the $WQ_D$ by the drainage area to calculate the $WQ_V$.

**Table 2.2 Equations for Required Water Quality Depth**

| Drain Time | Water Quality Depth |
|---|---|
| **48 hour** | y = 0.0093x + 0.0104 |
| **24 hour** | y = 0.0080x - 0.0009 |
| **12 hour** | y = 0.0068x - 0.0132 |

*Where:*
*x = percent impervious (%) for drainage area to BMP*
*y = water quality volume in inches*

Section 3 and the design spreadsheets included in Appendix E also include guidance for these estimates. The $WQ_V$ is based on the percent of the drainage area with impervious cover. By reducing the amount of impervious cover, a new development or re-development project can reduce the required footprint of BMPs.

## 2.4 BMP DESIGN

The design guidance in this manual is based on components. The components for each BMP are the critical elements required for that BMP to meet the water quality goals. Based on the type of BMP, components may include inlets, pretreatment, energy dissipation, area protection, storage media, media barriers, planting media, landscaping, and outlets/piping. To allow flexibility for specific sites, this manual provides alternatives for components that meet the design criteria. The required design specifications and components for each BMP are outlined in Section 3. Design sheets and conceptual layouts for the components are provided in Section 4.

### ADDITIONAL RESOURCES

[1] City of Fort Worth. December 20, 2012. Standard Construction Specification Documents.

[2] North Central Texas Council of Governments (NCTCOG). September 2014. “iSWM Technical Manual: Water Quality: 1.0 Water Quality Protection Volume and Peak Flow”, Arlington, Texas, April 2010, Revised September 2014, http://iswm.nctcog.org/Documents/technical_manual/Water%20Quality_9-2014.pdf

[4] San Antonio River Authority (SARA). 2013. San Antonio River Basin Low Impact Development Technical Guidance Manual.

[5] Texas Commission on Environmental Quality (TCEQ). July 2005. Complying with the Edwards Aquifer Rules: Technical Guidance on Best Management Practices.

[6] International Stormwater BMP Database. Accessed September 2017. BMP Database Tool: Texas BMPs. http://bmpdatabase.org/retrieveBMPs.asp

## SECTION 3

# Post-Construction Storm Water Quality Control Measures

This section provides information about the Best Management Practices (BMPs) that can be implemented to comply with the water quality requirements for Zones 1 and 2 (as presented in Section 1.4). The BMPs included in this section, if sized for the Water Quality Volume (WQv) (defined in Section 2) and designed in compliance with this manual, meet the water quality requirements for new and re-development projects in Zones 1 and 2, with two exceptions: grass swales and vegetated filter strips. These two BMPs are intended to treat only small impervious areas or act as pre-treatment or post-treatment for other BMPs. Specific requirements unique to Zone 1 (Panther Island) are discussed in Section 5. The following sections provide 1) a short description of each BMP, 2) information about the application of the BMP, 3) design criteria, and 4) maintenance considerations for design and construction. The design criteria describe the required components for each type of BMP and criteria for the components.

The general approach to identifying and designing appropriate BMPs includes the following steps:

1) Review the descriptions and applicability information provided in this section to determine what BMPs are most appropriate for the development.
2) Review the design criteria in this section to determine the necessary components and design elements for compliance with water quality requirements. The design criteria include references to applicable design details and specifications in Section 4. Review the maintenance considerations for design in this section to make any design adjustments that would simplify maintenance.
3) Identify the component details and specifications in Section 4 based on the components and references described in this Section. See Table 4.1 for major components.

Additional support included in Appendix E will assist in performing design calculations, sizing BMP structures and developing project submittal support information. The BMP design plan sheets and calculations, inspection and maintenance plans, as-builts, and other supporting information for projects in Zones 1 and 2 with $WQ_V$ treatment requirements must be submitted for review to TRWD.

## 3.1 SAND FILTERS

### 3.1.1 DESCRIPTION OF BMP

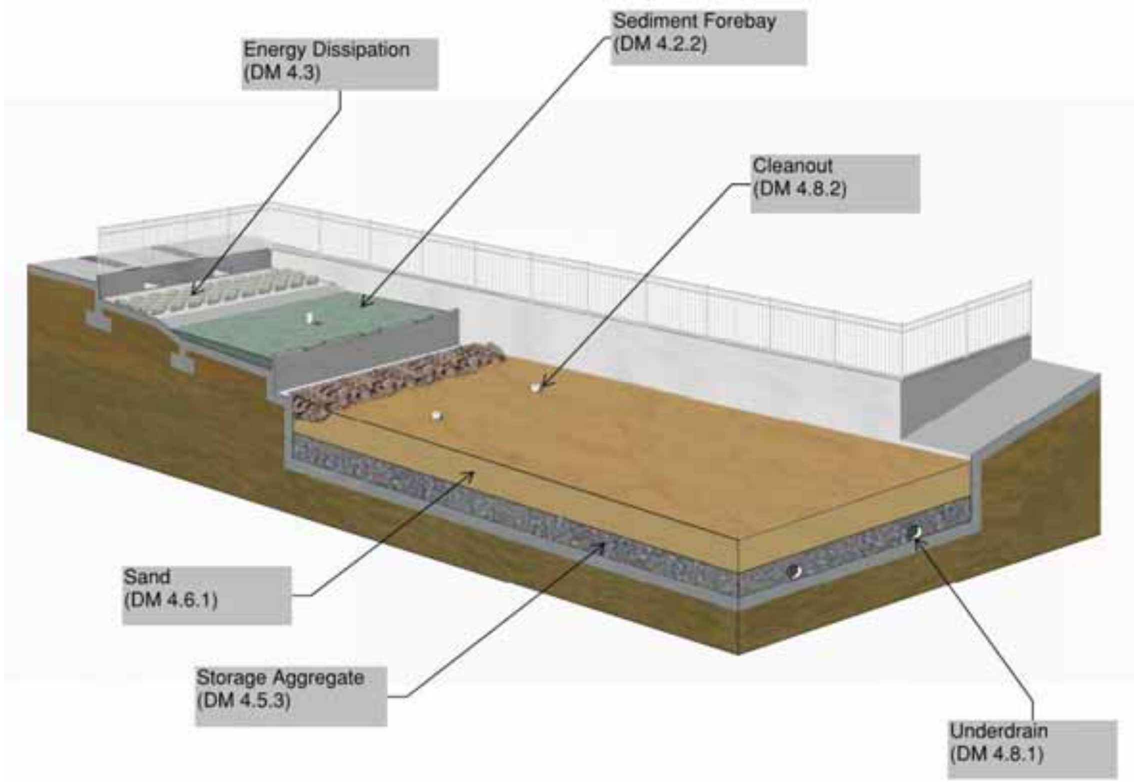
Sand filters and other types of media filters filter stormwater through sand or other media to remove pollutants. These BMPs can be implemented to treat a relatively large (generally up to 10-

acres) drainage area. This manual focuses on sand as the filtration media; other types of media may be considered on a case by case basis but are not specifically detailed in this section.

Two of the primary components are the sediment forebay (also referred to as sedimentation chamber) and the filtration chamber. The sediment forebay should be included for sand filters with drainage areas over 2-acres and can be included in smaller sand filters to remove floatables, large materials, and sediment before storm water is filtered through the sand or other media. The volume of water conveyed to the treatment system must be controlled by a diversion structure to prevent inflow rates that exceed the capacity of the BMP.

Component details and specifications are provided in Section 4. Figure 3.1 provides a conceptual rendering of a Concrete Sand Filter with major components identified for reference. The components may depend on the size and type of sand filter; these are described further in Section 3.1.3.

**Figure 3.1 Conceptual Rendering of a Concrete Sand Filter**




Due to the inherent dangers associated with confined spaces, which complicates routine inspections and maintenance, as well as the out-of-sight nature and inherent potential for neglect, underground structures/vaults are not discussed. Developers wishing to propose buried structures must provide conclusive supporting documentation regarding maintenance access and equivalent performance compared to above grade filters. These sand filters must be in compliance with all applicable confined space rules and regulations.

### 3.1.2 APPLICABILITY

The layout of sand filters is highly flexible. They can be incorporated within new development or as retrofits in re-development sites and can be used at locations with limited space or where other BMPs would be difficult to fit[2]. Although versatile in their potential application, sand filters are best suited for areas with highly impervious drainage areas. However, sites that produce heavy sediment loads will clog filtration media and without frequent maintenance, will render this BMP ineffective[2].

### 3.1.3 DESIGN CRITERIA

This section provides the design criteria for sand filters. The structural criteria provide information about the necessary components and include references to the component design section of this manual (Section 4). The details and specifications for the components are provided in that section. The design/review spreadsheet in Appendix E outlines the design steps and calculations for the BMPs.

1) General Criteria
    a. Runoff from all impervious surfaces should be directed to a BMP.
    b. The maintenance plan for sand filters must include, as a minimum, trash removal, accumulated sediment removal, inspection for standing water, and inspection for 24-hour drawdown in accordance with the *Stormwater Facility Maintenance Agreement – Water Quality Devices* and oultlined in Appendix D.
2) Site Conditions
    a. Drainage area – Sand filters are recommended for drainage areas less than 10-acres in size. Larger areas should be subdivided and treated by multiple devices.
    b. Depth to water table – A minimum of 2-feet are required between the bottom of the sand filter and the elevation of the seasonally high-water table.
    c. Soils – An underdrain is required for soils that do not allow sufficient infiltration.
    d. Floodplain – Where feasible, the BMP should be located outside of the 100-year floodplain. Where not feasible, the top of walls / embankments for the BMP should be above the 100-year floodplain and the BMP should be designed to protect against surcharge from downstream waters.
    e. Space required to achieve $WQ_V$ – Function of available head at the site, the holding time, WQv, and the surface area of the sand layer for the BMP (see design calculation procedures in Appendix E).
3) Structural Criteria
    a. Emptying / drain time – Design to drain within 24-hours.
    b. Minimum head – The elevation difference needed at a site between the inflow and the outflow is generally 5-feet.

c. Pre-treatment - A sediment forebay must be used for all sand filters treating over 2-acres and is recommended for all sand filters.

   i. The forebay should be designed to hold at least 25% of the WQv.

   ii. The sediment forebay should have a length-to-width ratio of at least 2:1.

   iii. Inlet and outlet structures should be located at opposite ends of the chamber to prevent short-circuiting (see Section 4.1 for additional information on inlet structures, Section 4.2 on the design of the sediment forebay, and Section 4.8 on outlet structures).

   iv. A vegetated filter strip or grass swale can be implemented in lieu of a sediment forebay where the drainage area is less than 2-acres.

d. Energy dissipation – Required to dissipate energy and prevent erosion at the inlet to the BMP (*see Section 4.3*).

e. Sand filter chamber – The structure of a surface sand filter may be constructed of impermeable material such as concrete or using earthen embankments and slopes.

   i. Size – The filtration chamber must be designed to hold 100% of the WQv (*see Sections 4.5 and 4.6 for additional information on layout criteria*).

   ii. Depth – Maximum design depth of WQv within filtration basin shall not exceed 5-feet. Note that surface area and depth of captured stormwater impacts maintenance requirements; a larger surface area (and resulting reduced stormwater depth) increases the ability of the sand filter to store sediment without clogging. Therefore, a depth greater than 3-feet may increase the frequency of required maintenance to keep the BMP effective.

   iii. BMP media – Primary BMP media used is sand consisting of 18-inch (minimum) to 24-inch layer of clean washed medium sand. A storage aggregate layer shall be placed at the bottom of the sand filter chamber for additional water storage capacity. (*see Section 4.5 for material, gradation, and design criteria*). Filter fabric can be used between the sand and gravel to prevent migration of fines; however, the material can clog and require additional maintenance. Alternatively, an aggregate layer is not required if a slotted underdrain is used to prevent sand from flowing into the underdrain pipe.

   iv. Media barrier – A geomembrane liner should be used to line the bottom and side slopes of the structure before installation for sand filters with earthen embankments (*see Section 4.6*). An impermeable liner must be used for installations adjacent to streets to prevent water from getting under the pavement into the base material.

   v. Underdrain - If the system includes an underdrain, the BMP media shall be located above the underdrain system and the underdrain shall be located within the storage aggregate layer (*see Section 4.8*).

vi. Note - Texas Commission on Environmental Quality (TCEQ) Dam Safety requirements shall be accounted for as required with higher depth structures.

f. Diversion structure – The diversion structure must be capable of passing the peak flow rate of the ten (10) year annual chance storm into the stormwater quality BMP and passing excess runoff, including up to the 100-year storm, through the diversion structure without overtopping the sidewalls of the pond. (*see Section 4.1 for additional information on diversion structures*).

### 3.1.4 MAINTENANCE CONSIDERATIONS FOR DESIGN AND CONSTRUCTION

Routine inspection and maintenance of sand filters is critical to their performance. The activities, schedule, and additional maintenance considerations and requirements are attached in Appendix D, the "BMP Inspection and Maintenance" section of this manual. The following should be considered during design and construction of the BMP:

- Access – Adequate access must be provided for all sand filter systems for inspection and maintenance, including the appropriate equipment and vehicles. An access ramp with a minimum width of 10-feet and a maximum slope of 25% shall be provided.
- Fencing – To prevent risk to the public, it is recommended that sand filter facilities be fenced in accordance with the City of Fort Worth requirements.
- Include cleanouts as discussed in Section 4.8. These can be used for inspection to make sure that the underdrain is intact, and for ongoing maintenance during and after construction.
- For earthen systems, include vegetated side slopes to pre-treat runoff and reduce the frequency of maintenance[2].
- The BMP should be kept offline until the construction activities are completed. However, the BMP excavation can be used as a sediment trap during construction before filtration or other media are placed in the basin. In that case, the bottom of the basin should not be excavated below 2-feet of the final grade. Temporary BMPs should be in place as detailed in the project Sediment and Erosion Control Plan to protect receiving waters during construction activities (the Sediment and Erosion Control Plan requirements are not discussed in this manual). Sediment discharged during construction can clog the system and would require additional maintenance.

---

City of Austin. (2017). Design Guidelines for Water Quality Controls. Environmental Criteria Manual.

[2] Urban Drainage and Flood Control District (UDFCD). (2010). Urban Storm Drainage Criteria Manual (USDCM): Volume 3 Stormwater Quality.

## 3.2 BIORETENTION BASINS

### 3.2.1 DESCRIPTION OF BMP

Bioretention basins (also referred to as rain gardens, biofiltration basins, or biofilters) use the chemical, biological, and physical properties of plants, microbes, and soils to remove pollutants from stormwater runoff via a system of distributed micro-scale storm water treatment devices.[1] The filter medium is an engineered mix of highly-permeable natural media, which are usually mixtures of soil, sand and organic matter, that facilitate pollutant removal via sedimentation, filtration, sorption, and precipitation.[1] The defining characteristic of a bioretention system is the integration of plants and microorganisms that are rooted in the filter medium and can provide more treatment of runoff, directly and by uptake by the filter medium[2]. Plants help sustain the permeability of the medium for longer periods and enhance removal of pollutants[1,2]. The composition of the BMP media is key to the system's overall effectiveness.[1]

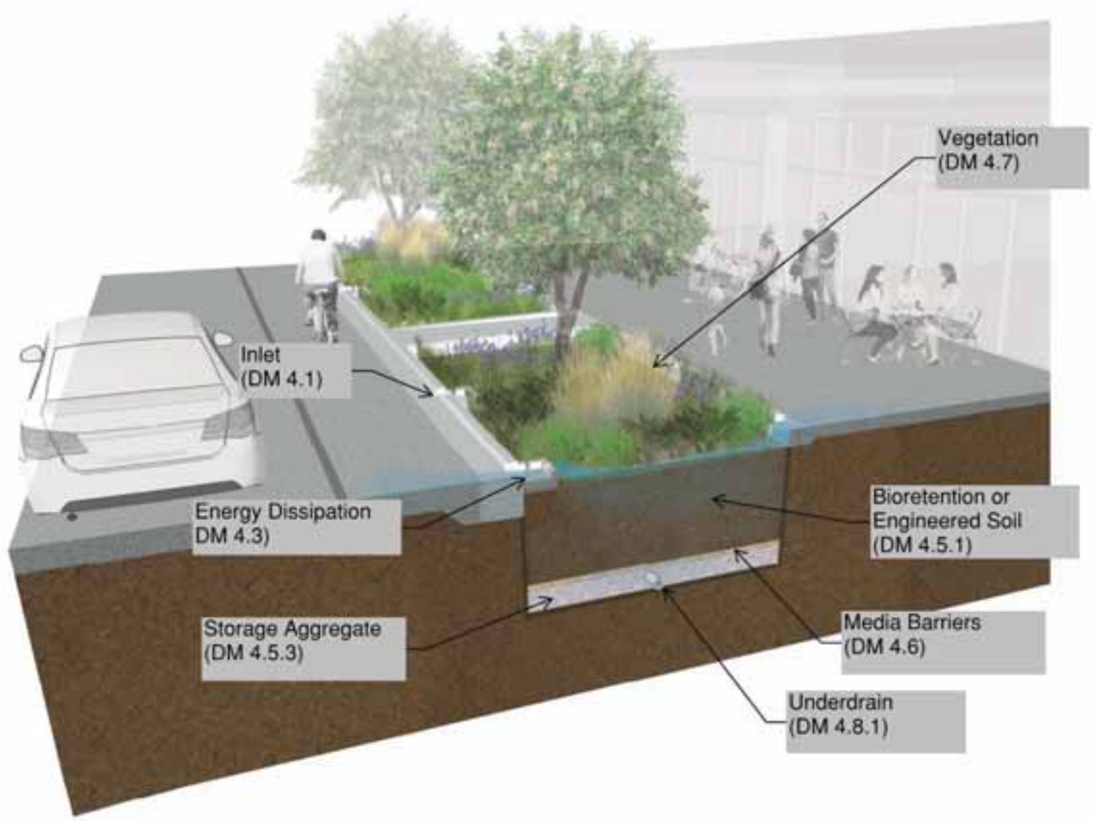
More information on the components for bioretention basins can be found in the design criteria discussion in Section 3.2.3 and the component details and specifications are provided in Section 4.

There are two types of bioretention basins that are addressed as part of this handbook – centralized and distributed bioretention basins. Centralized bioretention basins must be implemented for larger drainage areas and have additional elements as detailed below. These include a two-cell system. Distributive bioretention basins (i.e., rain gardens or green street infrastructure) can be implemented for drainage areas of 1-acre or less. These are smaller and shallower than the centralized systems and are often placed adjacent to the impervious cover runoff source. The primary components for these are different. Figure 3.2 provides a conceptual rendering of a distributive bioretention basin with the components identified. The components that are fundamental for distributive bioretention basins are shown in the figure. For larger centralized bioretention facilities, pre-treatment should be included. Additional area protection may also be considered.

### 3.2.2 APPLICABILITY

Given the variability of design as it relates to the drainage area and allowable ponding depth within the system, the selection of a bioretention basin design depends largely on the size of the contributing drainage area. Large centralized bioretention basins are well suited to service large residential subdivisions. However, these may also be used to treat commercial and industrial sites, although pretreatment should be considered, especially if there are high sediment loads anticipated. Bioretention basins are not recommended to treat drainage areas greater than 5-acres. Small bioretention basins (rain gardens) may serve these land use types; however, they are limited to sites that are less than an acre. Therefore, on large sites, the developer should consider distributing smaller systems throughout the site. Given the ability of a rain garden to be incorporated into the landscape, its use is extremely flexible and makes it ideal for roadway median strips and curb bump outs, parking lot islands, and roof downspout catchment areas[3].

**Figure 3.2 Conceptual Rendering of Distributive Bioretention Basin**




### 3.2.3 DESIGN CRITERIA

The following sections provide design criteria for both centralized and distributed bioretention basins. As noted above, the primary differences between the two are the allowable drainage area size and inclusion of the sediment forebay.

#### 3.2.3.1 CENTRALIZED BIORETENTION BASINS

This section provides the design criteria for large centralized bioretention basins (those serving drainage areas up to 5-acres). Note that some of the primary differences between sand filters and the centralized bioretention basin described in this section are the bioretention media and landscaping.

1) General Criteria

   a. Runoff from all impervious surfaces should be directed to a BMP.

   b. Maintenance plans – Maintenance plan contains a guarantee of maintenance in accordance with the *Stormwater Facility Maintenance Agreement – Water Quality Devices* and confirms with requirements in Appendix D.

2) Site Conditions

   a. Drainage Area – Not recommended for drainage areas greater than 5-acres; there is no minimum drainage area limitation. If proposed for drainage areas greater than 5-acres, additional information must be provided to ensure that the basin will perform effectively, and additional maintenance and inspections may be required to verify.

   b. Depth to Water Table – Consider depth of 4-feet to groundwater table when identifying appropriate locations for bioretention. A high groundwater level could damage the bioretention basin or limit the treatment by infiltration.

   c. Soils – the characteristics of the native soils will determine if infiltration would occur naturally outside of the bioretention basin.

   d. Floodplain – Where feasible, the BMP should be located outside of the 100-year floodplain. Where not feasible, the top of walls / embankments for the BMP should be above the 100-year floodplain and the BMP should be designed to protect against surcharge from downstream waters.

   e. Space Required – The BMP footprint is a function of the available head at the site, the size of the drainage area, and the designed surface area for the BMP.

3) Structural criteria

   a. Emptying / drain time – The optimal drain time for the BMP is 12-hours, but the drain time should be not be greater than 24-hours.

   b. Minimum Head – The elevation difference required at a site from the inflow to the outflow is generally 3 to 5-feet.

   c. Pre-treatment – For inlets where there is concentrated flow, the centralized bioretention cells should have a sediment forebay. The sediment forebay should be designed to hold 10% of the bioretention volume. For areas with sheet flow, the bioretention system should have vegetated filter strips or gravel to dissipate energy, minimize erosion, and capture sediment (*see Section 4.2*).

   d. Bioretention cell - The structure of the bioretention cell is constructed through the use of excavations and earthen embankments.

      i. Size – The bioretention cell must hold 100% of the $WQ_V$ (*see Sections 4.5 and 4.6 for additional information on layout criteria*).

      ii. Length to width – The bioretention cell should maximize the length-to-width ratio (*see Section 4.1 for additional information on inlet structures and Section 4.8 on outlet structures*).

      iii. Maximum depth – The maximum depth for captured WQv within the basin is 12-inches.

      iv. Area Protection – Curbing is advised in locations with pedestrian traffic and vehicular traffic. Bollards are advised in locations with vehicular traffic (*see Section 4.4*).

v. BMP Media – Centralized bioretention basins require a 30-inch (minimum) to 48-inch (maximum) layer of bioretention or engineered soil medium. A storage aggregate layer shall be placed below the centralized bioretention for additional water storage capacity (*see Sections 4.5*).

vi. Media barrier – Depending on site conditions, a permeable geotextile or geomembrane liner should be used to line the bottom and sides of the BMP before installation of the underdrain system and BMP media. A media barrier is also recommended between the bioretention or engineered soil and the storage aggregate layer to reduce sediment migration into the storage aggregate layer; permeable geotextile is not recommended because of the tendency for the material to clog and thus prevent water migration into the storage layer (*see Section 4.6*). An impermeable liner must be used for installations adjacent to streets to prevent water from getting under the pavement into the base material.

vii. Vegetation – Vegetation must be provided, and mulch used for areas where there is bare soil. Organic enhancers may be added to promote vegetation growth and use of heavy tackifier with hydro mulch and erosion mats staked to the soil can be used to help vegetation establish and stabilize the site (*see Section 4.7)*. Appendix C provides planting palettes for BMP facilities. These areas should not receive any fertilizers, pesticides, or herbicides. Vegetation on the pond embankments should be mowed as appropriate to prevent the establishment of woody vegetation.

viii. Underdrains - If the system includes an underdrain, the bioretention medium shall be located above the underdrain system and the underdrain shall be located within the storage aggregate layer (*see Section 4.8*).

e. The diversion structure must be capable of passing the peak flow rate of the ten (10)-year storm into the stormwater quality BMP and bypassing excess runoff, including up to the 100-year storm, away from the BMP (*see Section 4.1 for additional information on diversion structures*).

f. Note – Texas Commission on Environmental Quality (TCEQ) Dam Safety requirements shall be accounted for as required with higher depth structures.

### 3.2.3.2 DISTRIBUTIVE BIORETENTION BASINS (RAIN GARDENS)

This section provides the design criteria for distributive bioretention basins (hereafter referred to as rain gardens).

1) General criteria

a. Runoff from all impervious surfaces should be directed to a BMP.

b. Maintenance plans – Maintenance plan contains a guarantee of maintenance in accordance with the *Stormwater Facility Maintenance Agreement – Water Quality Devices* and confirms with requirements in Appendix D.

2) Site conditions

   a. Drainage Area – Maximum drainage area of 1-acre.

   b. Depth to Water Table – Consider depth of 4-feet to groundwater table when identifying appropriate locations for bioretention. A high groundwater level could damage the bioretention basin or limit the treatment by infiltration.

   c. Soils – the characteristics of the native soils will determine if infiltration would occur from the bioretention basin. Engineered media is required for the bioretention filtration media to perform effectively.

   d. Floodplain – Where feasible, the BMP should be located outside of the 100-year floodplain. Where not feasible, the top of walls / embankments for the BMP should be above the 100-year floodplain and the BMP should be designed to protect against surcharge from downstream waters.

   e. Space Required – The BMP footprint is a function of the available head at the site, the size of the drainage area, and the designed surface area for the BMP.

3) Structural criteria

   a. Emptying / drain time – The optimal drain time for the BMP is 12-hours, but the drain time should be not be greater than 24-hours.

   b. Minimum Head – The elevation difference needed at a site from the inflow to the outflow is generally 3 to 5-feet.

   c. Energy dissipation – Energy dissipation is recommended, especially for areas with concentrated flow. Gravel or vegetated filter strips can be used to dissipate energy (*see Section 4.3*).

   d. Bioretention cell – The structure of the bioretention cell is constructed through excavation and the construction of earthen embankments.

      i. Size – The entire treatment system must be designed for 100% of the WQv (*see Sections 4.5 and 4.6 for additional information on layout criteria*).

      ii. Maximum depth – The maximum depth of water within the rain garden bioretention cell is 12-inches.

      iii. Area Protection – Curbing is advised in locations with pedestrian traffic and vehicular traffic. Bollards are advised in locations with vehicular traffic (*see Section 4.4*).

      iv. BMP Media – The BMP media consists of 30-inch (minimum) to 48-inch layer of bioretention or engineered soil medium. A storage aggregate layer shall be placed at the bottom of the distributive bioretention for additional water storage capacity (*see Sections 4.5*).

      v. Media barrier – Depending on site conditions, a permeable geotextile or geomembrane liner should be used to line the bottom and sides of the BMP before installation of the underdrain system and BMP media. A media barrier is also recommended between the bioretention or engineered soil and the storage aggregate layer to reduce sediment migration into the storage aggregate layer; permeable geotextile is not recommended because of the tendency for the material to clog and thus prevent water migration into the storage layer (*see Section 4.6*). An impermeable liner must be used for installations adjacent to streets to prevent water from getting under the pavement into the base material.

vi. Vegetation – Vegetation must be provided, and mulch used for areas where there is bare soil. Organic enhancers may be added to promote vegetation growth and use of heavy tackifier with hydro mulch and erosion mats staked to the soil can be used to help vegetation establish and stabilize the site (*see Section 4.7*). Appendix C provides planting palettes for BMP facilities. These areas should not receive any fertilizers, pesticides, or herbicides. Vegetation on the pond embankments should be mowed as appropriate to prevent the establishment of woody vegetation.

vii. Underdrains - If the system includes an underdrain, the underdrain shall be located within the storage aggregate layer below the bioretention soil media (*see Section 4.8*).

### 3.2.4 MAINTENANCE CONSIDERATIONS DURING DESIGN AND CONSTRUCTION

Inspection and maintenance are critical to the performance of bioretention systems. The activities, schedule, and additional maintenance considerations and requirements are attached in Appendix D "BMP Inspection and Maintenance" of this manual. The following should be considered during design and construction of the BMP:

- Access – For centralized bioretention, adequate access must be provided for inspection and maintenance, including the appropriate equipment and vehicles. For larger facilities where access may be an issue, an access ramp with a minimum width of 10-feet and a maximum slope of 25% shall be provided. Distributive bioretention should be accessible for inspection and maintenance including the appropriate equipment; however, due to the smaller facilities, no access ramp is necessary.
- Fencing (optional) – To prevent access and damage to vegetation, it is recommended that centralized bioretention facilities be fenced to prevent public access and in accordance with City of Fort Worth requirements.
- The use of vegetation is preferred to mulch. Mulch can float and clog outlets. However, there must be effort taken to ensure successful implementation of the vegetation[3].
- Maintenance should be considered during the design and layout. For example, pruning and mowing of vegetation and accessibility to features that will need to be maintained[3].
- Include cleanouts as discussed in Section 4.8. These can be used for inspection to make sure that the underdrain is intact, and for ongoing maintenance during and after construction.
- Keep the BMP offline until the construction activities are completed. Temporary BMPs should be in place as detailed in the project Sediment and Erosion Control Plan to protect receiving waters during construction activities (the Sediment and Erosion Control Plan requirements

are not discussed in this manual). Sediment discharged during construction can clog the system and would require additional maintenance.

- Consider making the bioretention basin shallower, to make maintenance easier[3].

---

[1] Hsieh, C.-h., & Davis, A. P. November 2005. Evaluation and Optimization of Bioretention Media for Treatment of Urban Storm Water Runoff. Journal of Environmental Engineering, 1521-1531.
[2] City of Austin. (2017). Design Guidelines for Water Quality Controls. Environmental Criteria Manual.
[3] Urban Drainage and Flood Control District (UDFCD). (2010). Urban Storm Drainage Criteria Manual (USDCM): Volume 3 Stormwater Quality.

## 3.3 CONSTRUCTED WETLANDS

### 3.3.1 DESCRIPTION OF BMP

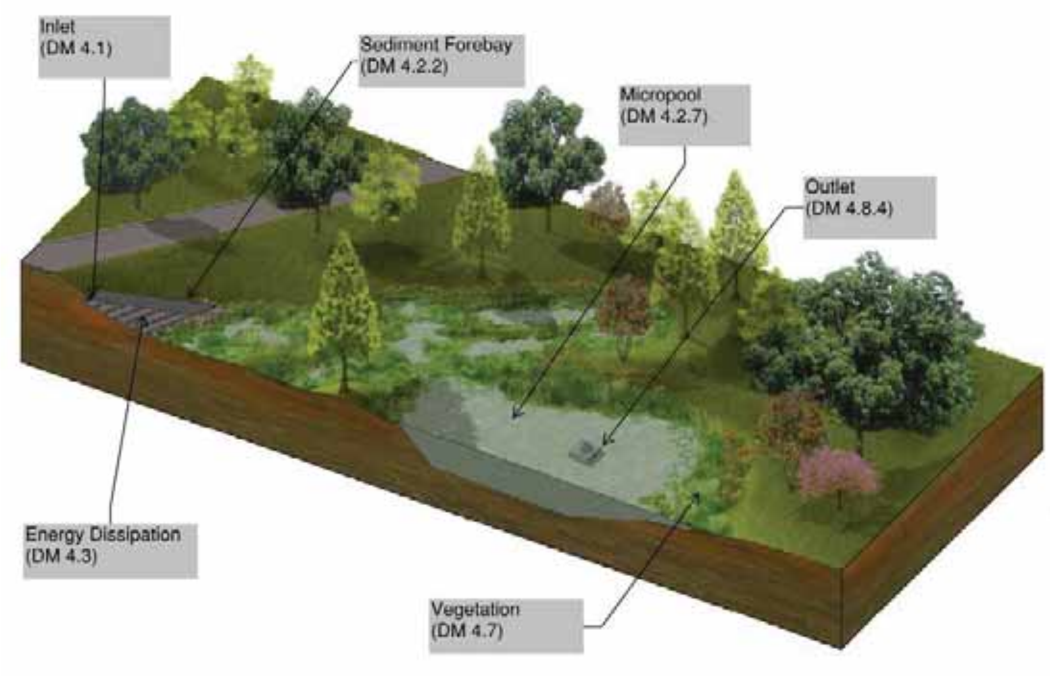
Constructed wetlands generally serve large drainage areas where the WQv is both stored and treated in the wetland facility. They may also provide additional capacity for flood control management. For water quality, these practices are often referred to as stormwater wetlands. The purpose of the constructed wetland is to provide treatment by way of a functional pool resulting in the settlement, filtration, and uptake of pollutants by a viable wetland ecosystem. Constructed wetlands sized for the WQv and designed in compliance with this manual meet the water quality requirements for new and re-development in Zone 2.

A Design/Review spreadsheet has been developed specifically for use with this document and is included in Appendix E. Figure 3.3 provides a conceptual rendering of a constructed wetland with major components identified. As will all detention facilities, constructed wetlands need to be designed such that public safety is maintained (such as using benching to keep deeper water further from shore and/or barriers on lookouts, walkways and the like, or where benching can't be accomplished cost-effectively.

### 3.3.2 APPLICABILITY

The selection of a constructed wetland depends largely on the ability to make sure the system is viable as a wetland ecosystem, performs the key functions of stormwater treatment, and minimizes potential vectors to protect human health. As such, considerable design expertise beyond hydrology, hydraulics, and water quality needs to be engaged to provide a sustainable wetland ecosystem that meets these criteria. Constructed wetlands are best suited for large areas often where flood control detention is also required and where the wetland can contribute additional value to the setting (e.g., such as a park system with trails where birdwatching, environmental education, and the like could occur). Therefore, the final condition of the developed site and the availability of a perennial source of water (and whether a wetland system can be viable with interruptions in water supply) should be considered before choosing constructed wetlands. Poorly designed constructed wetlands can become public nuisances because they lack the natural ability to mitigate mosquito populations.  As such, other practices (such as extended dry detention) should be considered before constructed wetlands where wetland viability is questionable.  Practices like extended dry detention can be designed with attractive landscape elements as well for inclusion in open spaces, park systems, etc.

**Figure 3.3 Conceptual Rendering of a Constructed Wetland**




### 3.3.3 DESIGN CRITERIA

This section provides the design criteria for constructed wetlands. The structural criteria provide information about the components and include references to the component design section of this manual (Section 4). The details and specifications for the components are provided in that section. The design/review spreadsheet in Appendix E outlines the design steps and calculations for the BMPs.

1) General Criteria

   a. Runoff from all impervious surfaces should be directed to a BMP.

   b. Maintenance plans – Maintenance plan for constructed wetlands must contain a guarantee of maintenance in accordance with the Stormwater Facility Maintenance Agreement for Water Quality Devices and be in conformance with the requirements outlined in Appendix D. The plan must be submitted for review by TRWD.

2) Site Conditions

   a. Drainage area – Constructed wetlands should be implemented at locations where there is a larger drainage area or where a wetland system is viable.

   b. Depth to water table – 2-feet are required between the bottom of the constructed wetland and the elevation of the seasonally high-water table.

   c. Soils – Infiltration into soils is not recommended to maintain a permanent pool. Permeable soils are not ideal for maintaining water levels within the constructed wetlands. An impermeable barrier may be needed to minimize water loss from the permanent pool *(See Section 4.6 for additional information on media barriers)*. A geomembrane liner must be used for installations adjacent to streets to prevent water from getting under the pavement into the base material.

d. Floodplain – Where feasible, the BMP should be located outside of the 100-year floodplain. Where not feasible, the top of walls / embankments for the BMP should be above the 100-year floodplain and the BMP should be designed to protect against surcharge from downstream waters.

e. Space – The space required for the BMP is a function of available head at the site, treatment WQv, and availability of make-up water.

3) Structural Criteria

a. Energy dissipation – The constructed wetland must be designed with energy dissipation structures at the inlet if the entrance velocities exceed the erosive velocity requirement of the BMP surface material *(See Section 4.3)*.

b. Diversion structure – The diversion structure should be sized to bypass flows from the 10-year annual probability storm and the channel should be able to convey flows from the 100-year annual probability storm without overtopping.

c. Sediment forebay – The constructed wetland must have a sediment forebay to prevent sediment accumulation in the wetland.

i. Size – The forebay volume should be sized to contain 0.1-inches of runoff from the impervious portion of the contributing drainage area. For example, for a two-acre drainage basin with 60% impervious cover, the forebay should be designed to hold 0.1 inches of runoff from 1.2 acres.

ii. The length to width ratio of the forebay should be at least 2:1 (length:width) and have a side slope ratio no steeper than 3:1 (horizontal:vertical).

iii. Drawdown – The forebay outlet should be sized such that the forebay drains within 24-hours.

d. Constructed wetland basin

i. Size – The basin should be sized to contain a permanent pool volume equal to 100% of the WQv and a surcharge volume sized to contain 120% of the WQv. The purpose of the additional storage volume is to account for the total volume lost through sediment accumulation over time. Ideally, constructed wetlands should have sinuous flow paths, a length to width ratio of 4:1, and side slopes no steeper than 3:1 (horizontal: vertical) (*See Section 4.4 for additional information on area protection*). It is recommended that the basin be lined with a filter fabric if constructed with earthen embankments.

ii. Depth – The permanent pool depth of the constructed wetland should have varying depths as outlined below, ending with a micropool before the outlet that is no more than 6-feet in depth. The surcharge depth should be 2-feet or less. Below are the different permanent pool depth zones that should be included in a constructed wetland.

1. Semi-Wet Zone – This zone lies at or above the permanent pool and is only inundated following storm events. *(See Section 4.7 for Plant List 4 through 8)*.

2. Aquatic Bench Zone – This zone has a depth of 18-inches below the permanent pool elevation. *(See Section 4.7 for Plant List 3)*.

3. Deep Water Zone – This zone has a depth from 18-inches to 6-feet below the permanent pool elevation. *(See Section 4.7 for Plant List 2)*.

iii. Vegetation – appropriate vegetation is a critical component of the effectiveness of the wetland system. The different zones must be planted with the appropriate vegetation for the depth of inundation (*see Section 4.7*). Appendix C provides planting palettes for BMP facilities. These areas should not receive any fertilizers, pesticides, or herbicides. Vegetation on the pond embankments should be mowed as appropriate to prevent the establishment of woody vegetation.

iv. Outlet – Design the outlet properly with the fine trash rack in front of the outlet orifices and is submerged the full depth of the micropool. This allows flow under the clogged portions of the trash rack.

v. Emptying / drain time – The surcharge of the wetland above the permanent pool volume should drain within 24-hours. *(See Section 4.8 for additional information on outlets/piping)*.

### 3.3.4 MAINTENANCE CONSIDERATIONS DURING DESIGN AND CONSTRUCTION

Inspection and maintenance are critical to the performance of constructed wetlands. The activities, schedule, and additional maintenance considerations and requirements are attached in Appendix D “BMP Inspection and Maintenance” of this manual. The following should be considered during design and construction of the BMP:

- Maintenance requirements should be considered during the design and layout. For example, pruning and mowing of vegetation and accessibility to features that will need to be maintained1. Access should be provided to the constructed wetland, particularly to the sediment forebay. A maintenance ramp should be a minimum of 10-feet in width and have a maximum slope of 25%. For mowing, it is recommended to keep side slopes at a maximum of 3:1 (horizontal:vertical). Sediment accumulation in the forebay should be monitored using vertical depth markers indicating when sediment accumulation equals 20% of the forebay volume.

- The BMP should be kept offline until the construction activities are completed. However, the BMP excavation can be used as a sediment trap during construction before filtration or other media are placed in the basin. In that case, the bottom of the basin should not be excavated below 2-feet of the final grade. Temporary BMPs should be in place as detailed in the project Sediment and Erosion Control Plan to protect receiving waters during construction activities (the Sediment and Erosion Control Plan requirements are not discussed in this manual). Sediment discharged during construction can clog the system and would require additional maintenance.

- Monitor and minimize use of fertilizers that can increase nutrient concentrations in discharge and cause algal blooms1.

[1] Urban Drainage and Flood Control District (UDFCD). (2010). Urban Storm Drainage Criteria Manual (USDCM): Volume 3 Stormwater Quality.

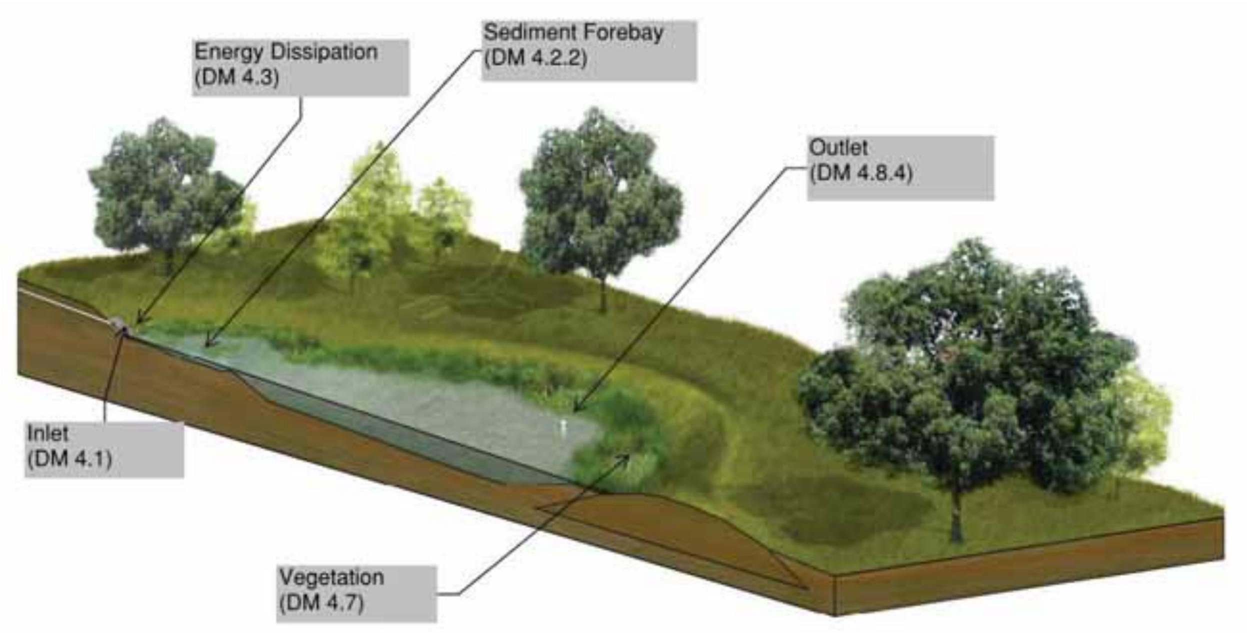
## 3.4 WET BASINS

### 3.4.1 DESCRIPTION OF BMP

Wet basins are designed to retain stormwater in ponds between runoff events to allow the retained volume to be treated for an extended period. These BMPs are also referred to as wet ponds, stormwater ponds, or retention ponds. They are best suited to treat large drainage areas and require a source of water to maintain the permanent pool. Wet basins sized for the WQv and designed in compliance with this manual meet the water quality requirements for new and re-development in Zone 2.

Wet basins remove pollutants by retaining stormwater and allowing for settling and plant uptake during that period. A design/review spreadsheet has been developed specifically for use with this document and is included in Appendix E. Figure 3.4 provides a conceptual rendering of a wet basin with major components identified. Area protection should also be considered.

**Figure 3.4 Conceptual Rendering of a Wet Basin**



### 3.4.2 APPLICABILITY

The selection of a wet basin depends largely on the availability of space, a large contributing drainage area, and the availability of a water source to ensure a permanent pool throughout the entire year. Having a source of water available to maintain a permanent pool is an important consideration when considering the use of wet basin as a BMP.

### 3.4.3 DESIGN CRITERIA

This section provides the design criteria for wet basins. The structural criteria provide information about the components and include references to the component design section of this manual (Section 4). The details and specifications for the components are provided in that section. The design/review spreadsheet in Appendix E outlines the design steps and calculations for the BMPs.

1) General Criteria

   a. Runoff from all impervious surfaces should be directed to a BMP.

   b. Maintenance plans – Maintenance plan for wet basins must contain a guarantee of maintenance in accordance with the Stormwater Facility Maintenance Agreement for Water Quality Devices and be in conformance with Appendix D. The plan must be submitted for review by TRWD.

2) Site Conditions

   a. Drainage area – Wet basins should be implemented at locations where there is a larger drainage area or a potential source of baseflow to maintain the water level.

   b. Depth to water table – 2-feet are required between the bottom of the wet basin and the elevation of the seasonally high-water table.

   c. Soils – Infiltration into soils is not recommended to maintain a permanent pool. Permeable soils are not ideal for maintaining water levels within the wet basins. An impermeable barrier may be needed to minimize water loss from the permanent pool. *(See Section 4.6 for additional information on media barriers).* A geomembrane liner must be used for installations adjacent to streets to prevent water from getting under the pavement into the base material.

   d. Floodplain – Where feasible, the BMP should be located outside of the 100-year floodplain. Where not feasible, the top of walls / embankments for the BMP should be above the 100-year floodplain and the BMP should be designed to protect against surcharge from downstream waters.

   e. Space – The space required for the BMP is a function of available head at the site, required treatment WQv, and availability of make-up water.

3) Structural criteria

   a. Energy dissipation – The wet basin must be designed with energy dissipation structures at the inlet if the entrance velocities exceed the erosive velocity requirement of the BMP surface material *(see Section 4.3)*.

b. Diversion structure – The diversion structure should be sized to bypass flows from the 10-year annual probability storm and the channel should be able to convey flows from the 100-year annual probability storm without overtopping.

c. Sediment forebay – The wet basin must have a sediment forebay to prevent sediment accumulation in the basin.

  i. Size – The forebay volume should be sized to hold 0.1-inches of runoff depth from the impervious portion of the contributing drainage area. For example, for a two-acre drainage basin with 60% impervious cover, the forebay should be designed to hold 0.1 inches of runoff from 1.2 acres.

  ii. The recommended length to width ratio is no less than 2:1 (length:width), and side slopes no steeper than 3:1 (horizontal:vertical).

  iii. Drawdown – The forebay outlet should be sized such that the forebay drains within less than 24-hours.

d. Wet Basin

  iv. Size – The wet basin should be designed to contain a permanent pool volume equal to or greater than the WQv and a surcharge volume of 120% of the WQv (*See Section 4.4 for additional information on area protection*). The purpose of the additional storage volume is to account for the total volume lost through sediment accumulation over time. The basin should be lined with a filter fabric if constructed with earthen embankments.

  v. Depth – The wet basin surcharge should have no more than 5-feet of depth. The wet basin should have a safety bench, or littoral zone, which makes up 15% of the total surface area of the basin.

  vi. Vegetation – Appropriate vegetation is a critical component of the effectiveness of the wetland system. The different zones must be planted with the appropriate vegetation for the depth *(See Section 4.7).* Appendix C provides planting palettes for BMP facilities. These areas should not receive any fertilizers, pesticides, or herbicides. Vegetation on the pond embankments should be mowed as appropriate to prevent the establishment of woody vegetation.

  vii. Outlet – Design the outlet properly with the fine trash rack in front of the outlet orifices and is submerged the full depth of the micropool. This allows flow under the clogged portions of the trash rack.

  viii. Drawdown – The surcharge of the wet basin should drain within 12-hours. *(See Section 4.8).*

e. Note – Texas Commission on Environmental Quality (TCEQ) Dam Safety requirements shall be accounted for as required with higher depth structures. For ponds with significant earthen embankments, prevent planting of woody vegetation in berms to comply with state dam safety rules.

### 3.4.4 MAINTENANCE CONSIDERATIONS DURING DESIGN AND CONSTRUCTION

Inspection and maintenance are critical to the performance of wet basins. The activities, schedule, and additional maintenance considerations and requirements are attached in Appendix D "BMP Inspection and Maintenance" of this manual. The following should be considered during design and construction of the BMP:

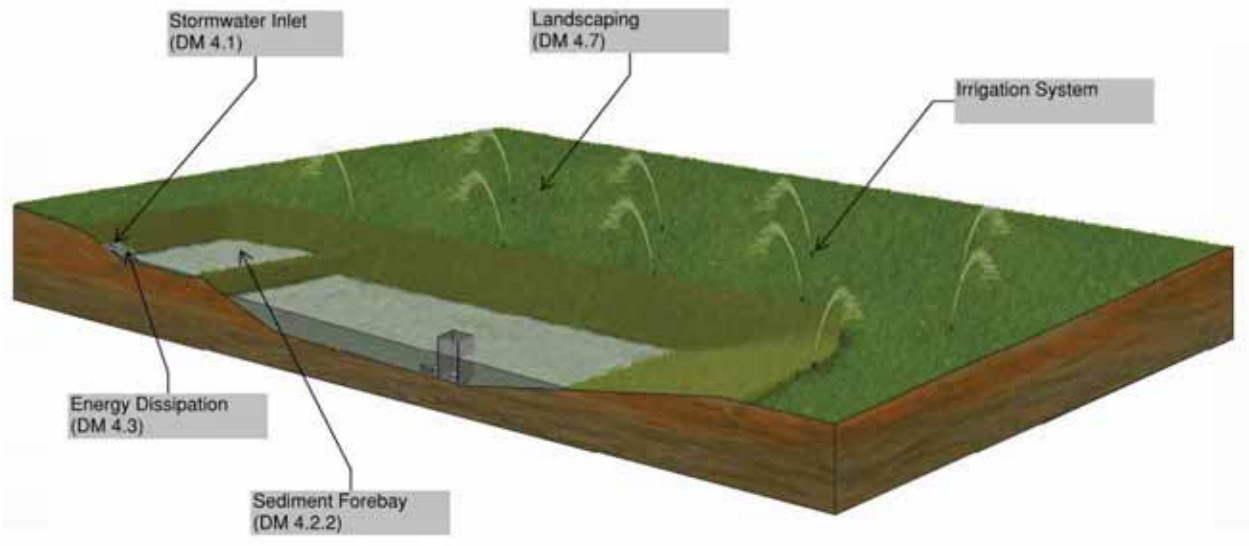
- Maintenance should be considered during the design and layout. For example, there must be easy accessibility to the outlet structure and other features that will need to be maintained[1]. Access should be provided to the wet basin, particularly to the sediment forebay. A maintenance ramp should be a minimum of 10-feet in width and have a maximum slope of 25%. For mowing, it is recommended to keep side slopes at a maximum of 3:1 (horizontal:vertical). Sediment accumulation in the forebay should be monitored using vertical depth markers to indicate when sediment accumulation equals 20% of the forebay volume.
- The BMP should be kept offline until the construction activities are completed. However, the BMP excavation can be used as a sediment trap during construction before filtration or other media are placed in the basin. In that case, the bottom of the basin should not be excavated below 2-feet of the final grade.
- Temporary BMPs should be in place as detailed in the project Sediment and Erosion Control Plan to protect receiving waters during construction activities (the Sediment and Erosion Control Plan requirements are not discussed in this manual). Sediment discharged during construction can clog the system and would require additional maintenance.
- Monitor and minimize use of fertilizers that can increase nutrient concentrations in discharge and cause algal blooms

[1] Urban Drainage and Flood Control District (UDFCD). (2010). Urban Storm Drainage Criteria Manual (USDCM): Volume 3 Stormwater Quality.

## 3.5 RETENTION / IRRIGATION BASIN[1]

The following description and design criteria is consistent with that provided in the Complying with the Edwards Aquifer Rules: Technical Guidance on Best Management Practices prepared by Michael E. Barrett, Ph.D., P.E. for the TCEQ (June 20, 2005). Figure 3.5 provides a conceptual rendering of a retention / irrigation basin with major components identified. Area protection should also be considered in the design.

**Figure 3.5 Conceptual Rendering of a Retention / Irrigation Basin**




* Note – wet well should be separated from wet basin where possible

## 3.5.1 DESCRIPTION OF BMP

Retention / irrigation refers to the capture of stormwater runoff in a holding pond, then use of the captured WQv for irrigation of appropriate landscape areas. Collection of roof runoff for subsequent use (rainwater harvesting) also qualifies as a retention / irrigation practice but should be operated and sized to provide adequate capture volume. Rainwater harvesting design will not be described in Section 3.5.

Retention / irrigation systems represent a highly effective approach to stormwater quality control. The goal of this technology is to use infiltration and evapotranspiration to treat runoff. Pollutant removal effectiveness is accomplished through physical filtration of solids in the soil profile and uptake of nutrients by vegetation. The primary drawback of this approach is the potentially high maintenance requirements for the irrigation system, which must remain operational for this BMP to function effectively.

Retention / irrigation can replace or reduce the use of potable water for irrigation. When properly designed, constructed, operated, and maintained, retention / irrigation systems are considered to be highly effective at removing pollutants for the water quality capture volume.

## 3.5.2 APPLICABILITY

Retention / irrigation systems depend heavily on available land for irrigation. Land uses should be limited to residential, commercial, or light industrial developments. Given the high infiltration rate of the designed system, this system should not be used for areas with the potential to contaminate groundwater such as areas with high levels of toxic compounds. Irrigation is assumed in this section; however, other uses of the retained water may be considered and submitted for consideration.

The system includes mechanical components; therefore, observation and maintenance will be required to ensure the system is performing as designed. Active sites that are routinely inspected and maintained are preferred. The long-term availability of irrigated lands should be considered during BMP selection.

### 3.5.3 DESIGN CRITERIA

This section provides the design criteria for retention / irrigation basins. Capture of stormwater in retention / irrigation systems can be accomplished in virtually any kind of runoff storage facility ranging from fully dry, concrete- lined to vegetated with a permanent pool. The design of the storage system can be quite flexible. The pump and wet well system should be automated with a rainfall or soil moisture sensor to allow for irrigation only during periods when required infiltration rates (based on soils, evapotranspiration rates, etc.) can be realized.

The structural criteria provide information about the components and include references to the component design section of this manual (Section 4). The details and specifications for the components are provided in that section. The design/review spreadsheet in Appendix E outlines the design steps and calculations for the BMPs.

1) General Criteria
    a. Runoff from all impervious surfaces should be directed to a BMP.
    b. Maintenance plans – Maintenance plan for retention / irrigation basins must contain a guarantee of maintenance in accordance with the Stormwater Facility Maintenance Agreement for Water Quality Devices and be in conformance with Appendix D. The plan must be submitted for review by TRWD.
2) Site Conditions
    a. Drainage area – Retention / irrigation basins should be implemented at locations where there is a larger drainage area. It is recommended that sites be less than 128-acres[2].
    b. Depth to water table – 2-feet are required between the bottom of the retention basin and the elevation of the seasonally high-water table.
    c. Floodplain – Where feasible, the BMP should be located outside of the 100-year floodplain. Where not feasible, the top of walls / embankments for the BMP should be above the 100-year floodplain and the BMP should be designed to protect against surcharge from downstream waters.
    d. Space – The space required for the BMP is a function of available head at the site, required treatment WQv, and availability of make-up water.
    e. Irrigated area – The irrigated area must be pervious and have an overall slope no greater than 10%. The area must be distinct from areas that are used for wastewater effluent irrigation, and it should be at least 100-feet from wells, septic systems, natural wetlands, and streams. The minimum area requires intermittent irrigation over a period of 60-hours at low rates to use the entire WQv without allowing runoff. This intensive irrigation may be harmful to vegetation that is not adapted to long periods of wet conditions *(see Section 4.7)*. In practice, a much larger

irrigation area will provide better use of the retained water and promote a healthy landscape.

f. Soils – The permeability of the soils in the area proposed for irrigation should be assessed. This can be determined using a double ring infiltrometer (ASTM D 3385-94) or from county soil surveys prepared by the Natural Resource Conservation Service. A geomembrane liner must be used for retention basin installations adjacent to streets to prevent water from getting under the pavement into the base material. There should be a minimum of 12-inches of soil cover for irrigated areas. If maintaining a permanent pool, minimize water loss by using an impermeable barrier to prevent infiltration.

3) Structural Criteria

a. Energy dissipation – The retention / irrigation basin must be designed with energy dissipation structures at the inlet if the entrance velocities exceed the erosive velocity requirement of the BMP surface material *(see Section 4.3)*.

b. Diversion structure – The diversion structure elevation should be equal to or greater than the surface elevation of WQv in the BMP. The diversion structure should be sized to bypass flows from the 10-year annual probability storm and the channel should be able to convey flows from the 100-year annual probability storm with less than 1-foot over the diversion weir.

c. Runoff storage facility configuration and sizing – The design of the runoff storage facility is flexible as long as an appropriate pump and wet well system can be accommodated.

d. Sediment forebay – The retention / irrigation basin should have a sediment forebay to prevent sediment accumulation in the basin and to protect the pumps and irrigation system.

i. Size – The forebay volume should be sized to contain 0.1-inches of runoff from the impervious portion of the contributing drainage area. For example, for a two-acre drainage basin with 60% impervious cover, the forebay should be designed to hold 0.1 inches of runoff from 1.2 acres.

ii. The length to width ratio should be no less than 2:1 (length:width), and the side slopes should be no steeper than 3:1 (horizontal: vertical).

iii. Drawdown – The forebay outlet should be sized such that the forebay drains within 24-hours.

e. Retention basin

i. Size –Three typical options for retention basins consist of dry, concrete-lined basin, vegetated basin, and vegetated basin with permanent pool. The permanent pool is sized to contain 100% of the WQv. The retention basin must be sized to contain the WQv, plus the permanent pool volume if included. The retention basin should allow enough freeboard such that the retention basin can pass the 100-year storm over the diversion structure without overtopping the side walls.

ii. Vegetation – If applicable, consult Section 4.7 for a list of appropriate vegetation for the retention basin.

iii. Outlet – Design the outlet properly with the fine trash rack in front of the outlet orifices.

iv. Drawdown – The surcharge of the retention basin must drain to the wet well within 72-hours. *(See Section 4.8)*.

v. Fencing – To prevent risk to the public, it is recommended that retention basins be fenced in accordance with the City of Fort Worth requirements. The contours of the retention basin should be managed to eliminate drop-offs and other hazards. Landscaping can also be used to impede access to the retention basin.

f. Note – Texas Commission on Environmental Quality (TCEQ) Dam Safety requirements shall be accounted for as required with higher depth structures.

g. Pump and wet well system - A reliable pump, wet well, and rainfall or soil moisture sensor system should be used to distribute the WQv.

i. Pumps – The pumps should be able to provide 100% of the design capacity and operate within 20% of their best operating efficiency.

ii. The valves should be located outside of the wet well on the discharge side of each pump to allow the pumps to be isolated for maintenance and throttling if necessary.

iii. A high/low-pressure pump shut off system should be installed in the pump discharge piping.

iv. Wet well – The wet well should be constructed of precast or cast in place concrete and located separate from the retention basin. The wet well and pump must be designed to be low enough to completely evacuate the retention basin.

h. Irrigation area and system - The details and specifications for irrigation systems are not part of this manual, and the specifications must be approved by a PE licensed in the state of Texas and submitted for review by the TRWD.

i. Pipes and valves should be marked to indicate that they contain non-potable water.

ii. The irrigation schedule should not begin within 12-hours of the end of the rainfall event so that direct storm runoff has ceased, and soils are not saturated.

iii. The length of active irrigation period is 60-hours with a cycling factor of ¼. The irrigation system should cease in the event that another rainfall event begins during the active irrigation period and should not begin within 12-hours of the end of the rainfall event. Continuous application on any section should be designed to prevent surface runoff from the irrigated area.

iv. Valves – All valves should be designed specifically for sediment bearing water and be of appropriate design for the intended purpose. All remote control, gate, and quick coupling valves should be located in 10-inch or larger plastic valve boxes.

v. Sprinklers – Sprinklers should operate at the required rate and distribute water in a uniform manner and not beyond the limits of the designated irrigation area. Sprinkler heads should be capable of passing solids that may pass through the intake. Sprinkler heads should be protected from mowing and service equipment.

vi. Vegetation – The irrigation area should have native and high water tolerant vegetation or be restored or re-established with native and high water tolerant vegetation *(see Section 4.7)*. Appendix C provides planting palettes for BMP facilities. These areas should not receive any fertilizers, pesticides, or herbicides. Vegetation on the pond embankments should be mowed as appropriate to prevent the establishment of woody vegetation.

### 3.5.4 MAINTENANCE CONSIDERATIONS DURING DESIGN AND CONSTRUCTION

Inspection and maintenance are critical to the performance of retention / irrigation basin. The activities, schedule, and additional maintenance considerations and requirements are attached in Appendix D "BMP Inspection and Maintenance" of this manual. The following should be considered during design and construction of the BMP:

- Maintenance should be considering during the design and layout. Depth markers should be installed in the forebay to monitor sediment accumulation and removal. The basin should be maintained when sediment accumulation is no more than 20% of the forebay volume. Earthen side slopes should not exceed 3:1 (horizontal:vertical) and should terminate on a flat safety bench area.
- Water from the retention basin should pass through a screen or filter to remove solid material and prevent clogging of pipes and sprinklers. The pump and other internal components of the wet well should be accessible through a locked cover to prevent unauthorized access. An isolation valve to prevent flow from the retention basin to the wet well during maintenance activities is recommended.
- Alarms - An alarm system should be provided that is protected against vandals and exposure to weather. The alarm system should be highly visible and should alert when the pumps are not functioning correctly. This could include the water level not being drawn down, the pump not shutting off with low levels of water, or issues with pump pressure.
- The BMP should be kept offline until the construction activities are completed. However, the BMP excavation can be used as a sediment trap during construction before filtration or other media are placed in the basin. In that case, the bottom of the basin should not be excavated below 2-feet of the final grade.

- Temporary BMPs should be in place as detailed in the project Sediment and Erosion Control Plan to protect receiving waters during construction activities (the Sediment and Erosion Control Plan requirements are not discussed in this manual). Sediment discharged during construction can clog the system and would require additional maintenance.
- Monitor and minimize use of fertilizers that can increase nutrient concentrations if there is runoff.
- To the greatest extent practicable, irrigation areas should remain in their natural state. However, vegetation must be maintained in the irrigation area such that it does not impede the spray of water from the irrigation heads. Tree and shrub trimmings and other large debris should be removed from the irrigation area.

---

[1] Barrett, Michael E. Ph.D., P.E. Complying with the Edwards Aquifer Rules Technical Guidance on Best Management Practices. TCEQ RG-348. Revised July 2005 with Addendum Sheet (updated January 2017).
[2] "Retention/Irrigation" Highland Lakes Watershed Ordinance Water Quality Management Technical Manual. LCRA. (2007). 7th ed. 4-31 to 4-36.

## 3.6 EXTENDED DRY DETENTION BASIN

### 3.6.1 BMP DESCRIPTION

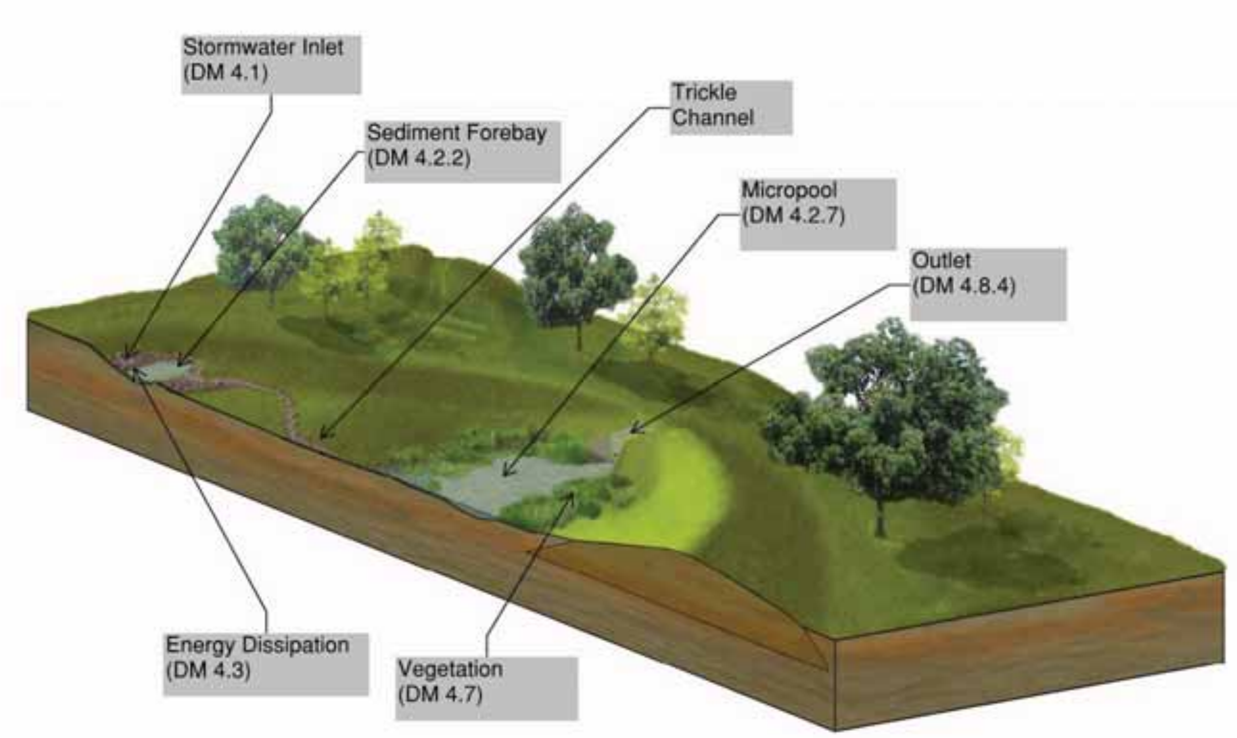
Extended dry detention basins are depressed basins that temporarily store stormwater runoff following a storm event. The water quality benefit of extended detention is achieved through the extended time for particulate pollutants to settle out and incorporating features to promote the capture of sediment, trash, and debris. Detention systems have traditionally been used for flood control to mitigate or regulate flow; however, by extending the detention time from flood control facilities and adding key features that improve water quality, these systems are effective at reducing pollutants. The City of Fort Worth also requires dry detention basins for streambank protection and flood control mitigation. The design and components of extended dry detention basins defined in this manual expand on these requirements and provide additional water quality features (COFW Stormwater Criteria Manual).

When used as a pre- or post-treatment or in conjunction with other water quality treatment systems (i.e. grass swales, vegetated filter systems, sand filters, bioretention basins, constructed wetlands) the performance of the overall BMP approach is increased. Extended dry detention basins must be designed following the criteria specified below and used in conjunction with pre- or post-treatment or other water quality treatment facilities. Figure 3.6 provides a conceptual rendering of an extended detention basin with major components identified. Area protection should also be considered.

### 3.6.2 DESIGN CRITERIA

This section provides the design criteria for extended detention basins. The structural criteria provide information about the components and include references to the component design section of this manual (Section 4); the details and specifications for the components are provided in that section. The design/review spreadsheet in Appendix E outlines the design steps and calculations for the BMPs.

**Figure 3.6 Conceptual Rendering of an Extended Dry Detention Basin**




A general overview of design criteria for consideration at the BMP selection stage of the site design process is provided below.

1) General Criteria

   a. Runoff from all impervious surfaces should be directed to a BMP.

   b. Maintenance plans – Maintenance plan for extended dry detention basins must contain a guarantee of maintenance in accordance with the Stormwater Facility Maintenance Agreement for Water Quality Devices and be in conformance with Appendix D. The plan must be submitted for review by TRWD.

2) Site Conditions

   a. Drainage area – Extended dry detention basins should be implemented at locations serving a drainage area greater than 5-acres but less than 100-acres. For larger basins, additional information must be provided to ensure that the basin will perform effectively, and additional maintenance and inspections may be required to verify.

   b. Depth to water table – 2-feet are required between the bottom of the extended dry detention basin and the elevation of the seasonally high-water table.

   c. Soils – Determine if native soils on site are sufficient for infiltration. A geomembrane liner must be used for installations adjacent to streets to prevent water from getting under the pavement into the base material.

d. Floodplain – Where feasible, the BMP should be located outside of the 100-year floodplain. Where not feasible, the top of walls / embankments for the BMP should be above the 100-year floodplain and the BMP should be designed to protect against surcharge from downstream waters.

e. Space – The space required for the BMP is a function of available head at the site, required treatment WQv, and availability of make-up water.

3) Structural Criteria

a. Energy dissipation – The extended dry detention basin must be designed with energy dissipation structures at the inlet if the entrance velocities exceed the erosive velocity requirement of the BMP surface material (*see Section 4.3*).

b. Diversion structure – The diversion structure should be sized to bypass flows from the 10-year annual probability storm and the channel should be able to convey flows from the 100-year annual probability storm without overtopping.

c. Forebay – The extended dry detention basin must have a sediment forebay to prevent sediment accumulation in the basin.

   i. Size – The forebay volume should be sized to contain 10% of the WQv. The length to width ratio should be no less than 2:1 (length:width), and the side slopes no steeper than 3:1 (horizontal:vertical).

   ii. Drawdown – The forebay outlet should be sized such that the forebay drains within 24-hours.

d. Basin

   i. Size – The extended dry detention basin should be designed to contain 100% of the WQv. Side slopes of the basin should be no steeper than 3:1 (horizontal: vertical). *(See Sections 4.4 for additional information on area protection)*.

   ii. Trickle channels should have a design slope of at least 3%. Extended dry detention basins should have a micropool that is at least 2.5-feet in depth at the end of the basin. The micropool does not have to drain within 48-hours.

   iii. Landscaping – The extended dry detention basin should be appropriately seeded for temporary inundation *(see Section 4.7)*.

   iv. Outlet – Design the outlet properly with the fine trash rack in front of the outlet orifices and submerged the full depth of the micropool. This allows flow under the clogged portions of the trash rack.

   v. Drawdown – The extended dry detention basin should drain the WQv within 40 to 48-hours. *(See Section 4.8)*.

e. Note – Texas Commission on Environmental Quality (TCEQ) Dam Safety requirements shall be accounted for as required with higher depth structures. For ponds with significant earthen embankments, prevent planting of woody vegetation in berms to comply with state dam safety rules.

### 3.6.3 MAINTENANCE CONSIDERATIONS DURING DESIGN AND CONSTRUCTION

Inspection and maintenance are critical to the performance of extended detention basins. The activities, schedule, and additional maintenance considerations and requirements are included in Appendix D "BMP Inspection and Maintenance" of this manual. The following should be considered during design and construction of the BMP:

- Maintenance should be considering during the design and layout. For example, pruning and mowing of vegetation and accessibility to other features that will need to be maintained[1]. Adequate access must be provided for inspection and maintenance, including the appropriate equipment and vehicles. An access ramp with a minimum width of 10-feet and a maximum slope of 25% shall be provided.
- The BMP should be kept offline until the construction activities are completed. However, the BMP excavation can be used as a sediment trap during construction before filtration or other media are placed in the basin. In that case, the bottom of the basin should not be excavated below 2-feet of the final grade.
- Temporary BMPs should be in place as detailed in the project Sediment and Erosion Control Plan to protect receiving waters during construction activities (the Sediment and Erosion Control Plan requirements are not discussed in this manual). Sediment discharged during construction can clog the system and would require additional maintenance.

[1] Urban Drainage and Flood Control District (UDFCD). (2010). Urban Storm Drainage Criteria Manual (USDCM): Volume 3 Stormwater Quality.

## 3.7 VEGETATED FILTER STRIP

### 3.7.1 DESCRIPTION OF BMP[1]

Vegetated filter strips are gently sloped flat vegetated areas designed to receive and maintain sheet flows over the entire width of the strip[2]. They are typically linear facilities that run parallel to the impervious surface. These systems are not intended to be used as a stand-alone or primary BMP system for a development. However, if a vegetated filter strip BMP system is used within close proximity to small, low-density impervious areas, the WQv for this area can be treated. For these areas, the area that drains to the BMP can be reduced from the total site area. Therefore, the $WQ_V$ from that area is reduced from the total $WQ_V$ for the site.

Vegetated filter strips treat stormwater runoff and can reduce velocity[2]. Vegetated filter strips remove pollutants by sedimentation, filtration, and infiltration. To function correctly, vegetated filter strips require shallow slopes and well drained soils that increase contact time and remove pollutants. Pollutant removal efficiencies are highly variable and primarily depend on the longitudinal slope, the length of the filter strip, and the amount of vegetation. These variables correspond to the contact time for filtration. The extent of infiltration also depends on the type of soil, the drainage capacity of the soil, as it relates to infiltration, the density of the grass, and the slope of the strip[3].

### 3.7.2 APPLICABILITY

These BMPs can be used most effectively in areas with low density impervious cover or linear impervious cover or as pre- or post-treatment for other water quality BMPs. Vegetated filter strips are intended to treat sheet flow only. They are commonly used to receive runoff from roads and highways, roof downspouts, very small parking areas, walkways and driveways, as well as pervious surfaces[1,3]. Filter strips can be easily integrated into the site design.

### 3.7.3 DESIGN CRITERIA

This section provides the design criteria for vegetative filter strips. The structural criteria provide information about the components and include references to the component design section of this manual (Section 4). The details and specifications for the components are provided in that section. The design/review spreadsheet in Appendix E outlines the design steps and calculations for the BMPs.

1) General criteria

   a. Maximum depth of sheet flow over the filter strip should not exceed 2-inches for the water quality event; 1-inch is preferred.

   b. Maintenance plans – The maintenance plan must contain a guarantee of maintenance and conform with requirements in Appendix D and the *Stormwater Facility Maintenance Agreement – Water Quality Devices*.

2) Site conditions

   a. Drainage Area – The length of the contributing drainage area in the direction of flow should not exceed 75-feet. A flow spreader device can be placed at the top of the filter strip for large flow lengths to promote sheet flow.

   b. Soils – Soils should have a minimum depth of 12-inches and must allow for dense vegetative coverage.

   c. Space Required – To achieve the desired level of treatment, the length of the filter strip in the direction of flow should be no less than 15-feet, and 25-feet is preferred. However, vegetated areas will provide some level of treatment at less than 15 feet. Therefore, if the available space does not allow for the length of the filter strip to be at least 15-feet, then including vegetated areas is still encouraged to help reduce sediment loads.

   d. Pedestrian traffic across filter strips shall be limited through channeling onto sidewalks.

3) Structural criteria

   a. Slope – The longitudinal (direction of flow) slope of a filter strip should be no less than 2% and no greater than 6%.

   b. Landscaping – An appropriate planting pallet should be selected to ensure vegetation is sustained over the course of wet and dry periods, capable of withstanding large rain events, and able to withstand relatively high velocity flows at the entrances in order to prevent erosion rills (*see Section 4.7*).

c. Permeable berms – Installed for enhanced filter strips should have a maximum height of 12-inches with a 3:1 side slope. They should be level and constructed with a non-settling core to prevent erosion or channelized flow downstream of the berm resulting from high flow storm events.

### 3.7.4 MAINTENANCE CONSIDERATIONS DURING DESIGN AND CONSTRUCTION

Inspection and maintenance are critical to the performance of vegetated filter strips. The activities, schedule, and additional maintenance considerations and requirements are attached in Appendix D "BMP Inspection and Maintenance" of this manual. The following should be considered during design and construction of the BMP:

- Access - Limit pedestrian access across filter strips by directing pedestrians to sidewalks or other marked walkways.
- Maintenance should be considering during the design and layout. For example, pruning and mowing of vegetation and accessibility to features that will need to be maintained[4].
- Consider installing vegetated filter strips 1 to 3-inches below adjacent impervious surfaces[4].
- Include soil amendments to improve plant establishment and reduce need for irrigation[4].

---

[1] Barrett, Michael E. Ph.D., P.E. Complying with the Edwards Aquifer Rules Technical Guidance on Best Management Practices. TCEQ RG-348. Revised July 2005 with Addendum Sheet (updated January 2017).
[2] King County. April 2016. Surface Water Design Manual
[3] North Central Texas Council of Governments. September 2014. iSWM™ Technical Manual.
[4] Urban Drainage and Flood Control District (UDFCD). (2010). Urban Storm Drainage Criteria Manual (USDCM): Volume 3 Stormwater Quality.

## 3.8 GRASS SWALE

### 3.8.1 DESCRIPTION OF BMP[1]

Grass (vegetated) swales are gently sloped channels that are designed to receive and treat stormwater as it is conveyed to a standalone or primary BMP or after discharge from a BMP[2]. These systems are not intended to be used as a stand-alone or primary BMP system for a development. However, if a grass swale BMP system is used within close proximity to small, low-density impervious areas, the WQv for this area can be treated. For these areas, the area that drains to the BMP can be reduced from the total site area. Therefore, the $WQ_V$ from that area is reduced from the total $WQ_V$ for the site.

These remove pollutants primarily by maintaining shallow flow through vegetation that encourages sedimentation or particle settling and infiltration[2]. These processes can be enhanced by resistance of vegetation to flow[2]. To a much lesser degree, pollutants may adhere or sorb to grass and thatch[2]. Swales generally do not remove dissolved pollutants effectively, although some infiltration to underlying soils may occur depending on the nature of those soils[1].

The pollutant removal efficiency of swales is highly variable and primarily depends on the density of the vegetation, the width of the swale and depth of flow, the length of the vegetated swale, which corresponds to the contact time for filtration, as well as the drainage capacity of the soil as it relates to infiltration[3]. There are two types of grass swales: simple and enhanced. An enhanced version includes the use of berms, check dams, or dense or specialized vegetation to slow the flow and increase the residence time. This section discusses each in further detail.

### 3.8.2 APPLICABILITY

They can be used most effectively in areas with low density impervious cover or linear impervious cover, such as roadways or sidewalks, or as pre- or post-treatment for other water quality BMPs. Grass swales are intended to treat shallow concentrated flow. They are commonly used to receive and convey runoff from road and highways, roof downspouts, parking areas, walkways and driveways, as well as pervious surfaces[1,3].

To function correctly, grass swales require shallow slopes and well drained soils that increase contact time and remove pollutants. They can be easily integrated into the site design.

### 3.8.3 DESIGN CRITERIA

This section provides the design criteria for grass swales. The structural criteria provide information about the components and include references to the component design section of this manual (Section 4). The details and specifications for the components are provided in that section. The design/review spreadsheet in Appendix E outlines the design steps and calculations for the BMPs.

1) General criteria

    a. Maximum depth of sheet flow over the filter strip should not exceed 4-inches during the water quality event.

    b. Maintenance plans – Maintenance plan must include a guarantee of maintenance and conforms with the requirements in Appendix D and the *Stormwater Facility Maintenance Agreement – Water Quality Devices*.

2) Site conditions

    a. Drainage Area – Less than 5-acres. If the practices are used on larger drainage areas, the flows and volumes through the channel become too large to allow for filtering and infiltration of runoff.

    b. Soils – Generally unrestricted. Swales should not be used on soils with infiltration rates less than 0.27-inches per hour if infiltration of small runoff flows is intended.

    c. Space Required – Dependent on the contributing drainage area and anticipated flow.

3) Structural criteria

    a. Cross section design - The swale should have a trapezoidal or parabolic cross section with relatively flat side slopes (generally 3:1 or flatter).

b. Channel bottom – The bottom of the channel should be between 2 and 6-feet wide. The minimum width ensures an adequate filtering surface for water quality treatment, and the maximum width prevents braiding, which is the formation of small channels within the swale bottom. The bottom width is a dependent variable in the calculation of velocity based on Manning's Equation. If a larger channel is needed, the use of a compound cross section is recommended.

c. Slope – Relatively flat slopes of less than 4%; channel slopes between 1% and 2% are recommended.

d. Maximum Velocity - Target maximum velocity less than 1.0-foot per second.[2]

e. Vegetation – An appropriate planting pallet should be selected to ensure vegetation is sustained over the course of wet and dry periods, as well as capable of withstanding large rain events, in order to prevent erosion rills (*see Section 4.7*). These areas should not receive any fertilizers, pesticides, or herbicides. Vegetation on the pond embankments should be mowed as appropriate to prevent the establishment of woody vegetation.

f. Permeable berms – Should have maximum height of 12-inches with a 3:1 side slope. They should be level and constructed with a non-settling core to prevent erosion or channelized flow downstream of the berm as a result of high flow storm events.

g. Riprap - Riprap-protected side slopes shall be no steeper than 2:1.[2]

h. Check Dams – If check dams are installed, then the ponding depth behind check dams shall be designed to infiltrate or drain stormwater runoff within less than 48 hours.

### 3.8.4 MAINTENANCE CONSIDERATIONS DURING DESIGN AND CONSTRUCTION

Inspection and maintenance are critical to the performance of grass swales. The activities, schedule, and additional maintenance considerations and requirements are attached in Appendix D "BMP Inspection and Maintenance" of this manual. The following should be considered during design and construction of the BMP:

- Access - Limit pedestrian access across filter strips by directing pedestrians to sidewalks or other marked walkways.
- Maintenance should be considering during the design and layout. For example, mowing of vegetation and accessibility to features that will need to be maintained[3].
- Include soil amendments to improve plant establishment and reduce need for irrigation[3].

---

[1] King County. April 2016. Surface Water Design Manual
[2] North Central Texas Council of Governments. September 2014. iSWM™ Technical Manual.
[3] Urban Drainage and Flood Control District (UDFCD). (2010). Urban Storm Drainage Criteria Manual (USDCM): Volume 3 Stormwater Quality.

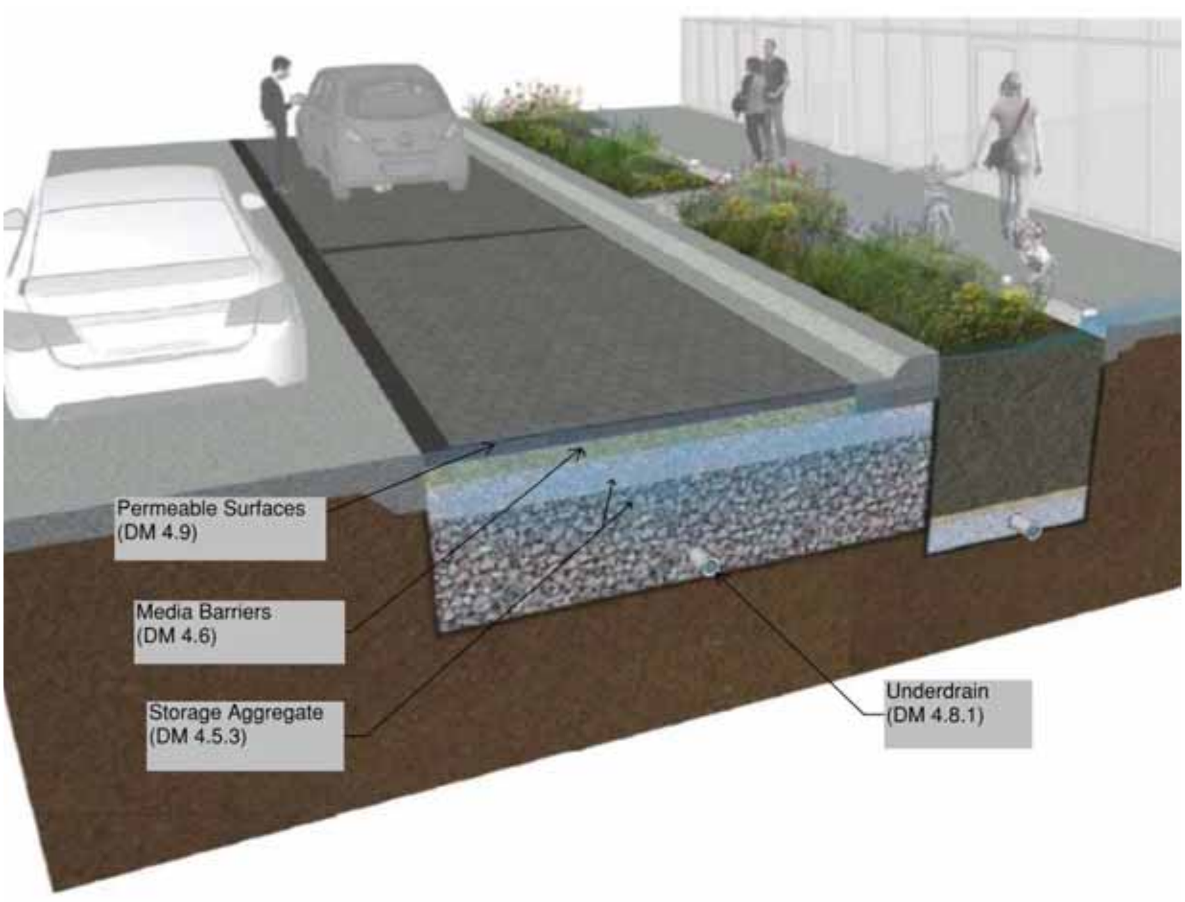
## 3.9 PERMEABLE SURFACES

### 3.9.1 DESCRIPTION OF BMP[1]

Permeable surfaces include permeable pavers, porous concrete, porous asphalt, and grassed modular grid systems. Permeable surfaces require careful design, construction, and maintenance in order to provide good service life and proper drainage. Permeable surfaces have been used to replace or use in place of impervious surfaces and be used to temporarily store water in the storage aggregate layer. This manual focuses on the use of permeable pavers. Other surfaces can be submitted for review. Porous asphalt is not allowed for compliance with water quality requirements. There are many types of proprietary permeable pavement systems on the market today. When applicable, and unless modified by a civil engineer's signed/sealed design, the manufacturer's recommendations should be strictly followed.

Permeable pavers are not recommended in areas with high sediment loads due to the potential for clogging and may require frequent maintenance to remain effective[2]. To prevent clogging, permeable pavers are recommended at a ratio of treatment drainage area to permeable paver surface area of 1.5 to 1. It is also recommended that impervious surfaces that drain to Permeable Surfaces are regularly swept by street sweepers. Figure 3.7 provides a conceptual rendering of a permeable paver system with an adjacent small bioretention basin.

**Figure 3.7 Conceptual Rendering of Permeable Pavers**



### 3.9.2 DESIGN CRITERIA

This section provides the design criteria for permeable pavers. The structural criteria provide information about the components and include references to the component design section of this manual (Section 4). The details and specifications for the components are provided in that section. The design/review spreadsheet in Appendix E outlines the design steps and calculations for the BMPs.

1) General conditions
    a. Specifications for permeable must contain technical information as detailed in Section 4.9.
    b. Maintenance plan for sand filters must include, at a minimum, trash removal, accumulated sediment removal, inspection for standing water, and inspection for 24-hour drawdown as specified in Appendix D
2) Site Conditions
    a. A minimum of 4-feet of clearance is recommended between the bottom of the gravel base course and underlying impermeable layers or the seasonally high groundwater table.
    b. Permeable pavers are recommended at a ratio of treatment drainage area to permeable paver surface area of 1.5 to 1.
3) Structural criteria
    a. Pretreatment – Vegetated filter strips are recommended to be installed for permeable surfaces that receive runoff from vegetated surfaces such as open fields or playgrounds.
    b. Slopes – Permeable paver systems should not be used on slopes greater than 5% with slopes of no greater than 2% recommended. For slopes greater than 1% barriers perpendicular to the direction of drainage should be installed in sub-grade material to keep runoff in the media from flowing downstream and surfacing at the toe, thus not providing the needed WQv under the pavement.
    c. Signage – A warning sign should be placed at the facility that states, "Permeable pavers used on this site to reduce pollution. Do not resurface with non-porous material or sand during icy weather."

### 3.9.3 MAINTENANCE CONSIDERATIONS DURING DESIGN AND CONSTRUCTION

Inspection and maintenance are critical to the performance of permeable pavers. The activities, schedule, and additional maintenance considerations and requirements are attached in Appendix D "BMP Inspection and Maintenance" of this manual. The following should be considered during design and construction of the BMP:

- Maintenance should be considering during the design and layout.
- Consider installation of an observation well to monitor drain time of the pavement over time.

- The BMP must be protected until the construction activities are completed. Temporary BMPs should be in place as detailed in the Sediment and Erosion Plan to protect permeable pavers and receiving waters during construction activities (this will not be covered in this manual). Sediment discharged during construction can clog the system and would require additional maintenance. A pre-construction meeting should be held to ensure the contractor is aware that the permeable pavers should be protected from sediment load. A construction fence can also be used during construction to prevent compaction

[1] King County. April 2016. Surface Water Design Manual
[2] Urban Drainage and Flood Control District (UDFCD). (2010). Urban Storm Drainage Criteria Manual (USDCM): Volume 3 Stormwater Quality.

## ADDITIONAL RESOURCES

1 City of Fort Worth. December 20, 2012. Standard Construction Specification Documents.

2 NCTCOG. September 2014. "iSWM™ Technical Manual: Water Quality: 1.0 Water Quality Protection Volume and Peak Flow", North Central Texas Council of Governments, Arlington, Texas, April 2010, Revised September 2014, http://iswm.nctcog.org/Documents/technical_manual/Water%20Quality_9-2014.pdf

3 Placer County, et. al. West Placer Storm Water Quality Design Manual. April 2016.

4 Texas Commission on Environmental Quality. November 2015. Rules and Regulations for Public Water Systems.

5 UWRI. October 5, 2015. Comparison of Water Quality Capture Volume Needs for Ft. Worth, TX Region to Capture of 85th Percentile Runoff Volume and Runoff Events, Urban Watershed Research Institute.

This page intentionally left blank.

SECTION 4

## Permanent BMP Design Components

Design components are defined to be the fundamental elements required for a Best Management Practice (BMP) to function. The design components are essentially the building blocks of the BMP that not only facilitate stormwater entering, moving, and discharging from the practice but also consider integration of the BMP within its surroundings to optimize its performance and long-term function. This section provides both designers and TRWD reviewers a standard set of requirements for each BMP component necessary for the design and construction of the BMP practice as a whole. **Figure 4.1** displays an example of how design components are integrated to create a bioretention BMP.

**Figure 4.1 Example of Design Components in Bioretention BMP**


BMP design components include stormwater inlets, pre-treatment and post-treatment, energy dissipation, area protection, BMP media, media barriers, landscaping, outlets/piping, and/or permeable surfaces. For certain design components, a developer manual-detail component (DM-DC) is shown to give a typical design detail. Because every BMP design and installation is site-specific, not all components will be applicable for every site. Each BMP practice requires a different menu of design components dependent on its intended function. The BMP types and their minimum applicable design components are outlined in **Table 4.1**. Minimum applicable design components, marked with "X" in **Table 4.1** are the components a designer is required to evaluate for each BMP site to promote proper long-term function. The designer should evaluate the components, determine if they are applicable and necessary for their BMP site, and provide the required design submittal material for each. If a minimum applicable component is determined unnecessary, the designer must submit justification as to why the component is omitted from the design using the Design Review Checklist provided in **Appendix A** (to be submitted to TRWD). Additional components not identified as the minimum applicable design component for a BMP may be used for improved site-specific aesthetics or function.

**Table 4.1 Minimum Applicable Design Components by BMP Practice**

| BMP | DESIGN COMPONENT | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Stormwater Inlet | Pre-treatment/ Post-treatment[1] | Energy Dissipation | Area Protection | BMP Media | Media Barriers | Land-scaping | Outlets /Piping | Permeable Surfaces |
| Permeable Surfaces | - | ✓ | - | ✓ | ✓ | ✓ | - | ✓ | ✓ |
| Bioretention Basins | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | - |
| Constructed Wetlands | ✓ | ✓ | ✓ | ✓ | - | - | ✓ | ✓ | - |
| Sand Filters | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | - |
| Wet Basins | ✓ | ✓ | ✓ | ✓ | - | - | ✓ | ✓ | - |
| Extended Detention Basin | ✓ | ✓ | ✓ | ✓ | - | - | ✓ | ✓ | - |
| Retention/ Irrigation Basin | ✓ | ✓ | ✓ | ✓ | - | - | - | ✓ | - |
| Vegetative Filter Strip / Grass Swale | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | - |

[1]Pre-treatment is required for drainage areas greater than 2-acres and recommend for drainage areas less than 2-acres.

Each design component is described in more detail in the following subsections. Each subsection includes discussion on the following:

- DESCRIPTION – Summary of the primary function of the design component within the BMP practice
- WHERE TO USE – Description of where the design component should be used within the BMP practice and when it is or is not appropriate
- DESIGN CONSIDERATIONS – Minimum specifications required for application of the design component to function as intended
- DESIGN SUBMITTAL REQUIREMENTS CHECKLIST – Description of plan submittal requirements for each design component TRWD review and approval of the BMP practice
- DETAILS – Defined design components and typical DM-DC for consideration when developing design drawings

- ADDITIONAL RESOURCES – Where additional information can be found, including background on requirements and standards used for development of the design component detail and write-up

Design components of BMPs to be described in this manual include the following:

- SECTION 4.1 – INLETS: Inlets include design components that collect and allow stormwater to enter a BMP.
- SECTION 4.2 – PRE -TREATMENT AND POST-TREATMENT: Pre-treatment design components reduce or prevent sediment, trash, and/or oil from either entering a BMP and post-treatment design components reduce or prevent sediment and trash in stormwater from exiting the BMP.
- SECTION 4.3– ENERGY DISSIPATION: Energy dissipation includes design components that dissipate the energy of stormwater entering a BMP to prevent and reduce potential erosion from incoming stormwater.
- SECTION 4.4 – AREA PROTECTION: Area protection includes design components that provide some level of protection between a BMP and the pedestrian environment.
- SECTION 4.5 – BMP MEDIA: BMP media includes the media layers within a BMP that filter, store, and infiltrate stormwater underground to help achieve the required water quality volume. Media layers may not be applicable to all BMPs.
- SECTION 4.6 – MEDIA BARRIERS: Media barriers include permeable or impermeable barriers within the BMP that allow for the control or prevention of soil, aggregate, and/or stormwater migration through the BMP.
- SECTION 4.7 – LANDSCAPING: Landscaping includes planting and landscape materials for the application of BMPs.
- SECTION 4.8 – OUTLETS/PIPING: Outlets/piping include design components that convey stormwater, protect piping, allow access to piping, allow monitoring of a BMP, and/or provide a safe release of stormwater from a BMP.
- SECTION 4.9 – PERMEABLE SURFACES: Permeable surfaces include design components that allow stormwater to infiltrate through the surface of a permeable pavement system into the BMP media layer.

## 4.1 STORMWATER INLETS

### DESCRIPTION

Inlets facilitate directing of stormwater runoff into the BMP. Inlets that collect stormwater runoff at a single concentrated point include curb cuts, depressed curbs, trench drains, gutter apron, manufactured at-grade inlets, flow splitters, and distribution piping. Guidance on inlet types not discussed in this section can be found in City of Fort Worth Stormwater Criteria Manual1[1].

### WHERE TO USE

An inlet should be used in applications where it is necessary to collect and/or convey stormwater into a BMP system. Curb cuts, depressed curbs, trench drains, manufactured at-grade inlets, and gutter aprons should be used in locations where it is necessary to collect stormwater from the street or sidewalk and convey it to the surface of a BMP facility. Manufactured at-grade inlets may also be used in locations where there are higher sediment loads, such as streets or parking lots, to remove sediments prior to the stormwater runoff entering the BMP. Trench drains may also serve as an inlet to collect or intercept stormwater across a path of travel such as a sidewalk or parking lot. Flow splitters should be used in locations upstream of the BMP. Distribution piping should be used when stormwater runoff cannot be discharged to the surface of the BMP due to site grading or stormwater collection system constraints.

### DESIGN CONSIDERATIONS

- Inlets shall be sized to collect the water quality volume or design control volume. BMP flow splitters should be analyzed in conjunction with the existing storm system to verify adequate bypass for larger storm events is provided.
- Inlets collecting concentrated flow may require energy dissipation (Section 4.3) to mitigate erosion of the BMP at the stormwater entrance.
- Pretreatment components (Section 4.2) should also be considered to remove coarse materials that could result in erosion or clogging of the BMP system.
- A metal wheel guard across the top of the inlet should be considered for curb cuts and depressed curbs within the street cross section to protect the curb and prevent unintentional movement of the vehicle into the BMP.
- It is recommended that bypass around the BMP is provided for stormwater exceeding either the water quality volume or the 10-year storm events to mitigate scouring of the BMP. This will depend on the size and type of the BMP.

## DETAILS

### 4.1.1 CURB CUT/DEPRESSED CURB

A curb cut or depressed curb allows stormwater runoff from the pavement or sidewalk to enter a BMP system located directly behind the back edge of the curb cut. A curb cut is a notch cut in standard roadway curb. A depressed curb is a new curb that is poured with one or more sides tapered down to an at-grade opening. See detail DM-DC 4.1.1 for additional information.


*Photo Credit: San Francisco Public Utilities Commission[2]*

### 4.1.2 TRENCH DRAIN

A trench drain is a shallow concrete trench with a grate or solid cover over the top of the trench that allows collection and conveyance of stormwater runoff across a paved surface including sidewalks or vehicular pavement. A trench drain can convey water at or just below the surface. See detail DM-DC 4.1.2 for additional information.

*Photo Credit: CDM Smith, designed by others*

### 4.1.3 GUTTER APRON

*Photo Credit: National Association of City Transportation Officials[3]*

A gutter apron is a depressed section of gutter with increased cross and longitudinal slope placed in front of a BMP inlet to increase stormwater capture. See detail DM-DC 4.1.3 for additional information.

### 4.1.4 MANUFACTURED AT-GRADE INLET

A manufactured at-grade inlet is a proprietary type of stormwater inlet that collects from the curb line of pavement and may include a built-in pre-treatment function allowing for the removal of debris, such as sediment, leaves, and sand, prior to stormwater entering the BMP. Pre-treatment prevents debris from clogging the BMP and improves long-term performance. Rain Guardian™ is an example of a manufactured at grade-inlet which provides debris and sediment management for stormwater entering a BMP.

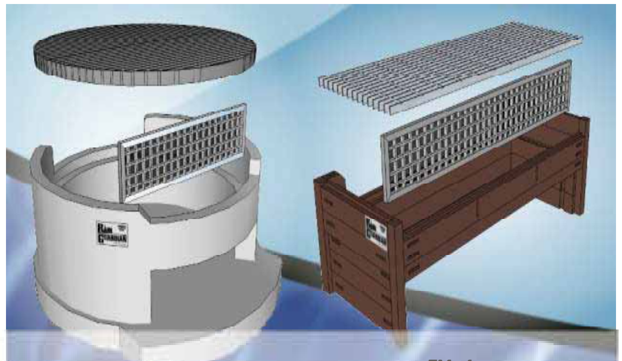


*Photo Credit: Rain Guardian™, 4*

*Photo Credit: Rain Guardian™*

### 4.1.5 FLOW SPLITTER

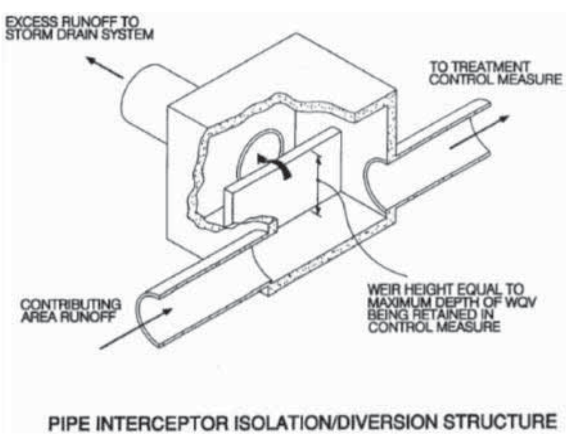



*Photo Credit: iSWM Guidance Manual[5]*

A flow splitter, also known as flow regulator, is a component that is designed to convey only the water quality volume into the BMP and to allow flow in excess of that volume to be bypassed or diverted. It may also be used to regulate peak flow rates into the BMP to minimize potential erosion. A flow splitter or flow regulator is used in off-line facilities where the entire storm event is not routed through the BMP. This differentiates the BMP from the on-line version which receives but does necessarily treat the entire storm event. A low flow orifice, weir, baffle structure, or other device can be used to regulate the flow to the BMP.

### 4.1.6 DISTRIBUTION PIPE

A distribution pipe conveys stormwater to the storage aggregate layer of the BMP and distributes flow through perforations in the pipe. Distribution piping must meet the following parameters, see detail DM-DC 4.1.4 for additional design information:

- Distribution pipes shall be a minimum of 6-inches in diameter.
- Acceptable pipe materials and fittings including PVC pipe shall be in accordance with City of Fort Worth STD Specification 33 46 00.
- Bedding and granular backfill shall consist of crushed rock per Section 4.5.3.
- Distribution pipes shall consist of solid piping when passing through areas where stormwater needs to be conveyed without exfiltration from the pipe such as from the extents of the BMP system to the existing drainage system or outfall point.

*Photo Credit: CDM Smith*

### DESIGN SUBMITTAL REQUIREMENTS CHECKLIST

Design submittal requirements checklist may be applicable to all or some of the inlet components:

- Plan and detail view of inlet including northing/easting locations, invert and RIM elevations, opening size, and base materials with specified depths, as applicable. Specify longitudinal slopes, cross slopes, and transition to adjacent grade.
- Calculation summary sheet for allowable concentrated flows and capacities for an inlet.
- Specify manufacturer information including product number, materials, painting specifications, and fastener and frame details, as applicable.

Inlet designs and specifications outside the parameters of this guideline shall be submitted to a licensed PE for review and approval.

## ADDITIONAL RESOURCES

[1] City of Fort Worth. September 29, 2015. City of Fort Worth Stormwater Criteria Manual.

[2] Curb cut. San Francisco Public Utilities Commission. Accessed January 2018.

[3] Gutter aprons. National Association of City Transportation Officials. Accessed January 2018. https://nacto.org/publication/urban-street-design-guide/

[4] American Society of State Highway and Transportation Officials. AASHTO HS-20 Loading.

[5] City of Fort Worth. August 31, 2012. Standard Construction Drawings. *Detail D534 – Standard Curb & Gutter*.

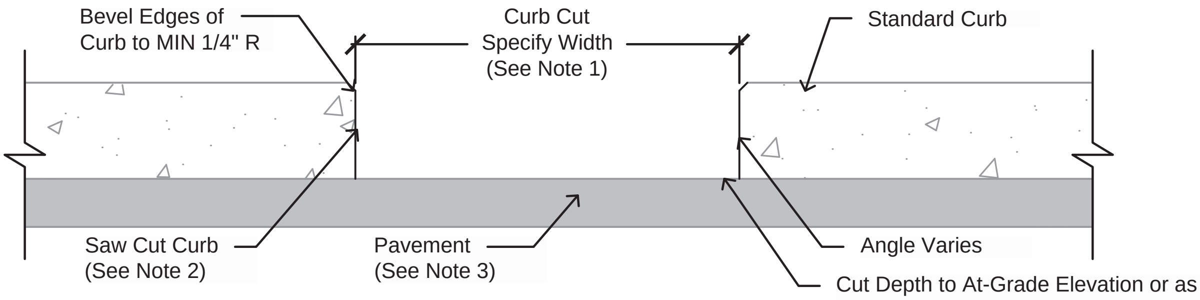
[6] City of Fort Worth. May 22, 2015. Standard Construction Drawings. *Detail D405 – Standard Strom Drain Inlet.*

[7] Rain Guardian. Accessed: April 26, 2017. Web address: http://www.rainguardian.biz/.

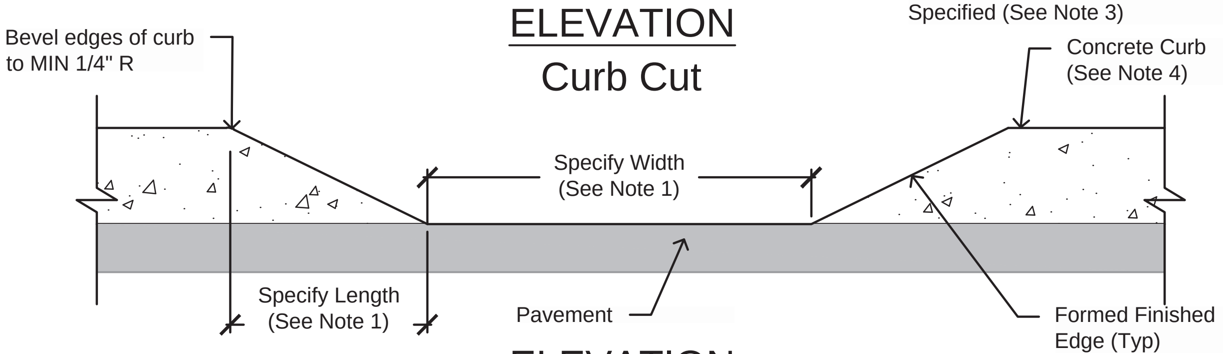
[8] iSWM Technical Manual. April 2010, revised September 2014. Site Development Controls.

### DM-DC DRAWING RESOURCES

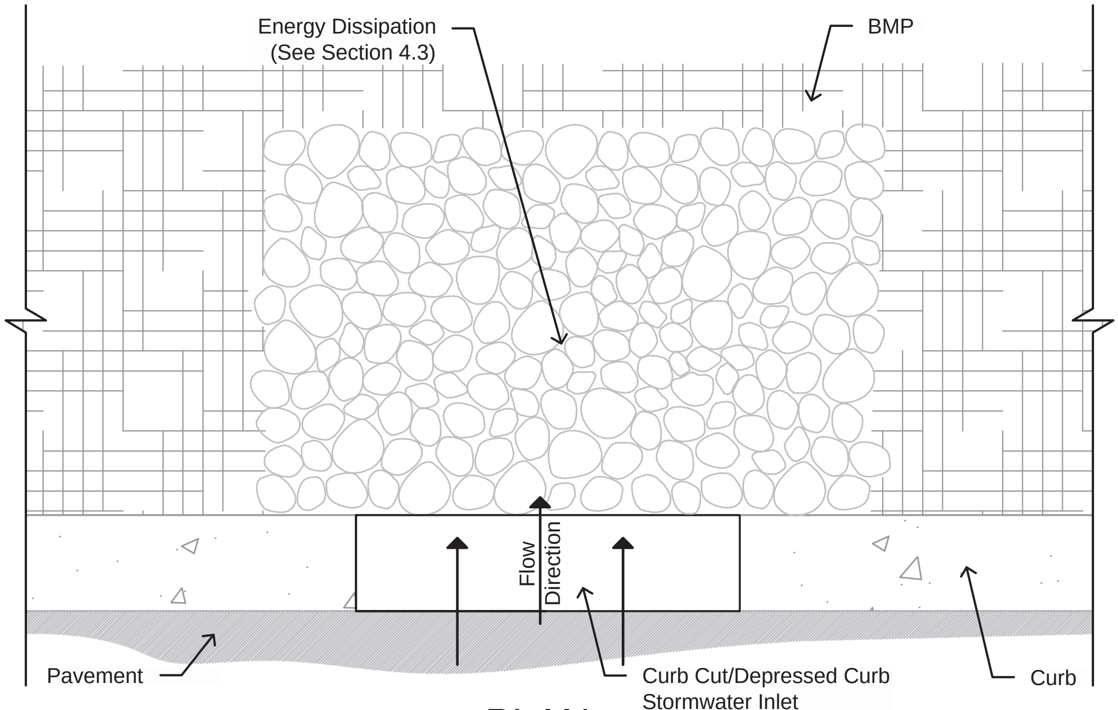
- City of Fort Worth. December 20, 2012. Standard Construction Specification Documents. Section 02 41 15 Utility Removal/Abandonment.
- City of Fort Worth. December 20, 2012. Standard Construction Specification Documents. Section 32 13 13 Concrete Paving.
- City of Fort Worth. December 12, 2016. Standard Construction Specification Documents. Section 33 05 10 Utility Trench Excavation, Embedment and Backfill.
- City of Fort Worth. July 1, 2011. Standard Construction Specification Documents. Section 33 46 02 Trench Drains.
- Texas Department of Licensing and Regulation. March 15, 2012. 2012 Texas Accessibility Standards.




## ELEVATION
Curb Cut




## ELEVATION
Depressed Curb




## PLAN

Notes

1. A curb cut is a cut in an existing curb, and a depressed curb is a curb poured in-place with a tapered opening. Width and angle of curb cut or taper varies based on site and stormwater capture requirements. If existing curb is damaged beyond extents specified for cut, curb shall be replaced to the nearest joint.

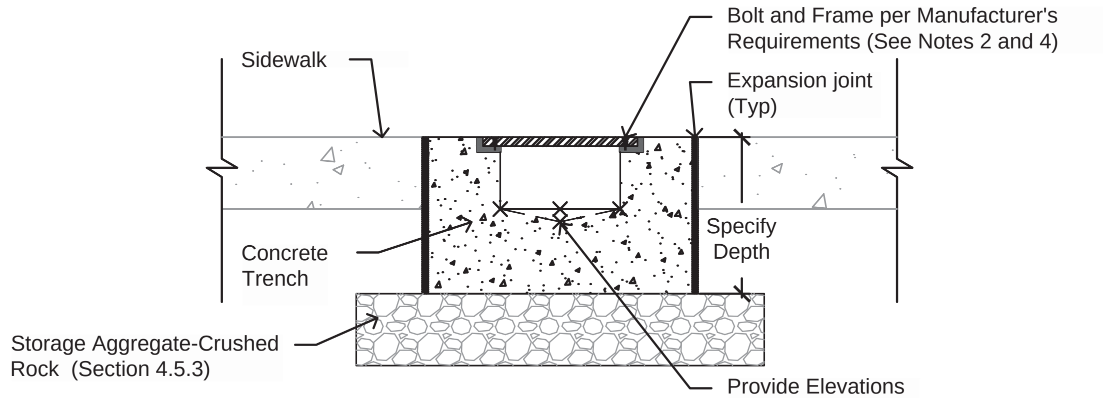
2. Curb cuts must be saw-cut such that all edges are square and edges beveled to a min $\frac{1}{4}$" radius. Saw-cut per City of Fort Worth STD Specification 02 41 15.

3. Horizontal surface must have positive slope toward BMP installation.

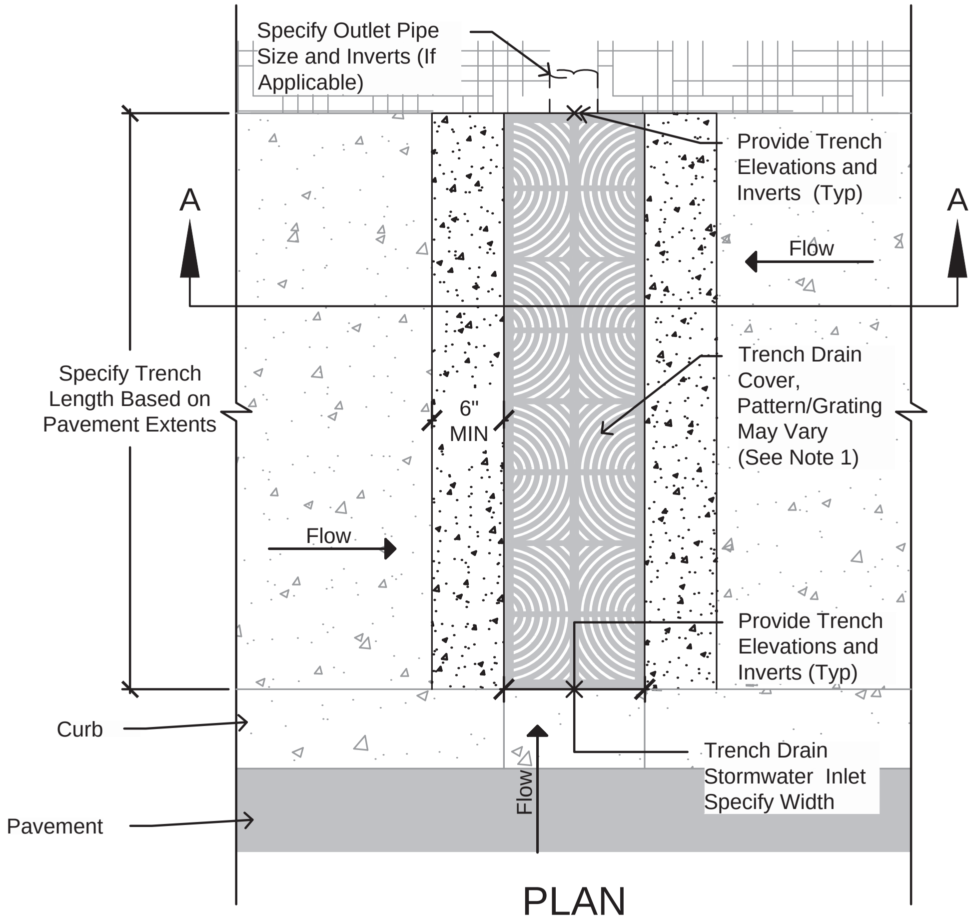
4. Concrete curb materials shall conform to City of Fort Worth STD Specification 32 13 13. All exposed surfaces shall have a broom finish.

5. Depressed curb shall transition to typical curb section per City of Fort Worth STD DWG D534.

| trwd Tarrant Regional Water District | TARRANT REGIONAL WATER DISTRICT | REVISED: JANUARY 2018 |
|---|---|---|
| | **Curb Cut / Depressed Curb** | **DM-DC 4.1.1** |



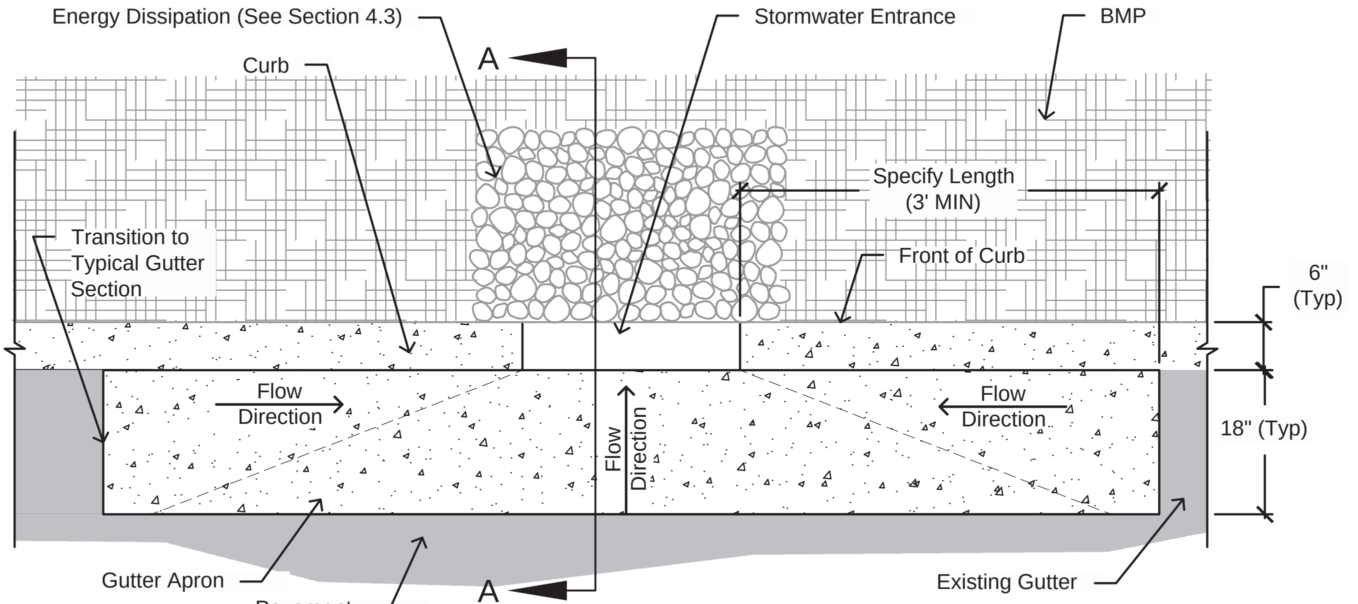

## SECTION A-A



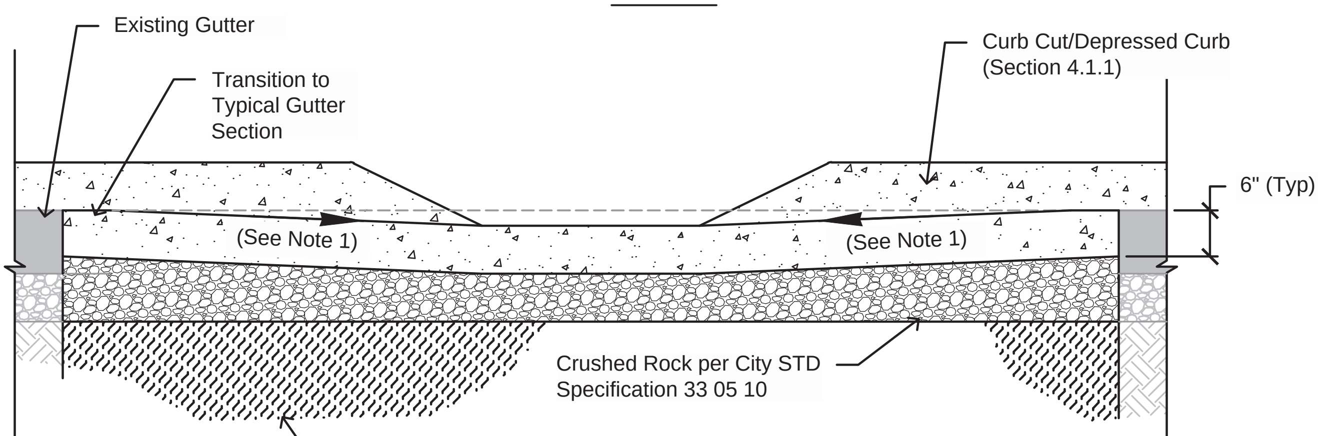

## PLAN

Notes

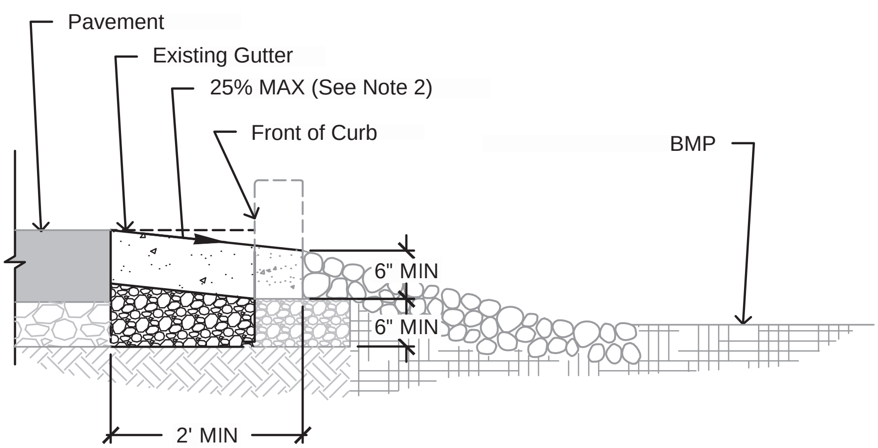
1. Grated located in walking surface shall have openings no greater than 1/2" in one direction, and elongated openings shall be placed so that the long dimension is perpendicular to the dominant direction of travel per Texas Accessibility Standards.
2. If trench drain assembly includes metal frame and channel, install per manufacturer instructions.
3. Cross slope and longitudinal slope of trench channel bottom may vary by design.
4. Bolt down grate and frame is required. All bolts shall be flush with existing grade of the paved surface.
5. Trench drain materials, installation, and other considerations shall comply with City of Fort Worth STD Specification 33 46 02 including compliance with AASHTO HS-20 loading.




PLAN




ELEVATION




SECTION A-A

## Notes

1. Max Slope of apron parallel to the curb is 16.67% per City of Fort Worth STD DWG D405.

2. Max Slope of gutter apron cross slope is 25% per City of Fort Worth STD DWG D405. Slopes will be governed by stormwater capture requirements and entrance velocities.

3. Concrete shall conform to City of Fort Worth STD Specification 32 13 13.

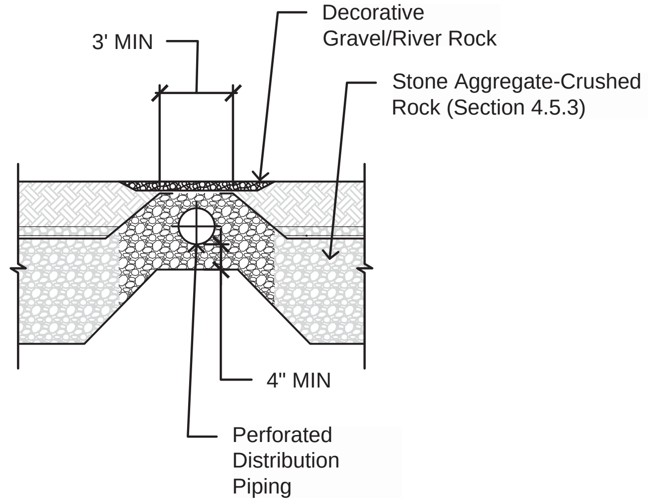
trwd Tarrant Regional Water District

TARRANT REGIONAL WATER DISTRICT

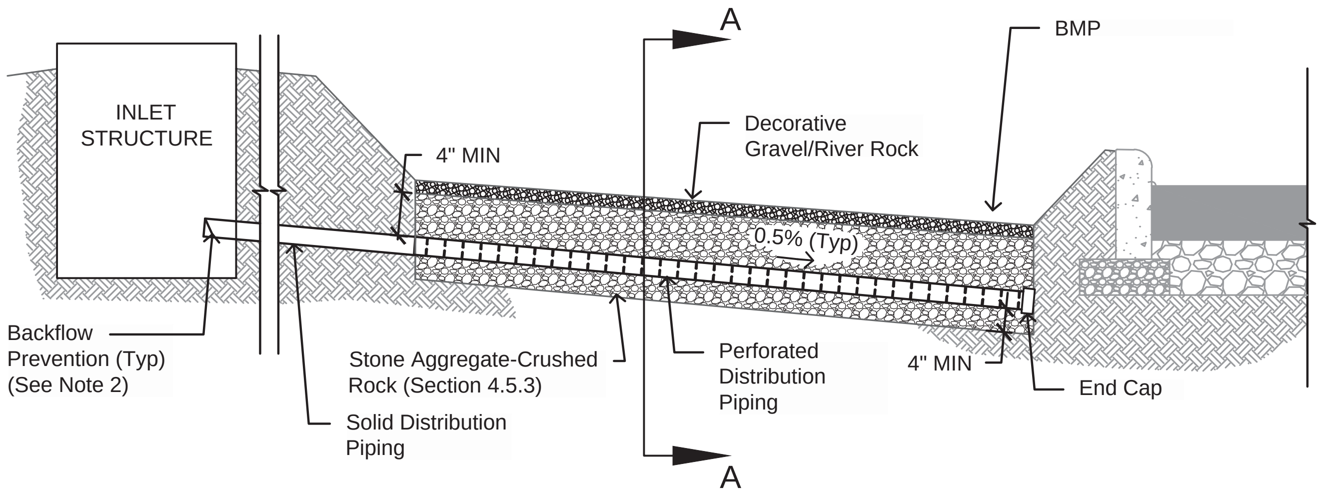
**Gutter Apron**

REVISED: FEBRUARY 2018

**DM-DC 4.1.3**




## SECTION A-A




## PROFILE

Notes

1. Acceptable pipe materials shall be in accordance with City of Fort Worth STD Specification 33 46 00.

2. Distribution piping shall include a backflow prevention device such as a check valve, a flap gate, or other appropriate measure to prevent the flow of ponded water back into the inlet structure.

## 4.2 PRE-TREATMENT/POST-TREATMENT

### DESCRIPTION

Pre-treatment/post-treatment is a component of the BMP practice which provides additional treatment of stormwater. Pre-treatment of stormwater is intended to enhance the long-term performance of BMPs and reduce routine maintenance events for BMPs by removing floatable matter (i.e., trash, leaves, debris, etc.), settling particles, capturing hydrocarbons, and providing for bacteria load reduction. Post-treatment of stormwater may reduce discharge velocities of stormwater and encourage additional settling and infiltration. Pre-treatment components include vegetated filter strip, floatable separators, grass swale, hydrodynamic separator, and gravity (oil-grit) separator. Post-treatment components include a grass swale or micropool. A grass swale may be used for either pre-treatment or post-treatment depending on stormwater being conveyed to or away from a BMP. This manual does not discuss nonstructural pre-treatment practices, such as litter and animal waste control that would reduce and/or prevent the stormwater runoff from collecting these pollutants.

### WHERE TO USE

Both pre-treatment and post-treatment components are located in urbanized areas to assist with stormwater quality control. Pre-treatment components are typically placed at or upstream of a BMP inlet and can be located beneath the ground surface to maximize land use. Pre-treatment components are important to BMPs that function as infiltration and filtration BMPs because pre-treatment removes floatable material, sediment, and oil products that may otherwise clog a BMP. As discussed Section 2, runoff from rooftops and parking lots will require pre-treatment prior to conveyance to approved BMPs. Post-treatment components are typically placed at the outlet of a BMP for stormwater treatment prior to the stormwater being conveyed to a receiving water body. Post-treatment components may be applied to any type of BMP.

### DESIGN CONSIDERATIONS

- Floatable separators, hydrodynamic separators, and gravity (oil grit) separators may be placed below ground to maximize land use.
- Underdrains (Section 4.9.1) shall be installed for vegetated filter strips, sediment forebays, and grass swales as necessary to prevent ponding water for prolonged periods of time. Underdrains shall be shown on the project's design drawings.
- Consider placement of pre-treatment and post-treatment components in locations where maintenance can be easily conducted.

## DETAILS

### 4.2.1 VEGETATED FILTER STRIP

Photo credit: Cleanwater Nashville[1]

A vegetated filter strip is a narrow section of grass that is typically placed along impervious areas such as parking lots and streets to capture stormwater for velocity dissipation and initial filtration of sediment prior to stormwater entering a BMP. Vegetated filter strips may be placed along streets between the back of the curb and the BMP or may be placed along a street with no curb to capture stormwater from streets or parking lots. A vegetated filter strip treats stormwater effectively for small impervious areas that maintain sheet flows in order to remove sediment across the reach of the vegetated filter strip. By removing sediment prior to a BMP, the BMP may perform more efficiently and effectively between maintenance periods. See detail DM-DC 4.2.1 for additional design information for vegetated filter strips. For design and maintenance criteria, see Section 3.7.

### 4.2.2 SEDIMENT FOREBAY

A sediment forebay is typically used for pre-treatment and consists of an isolated basin that allows stormwater runoff to settle sediments. By removing sediment prior to stormwater entering a BMP, the BMP may perform more efficiently and effectively between maintenance periods. To ensure maintenance will be easily performed, place sediment forebay in easily accessible locations.

Photo credit: CDM Smith

- Sizing requirements for specific BMP sediment forebays are discussed accordingly in Section 3.
- Hardscape materials, such as riprap, concrete, articulating concrete block mat products such as Flexamat® or approved comparable product are acceptable. The product chosen should be reviewed by a licensed PE. The product shall line the bottom of the basin to allow for easier removal of sediment and to protect against scour and erosion.

### 4.2.3 FLOATABLE SEPARATORS

A floatable separator is typically a proprietary technology that consist of screens to separate out coarse trash and debris from incoming stormwater prior to stormwater entering the BMP. Floatable separators remove the majority of trash and debris within the inlet chamber, which limits the amount of floatable material entering a downstream BMP. This may improve the function of the BMP by preventing buildup of trash and clogging from debris in downstream BMPs.

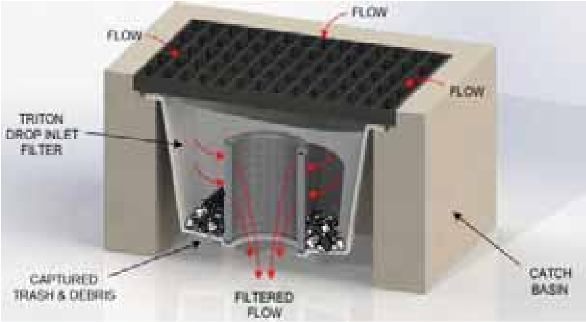



***Photo credit: REM Triton Filters Website[2]***

### 4.2.4 HYDRODYNAMIC SEPARATOR

A hydrodynamic separator is usually a proprietary technology that is installed underground as a flow through structure which uses the energy of the flowing water to physically remove suspended sediments, floatables, and oils from stormwater prior to stormwater entering a BMP. Hydrodynamic separators are typically placed underground in order to maximize useable land space above ground and may be designed to handle multiple stormwater inlets. A typical hydrodynamic separator uses cyclonic separation and/or indirect filtration in order to settle sediments and separate floatables and oils from stormwater runoff.

***Photo credit: Humes Website[3]***

### 4.2.5 GRAVITY (OIL GRIT) SEPARATOR

A gravity (oil grit) separator is typically a proprietary technology that removes sediments, floatables, and oils from stormwater through gravitational settling and trapping prior to stormwater entering a BMP. A gravity separator typically consists of multiple separation/storage chambers to allow for suspended solids to settle, floatables to be trapped, and oil and grease to be stored in a secondary chamber until removal during maintenance. Since re-suspension of settled sediments is possible during peak flows, gravity separators are typically installed off-line to limit excess flows from entering the device.

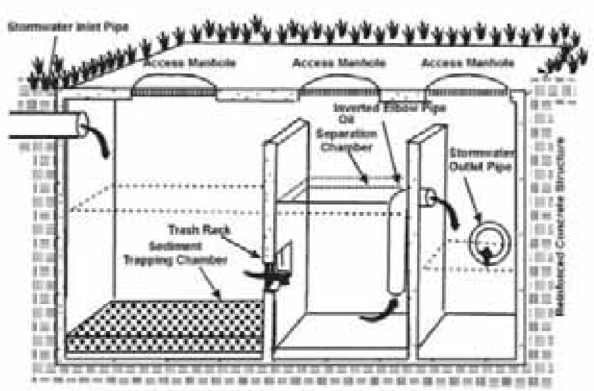



***Photo credit: Georgia Stormwater Management Manual[4]***

### 4.2.6 GRASS SWALE

Grass swales are shallow, vegetated open channels that are graded to reduce the velocity of stormwater conveyance to allow treatment through filtration and potentially infiltration while stormwater is conveyed to or away from a BMP. Check dams maybe utilized to slow the flow of stormwater and encourage temporary ponding which will promote capture of sediments. A grass swale may be used as a pre-treatment or post-treatment component to a BMP. Stormwater conveyed from a grass swale to a BMP is considered as pre-treatment, and stormwater discharging from a BMP into a grass swale is considered post-treatment. For design and maintenance criteria, see Section 3.7.

*Photo credit: Chesapeake Stormwater Network*[5]

### 4.2.7 MICROPOOL

Micropools are smaller permanent pools typically placed at the outlet of a BMP to control re-suspension of solids and floatable materials. A micropool is typically used as a post-treatment component to an extended detention basin in order to provide additional treatment prior to the stormwater being discharged.

*Photo credit: Urban Drainage and Flood Control*[6]

## DESIGN SUBMITTAL REQUIREMENTS CHECKLIST

Design submittal requirements checklist may be applicable to all or some of the pre-treatment/post-treatment components:

- Plan and detail views of pre-treatment/post-treatment components including inlet and outlet invert elevations, pipe diameters, manhole or inlet RIM elevation, and dimensions of components, as applicable.
- Calculation summary sheet for average and/or peak flows through and/or exiting the pre-treatment/post-treatment components.
- Pre-treatment/post-treatment capacity calculation summary sheet including storage volume of floatables, sediment, and oil, as applicable.
- Specify pollutant removal efficiencies.

- Specify relevant manufacturer information including product number, materials, painting specifications, and fastener and frame details, and installation requirements as applicable.
- Pre-treatment/post-treatment component designs and specifications outside the parameters of this guideline shall be reviewed and approved by a licensed PE and submitted to TRWD.

## ADDITIONAL RESOURCES

[1] Cleanwater Nashville: Overflow Abatement Program. Green Infrastructure. Accessed: March 23, 2018. Web address: http://www.cleanwaternashville.org/_about-green-infrastructure

[2] REM Filters. Accessed: August 14, 2017. Web address: http://remfilters.com/drop-inlet-filters/

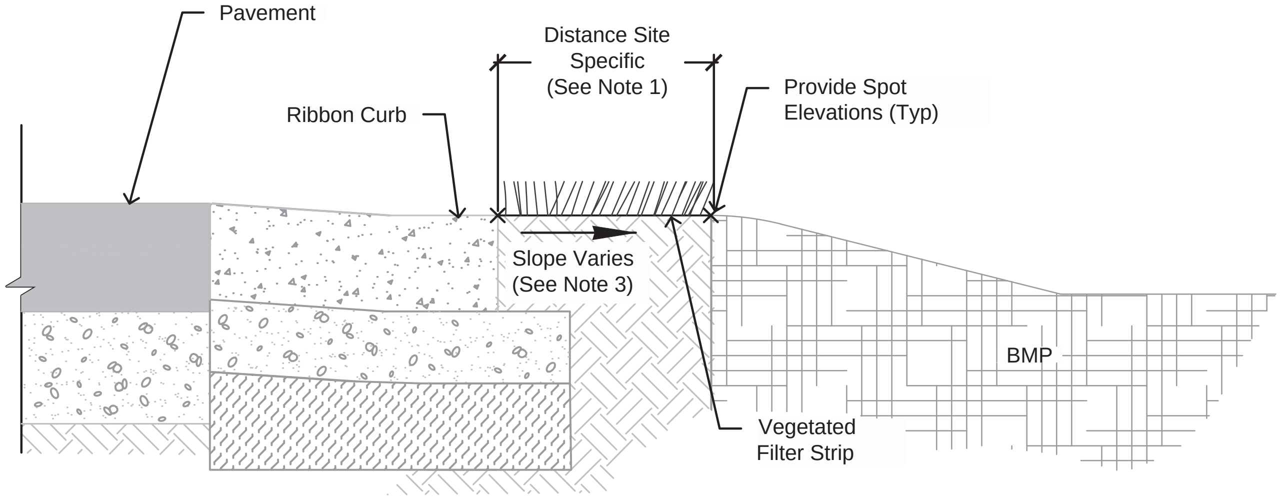
[3] Humes. Stormwater Solutions. Accessed: August 11, 2017. Web address: http://www.humes.com.au/precast-concrete-solutions/stormwater-solutions/stormwater-treatment/secondary.html

[4] Werntz, G. Georgia Stormwater management Manual Post Construction Water Quality BMP Overview. Accessed: August 14, 2017. Web address: https://www.slideshare.net/gwerntz24/post-construction-water-quality-bmps

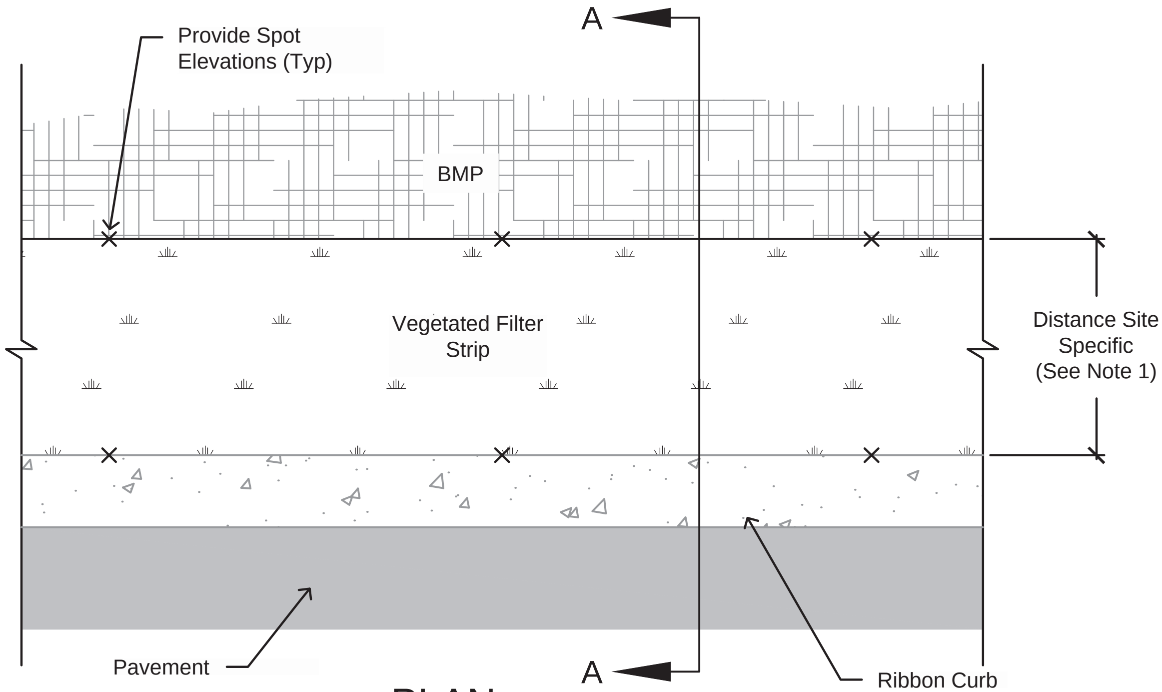
[5] Chesapeake Stormwater Network. Accessed: August 15, 2017. Web address: http://chesapeakestormwater.net/events/webcast-advanced-stormwater-design-grass-swales-and-channels/

[6] Extended Detention Basin at Grant Ranch. Urban Drainage and Flood Control District. Accessed January 29, 2018. Web address: http://udfcd.org/extended-detention-basin/

[7] iSWM Technical Manual. April 2010, revised September 2014. Site Development Controls.




## SECTION A-A




## PLAN

Notes

1. For optimal filtration performance, a vegetated filter strip shall have a minimum length of 15-feet in the direction of the flow unless site constraints prevent meeting this requirement.
2. The longitudinal (direction of flow) slope of a filter strip should be no less than 2% and no greater than 6%. The transverse slope should be no more than 2% and preferably 1%.
3. Filter strip shall be parallel to the adjacent pavement grade.

## 4.3 ENERGY DISSIPATION

### DESCRIPTION

Energy dissipation is a component to reduce the velocity of stormwater entering a BMP to minimize erosion and potential damage caused by the incoming stormwater. Energy dissipation typically consists of either a splash pad or a sump condition at the entrance of a BMP to slow the flow of the stormwater entering the facility. Splash pads are comprised of aggregate material that may be loose or embedded in concrete for greater stability and ease of maintenance.

*Photo credit: NRCS – Illinois*[1]

### WHERE TO USE

Energy dissipation shall be included when concentrated stormwater flows are entering a BMP and may cause erosion of BMP media. Energy dissipation may also be used around the perimeter of BMPs accepting sheet flow, acting as a level spreader to trap sediment and better distribute stormwater inflow. This is applicable in BMPs with surface layers containing sand, soil, mulch, vegetation, or other materials with the potential for erosion.

### DESIGN CONSIDERATIONS

- **Table 4.2** shows the allowable channel velocities for surface materials per iSWM Technical Manual[2]. If the entrance velocity of the stormwater exceeds the permissible velocity, energy dissipation is required to prevent erosion.

**Table 4.2 Maximum Permissible Entrance Velocities for Typical BMP Surface Materials**

| *Typical BMP Surface Material* | *Maximum Permissible Channel Velocity (ft/s)* |
|---|---|
| ***Bermuda Grass – Clay*** | 6 |
| ***Bermuda Grass – Sandy and Silty Soils*** | 5 |
| ***Sandy Soils*** | 2.5 |
| ***Silts*** | 1.5 |
| ***Sandy Silts*** | 3.0 |
| ***Clays*** | 5.0 |
| ***Coarse Gravels*** | 6.0 |
| ***Shale*** | 10.0 |
| ***Rock*** | 15.0 |

- Include concrete energy dissipation devices in situations where the entrance velocity exceeds 6.0 ft/s.

- Widths and lengths of energy dissipation will vary based on type and size of inlet used and velocity of stormwater entering the BMP. Designer shall provide entrance velocity calculations based on the inlet condition.
- Decorative gravel, river rock, or cobble should be considered when using hardscape materials to provide a more aesthetically pleasing energy dissipation component.
- Accessibility and ease of maintenance energy dissipaters must be considered during design to prevent coarse sediment and other debris from clogging inlets to the BMP.
- The size and weight of individual components shall be sufficient to resist movement due to water entrance velocities.

## DETAILS

### 4.3.1 SPLASH PAD

A splash pad consists of hardscape material, such as aggregate or brick, which may be embedded in concrete for increased stability and ease of maintenance. See detail DM-DC 4.3.1 for additional design information for concrete embedded splash pads.

*Photo credit: SvR Design[3]*

### 4.3.2 SUMP

Sumps are shallow depressions placed directly behind the inlet opening that dissipate energy by allowing stormwater to pond and slowly drain into the BMP through openings in the sump structure. See detail DM-DC 4.3.2 for additional design information for sumps.

*Photo credit: CDM Smith; designed by AECOM[4]*

## DESIGN SUBMITTAL REQUIREMENTS CHECKLIST

- Design calculations for entrance flow and velocity of stormwater entering the BMP
- Plan view and typical detail of splash pad, including placement northing/easting locations, length, width, materials, and cross section

Splash pad designs and specifications outside the parameters of this guideline shall be reviewed and approved by a Professional Engineer and submitted for review and approval to the TRWD.

## ADDITIONAL RESOURCES

[1] Natural Resources Conservation Service - Illinois. Accessed: August 29, 2017. Web address: http://infohouse.p2ric.org/ref/02/01524/urbst910.htm

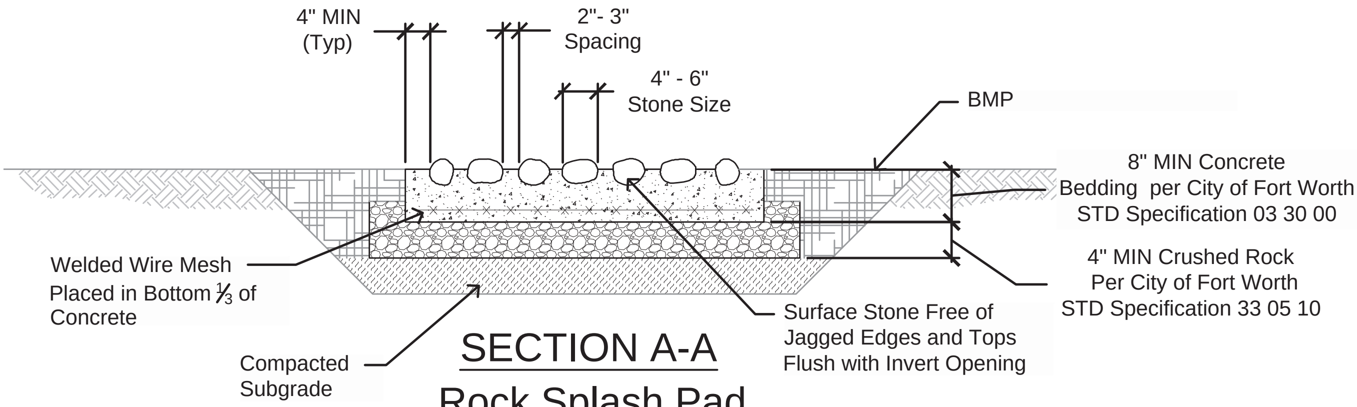
[2] iSWM Technical Manual. April 2010, revised September 2014. Hydraulics.

[3] SvR Design. Washington. Accessed January 2018. Web address: http://www.svrdesign.com/streets-mobility/

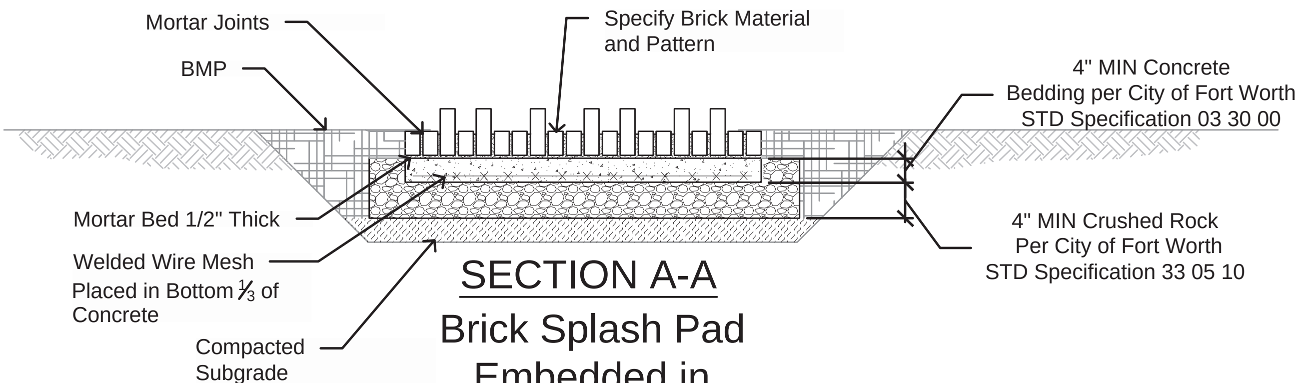
[4] Curb cut and sump. Designed by David Dods-AECOM. Photo credit to CDM Smith.

### DM-DC DRAWING RESOURCES

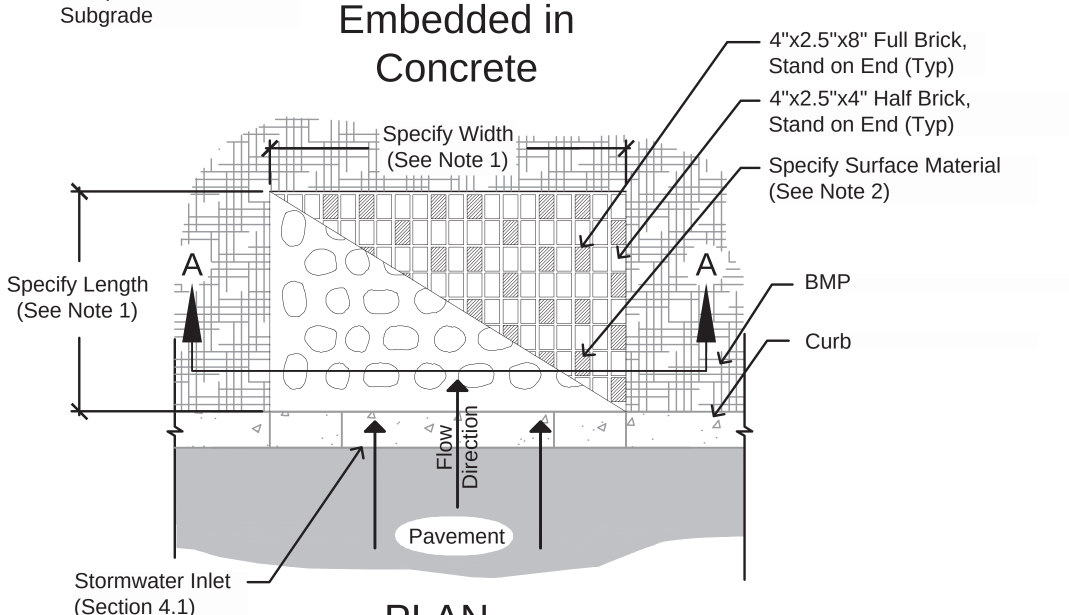
- City of Fort Worth. December 20, 2012. Standard Construction Specification Documents. Section 03 30 00 Cast-in-Place Concrete.
- City of Fort Worth. December 12, 2016. Standard Construction Specification Documents. Section 33 05 10 Utility Trench Excavation, Embedment and Backfill.




## SECTION A-A
## Rock Splash Pad Embedded in Concrete




## SECTION A-A
## Brick Splash Pad Embedded in Concrete




## PLAN

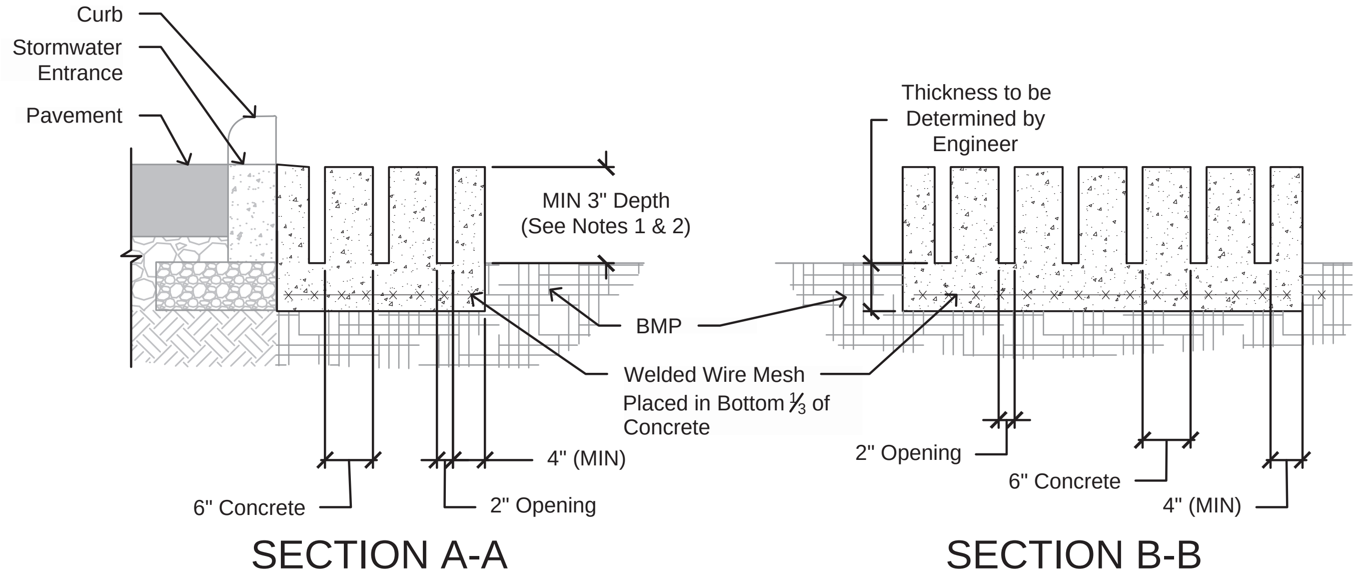
Notes

1. Dimensions of splash pad are dependent on inlet size and type, and the velocity of stormwater entering the BMP. Width of splash pad shall be greater than total stormwater entrance width and consider potential for erosion adjacent to splash pad.

2. Surface material shall be clean washed aggregate or clay bricks. Splash pad not embedded in concrete must use aggregate with a minimum 2" diameter surrounded with permanent edging, such as anchored angle iron or concrete, to prevent material from migrating into the BMP. Loose surface material shall require a permeable geotextile (Section 4.6.3) to separate the energy dissipation aggregate and underlying BMP media.

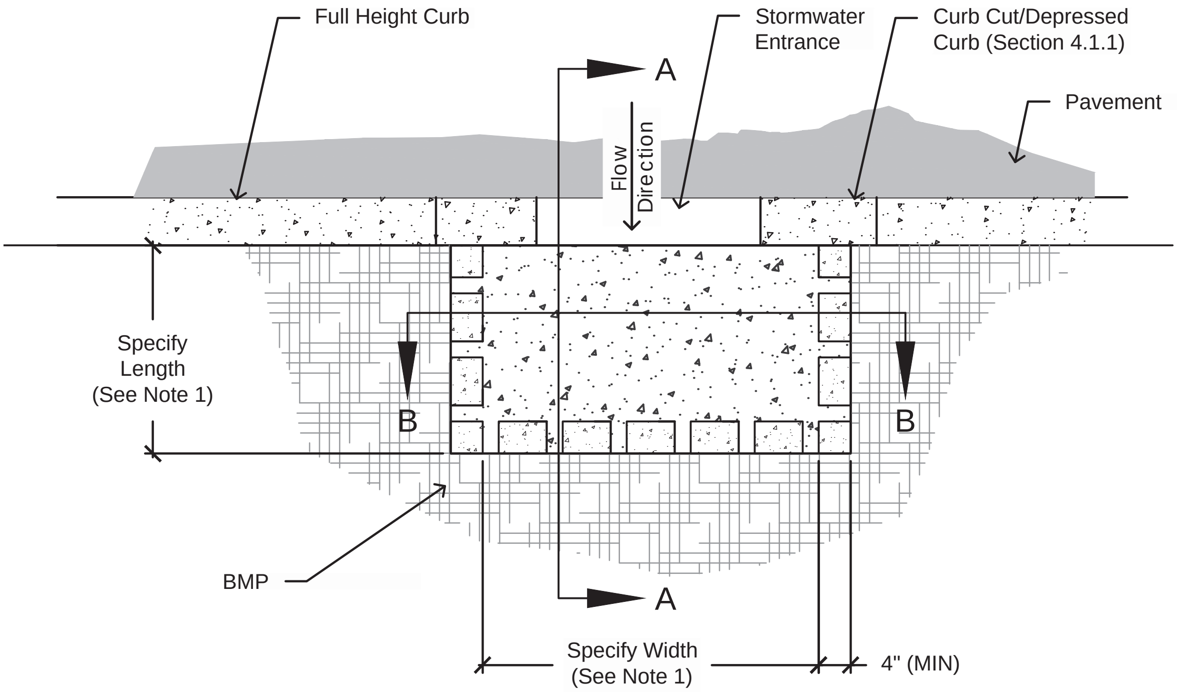
3. A minimum 3" of freeboard is required between the top of energy dissipation material and the inlet grade elevation to account for sediment accumulation.

| | | |
|---|---|---|
| trwd Tarrant Regional Water District | TARRANT REGIONAL WATER DISTRICT | REVISED: FEBRUARY 2018 |
| | **Splash Pad** | **DM-DC 4.3.1** |




SECTION A-A

SECTION B-B




PLAN

Notes

1. Dimensions of sump are dependent on inlet size and type, and the velocity of stormwater entering the BMP.
2. A minimum of 3" of freeboard is required between the top of energy dissipation sump and inlet to account for sediment accumulation.
3. Steel reinforcement shall be determined by the engineer.

TARRANT REGIONAL WATER DISTRICT

**Energy Dissipation Sump**

REVISED: FEBRUARY 2018

**DM-DC 4.3.2**

## 4.4 AREA PROTECTION

### DESCRIPTION

Area protection is a component used to provide a physical barrier between the BMP and adjacent pedestrian, bicycle, and/or vehicle travel areas. Barriers protect both the BMP and pedestrians by providing a visible delineation to prevent pedestrian and/or vehicular traffic from entering the BMP. The area protection may expand the entire perimeter of the BMP to separate the facility from the surrounding features or may be a vertical demarcation to provide visual awareness of the practice. Acceptable types of area protection include curbing and bollards.

### WHERE TO USE

The design engineer should consider area protection for safety of pedestrians and motorists. Area protection is suggested when the BMP is directly adjacent to pedestrian and/or vehicular traffic areas where no other horizontal buffer or physical demarcation exists. If the BMP side slopes are steeper than 4:1, or if a 6 inch or greater drop from the adjacent grade to the top of the BMP exists, then area protection is suggested.

### DESIGN CONSIDERATIONS

- Area protection should be designed in compliance with City of Fort Worth and other local requirements.
- When BMP is applied adjacent to on-street parking zones, a minimum of 2-feet of clearance between the edge of pavement and the area protection or edge of the BMP should be incorporated for vehicular door opening. If the area protection exceeds 12-inches in height, a 3-foot minimum buffer should be incorporated.
- When area protection is applied within pedestrian areas, a sidewalk clear zone minimum width of 3-feet must be maintained per Section 403 of Texas Accessibility Standards[1].
- Area protection greater than 24-inch in height applied at intersections must not obstruct the minimum sight triangles per Public Work's Traffic Engineering Design Standards and Policy Guidelines[2].

## DETAILS

### 4.4.1 CURB

Curbing used for BMP area protection is a concrete barrier along the outside edge or edges of the BMP similar to that used for standard roadway construction. Ribbon curb may also be used to protect the asphalt edge, separate paving materials, or delineate the edge of the BMP for maintenance purposes when combined with a bollard (Section 4.4.2) to provide a vertical barrier. Below are photographs of examples of curbing that have been used for BMPs in other parts of the country. See detail DM-DC 4.4.1 for additional design information.

*Photo Credit: CDM Smith, designed by AECOM*[3]

*Photo Credit: CDM Smith*

### 4.4.2 BOLLARDS

Bollards used for area protection are a fixed vertical post placed at specified intervals around the BMP to provide visual barriers and vertical demarcation for traffic and pedestrians. Bollards are encouraged for BMP bumpout applications to provide a vertical warning easily visible to drivers. Below are photographs of examples of bollards that have been used for BMPs in other parts of the country. See detail DM-DC 4.4.2 for additional design information.

*Photo Credit: BEGA©*[4]

*Photo Credit: CDM Smith, designed by AECOM*[5]

## DESIGN SUBMITTAL REQUIREMENTS CHECKLIST

- Plan view of area protection alignment, including northing/easting and elevation points, total length and/or spacing, radii (if applicable), and offset dimensions from existing pavement and proposed BMP
- Cross-sectional view of the area protection, including bedding or anchoring/embedment material and dimensions as well as offset dimension from BMP such as side slope and/or depth from adjacent grade
- Manufacturer details, including materials or painting specifications (optional)

Area protection designs and specifications outside the parameters of this guideline shall be reviewed and approved by a licensed PE and submitted to TRWD.

## ADDITIONAL RESOURCES


[1] Texas Department of Licensing and Regulation. March 15, 2012. 2012 Texas Accessibility Standards.

[2] Department of Transportation and Public Works City of Fort Worth, Texas. July 1987. Traffic Engineering Design Standards and Policy Guidelines.

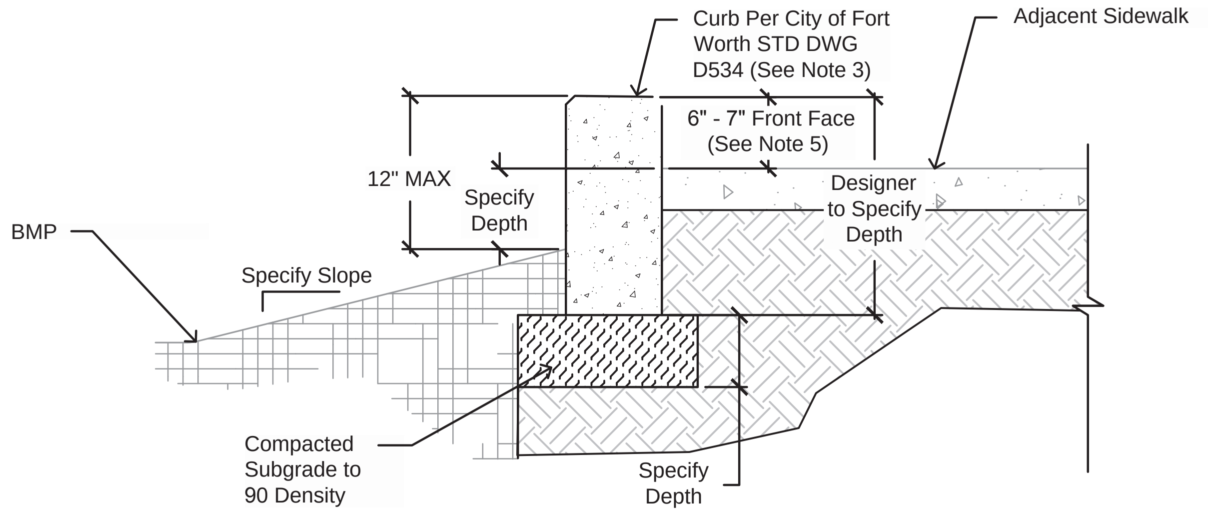
[3] Curb-Area Protection. Designed by David Dods-AECOM. Photo credit to CDM Smith.

[4] BEGA©. Accessed: August 29, 2017. Web address: https://www.bega.de/en/products/led-garden-and-pathway-luminaires-for-the-private-sector-77237/.

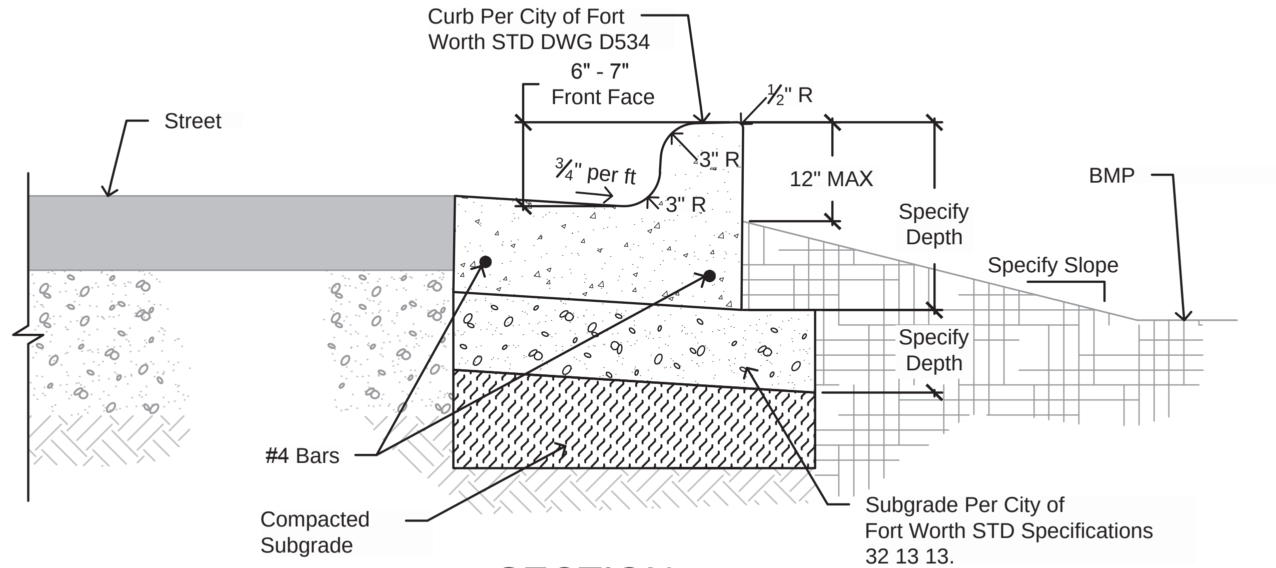
[5] Bollard-Area Protection. Designed by David Dods-AECOM. Photo credit to CDM Smith.


### DM-DC DRAWING RESOURCES


- Texas Department of Transportation. October 2014. Roadway Design Manual.
- City of Fort Worth. August 31, 2012. Standard Construction Drawings. *Detail D534 – Standard Curb & Gutter*.
- City of Fort Worth. August 31, 2012. Standard Construction Drawings. *Detail D546 – Sidewalk Details*.
- City of Fort Worth. December 20, 2012. Standard Construction Specification Documents. *Section 32 13 13 Concrete Paving.*




SECTION
Straight Curb




SECTION
Curb & Gutter

Notes

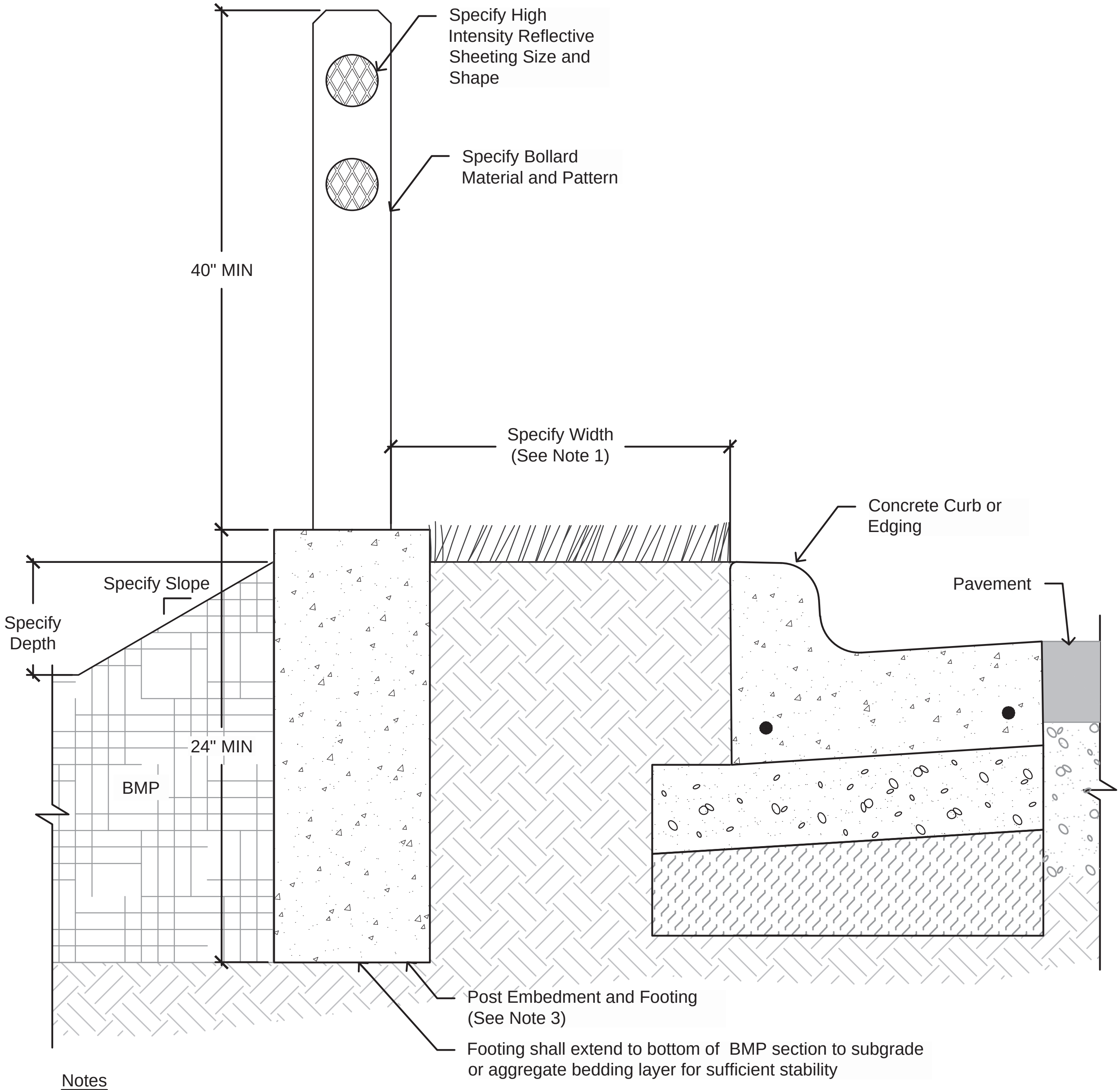
1. Curbing shall conform to City of Fort Worth STD DWG D534 - Standard Curb and Gutter.

2. Combination curb and gutter is preferred for curbing on existing curb and gutter street sections. Straight back curb per may be used where curb is proposed for existing non-curb and gutter street sections, permeable pavement applications, and for sidewalk butting the BMP.

3. Curb heights exceeding 7" on the front face shall be considered a curb with retaining wall and shall conform to City of Fort Worth STD DWG D534.

4. Concrete curb materials shall conform to City of Fort Worth STD Specification 32 13 13. All exposed surfaces shall have a brushed finish.

5. Ribbon curb may be used to facilitate overland sheet flow to BMP where applicable. Ribbon curb shall have the same design as the standard curb, with the exception that the top of curb elevation shall be flush with the surrounding grade.




Notes

1. When BMP is applied adjacent to on street parking zones, a minimum 2' clearance for vehicular door openings will be required between the back of curb or edge of pavement and the edge of the BMP. Bollards applied at intersections must not obstruct the minimum sight triangles per City of Fort Worth Public Work's Traffic Engineering Design Standards and Policy Guidelines.

2. Bollard design shall conform to manufacturer specifications and requirements. Product manufacturer or equal shall be specified on the detail.

3. Bollard post embedment shall be site specific. Footing may be embedded directly in BMP planting media or within adjacent sidewalk area. Bollards that require embedment for additional or traffic rated stability shall be designed by an engineer licensed in the State of Texas.

4. Bollards located within sidewalk area shall maintain a minimum 3' clear zone in the pedestrian pathway per ADA requirements. See City of Fort Worth STD DWG D546 for minimum sidewalk widths.

5. For Bollards located in BMPs without curb, local DOT standards shall be used to determine placement of bollard.

| trwd Tarrant Regional Water District | TARRANT REGIONAL WATER DISTRICT | REVISED: FEBRUARY 2018 |
|---|---|---|
| | **Bollard** | **DM-DC 4.4.2** |

## 4.5 BMP MEDIA

### DESCRIPTION

BMP media provides two primary functions within a BMP practice: filtration and storage. Stormwater is captured by the BMP, temporarily stored in the BMP media layers, and either filtered and discharged through an underdrain or infiltrated into the surrounding native soil. BMP media typically consists of bioretention or engineered soil mixture, or sand that removes pollutants primarily through filtration. While the BMP media provides some storage capacity, aggregate with greater void space offers more available volume for stormwater storage.

*Photo credit: CDM Smith*

### WHERE TO USE

BMP media includes bioretention or engineered soil media, sand, and coarse aggregate used as the primary media within a BMP practice. Bioretention or engineered soil is used in bioretention or media filter basins. Sand is used in sand filters or sand filter basins. Aggregate can be used in a BMP practice where additional below grade storage is needed such as permeable pavements or below the bioretention soil media. Aggregate is also used for underdrain bedding, where applicable.

### DESIGN CONSIDERATIONS

- Bioretention or engineered soil media layer that will be planted with vegetation must maintain a minimum depth of 30-inches to allow for adequate root establishment.
- Storage volumes and depths will vary by BMP and site application. Designers shall provide storage capacity calculations based on the BMP media components used and the water quality volume calculations outlined in **Section 2** and BMP requirements discussed in **Section 3**.
- All BMP aggregate and sand media shall be clean, washed, and free of fines.

## DETAILS

### 4.5.1 BIORETENTION OR ENGINEERED SOIL

Photo credit: CDM Smith

Bioretention or engineered soil media is soil mix consisting of native soil or shale, sand, and compost that is typically classified as a sandy loam, loamy sand, or loam. Bioretention media must meet the following parameters:

- Media porosity assumption of 0.30.
- Bioretention soil media layer thickness shall be a minimum depth of 30-inches and is recommended not to exceed 48-inches.
- Pre- and post-construction permeability tests per ASTM D5093 or D6391 are required to verify installed soil meets a minimum permeability of 1.0 feet per day (0.5 inch per hour). It is recommended that additional post-construction permeability tests be performed 6 months following construction to determine if compaction or clogging has occurred during the initial months of operation.
- Bioretention soil media shall not include stones, stumps, roots, or other woody material over 1-inch in diameter.
- Bioretention component mix proportions are as follows:
    - Compost – 50 percent: Compost component of the bioretention mix shall be derived from plant material and the result of aerobic (biological) decomposition of organic matter. Compost shall not include food waste, stable waste, treated lumber, pallets, pine bark, raw manure, or mushroom compost waste. Compost used must meet the parameters shown in **Table 4.3**.

**Table 4.3 Compost for Bioretention Soil Mix Testing Parameter Requirements**

| *Parameter* | *Value* | *Test Method* |
|---|---|---|
| ***pH range*** | 7.9–8.9 | ASTM D4972 |
| ***Maturity (Germination and Vigor)*** | ≥ 90% | TMECC 5.05-A |
| ***Solvita® Compost Maturity Index*** | ≥ 7 | Solvita® Compost Maturity Test or Approved Equal |
| ***Composting Time*** | 6–12 Months | n/a |
| ***Percent Passing ¾-inch sieve*** | ≥ 99% | ASTM C33 |
| ***Percent Passing ½-inch sieve*** | 97% | ASTM C33 |

- Expanded Shale, Washed Sand, or Native Soil (if acceptable) – 25 percent
  - *Expanded Shale component of the bioretention soil mix shall be 3/8-inch Expanded Shale (Horticulture Grade, G Pile) as manufactured by Trinity Lightweight or comparable material and must meet the gradation shown in* ***Table 4.4****.*

**Table 4.4 Expanded Shale Gradation Requirements**

| Sieve Size | Percent Passing |
|---|---|
| ½-inch (12.5 mm) | 100 |
| 3/8-inch (9.5 mm) | 90–100 |
| No. 4 (4.75 mm) | 40–90 |
| No. 8 (2.36 mm) | 0–20 |
| No. 16 (1.18 mm) | 0–10 |

  - *Native soil may be used in lieu of expanded shale component of the bioretention soil mix, if material is acceptable. Native soil must be free of weeds, deleterious materials, rocks, and debris with 100 percent passing through a ¾-inch sieve and less than 25 percent passing through a #200 sieve. This should be specified in the BMP plans and verified by construction inspectors.*
  - *Washed sand also may be used in lieu of the expanded shale component, making up a full 50 percent of the bioretention soil mix with approval from a licensed PE. Sand must meet comply with Section 4.5.2.*
- Washed Sand – 25 percent (see Section 4.5.2 for sand requirements)

- Bioretention soil media mix shall be tested and meet the parameters in **Table 4.5**.

**Table 4.5 Bioretention Soil Mix Testing Parameter Requirements**

| Parameter | Value | Test Method |
|---|---|---|
| pH range | 5.2 to 7.0 | ASTM D4972 |
| Organic matter | 1.5 to 4.0% | AASHTO T194 |
| Magnesium | 35 lbs/acre, minimum (0.0072 lbs/sq yd) | TMECC 4.05-Mg |
| Phosphorus (P2O5) | 75 lbs/acre, minimum (0.0154 lbs/sq yd) | TMECC 4.03-A |
| Potassium (K2O) | 85 lbs/acre, minimum (0.0175 lbs/sq yd) | TMECC 4.04-A |
| Soluble salts | 500 ppm | TMECC 4.10-A |
| Infiltration Rate | 0.25 inch/hour (minimum) | ASTM D3385 |

### 4.5.2 SAND


Photo credit: Storm-Tex Services[1]

Sand is used as the primary BMP media and typically used in sand filters.

Note that sand used as a media barrier (Section 4.6.1) is a thin layer of sand primarily used to filter sediment to prevent clogging in transitional layers and may be applicable in various types of BMP practices.

Sand media for sand filters must meet the following parameters:

- Media porosity minimum of 0.32.[2]
- Sand media thickness shall be between 12-inch and 24-inch.[2]
- Sand media must meet gradation requirements per TxDOT Fine Aggregate Grade No. 1.[2]
- Alternative sand media gradation per ASTM C-33, Standard Specification for Concrete Aggregates, is also acceptable.[3]

### 4.5.3 STORAGE AGGREGATE


Photo credit: CDM Smith

Aggregate storage materials include No. 3, 56, 57, and 67 stone. Use a No. 56, 57, or 67 size aggregate within the underdrain collection system layer or as the primary aggregate storage layer. A No. 3 size aggregate storage layer can be placed below the No. 56, 57, or 67 layer if additional storage capacity is required. Storage aggregate media must meet the following parameters:

- Void space in open graded No. 56, 57, or 67 and No. 3 aggregate ranges from 30 to 40 percent. This void space is available for water storage.

***Crushed Rock Storage Layer***

- Media porosity assumption of 0.40.
- Crushed rock shall be per City of Fort Worth Standard Specification 33 05 10 and all aggregate must be clean, washed, and free of fines.[4] If using recycled concrete as aggregate, the crushed recycled concrete will need to be approved for use as a storage layer within the BMP by a licensed PE due to potential oil or organics that may be in the existing concrete.
- Coarse-aggregate grading sizes No. 56, 57, or 67 or crushed rock per City of Fort Worth STD Specification 33 05 10 and ASTM D448, as shown in **Table 4.6**.

**Table 4.6 Crushed Rock Aggregate Gradation**

| Sieve Size | Percent Passing | | |
|---|---|---|---|
| | No. 56 | No. 57 | No. 67 |
| 1 ½-inch (37.55 mm) | 100 | 100 | - |
| 1-inch (25.0 mm) | 90–100 | 95–100 | 100 |
| ¾-inch (19.0 mm) | 40–85 | - | 90–100 |
| ½-inch (12.5 mm) | 10–40 | 26–60 | - |
| 3/8-inch (9.5 mm) | 0–15 | - | 20–55 |
| No. 4 (4.75 mm) | 0–5 | 0–10 | 0–10 |
| No. 8 (2.36 mm) | - | 0–5 | 0–5 |

### *No. 3 Storage Layer*

- Media porosity assumption of 0.40[4]
- Coarse-aggregate grading size No. 3 per ASTM D488 as shown in **Table 4.7**.

*Photo credit: CDM Smith*

**Table 4.7 No. 3 Aggregate Storage Gradation Requirements**

| Sieve Size | Percent Passing |
|---|---|
| 2 ½-inch (63 mm) | 100 |
| 2-inch (50 mm) | 90–100 |
| 1 ½-inch (37.55 mm) | 35–70 |
| 1-inch (25.0 mm) | 0–15 |
| ½-inch (12.5 mm) | 0–5 |

## DESIGN SUBMITTAL REQUIREMENTS CHECKLIST

- Plan view of BMP practice specifying extents of media with northing/easting points
- Section view of BMP practice specifying depth of all media layers used and material specifications of the BMP media
- BMP media storage capacity calculations and corresponding design water quality volume
- All BMP media specifications for BMP practice design
- Results of BMP media and soil testing

BMP media designs and specifications outside the parameters of this guideline shall be reviewed and approved by a licensed PE and submitted to TRWD.

## ADDITIONAL RESOURCES

[1] Storm-Tex Services. Sand Filter basins and Ponds. Accessed: August 29, 2017. Web address: http://www.storm-tex.com/sand-filter-basins-ponds/.

[2] North Central Texas Council of Governments. September 2014. iSWM™ Technical Manual. *Site Development Controls.*

[3] American Society for Testing and Materials International. February 2016. ASTM C33/C33M Standard Specification for Concrete Aggregates.

[4] City of Fort Worth. December 12, 2016. Standard Construction Specification Documents. *Section 33 05 10 Utility Trench Excavation, Embedment and Backfill.*

### TESTING STANDARDS RESOURCES

- Texas Department of Transportation. November 1, 2014. Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges. *Item 421 Hydraulic Cement Concrete*.
- StormTech. November 2012. Tech Sheet #1. *Porosity of Structural Backfill*.
- American Society for Testing and Materials International. 2012. ASTM D448 Standard Classification for Sizes of Aggregate for Road and Bridge Construction.
- American Society for Testing and Materials International. November 2013. ASTM D4972 Standard Test Method for pH of Soils.
- American Society for Testing and Materials International. 2015. ASTM D5093 Standard Test Method for Field Measurement of Infiltration Rate Using Double-Ring Infiltrometer with Sealed-Inner Ring.
- American Society for Testing and Materials International. 2011. ASTM D6193 Standard Test Method for Field Measurement of Hydraulic Conductivity Using Borehole Infiltration.

- American Society for Testing and Materials International. 2010. F1632 Standard Test Method for Particle Size Analysis and Sand Shape Grading of Golf Course Putting Green and Sports Field Rootzone Mixes.
- American Society of State Highway and Transportation Officials. 2013. AASHTO T 194 Determination of Organic Matter in Soils by Wet Combustion.
- USDA and US Composting Council. 2002. Test Methods for Examination of Composting and Compost. *TMECC 4.03-A Total Phosphorus.*
- USDA and US Composting Council. 2002. Test Methods for Examination of Composting and Compost. *TMECC 4.04-A Total Potassium.*
- USDA and US Composting Council. 2002. Test Methods for Examination of Composting and Compost. *TMECC 4.05-Mg Magnesium.*
- USDA and US Composting Council. 2002. Test Methods for Examination of Composting and Compost. *TMECC 4.10-A 1:5 Slurry pH.*
- USDA and US Composting Council. 2002. Test Methods for Examination of Composting and Compost. *TMECC 5.05-A Seedling Emergence and Relative Growth.*

## 4.6 MEDIA BARRIERS

### DESCRIPTION

A media barrier is a permeable or impermeable layer used to control or prevent the migration of soil, aggregate, and/or stormwater runoff within the subsurface or out of a BMP practice. Permeable media barriers include sand, pea gravel, and permeable geotextile, which control the movement of soil materials within the BMP while allowing stormwater to permeate. Impermeable media barriers include geomembrane sheets and clay liners, which prevent stormwater from migrating out of the BMP practice.


*Photo credit: CDM Smith*

### WHERE TO USE

Media barriers may be used in any BMP practice as transitional layers between differing BMP media and the surrounding soil in both horizontal and vertical applications. A permeable media barrier is typically placed between overlying soil or sand layers and aggregate storage layers to provide a transition between the media functions and surrounding underdrains to prevent clogging. Vertical separation may also be desired between BMP media and surrounding soil or subgrade to prevent mixing of the surrounding native soil with the BMP media.

An impermeable media barrier shall be installed wherever the infiltration into surrounding native soil is not desired or a potential exists for stormwater runoff to migrate away from the BMP practice toward a below grade feature that must be protected from contact with water such as an underground utility, building foundation, or street/parking lot subgrade (see Section 2 and respective utility's guidance regarding proximity of other utilities for reference). Impermeable barriers may also be appropriate when potential exists for water to migrate into contaminated soil or to prevent leakage when a permanent pool is installed.

### DESIGN CONSIDERATIONS

- All media barrier aggregate and sand shall be clean, washed, and free of fines.
- Impermeable barriers shall be geomembrane sheets, compacted clays, or other impermeable material as approved by a licensed PE. Impermeable barriers shall have a permeability of no more than 1 x $10^{-7}$ cm/s.
- An anti-seep collar (Section 4.9.6) should be considered where impermeable barriers are used for installation at the edge of the BMP facility for outlet piping that passes through non-BMP areas before connection to an outlet structure.

- It is preferred that all utilities be located outside of the BMP facility rather than using an anti-seep or impermeable barrier.

## DETAILS

### 4.6.1 SAND

Sand media barriers allow for filtering of smaller particles and pollutants to avoid clogging potential within the transitional layers within the subsurface of the BMP practice. Within the entire BMP practice, the sand is a thin layer and has applicability within various types of BMP practices. It should be noted that the sand material used for media barriers is the same material as the sand BMP media (Section 4.5.2) layer used in sand filters or sand filter basins. When used as a media barrier, sand functions as a thin filter layer rather than the primary BMP media.

- Sand media thickness shall be between 4 and 6 inches.[1]
- Sand media must meet gradation requirements per TxDOT[2] Fine Aggregate Grade No. 1.
- Alternative sand media gradation per ASTM C-33, Standard Specification for Concrete Aggregates, is also acceptable.[3]

### 4.6.2 PEA GRAVEL (NO. 7 OR 8)

Pea gravel is a coarse-aggregate comprised of No. 7 or 8 stone. Pea gravel allows for the settling of soil material and pollutants within the void spaces and acts as a level spreader for stormwater runoff flows in the subsurface of the BMP practice. Pea gravel may be used between transitional layers in the subsurface of the BMP or on the BMP surface to dissipate flow and separate surface storage areas of the BMP. Pea gravel must meet the following parameters:

- Pea gravel media thickness shall be between 2 and 6 inches.[1]
- Coarse-aggregate grading sizes No. 7 or 8 must meet the gradation requirements per ASTM D448 as shown in **Table 4.8.**

*Photo credit: CDM Smith*

**Table 4.8 No. 7 and No. 8 (Pea Gravel) Gradation Requirements**

| Sieve Size | Percent Passing | |
|---|---|---|
| | No. 7 | No. 8 |
| ¾-inch (19.0 mm) | 100 | - |
| ½-inch (12.5 mm) | 90–100 | 100 |
| 3/8-inch (9.5 mm) | 40–70 | 85–100 |
| No. 4 (4.75 mm) | 0–15 | 10–30 |
| No. 8 (2.36 mm) | 0–5 | 0–10 |
| No. 16 (1.18 mm) | - | 0–5 |

### 4.6.3 PERMEABLE GEOTEXTILE

Permeable geotextile is a fabric-based filter material, often referred to as geotextile filter fabric. Permeable geotextile must meet the following parameters:

Photo credit: CDM Smith

- Permeable geotextile is preferred only to be used in vertical or near-vertical applications. A horizontal application on the bottom of the BMP facility may be considered. Designer should consider the higher clogging potential when using the geotextile in a horizontal application.
- Permeable geotextile may be used to prevent native soil from migrating by lining the side slopes and bottom of the BMP. Geomembrane liner (Section 4.6.4) may be used if the intent is to prevent the migration of water from exiting the BMP (i.e., near buildings with basements or road sections)
- If permeable geotextile is applied horizontally between BMP media layers or on the bottom of the BMP facility, a permeable pea gravel or sand filter aggregate layer should be included over the geotextile.
- Permeable geotextile shall comply with City of Fort Worth STD Specification 33 05 10 – Utility Trench Excavation, Embedment and Backfill.[4] Material and ASTM requirements are dependent on soil classifications, as follows:
  - Soils classified as ML or OH per ASTM D2487, Mirafi FW402 or comparable shall be used.
  - Soils classified as other than ML or OH per ASTM D2487, Mirafi 140N or comparable shall be used.
- At a minimum, permeable geotextiles shall comply with iSWM Technical Manual[1], as shown in **Table 4.9**.

**Table 4.9 Permeable Geotextile Requirements**

| *Geotextile Property* | *Value* | *Test Method* |
|---|---|---|
| *Trapezoidal Tear* | 40 lbs | ASTM D4533 |
| *Permeability* | 0.2 cm/sec | ASTM D4491 |
| *AOS* | #60–#70 sieve size | ASTM D4751 |
| *Ultraviolent Resistance* | 70% or greater | ASTM D4355 |

### 4.6.4 GEOMEMBRANE LINER

Geomembrane, or impermeable liner, is a synthetic material with a very low permeability that acts as a barrier to prevent the migration of water into or out of the BMP. Geomembrane liners must meet the following parameters:

- The geomembrane material shall be free of holes, blisters, undispersed raw materials, or any sign of contamination by foreign matter.
- Geomembrane sheets shall at a minimum meet TxDOT Special Specification[2] values as shown in **Table 4.10**.

*Photo credit: CDM Smith*

**Table 4.10 Geomembrane Requirements**

| *Property* | *Value* | *Test Method* |
|---|---|---|
| *Nominal Thickness* | 30 mil (mm) | N/A |
| *Density* | 0.033 oz/cm$^3$ | ASTM D1505 |
| *Tensile Strength at Break* | 240 lbs/in-width | N/A |
| *Tensile Strength at Yield* | 140 lbs/in-width | N/A |
| *Elongation at Break* | 700% | N/A |
| *Elongation at Yield* | 13% | N/A |
| *Tear Resistance Initiation* | 45.0 lbs | ASTM D1004 |
| *Puncture Resistance* | 80 lbs | FTMS 101c Method 2065 |
| *Carbon Black Content* | 2–3% | N/A |

- Geomembrane adjacent strips shall overlap by a maximum of 4 inches for an extrusion weld prior to the welding or a maximum overlap of 5 inches for a hot wedge weld prior to welding per TxDOT Special Specification[2].
- If adjacent strips of the geomembrane are not to be welded, then the adjacent strips need to be bound as specified by the manufacturer and approved by a licensed PE.

### 4.6.5 CLAY LINER

A clay liner is comprised of compacted clays with a very low permeability that act as a barrier to prevent the migration of stormwater through the liner.

- Recommended soil physical characteristics for compacted clay impermeable barriers include >50 percent fines, liquid limit between 35 and 60, and a plasticity index versus liquid limit above the A-line. USCS Soil Classification of CH, CL, MH are recommended.
- Field compaction should achieve 95 percent standard max density as determined by ASTM D698. Proctor testing to determine the optimum moisture content for compaction should be performed and results should be retained.

## DESIGN SUBMITTAL REQUIREMENTS CHECKLIST

- Plan view of BMP practice specifying extents of media with northing/easting points.
- Section view of BMP facility noting the location, limits, thickness, and material specifications of the media barrier.
- Sieve analysis shall be submitted when applicable.
- Specify product manufacturer, if applicable, and submit product details, including material, performance standards, and installation requirements.

Media barrier component designs and specifications outside the parameters of this guideline shall be reviewed and approved by a licensed PE and submitted to TRWD.

## ADDITIONAL RESOURCES

[1] iSWM Technical Manual. April 2010, revised September 2014. Site Development Controls.

[2] Texas Department of Transportation. 2014. Special Specification 5056: Impermeable Liner.

[3] American Society for Testing and Materials International. February 2016. ASTM C33/C33M Standard Specification for Concrete Aggregates.

[4] City of Fort Worth. December 12, 2016. Standard Construction Specification Documents. *Section 33 05 10 Utility Trench Excavation, Embedment and Backfill.*

### TESTING STANDARD RESOURCES

- American Society for Testing and Materials International. 2012. ASTM D448 Standard Classification for Sizes of Aggregate for Road and Bridge Construction.
- American Society for Testing and Materials International. May 2012. ASTM D698 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft3 (600 kN-m/m3)).
- American Society for Testing and Materials International. April 2013. ASTM D1004 Standard Test Method for Tear Resistance (Graves Tear) of Plastic Film and Sheeting.
- American Society for Testing and Materials International. July 2010. ASTM D1505 Standard Test Method for Density of Plastics by the Density-Gradient Technique.

- American Society for Testing and Materials International. May 2011. ASTM D2487 Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System).
- American Society for Testing and Materials International. 2014. ASTM D4355 Standard Test Method for Deterioration of Geotextiles by Exposure to Light, Moisture and Heat in a Xenon Arc Type Apparatus.
- American Society for Testing and Materials International. 2017. ASTM D4491 Standard Test Methods for Water Permeability of Geotextiles by Permittivity.
- American Society for Testing and Materials International. 2016. ASTM D4751 Standard Test Methods for Determining Apparent Opening Size of a Geotextile.
- Federal Test Method Standards. March 1980. FTMS 101C – Method 2065. Test Method for Puncture Resistance and Elongation Test (1/8 in. radius probe).

## 4.7 LANDSCAPING

### DESCRIPTION

Plant selection for green stormwater infrastructure is crucial for the successful performance and aesthetic of that feature or facility. The plant types, species, sizes, and varieties are determined by the applications and requirements to stabilize soils, grow in varying soil moisture conditions, and detain, retain, and treat stormwater. The recommended plant lists for seeding and plants have been selected for use in each of the different BMP practices.

### WHERE TO USE

These plant types are recommended for use in bioretention basins, constructed wetlands, sand/media filter slopes, wet ponds, extended dry detention basins, retention/irrigation basins, and vegetative filter strips/swales. Plants in these environments should be tolerant of the soils types and media for the varying conditions; be of appropriate size for each type of application regrading maintenance and mature height; be drought tolerant for this region to adapt to varying rainfall events and seasons; be tolerant of dry, hot conditions; not require supplemental irrigation once well established for the larger practice features; be provided with permanent irrigation to provide supplemental water to establish larger shrubs, and trees; be provided with permanent irrigation for supplemental watering within bioretention basins and extensive centralized bioretention areas in the right-of-way due to extended drought conditions; be native or adaptive to the North Texas region or non-invasive if not native; be capable of living in the soil media and amended soils for each type of BMP practice; and be commonly available in the regional seed or nursery trade.

### DESIGN CONSIDERATIONS

- Other plants not specifically listed in the seeding or plant list palettes may be suitable and available. The seed and plant lists does exclude non-cultivars and other varieties of plants and grasses. Plants and herbaceous perennials not specifically listed on the seed mix and plant lists must be submitted to TRWD for review.
- Plant and Seed (and/or sod) selection and location must be coordinated with the specific requirements, application, and local attributes of each feature and practice. Selection and application of the plants are based on: size and location of basin, grading plan, slope stabilization, amount of water received, water retention depth, drawdown time, subsurface or water table elevations, depth of surface soils/subbase/restrictive soils, remediation of soil compaction for root penetration, coefficient of runoff, infiltration rate of the planting and drainage media, soil media composition and depth, root zone volume, drought resistance/hardiness and adaptability, sun exposure, diversity to adapt to changing rainfall events and environment, and type of roadway or runoff area.
- Plant density will vary depending on feature’s basin size, plant species size, available root zone volume, and appropriate application for different sized and types of features. To prevent root competition, plant densities should be considered and sufficient spacing should be provided for plants.

- Seeds should be supplied by local seed suppliers for seed gathered or produced and shall be in compliance with TDA (Texas Department of Agriculture) seed laws. All seeds shall be tested by independent laboratories utilizing standards approved by AOSA (Association of Official Seed Analysts). Noxious weed seeds and non-native species shall not be included in seed mixes, unless specifically called out for application. Plants shall be nursery or contract nursery grown for regional adaptability, and will meet the requirements of local codes and ordinances. Plants should be of sufficient size to establish successfully.
- For BMP features at intersections, mature plant height shall not exceed 2.5 feet to avoid sight-line or visibility triangle obstructions within the clear vision triangle, per City of Fort Worth codes and DPS Site Distances at Intersections Policy.
- Planting plans for BMP features shall have a limited variety of species to provide for ease of maintenance. Depending on size of the BMP feature, 3 to 7 species are recommended with no more than 50 percent of plantings of one species. Grouping of plant species allows for ease of maintenance and visual impact, but is not required. The planting design style should be based on the context of the application.
- All planting areas, not seeded or sodded, should be covered with a 3-inch layer of double shredded and/or hammer mill processed native hardwood mulch. Mulch should be natural, undyed, heat processed to eliminate latent weed seeds or harmful diseases; recommended size range: 8 inches maximum, 2 inch minimum for high volume features, or size range: 4 inches maximum, 1 inch minimum for smaller low volume features; pH 6.5 – 8.5. Water all mulch with fine spray immediately following installation to minimize mulch flotation.
- Separate mulched areas from sodded areas with perforated metal, concrete mow strips, or stone block edging.
- Decorative gravel aggregate, river rock, or rip-rap, may be used at inflow into the BMP feature to minimize wash-out of native hardwood mulch, but not throughout an entire planting bed since it is not a BMP media barrier (such as aggregate used to direct the flow path in a basin). Decorative gravel aggregate shall be locally available, washed, crushed graded stone, or rounded river gravel or river rock.
- Provide temporary fencing, if required, to protect the BMP from traffic through and around the feature until it is established. Provide temporary runoff protection to prevent soil erosion and to allow establishment of seeded and planted surfaces.
- Irrigation systems, both temporary and/or permanent, will be installed to establish and maintain planted features depending on location, type, and visibility. Temporary irrigation shall be provided to establish seeded areas with supplemental permanent irrigation to provide for long term establishment of larger plant materials such as shrubs and trees. Permanent irrigation should be included in smaller high visibility features, and to provide supplemental water in extended drought periods.
- Existing trees shall be protected and incorporated into BMP designs where opportunity allows.
- Consider both short and long-term maintenance requirements and specify, as applicable.
- Comply with local codes and ordinances where implemented.

## DETAILS

### 4.7.1 CHART FOR APPLICATION OF LANDSCAPING

| BMP | Seed or Plant Mix |
|---|---|
| ***Bioretention Basin*** | Plant List 1 – size & species of plants selected according to size of basin, location, visibility, and specific application |
| ***Constructed Wetland*** | Plant Lists 2, 3, 4, 5, 6, 7 and 8 |
| ***Sand/Media Filter*** | Seed Mix determined by slope of bank, location, and visual application |
| ***Wet Pond*** | Nurse Crop if needed, Seed Mixes 1, 2, 3, 4 and 5 for access roads/ramps |
| ***Extended Dry Detention*** | Nurse Crop if needed, Seed Mixes 2, 3, and 5 for access roads/ramps |
| ***Retention / Irrigation Basin*** | Seed Mix or Plant List determined by slope of bank, location, and adjacent conditions for irrigation application |
| ***Vegetative Filter Strip / Swale*** | Nurse Crop if needed, Seed Mixes 1 and 2 |
| ***^Access Roads / Pedestrian Access Ramps*** | Nurse Crop if needed, Seed Mix 5 |

^ Supplemental to each BMP depending on project conditions and access requirements for maintenance.

### 4.7.2 SEED MIXES

#### 4.7.2.1 NURSE CROP SEED MIX

Seed mix to establish and provide soil stabilization in all applications for cool-season nurse crop. Installation window is October to March 1st as a nurse crop (over seed) to other seed mixes for immediate germination and stabilization until other seeds can establish.

**Table 4.7.2.1 Nurse Crop**

| Herbaceous Species - Grasses | Percentage (%) by Weight | Germination Percentage (%) |
|---|---|---|
| ***Cereal Rye*** | 100.00 | 100 |
| **Application Rate = 100 lbs./acre (1 lb./436 sf.)** | | |

#### 4.7.2.2 SEED MIX 1: DRY/WET CONDITIONS – BOTTOM AND SIDES

Seed mix to establish and provide soil stabilization to the bottoms and sides of BMP features with conditions that vary from dry to wet. The grass mix below is a warm-season crop. Installation window is Spring (March 1st -May 15th) or Fall (September 1st – November 15th) if installed with Seed Mix 3.

**Table 4.7.2.2 Seed Mix 1**

| Herbaceous Species - Grasses | Percentage (%) by Weight <> | Germination Percentage (%) |
|---|---|---|
| ***Blue Grama*** | 31.05 | 75 |
| ***Buffalograss*** | 11.00 | 94 |
| ***Little Bluestem*** | 11.00 | 42 |
| ***Sideoats Grama*** | 10.18 | 86 |
| ***Big Bluestem*** | 4.95 | * |
| ***Green Sprangletop*** | 4.90 | * |
| ***Eastern Gamagrass*** | 4.90 | * |
| ***Sand Dropseed*** | 4.90 | * |

| Herbaceous Species - Grasses | Percentage (%) by Weight <> | Germination Percentage (%) |
|---|---|---|
| Prairie Wildrye | 4.75 | * |
| Switchgrass | 3.50 | * |
| Sand Lovegrass | 3.02 | * |
| Indiangrass | 2.90 | * |
| Western Wheatgrass | 1.00 | * |
| Cane Bluestem | 0.07 | * |
| Texas Cupgrass | 0.55 | * |
| Curly Mesquite | 0.25 | * |
| White Tridens | 0.20 | * |
| Bushy Bluestem or Halls Panicum | 0.20 | * |
| **Application Rate = 22 lbs./acre (1 lb./2,000 sf.)** | | |

<> Percentage (%) by Weight may vary depending on seed availability
* Germination Percentage (%) not required by TDA (Texas Department of Agriculture)

#### 4.7.2.3 SEED MIX 2: DRY/WET CONDITIONS – BOTTOM

Seed mix to establish and provide soil stabilization to the bottoms of BMP features with conditions that vary from dry to wet. The mix below is a cool-season crop and provides seasonal flowers. Installation window is Fall (September $1^{st}$ – November $15^{th}$) or Spring (March $1^{st}$ -May $15^{th}$) if installed with Seed Mix 1.

**Table 4.7.2.3 Seed Mix 2**

| Herbaceous Species - Perennials | Percentage (%) by Weight <> | Germination Percentage (%) |
|---|---|---|
| American Basketflower | 49.66 | 8 |
| Illinois Bundleflower | 23.91 | 12 |
| Clasping Coneflower | 8.07 | 99 |
| Plains Coreopsis | 3.23 | * |
| Black-eyed Susan | 3.23 | * |
| Scarlet Sage | 3.07 | * |
| Cutleaf Daisy | 2.67 | * |
| Pink Evening Primrose | 1.94 | * |
| Maximillian Sunflower | 0.96 | * |
| Giant Goldenrod | 0.17 | * |
| **Application Rate = 22 lbs./acre (1 lb./2,000 sf.)** | | |

<> Percentage (%) by Weight may vary depending on seed availability
* Germination Percentage (%) not required by TDA (Texas Department of Agriculture)

### 4.7.2.4 SEED MIX 3: DRY CONDITIONS – UPPER AND BACK SLOPES

Seed mix to establish and provide soil stabilization to the upper and back slopes of BMP features with conditions that are dry. The mix below is a cool-season crop. Installation window is Fall (September 1st – November 15th) or Spring (March 1st -May 15th) if installed with Seed Mix 1.

**Table 4.7.2.4 Seed Mix 3**

| Herbaceous Species - Perennials | Percentage (%) by Weight <> | Germination Percentage (%) |
|---|---|---|
| American Basketflower | 19.93 | 8 |
| Texas Bluebonnet | 18.23 | 21 |
| Plains Coreopsis | 15.52 | 15 |
| Indian Blanket | 15.32 | 88 |
| Lemon Mint | 11.82 | 77 |
| Purple Prairie Clover | 10.31 | 26 |
| White Prairie Clover | 6.66 | 91 |
| Partridge Pea | 1.90 | * |
| Gayfeather | 0.20 | * |
| Tall Goldenrod | 0.10 | * |
| Texas Yellow Star | 0.01 | * |
| **Application Rate = 22 lbs./acre (1 lb./2,000 sf.)** | | |

<> Percentage (%) by Weight may vary depending on seed availability

* Germination Percentage (%) not required by TDA (Texas Department of Agriculture)

### 4.7.2.5 SEED MIX 4 – OVERSEED: WET AND MOIST CONDITIONS – REGULAR DRAINAGE OR SEEPAGE ALONG BOTTOM

Seed mix to establish and provide soil stabilization for wet or moist conditions where there is regular drainage or seepage along the bottom of a BMP feature. The mix below is a nurse crop (Cereal Rye Grain) mixed with a warm-season crop to initially hold and stabilize the soils and for the grasses to germinate in the warmer season. Installation window is Winter (November 1st – February) installed *over* Seed Mix 2.

**Table 4.7.2.5 Seed Mix 4**

| Grasses | Percentage (%) by Weight <> | Germination Percentage (%) |
|---|---|---|
| Cereal Rye Grain | 75.4 | 98 |
| Big Bluestem | 8.20 | 98 |
| Eastern Gamagrass | 4.99 | * |
| Switchgrass | 4.00 | * |
| Prairie Wildrye | 3.00 | * |
| Green Sprangletop | 2.80 | * |
| White Tridens | 0.75 | * |
| Broomsedge Bluestem | 0.04 | * |
| **Application Rate = 218 lbs./acre (1 lb./200 sf.)** | | |

<> Percentage (%) by Weight may vary depending on seed availability

* Germination Percentage (%) not required by TDA (Texas Department of Agriculture)

### 4.7.2.6 SEED MIX 5: ACCESS ROADS OR PEDESTRIAN ACCESS RAMPS

Seed mix to establish and provide soil stabilization for access roads and pedestrian access ramps. The mix below is a warm-season crop mixed with a nurse crop to hold and stabilize surface soils. Installation window is Spring (March 1st -May 15th) or Fall (September 1st – November 15th) if regular rain has occurred and up to 8 weeks before average frost date.

**Table 4.7.2.6 Seed Mix 5**

| *Grasses* | *Percentage (%) by Weight* | *Germination Percentage (%)* |
|---|---|---|
| ***Buffalograss*** | 82.00 | 98 |
| ***Blue Grama*** | 17.00 | 98 |
| ***Curly Mesquite*** | 1.00 | * |
| **Application Rate = 44 lbs./acre (3 lbs./1,000 sf. or 1 lb./333 sf.)** | | |

<> Percentage (%) by Weight may vary depending on seed availability

* Germination Percentage (%) not required by TDA (Texas Department of Agriculture)

### 4.7.2.7 PLANT LIST 1: BIORETENTION

Plants recommended for Bioretention application due to size, visibility clearances, maintenance, and appearance. Plants within visibility/sight distance triangles at intersections shall be less than 30" height and shall comply with all codes per application location to prevent obstruction.

**Table 4.7.2.7 Plant List 1**

| ***Herbaceous Species – Perennials*** | | | | |
|---|---|---|---|---|
| ***Common Name*** *(Scientific name)* | ***Size (Height x Spread)*** | ***Evergreen or Deciduous*** | ***Sun or Shade*** | ***Location (Wet or Dry Range)*** |
| ***Zexmenia*** *(Wedelia acupulcensis var. hispida)* | 1'-2' x 2'-3' | Evergreen/Semi-Evergreen | Sun/Part Shade | Semi-Wet/Dry |
| ***Aromatic Aster*** *(Symphyotrichum oblongifolium)* | 1'-3' x 1'-2' | Winter Dieback | Sun/Part Shade | Semi-Wet/Dry |
| ***Gregg's Mistflower*** *(Conoclinium gregii)* | 18"-2' x 2'-3' | Winter Dieback | Sun/Part Shade | Semi-Wet/Semi-Dry/Dry |
| ***Mealy Blue Sage*** *(Salvia farinacea)* | 2'-3' x 2'-3' | Winter Dieback | Sun | Semi-Wet/Semi-Dry/Dry |
| ***Black-Eyed Susan*** (Rudbeckia hirta) | 2' x 2' | Winter Dieback | Sun | Wet/Dry |
| ***Turk's Cap*** *(Malvaviscus drummondii)* | 2'-3' x 3'-4' | Winter Dieback | Part Shade/Shade | Wet/Dry |
| ***Tall Aster*** *(Symphyotrichum praealtum vaf. Praealtum)* | 1'-3' x 1'-2' | Winter Dieback | Sun/Part Shade/Shade | Wet/Semi-Wet |
| ***Joe Pye Weed*** *(Euptorium fistolosum)* | 4' x 2' | Winter Dieback | Part Shade/Shade | Wet/Semi-Wet |
| ***Cardinal Flower*** *(Lobelia cardinalis)* | 2' x 2'-4' | Winter Dieback | Part Shade/Shade | Wet/Semi-Wet |

| | | | | |
|---|---|---|---|---|
| ***Louisiana Iris*** *(Iris ser. Hexagonae)* | 3' x 6" | Evergreen/Semi-Evergreen | Part Shade/Shade | Wet/Semi-Wet |
| ***Herbaceous Species – Ornamental Grasses*** | | | | |
| ***Common Name*** *(Scientific name)* | ***Size (Height x Spread)*** | ***Evergreen or Deciduous*** | ***Sun or Shade*** | ***Location (Wet or Dry)*** |
| ***'Regal Mist' Gulf Muhly*** *(Muhlenbergia capillaris 'Regal Mist')* | 2' x 3' | Yes | Sun | Wet/Dry |
| ***Lindheimer Muhly*** *(Muhlenbergia lindheimeri)* | 4'-5' x 3'-4' | Evergreen/Semi-Evergreen | Sun/Part Shade | Wet/Dry |
| ***Cherokee Sedge*** *(Carex cherokeensis)* | 1'-2' x 1'-2' | Evergreen | Part Shade/Shade | Wet/Dry |
| ***Emory's Sedge*** *(Carex emoryi)* | 2' x 2' | Semi-Evergreen | Sun/Part Shade | Wet/Semi-Dry |
| ***Inland Sea Oats*** *(Chasmanthium latifolium)* | 3'-4' x 2' | Yes | Part Shade/Shade | Wet/Semi-Dry |
| ***Shrubs*** | | | | |
| ***Common Name*** *(Scientific name)* | ***Size (Height x Spread)*** | ***Evergreen or Deciduous*** | ***Sun or Shade*** | ***Location (Wet or Dry)*** |
| ***Dwarf Yaupon Holly*** *(Ilex vomitoria 'Nana')* | 3' x 3' | Evergreen | Sun/Shade | Semi-Wet/Dry |
| ***Pale Leaf Yucca*** *(Yucca pallida)* | 1'-2' x 1'-3' | Evergreen | Sun | Wet/Dry |
| ***Cast Iron Plant*** *(Aspidistra elatior)* | 2' x 2' | Evergreen/Semi-Evergreen | Part Shade/Shade | Wet/Dry |
| ***American Beautyberry*** *(Callicarpa americana)* | 4'-6' x 5'-8' | Deciduous | Part Shade/Shade | Wet/Dry |
| ***Dwarf Palmetto*** *(Sabal minor)* | 4' x 5' | Evergreen | Shade | Wet/Dry |
| ***Dwarf Wax Myrtle*** *(Morella cerifera var. pumilla or Myrica pusilla)* | 3' x 3'-5' | Evergreen | Sun/Part Shade | Wet/Dry |
| ***Ornamental Trees*** | | | | |
| ***Common Name*** *(Scientific name)* | ***Size (Height x Spread)*** | ***Evergreen or Deciduous*** | ***Sun or Shade*** | ***Location (Wet or Dry)*** |
| ***Redbud var. – 'Oklahoma', Texas, or Mexican*** *(Cercis canadensis var.)* | 20' x 20' | Deciduous | Sun/Part Shade/ Shade | Dry |
| ***Reverchon Hawthorn*** *(Crataegus reverchonii)* | 20' x 15'-20' | Deciduous | Part Sun/Part Shade | Semi-Wet/Dry |
| ***Eve's Necklace*** *(Sophora affinis)* | 30' x 20' | Deciduous | Sun/Shade | Semi-Wet/Dry |
| ***Shantung Maple*** *(Acer truncatum)* | 25' x 20' | Deciduous | Sun/Part Shade | Semi-Wet/Dry |

| | | | | |
|---|---|---|---|---|
| ***Possumhaw (Deciduous Holly - away from road edges)*** *(Ilex decidua)* | 15'-30' x 15'-20' | Deciduous | Sun/Part Shade | Wet/Dry |
| ***Yaupon Holly (Male by roadways)*** *(Ilex vomitoria)* | 20' x 20' | Evergreen | Sun/Part Shade/ Shade | Wet/Dry |
| ***Yaupon Holly (Female – away from roads)*** *(Ilex vomitoria)* | 20' x 20' | Evergreen (with berries) | Sun/Part Shade/ Shade | Wet/Dry |
| ***Southern Waxmyrtle*** *(Myrica cerifera)* | 6'-12' x 12'-15' | Evergreen | Sun/Part Shade | Wet/Semi-Wet |
| ***Trees*** | | | | |
| ***Common Name*** *(Scientific name)* | ***Size (Height x Spread)*** | ***Evergreen or Deciduous*** | ***Sun or Shade*** | ***Location (Wet or Dry)*** |
| ***Texas Ash*** *(Fraxinus albicans)* | 30'-40' x 25'-35' | Deciduous | Sun/Part Shade | Semi-Wet/Dry |
| ***Slippery Elm*** *(Ulmus rubra)* | 40'-60' x 30'-50' | Deciduous | Sun | Semi-Wet/Dry |
| ***Bald Cypress*** *(Taxodium distichum)* | 50'-70' x 20'-40' | Deciduous | Sun | Wet/Semi-Dry |
| ***Montezuma Cypress*** *(Taxodium mucronatum)* | 45'-80' x 40'-50' | Evergreen | Sun | Wet/Semi-Wet |
| ***Pond Cypress*** *(Taxodium ascendens)* | 30'-70' x 15'-20' | Deciduous | Sun | Wet/Semi-Wet |
| ***Cedar Elm*** *(Ulmus crassifolia)* | 60' x 30' | Deciduous | Sun | Wet/Dry |

### 4.7.2.8 PLANT LIST 2: DEEP WATER ZONE (18" DEEP TO 6' DEEP)

Plants recommended for Constructed Wetland for water depths ranging from 18" to 6'.

**Table 4.7.2.8 Plant List 2**

| ***Aquatic Plants*** | |
|---|---|
| ***Common Name*** | ***Scientific Name*** |
| ***Yellow Water Lily*** | *Mympheae mexicana* |
| ***Fragrant Water Lily*** | *Mynphaea odorata* |
| ***Spatterdock*** | *Nuphar luteum* |

### 4.7.2.9 PLANT LIST 3: AQUATIC BENCH (18" DEEP TO NORMAL WATER LEVEL)

Plants recommended for Aquatic Bench applications for Wet Pond and Constructed Wetland for water depths ranging from 18" to normal water level.

**Table 4.7.2.9 Plant List 3**

| *Herbaceous Species - Perennials and Grasses* | |
|---|---|
| ***Common Name*** | ***Scientific Name*** |
| ***Sweetflag*** | *Acrous calumus* |
| ***Caric Sedge*** | *Carex spp.* |
| ***Square Stem Spikerush*** | *Elocharis quandrangulata* |
| ***Swamp Sunflower*** | *Helianthus angustifloius* |
| ***Halberdleaf Hibiscus*** | *Hibiscus laevis* |
| ***Soft Rush*** | *Juncus effusus* |
| ***Rice Cut Grass*** | *Leersia oryzoides* |
| ***Switchgrass*** | *Panicum virgatum* |
| ***Green Arum*** | *Peltandra virginica* |
| ***Smartweed*** | *Polygonum hydropiperoides* |
| ***Pickerelweed*** | *Pontederia cordata* |
| ***Pickerelweed*** | *Pontederia lanceolata* |
| ***Lance-leaf Arrowhead*** | *Sagittaria landifolia* |
| ***Duck Potato*** | *Sagittaria latifolia* |
| ***Lizard's Tail*** | *Saururus cernuus* |
| ***Three-square*** | *Scirpus americanus* |
| ***Giant Bulrush*** | *Scirpus californicus* |
| ***Softstem Bulrush*** | *Scirpus validus* |
| ***Virginia Chain Fern*** | *Woodwardia virginica* |

### 4.7.2.10 PLANT LIST 4: WETLAND PLANTS (NORMAL WATER LEVEL TO +6")

Plants recommended for Wet Ponds and Constructed Wetlands for water depths ranging from normal water level to +6" above.

**Table 4.7.2.10 Plant List 4**

| Herbaceous Species - Perennials and Grasses | |
|---|---|
| **Common Name** | **Scientific Name** |
| **Bushy Broom Grass** | *Andropogon glomeratus* |
| **Upland Sea Oats** | *Chasmanthium latifolium* |
| **Dwarf Tickseed** | *Coreopsis tinctoria* |
| **Late Boneset** | *Euptorium serotinum* |
| **Maximilian Sunflower** | *Helianthus maximiliani* |
| **Halberdleaf Hibiscus** | *Hibiscus laevis* |
| **Spiked Gayfeather** | *Liatris spicata* |
| **Cardinal Flower** | *Lobelia cardinalis* |
| **Cinnamon Fern** | *Osmunda cinnamomea* |
| **Royal Fern** | *Osmunda regalis* |
| **Witchgrass** | *Panicum capillare* |
| **Pickerelweed** | *Pontederia cordata* |
| **Softstem Bulrush** | *Scirpus validus* |
| **Eastern Gamagrass** | *Tripsacum dactyloides* |

### 4.7.2.11 PLANT LIST 5: SEMI-WET ZONE (NORMAL WATER LEVEL TO +4')

Plants recommended for Wet Ponds and Constructed Wetlands for water depths ranging from normal water level to +4' above.

**Table 4.7.2.11 Plant List 5**

| Herbaceous Species - Perennials and Grasses | |
|---|---|
| **Common Name** | **Scientific Name** |
| **Bushy Broom Grass** | *Andropogon glomeratus* |
| **Broom Grass** | *Andropogon virginicus* |
| **Upland Sea Oats** | *Chasmanthium latifolium* |
| **Dwarf Tickseed** | *Coreopsis tinctoria* |
| **Canada Wildrye** | *Elymus Candensis* |
| **Virginia Wildrye** | *Elymus virginicus* |
| **Joe Pye Weed** | *Euptorium fistolosum* |
| **Late Boneset** | *Euptorium serotinum* |
| **Texas Bluebells** | *Eustoma grandiflora* |
| **Maximilian Sunflower** | *Helianthus maximiliani* |
| **Halberdleaf Hibiscus** | *Hibiscus laevis* |
| **Spiked Gayfeather** | *Liatris spicata* |
| **Cardinal Flower** | *Lobelia cardinalis* |
| **Turk's Cap** | *Malvaviscus drummondii* |
| **Cinnamon Fern** | *Osmunda cinnamomea* |
| **Royal Fern** | *Osmunda regalis* |
| **Witchgrass** | *Panicum capillare* |

**Table 4.7.2.11 Plant List 5**

| Herbaceous Species - Perennials and Grasses | |
|---|---|
| **Common Name** | **Scientific Name** |
| **Pickerelweed** | *Pontederia cordata* |
| **Black-eyed Susan** | *Rudbeckia hirta* |
| **Softstem Bulrush** | *Scirpus validus* |
| **Yellow Indian Grass** | *Sorgham nutans* |
| **Eastern Gamagrass** | *Tripsacum dactyloides* |

### 4.7.2.12 PLANT LIST 6: WOODED VEGETATION (+6" ABOVE NORMAL WATER LEVEL AND UP)

Plants recommended for Wet Ponds, Constructed Wetlands and other BMP features for elevations ranging from +6" above normal water level to 4' that are regularly inundated.

**Table 4.7.2.12 Plant List 6**

| Herbaceous Species - Perennials and Grasses | |
|---|---|
| **Common Name** | **Scientific Name** |
| **Broom Grass** | *Andropogon virginicus* |
| **Canada Wildrye** | *Elymus Candensis* |
| **Virginia Wildrye** | *Elymus virginicus* |
| **Late Boneset** | *Euptorium serotinum* |
| **Texas Bluebells** | *Eustoma grandiflora* |
| **Maximilian Sunflower** | *Helianthus maximiliani* |
| **Turk's Cap** | *Malvaviscus drummondii* |
| **Witchgrass** | *Panicum capillare* |
| **Black-eyed Susan** | *Rudbeckia hirta* |
| **Yellow Indian Grass** | *Sorgham nutans* |
| **Eastern Gamagrass** | *Tripsacum dactyloides* |
| ***Shrubs and Ornamental Trees*** | |
| **Common Name** | **Scientific Name** |
| **Common Buttonbush** | *Cephalanthus occidentalis* |
| **Possumhaw (Deciduous Holly)** | *Ilex decidua* |
| **Southern Waxmyrtle** | *Myrica cerifera* |
| **Wafer Ash** | *Ptelea trifoliata* |
| ***Trees*** | |
| **Common Name** | **Scientific Name** |
| **Green Ash** | *Fraxinus pennsylvanica* |
| **Bald Cypress** | *Taxodium distichum* |
| **Pond Cypress** | *Taxodium distichum var. nutans* |

### 4.7.2.13 PLANT LIST 7: PERIODICALLY INUNDATED (+4' AND UP)

Plants recommended for Wet Ponds, Constructed Wetlands and other BMP features for elevations ranging from 4' above normal water level and up that are periodically inundated.

**Table 4.7.2.13 Plant List 7**

| *Herbaceous Species – Perennials and Grasses* | |
|---|---|
| ***Common Name*** | ***Scientific Name*** |
| ***Common Milkweed*** | *Asclepias syriaca* |
| ***Buffalograss*** | *Bouteloua dactyloides* |
| ***Partridge Pea*** | *Chamaecrista fasciculata* |
| ***Canada Wildrye*** | *Elymus Candensis* |
| ***Virginia Wildrye*** | *Elymus virginicus* |
| ***Texas Cupgrass*** | *Eriochloa sericea* |
| ***Turk's Cap*** | *Malvaviscus drummondii* |
| ***Halls Panicum*** | *Panicum hallii* |
| ***Obedient Plant*** | *Physostegia virginiana* |
| ***Black-eyed Susan*** | *Rudbeckia hirta* |
| *Shrubs and Ornamental Trees* | |
| ***Common Name*** | ***Scientific Name*** |
| ***Possumhaw (Deciduous Holly)*** | *Ilex decidua* |
| ***Yaupon Holly*** | *Ilex vomitoria* |
| ***Southern Waxmyrtle*** | *Myrica cerifera* |
| *Trees* | |
| ***Common Name*** | ***Scientific Name*** |
| ***Pecan*** | *Carya illinoensis* |
| ***Common Persimmon*** | *Diospyros virginiana* |
| ***Texas Ash*** | *Fraxinus texensis* |
| ***Bur Oak*** | *Quercus macrocarpa* |
| ***Chinkapin Oak*** | *Quercus muhlenbergii* |
| ***Shumard Oak*** | *Quercus shumardii* |
| ***Live Oak*** | *Quercus virginiana* |
| ***Bald Cypress*** | *Taxodium distichum* |
| ***Pond Cypress*** | *Taxodium distichum var. nutans* |
| ***Cedar Elm*** | *Ulmus crassifolia* |
| ***Slippery Elm*** | *Ulmus rubra* |

### 4.7.2.14 PLANT LIST 8: INFREQUENTLY INUNDATED

Plants recommended for Constructed Wetlands and other BMP features for elevations that are infrequently inundated.

**Table 4.7.2.14 Plant List 8**

| Herbaceous Species – Perennials and Grasses | |
|---|---|
| **Common Name** | **Scientific Name** |
| Big Bluestem | *Andropogon gerardii* |
| Butterfly-weed | *Asclepias tuberosa* |
| Sideoats Grama | *Bouteloua certipendula* |
| Buffalograss | *Bouteloua (Buchloe) dactyloides* |
| Bermuda Grass | *Cynodon dactylon* |
| Texas Cupgrass | *Eriochloa sericea* |
| Purple Coneflower | *Echinacea purpurea* |
| Green Sprangletop | *Leptochola dubia* |
| Texas Gayfeather | *Liatris puncata var. mucronatum* |
| Turk's Cap | *Malvaviscus drummondii* |
| Witchgrass | *Panicum capillare* |
| Texas Bluegrass | *Poa arachnifera* |
| Mealy Blue Salvia | *Salvia farinacea* |
| Autumn Sage | *Salvia greggii* |
| Little Bluestem | *Schizachyrium scoparium* |
| White Tridens | *Tribens albescens* |
| **Shrubs and Ornamental Trees** | |
| **Common Name** | **Scientific Name** |
| Texas Redbud | *Cercis canadensis var. texensis* |
| Reverchon Hawthorn | *Crataegus reverchonii* |
| Possumhaw (Deciduous Holly) | *Ilex decidua* |
| Yaupon Holly | *Ilex vomitoria* |
| Southern Waxmyrtle | *Myrica cerifera* |
| **Trees** | |
| **Common Name** | **Scientific Name** |
| Pecan | *Carya illinoensis* |
| Texas Ash | *Fraxinus texensis* |
| Bur Oak | *Quercus macrocarpa* |
| Chinkapin Oak | *Quercus muhlenbergii* |
| Shumard Oak | *Quercus shumardii* |
| Live Oak | *Quercus virginiana* |
| Bald Cypress | *Taxodium distichum* |
| Cedar Elm | *Ulmus crassifolia* |
| Slippery Elm | *Ulmus rubra* |
| Green Ash | *Fraxinus pennsylvanica* |

### 4.7.3 MAINTENANCE

Specific knowledge and experience in the establishment and maintenance of the BMP practices and applications within the Dallas-Fort Worth Region requires understanding of our climate, seasons, soils, plants, weeds, and irrigation, along with related products and equipment. Each different practice requires specific maintenance and frequency of maintenance in order to function as designed.

Grasses, perennials, shrubs, trees and aquatic plants shall be protected, maintained and established. Weeding is crucial to remove competitive and invasive plants from seeding, establishing, and choking out the designed plant applications.

Applications of chemical herbicides, fungicides, and pesticides are discouraged due to their detrimental effect on beneficial mycorrhizal fungi and other soil microorganisms that contribute to soil porosity, root health, and adaptation of the plants. Organic materials and methods are preferred.

Additional activities include, but are not limited to, temporary protections, site erosion stabilization, sedimentation removal, maintain the mulch and aggregates, trash collection, testing, inspections, and reporting.

| ***Maintenance*** | | |
|---|---|---|
| ***Activity*** | ***Time of Year*** | ***Frequency per Year*** |
| ***Tree straightening*** | Depending on install date | Varies |
| ***Tree pruning to provide canopy clearance over walks & visibility sight lines*** | January, February, March, & December | Varies |
| ***Trees – remove dead wood and suckers*** | As needed | Varies |
| ***Trees – remove excess soil from base of tree to expose root flare*** | As needed | Varies |
| ***Trees – treat damage to trunks by vandalism or natural event*** | As needed | Varies |
| ***Trim/ cut back warm season ornamental grasses to 1/3$^{rd}$ plant height & remove cuttings*** | February | 0.5 – every 2 years |
| ***Lindheimer's Muhly – comb & pull dried seed stalks by hand with rubber gloves yearly; only cut back to 1/3$^{rd}$ overall plant height every 3 years*** | February<br>February | 1<br>0.3 – every 3 years |
| ***Trim / cut back sedge to 1/3$^{rd}$ plant height & remove cuttings*** | September | 0.5 – every 2 years |
| ***Trim spent yucca blooms & remove dead lower foliage if it easily releases or pulls out*** | Varies per species | 1 |
| ***Dead head perennials – pick prune by hand or with pruning tools and remove cuttings - Bioretention basins (publicly visible)*** | As needed | Varies |
| ***Trim back dead stalks of perennials after plant becomes dormant to 6 inch height – Bioretention basins (publicly visible)*** | October, November, December | Varies |
| ***Pick prune all shrubs to maintain natural character – no shearing or topping*** | As needed | Varies |
| ***Repair & restore erosion protection to allow plant establishment*** | As needed | Varies |
| ***Replace dead plants & reseed to retain soils*** | As needed | Varies |
| ***Mowing of grasses and perennials to no less than 6 to 8 inch height*** | January and July | 2 |

| Maintenance | | |
|---|---|---|
| ***Activity*** | ***Time of Year*** | ***Frequency per Year*** |
| ***Remove all debris, trimmings, fallen branches, leaves & thatch to prevent clogging of system*** | As needed | Varies |
| ***Applications & treatments with organic: insecticides, herbicides & fungicides*** | April and July | 2 |
| ***Ant control – organic herbicide*** | As needed | 8 |
| ***Apply organic biological fertilizer – Bioretention basins only*** | March and October | 2 |
| ***Remove decomposed mulch around outlet drains & catch basins*** | March and October | 2 |
| ***Apply mulch to maintain a full 3 inch depth to help control weeds – Bioretention basins & mulch dependent features*** | March and October | 2 |
| ***Refresh, topdress, & remove sediment & debris from surface*** | March and October | 2 |
| ***Clean & remove sediments from energy dissipation & media barriers*** | June | 1 |
| ***Irrigation inspection & repair*** | As needed | Varies |
| ***Remove litter*** | Weekly | 52 |
| ***Snow, Ice & Sand removal from curb openings & forebays after ice storm event*** | As needed | 1 |
| ***Hydraulic Conductivity Test – at base of exposed media around and adjacent to outlet drains & catch basins*** | March | 1 |
| ***Inspection with Owner /3rd Party/Landscape Architect for inspection of systems pertaining to applications/maintenance*** | March | 1 |
| ***Reporting*** | March | 1 |

## DESIGN SUBMITTAL REQUIREMENTS CHECKLIST

- Planting plans, schedules, details, and specifications to be designed specific to each BMP feature or basin by a professional landscape architect licensed in the State of Texas
- Planting plan to reflect application extents of different seed mixes per elevations related to normal water level, or for BMP features that do not retain water
- Plant schedule for BMP feature specifying types, species, sizes, spacing and locations of different plants, seed mixes, topdressing mulch, and aggregate/gravel/river rock surfacing.
- Details for planting and stabilizing plants below water level and on slopes
- Specifications for planting bed soil preparation for each different seed mix or plant type bed depth. Refer to Section 4.5.1 for information about compost and expanded shale. Additional materials and treatments to be included in the specifications are noted below, but are not exhaustive:
    - Soil compaction remediation
    - Topsoil
    - Topdressing – Mulch
    - Topdressing at BMP entry - Aggregates/Gravel/River rock

   - Applications of organic herbicides, fungicides and fertilizer due to runoff issues with chemical fertilizers and detrimental effect to soils

- Bioretention Soil Mix refer to Section 4.5.1 Bioretention or Engineered Soil.
- Irrigation plan for both temporary establishment and permanent systems for each BMP feature or basin designed by an irrigation consultant licensed in the State of Texas
- Plant palette designs and specifications outside the parameters of this guideline shall be reviewed and approved by a licensed Professional Engineer and submitted to TRWD for review.

### ADDITIONAL RESOURCES

[1] American Standard for Nursery Stock, Edition approved May 12, 2004 by American Nursery and Landscape Association (ANSI Z60.1-2004) – plant materials.

[2] Hortus Third, 1976 – Cornell University – plant nomenclature.

[3] iSWM Technical Manual. April 2010, revised September 2014. Landscape and Aesthetics Guidance.

[4] Seed Certification. Texas Department of Agriculture - Licenses and Registrations, 2017.

[5] Seed Testing. Association of Official Seed Analysts – AOSA Rules for Testing Seeds, updated 2014.

## 4.8 OUTLETS/PIPING

### DESCRIPTION

Piping primarily consists of PVC or HDPE components and appurtenances with the purpose of controlling stormwater conveyance into and out of the BMP and/or providing access to or observation of other BMP components. BMP piping and outlet components include underdrains, distribution pipes, cleanouts, observation wells, anti-seep collars, and utility sleeves.

### WHERE TO USE

Piping and outlet component use depends on the primary intended function such as to convey, access, monitor, or protect the BMP or adjacent utilities. Underdrains and distribution pipes are in the subsurface layers of the BMP to regulate the conveyance of stormwater in or out of the BMP facility. Cleanouts and observation wells provide access from the surface of the BMP facility to the below grade piping and/or media in order to maintain or monitor. Anti-seep collars and utility sleeves are used to prevent exfiltration of stormwater at the edge of the BMP facility or protect existing utilities adjacent to or through the BMP. Outlets are used to provide controlled release of the design volume or allow overflow/bypass of larger stormwater flows out of the BMP.

### DESIGN CONSIDERATIONS

- Underdrains to facilitate stormwater outflow from the BMP facility are recommended for all sites with underlying soil infiltration rates less than 0.5 inches per hour. If a BMP is a function of infiltration, the designer must conduct subsurface soil investigation to determine the soil characteristics for BMP design and drainage system needs. A minimum of two geotechnical borings should be performed per BMP site to determine the NRCS soil textural classification and infiltration rate[4].
- Underdrain or distribution piping shall be sized to convey at a minimum the water quality volume into or out of the BMP. A minimum slope of 0.5 percent should be used to maintain positive drainage and mitigate sediment buildup in the pipe.
- Outflow rate should be calculated based on BMP capacity, required drawdown rate, and target water quality volume.
- Outflow control devices, such as valves, orifice plates, upturned elbows or weirs, are highly recommended within underdrain piping and outlets to maximize the treatment capacity of the BMP.
- An overflow or bypass path must be identified to address stormwater flows in excess of the design. Outlets may be used as part of this overflow control.

## DETAILS

### 4.8.1 UNDERDRAIN

Underdrains are perforated pipes used to intercept, collect, and convey stormwater from the storage or subsurface layers of a BMP. Underdrains must meet the following parameters, see detail DM-DC 4.8.1 for additional design information:

- BMPs that use infiltration as a function the BMP facility shall include underdrains unless results of infiltration testing show that in situ soils are adequate for infiltration within the required drawdown time of the BMP. Drawdown times for infiltration BMPS shall be no longer than 48 hours.
- All underdrains shall be capable of withstanding the expected loading applied above it, including vehicular or pedestrian loading for underground BMPs.
- Underdrains shall be capable of exceeding the drainage capacity of the soil media layers of the BMP system.
- Sites expected to produce greater fines in runoff or in planting soil should use an aggregate permeable media barrier (Section 4.6) between the BMP media and the underdrain aggregate. Bedding and filter aggregate shall be double washed prior to installation to reduce suspended solids and the potential for clogging.
- Perforations for underdrains shall be based on the allowable storage aggregate size (Section 4.5.3). Perforated pipes shall at a minimum meet the following sizes as shown in **Table 4.11**.

**Table 4.11 Sizing Perforated Pipes**

| *Allowable Storage Aggregate Size* | *Maximum Hole Diameter (in)* | *Open Area (per ft)* |
|---|---|---|
| No. 56 | 3/8 | 1.98 in$^2$ |
| No. 57 | 3/8 | |
| No. 67 | 1/4 | |
| No. 3 | 7/8 | |

### 4.8.2 CLEANOUT

Cleanouts are vertical pipes extending from subsurface piping to the surface of the BMP that provide access to piping for inspection, maintenance, and cleaning. If cleanouts are placed within a ponding area, at least one cleanout shall extend out of the filter bed to be accessible even if the pond is full. See detail DM-DC 4.8.2 for additional design information.

*Photo Credit: CDM Smith*

### 4.8.3 OVERFLOW RISER

Overflow risers are components used to provide a safe release of excess flows greater than the water quality volume or to facilitate a faster drawdown time for larger stormwater events from a BMP facility. Overflow risers typically consist of a vertical riser pipe or structure with a grated lid located within a BMP facility to allow overflow of stormwater runoff above the design ponding elevation to the existing BMP. Grated inlet risers should be sized assuming 50% clogging at the entry. See detail DM-DC 4.8.3 for additional design information.


*Photo Credit: CDM Smith*

### 4.8.4 MULTI-STAGE OUTLET STRUCTURE

Multi-stage outlet structure is a component similar to the overflow riser but should be applied to larger centralized BMPs that can be utilized to control stormwater volumes and rates in excess of water quality requirements. The outlet structure should provide a safe and controlled release of excess flows greater than the water quality volume or to facilitate a faster drawdown time for larger stormwater events from a BMP facility. Multi-stage outlet structure typically consists of a trash rack, orifice, and BMP maintenance drain. Depending on the type of BMP, an underdrain (Section 4.8.1) may be a necessary component. See detail DM-DC 4.8.4 for additional design information.


*Photo Credit: CDM Smith*

### 4.8.5 OBSERVATION WELL

Observation wells consist of vertical slotted piping that extends through the BMP media layers and allows for measurement of the sub-surface water level to evaluate infiltration performance of the BMP. Observation wells are recommended for all BMP facilities that are designed for infiltration and/or storage. See detail DM-DC 4.8.5 for additional design information.

### 4.8.6 ANTI-SEEP COLLAR

An anti-seep collar is used to prohibit exfiltration of stormwater laterally along piping from the BMP toward adjacent utilities or surrounding subgrade. Anti-seep collars are installed on both upstream and downstream ends of utility sleeves (Section 4.8.7) or on BMP piping transitioning from perforated to solid pipe that passes through the edge of the BMP facility. Typical anti-seep collars consist of a collar, clamp, and/or bands connected to and surrounding the pipe. See detail DM-DC 4.8.6 for additional design information.

### 4.8.7 UTILITY SLEEVE

Utility sleeves are components used to protect existing utilities from exfiltration of stormwater from the BMP toward the adjacent utility or to protect the BMP from the utility service. Utility sleeves typically consist of solid PVC or HDPE piping installed over utility piping or other service piping that passes through or is directly adjacent to the BMP facility. It is recommended to avoid locating utilities within the extents of the BMP. When possible, a utility should be removed and relocated outside of the BMP footprint. See detail DM-DC 4.8.7 for additional design information.

## DESIGN SUBMITTAL REQUIREMENTS CHECKLIST

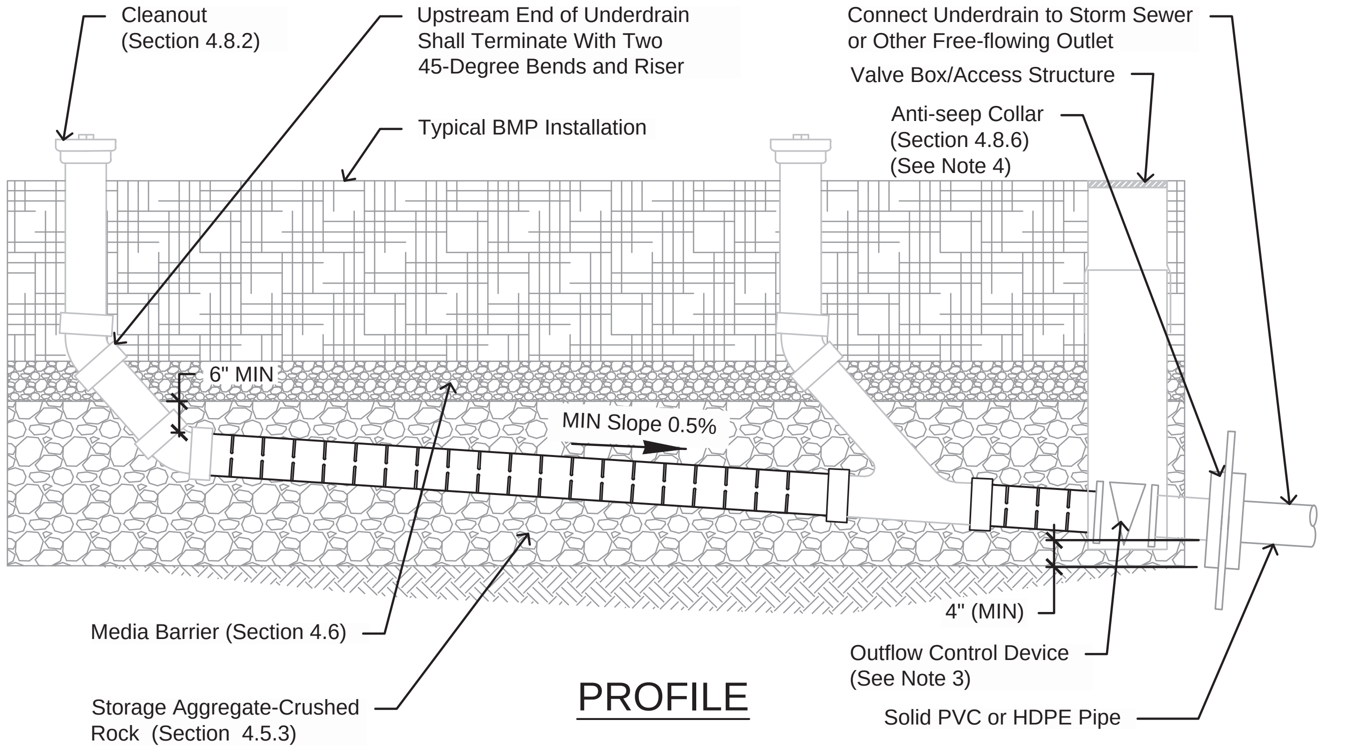
- Pipe sizing, design flow rates, maximum flow rates, and minimum and maximum velocity calculations.
- Plan view of piping component placement within the BMP, including northing/easting, RIM and invert elevations, and stationing, as applicable. Outlets should include grading and spot elevations to determine drainage and overflow pathways and verify that overflow discharge will not damage adjacent property or structures.
- Cross-sectional view of piping component, including details of all materials, fittings, required depths, and offset dimensions.
- Manufacturer details, including product number, materials, painting specifications, and fastener and frame, as applicable.
- Detail of existing drainage system connection or outlet and discharge control mechanisms used.
- Design calculations for flows and velocities entering and discharging from piping and outlet components.
- A plan view of the BMP facility showing all overflow pathways and elevations, confirming that overflows are maintained on public property and do not flow onto private property or into any structure.

Piping and Outlet component designs and specifications outside the parameters of this guideline shall be submitted for review and approval by a licensed PE.

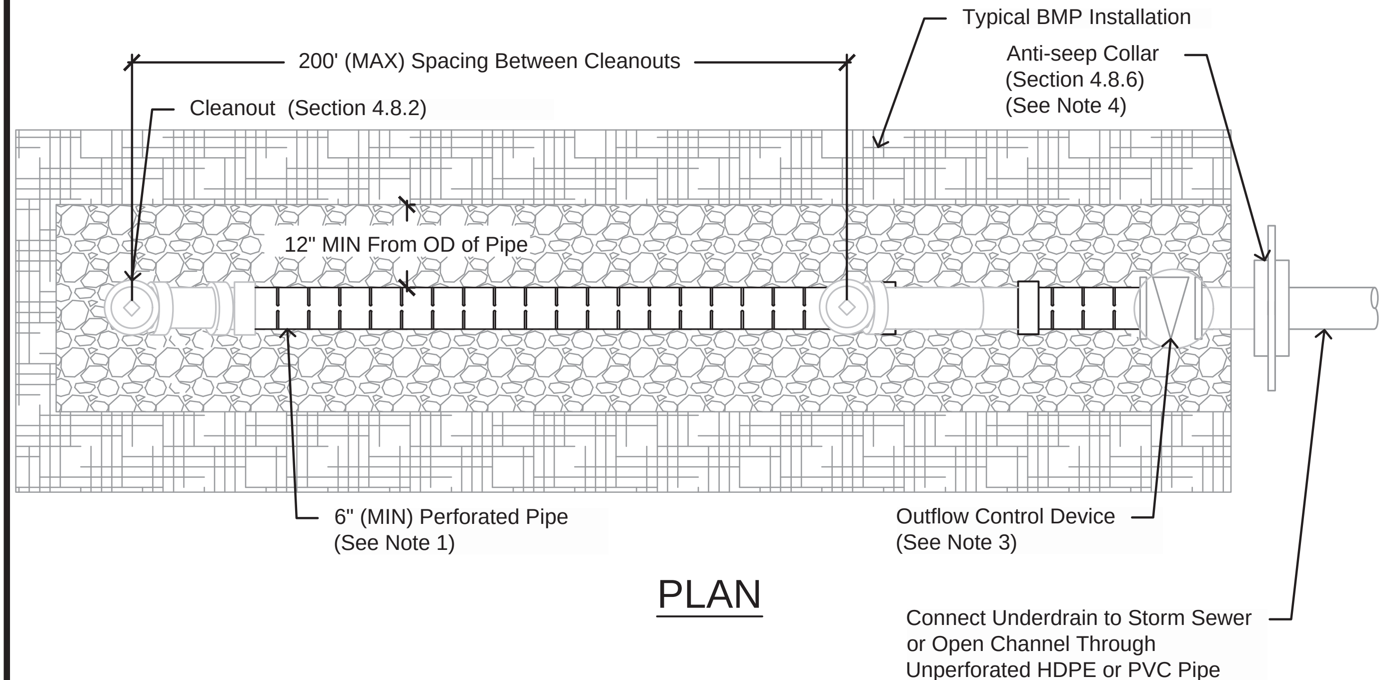
## ADDITIONAL RESOURCES

### DM-DC DRAWING RESOURCES


- City of Fort Worth. December 20, 2016. Standard Construction Specification Documents. Section 33 46 00 Subdrainage.
- City of Fort Worth. December 12, 2016. Standard Construction Specification Documents. Section 33 05 10 Utility Trench Excavation, Embedment and Backfill.
- City of Fort Worth. June 19, 2013. Standard Construction Specification Documents. Section 33 31 20 Polyvinyl Chloride (PVC) Gravity Sanitary Sewer Pipe.
- City of Fort Worth. August 31, 2012. Standard Construction Drawings. Detail D416 – Concrete Pipe Collar.
- North Central Texas Council of Governments. September 2014. iSWM Technical Manual. Site Development Controls.




PROFILE

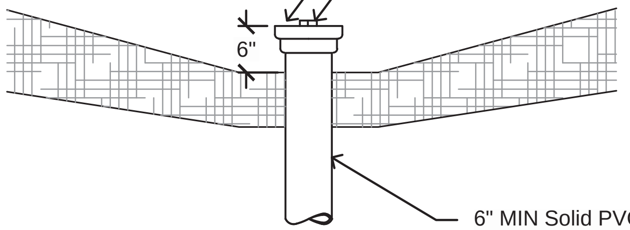



PLAN

Notes

1. Acceptable pipe materials shall be in accordance with City of Fort Worth STD Specification 33 46 00.
2. Lateral or parallel underdrains may be installed if necessary depending on size and slope of BMP. Intersecting underdrains shall be installed such that flow enters the pipe in the downstream direction.
3. A flow control mechanism such as a valve, orifice, or upturned elbow is highly recommended to be installed on the downstream end of underdrains to control discharge from the BMP.
4. Anti-seep collar should be completely free of bedding.

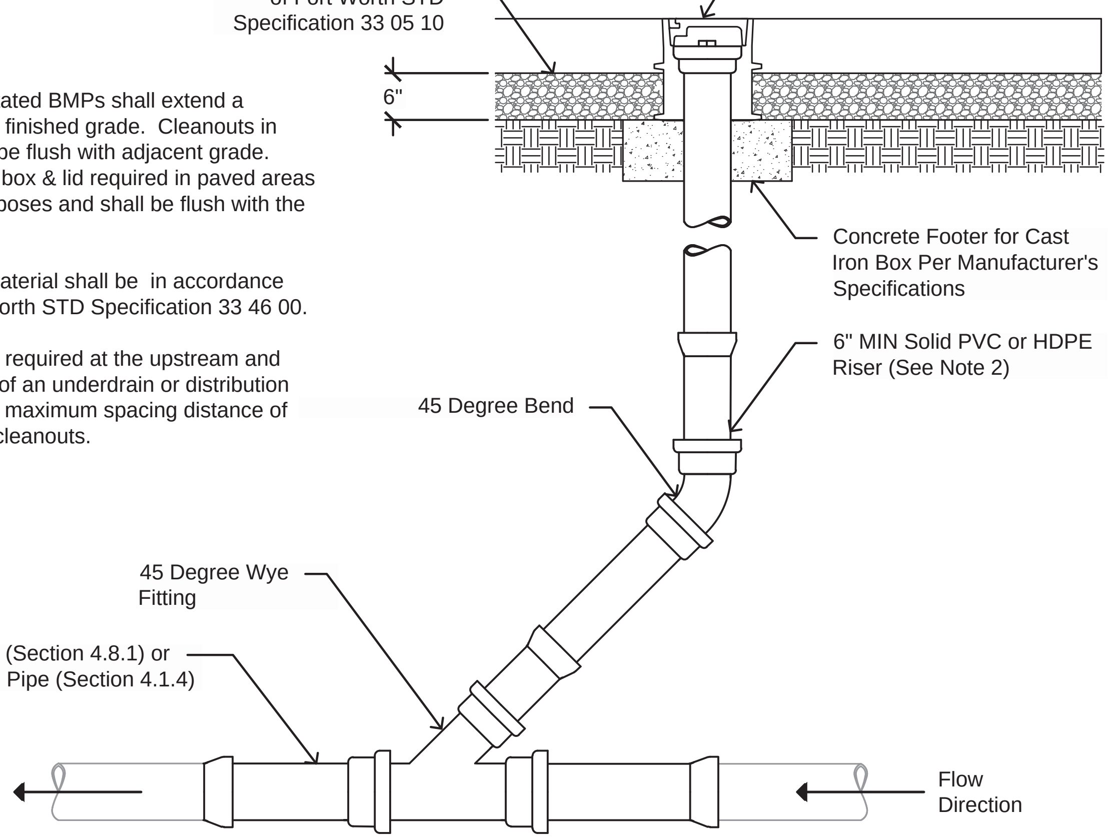
| trwd Tarrant Regional Water District | TARRANT REGIONAL WATER DISTRICT<br>**Underdrain** | REVISED: FEBRUARY 2018<br>**DM-DC 4.8.1** |
|---|---|---|




## CLEANOUT IN SOIL

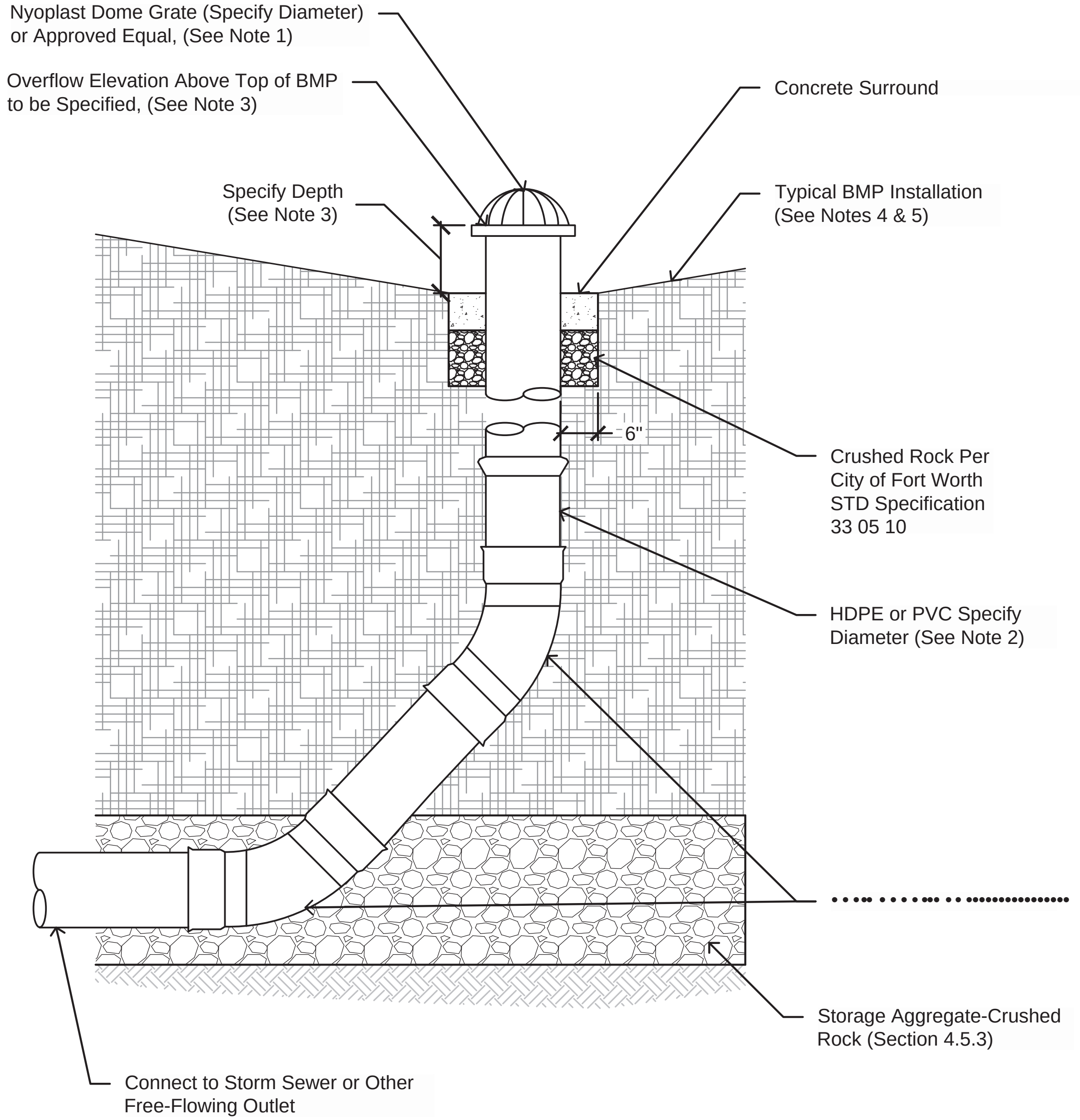
Notes

1. Cleanouts in vegetated BMPs shall extend a minimum 6" above finished grade. Cleanouts in paved areas shall be flush with adjacent grade. Cleanout cast iron box & lid required in paved areas used for traffic purposes and shall be flush with the paved surface.
2. Acceptable pipe material shall be in accordance with City of Fort Worth STD Specification 33 46 00.
3. Cleanouts shall be required at the upstream and downstream ends of an underdrain or distribution pipe system with a maximum spacing distance of 200 feet between cleanouts.




## CLEANOUT IN PAVED SURFACE

| | | |
|---|---|---|
| trwd Tarrant Regional Water District | TARRANT REGIONAL WATER DISTRICT | REVISED: FEBRUARY 2018 |
| | **Cleanout** | **DM-DC 4.8.2** |




SECTION

Notes

1. Nyoplast Drain Basin or equal is an acceptable alternative to standpipe overflow. Bedding and anchoring details shall be per manufacturer requirements.

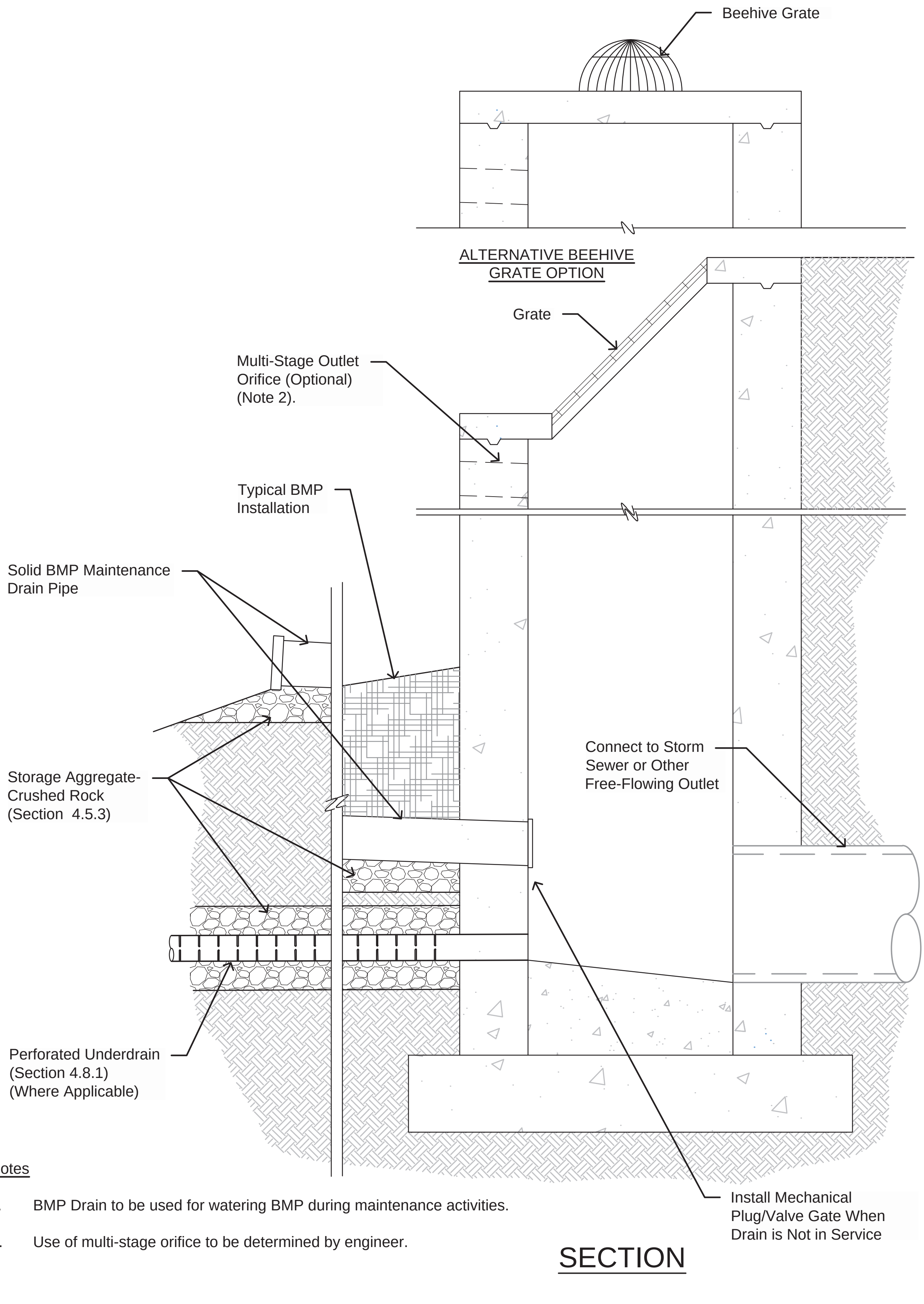
2. Riser piping shall be made of soil tight seals and fittings and conform to City of Fort Worth STD Specification 33 31 20.

3. Overflow elevations shall be set at or above design ponding height such that overflow occurs only as necessary to prevent flooding of BMP facility and surrounding area.

4. Vegetation placed in the vicinity of the outlet shall maintain a minimum distance of 12-inches to prevent plant debris from clogging the structure.

5. Surface of the BMP shall be graded for positive drainage towards the outlet.

| | | |
|---|---|---|
| trwd Tarrant Regional Water District | TARRANT REGIONAL WATER DISTRICT | REVISED: FEBRUARY 2018 |
| | **Outflow Riser** | **DM-DC 4.8.3** |

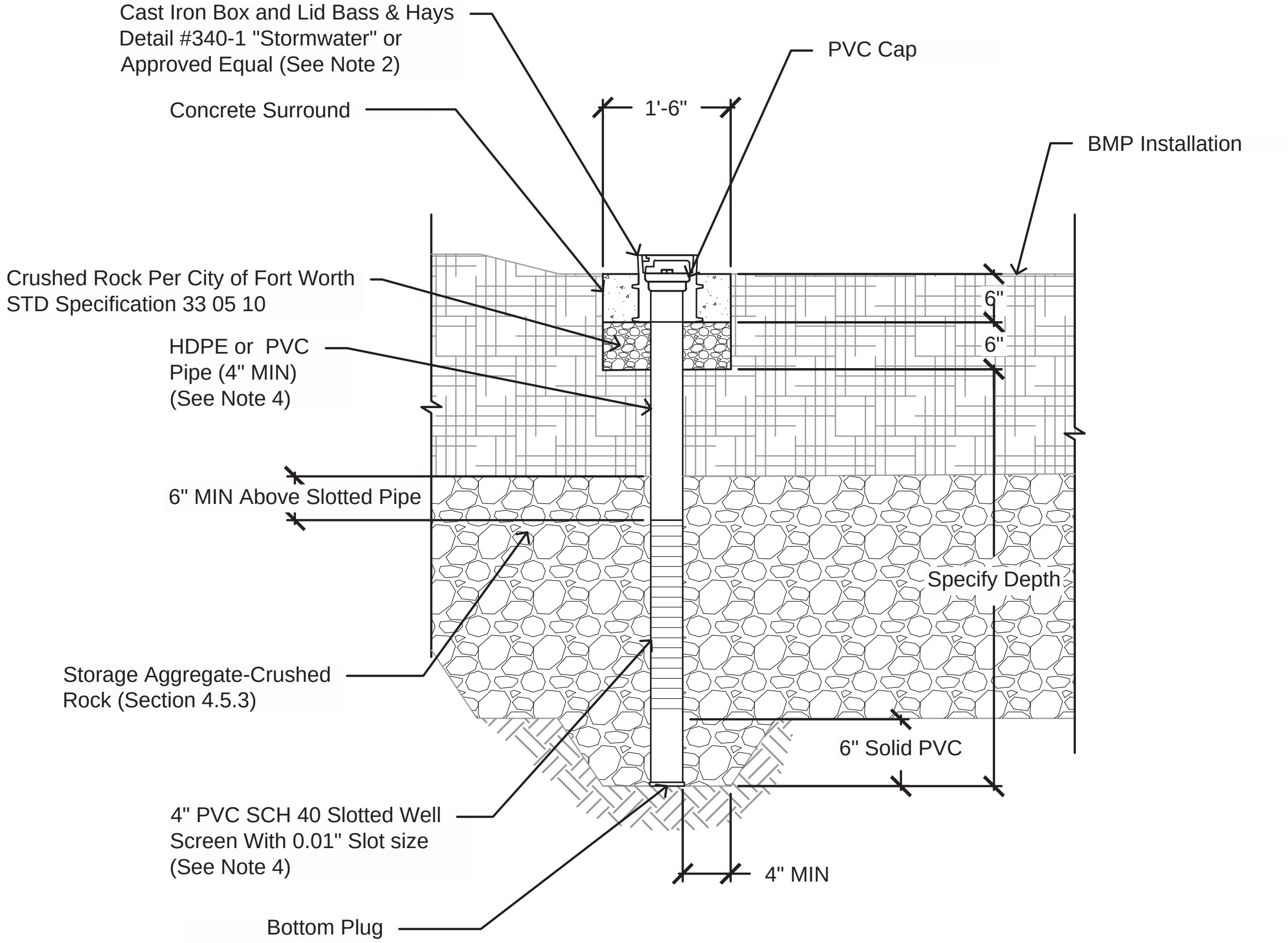



Notes

1. BMP Drain to be used for watering BMP during maintenance activities.
2. Use of multi-stage orifice to be determined by engineer.

SECTION

| | | |
|---|---|---|
| trwd Tarrant Regional Water District | TARRANT REGIONAL WATER DISTRICT | REVISED: FEBRUARY 2018 |
| | **Multi-Stage Outlet Structure** | **DM-DC 4.8.4** |




# SECTION

Notes

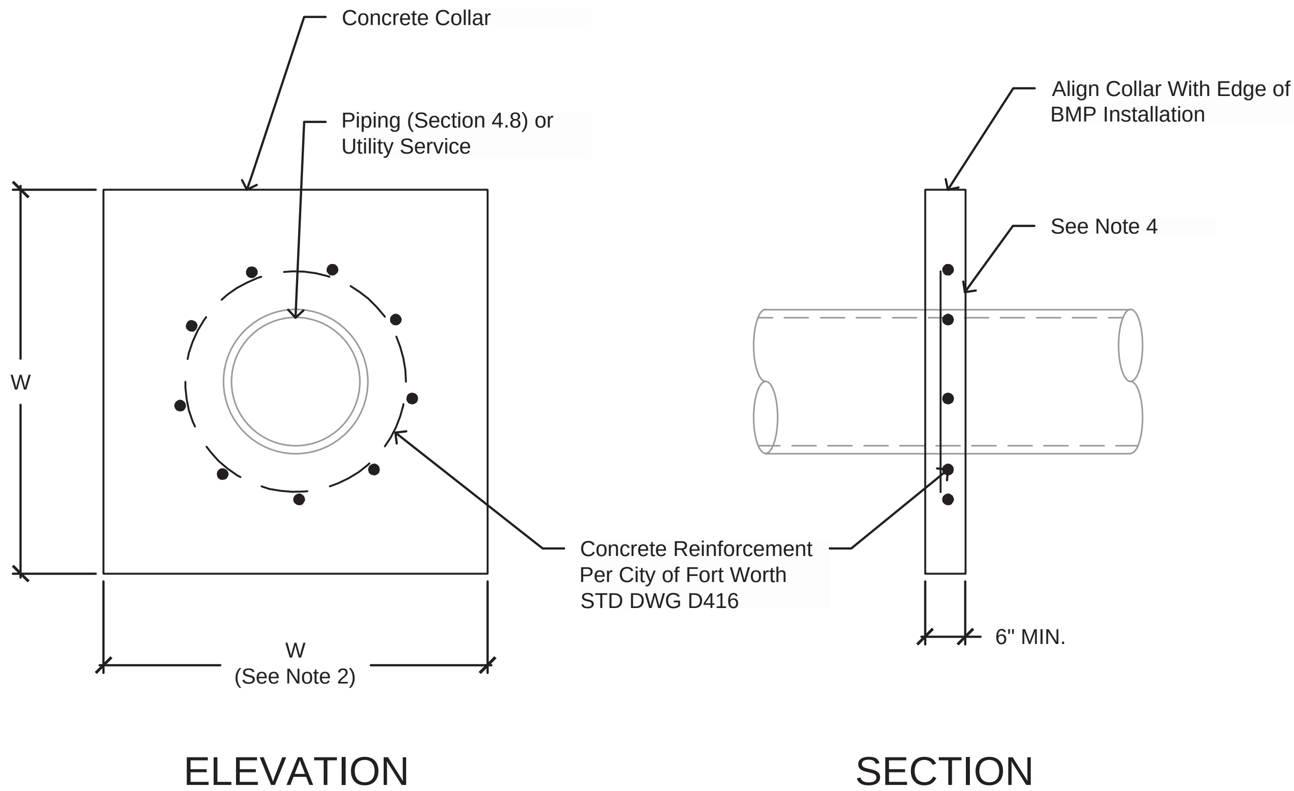
1. If the observation well is located within a parking area, then it shall be flush with the paved surface. Not recommended to place observation wells in areas with high vehicular traffic due to safety concerns.

2. Well covers shall be secured in concrete surround if not secured in pavement surface restoration. Well covers in pavement shall be flush with finished grade.

3. Area surrounding well shall be restored in kind with the adjoining area. Any geotextile filter fabric penetrated during installation shall be cut and wrapped to a height of 6" upward along the solid well section.

4. Larger piping material may be required to accommodate need for monitoring or data recording equipment.

| | | |
|---|---|---|
| trwd Tarrant Regional Water District | TARRANT REGIONAL WATER DISTRICT | REVISED: FEBRUARY 2018 |
| | **Observation Well** | **DM-DC 4.8.5** |




Notes

1. Anti-seep collars used in conjunction with Utility Sleeves (Section 4.8.7) shall be installed on the upstream and downstream end of the piping at each edge of the BMP facility. Anti-seep collars and Utility sleeves shall also be installed on all utility piping joints, bends, and splices that are within the BMP.

2. 'W' shall be 3' for pipes 12" and smaller.

3. Collar shall be constructed of 4000 psi compressive strength concrete or other material providing watertight connection compatible to pipe, as approved by a PE and reviewed by the TRWD.

4. Geomembrane Liner (Section 4.6.4) shall be used where anti-seep collars are required on vertical sides of the BMP. Liners shall be minimally cut to allow for the collar and sealed with the external sheets of the anti-seep collar.

5. All fittings and seals to be installed and tested to a water-tight seal per manufacturer specifications.

6. Hydrophilic water stops may be an allowable substitute for anti-seep collars for situations where the utility or other piping passes through a concrete structure.

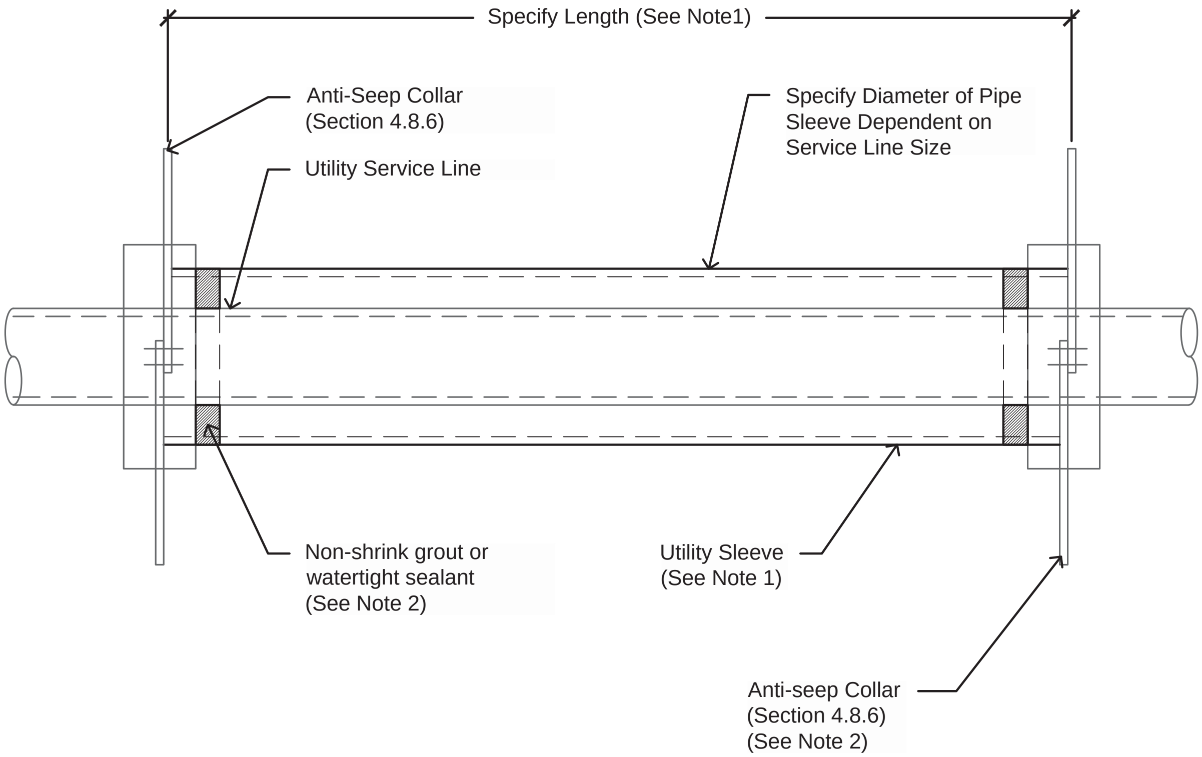
trwd Tarrant Regional Water District

TARRANT REGIONAL WATER DISTRICT

**Anti-Seep Collar**

REVISED: FEBRUARY 2018

**DM-DC 4.8.6**




# PROFILE

Notes

1. Length of required utility sleeve dependent on type of utility service and location within or adjacent to the BMP.
2. Seal surface of utility, utility sleeve and anti-seep collar (if necessary) with non-shrink grout or other sealant.
3. Anti-seep collars (Section 4.8.6) used in conjunction with utility sleeves shall be installed on the upstream and downstream end of the piping at each edge of the BMP facility. Anti-seep collars and Utility sleeves shall also be installed on all utility piping joints, bends, and splices that are within the BMP.

trwd Tarrant Regional Water District

TARRANT REGIONAL WATER DISTRICT

**Utility Sleeve**

REVISED: FEBRUARY 2018

**DM-DC 4.8.7**

## 4.9 PERMEABLE SURFACES

### DESCRIPTION

Permeable surfaces essentially function as inlets, collecting stormwater runoff that sheet flows from the surrounding area and allows it to infiltrate through the surface of the permeable pavement system and into the BMP media layer. Allowable permeable pavement systems include permeable pavers and porous pavers. Permeable asphalt is not an allowable permeable pavement system because this system is a developing practice that presents significant challenges during manufacturing and construction that can result in inconsistent performance.

### WHERE TO USE

Permeable surfaces could be considered in all areas where traditional concrete would be used, including, but not limited to sidewalks, street parking, and parking lots. In this type of application, the permeable surface infiltrates stormwater where it can be collected and conveyed subgrade to the BMP facility.

### DESIGN CONSIDERATIONS

- Permeable surfaces should not be implemented in areas where significant sedimentation or organic matter, such as nuts and leaves, is expected to accumulate.
- Permeable surfaces should be located downgradient and maintain a minimum distance of 10-feet from buildings and 50-feet from drinking water wells[1].
- Permeable surfaces should be designed to collect sheet flow.  Concentrated or point loading of stormwater runoff is not recommended.
- Underdrains (Section 4.8.1) shall be installed with all permeable surfaces used as an inlet. Underdrains shall be shown on the project's design drawings.

### DETAILS

#### 4.9.1 PERMEABLE PAVERS

Permeable pavers are solid, interlocking paving comprised of standard concrete or clay pavers that allow water to flow through joints between the individual paving units. The joints can be filled with open-graded, small aggregate or left open to allow for higher infiltration rates and ease of maintenance. Pavers can come in various shapes, sizes, finishes, and colors. See detail DM-DC 4.9.1 for additional information.

*Photo credit: CDM Smith*

*Photo credit: CDM Smith*

### 4.9.2 POROUS PAVERS

Porous pavers are typically comprised of cellular grid systems filled with porous material such as grass, sand, sand, or gravel. Stormwater is able to both infiltrate through and be stored in the porous material. The type of cellular grid system is dependent on vehicular or pedestrian usage. The grid systems are proprietary technology and require specific aggregate gradations to fill the grid system. TrueGrid® or approved comparable device are acceptable porous pavers. All products to be used for porous pavers will require approval by a licensed PE.


*Photo Credit: TrueGrid®[2]*


*Photo Credit: TrueGrid®*

### DESIGN SUBMITTAL REQUIREMENTS CHECKLIST

Design submittal requirements checklist may be applicable to all or some of the inlet components:

- Plan and detail view of permeable surfaces, including northing/easting of pavement extents, total surface area of permeable surface, and grading showing longitudinal slopes, cross slopes, and transition to adjacent grade.
- Typical detail of permeable surface layout pattern, if applicable.
- Calculation summary sheet for allowable sheet flows onto permeable surface area.
- Manufacturer information, including product number, materials, painting specifications, and fastener and frame details, as applicable.
- Approval of the fire department/emergency services if proposed in a fire lane area.

Component designs and specifications outside the parameters of this guideline shall be reviewed and approved by a licensed PE and submitted to TRWD for review.

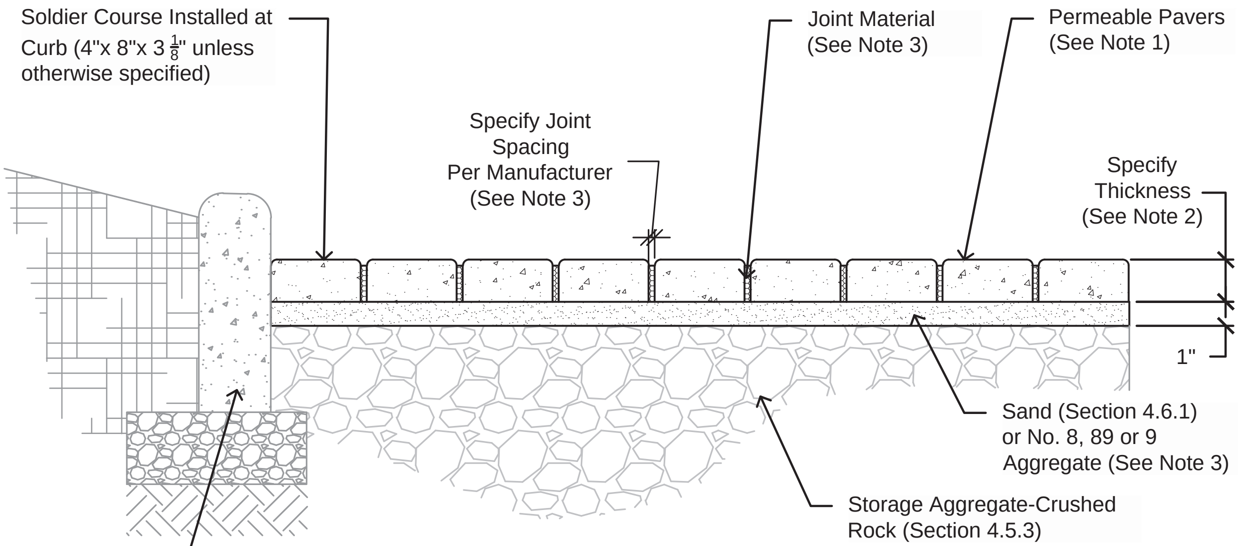
## ADDITIONAL RESOURCES

[1] North Central Texas Council of Governments. September 2014. iSWM™ Technical Manual. *Site Development Controls.*

[2] Porous pavers. TrueGrid®. Accessed August 2017. www.truegridpaver.com.

### DM-DC DRAWING RESOURCES

- American Society of State Highway and Transportation Officials. AASHTO HS-20 Loading.
- American Society for Testing and Materials International. 2016. C936 Standard Specification for Sold Concrete Interlocking Paving Units.
- American Society for Testing and Materials International. 2016. C1272 Standard for Heavy Vehicular Paving Brick.
- Texas Department of Licensing and Regulation. March 15, 2012. 2012 Texas Accessibility Standards.
- City of Fort Worth. December 12, 2016. Standard Construction Specification Documents. Section 33 05 10 Utility Trench Excavation, Embedment and Backfill.
- City of Fort Worth. December 20, 2012. Standard Construction Specification Documents. Section 32 14 16 Brick Unit Paving.
- Kevern, J. Pervious Concrete Mix Designs. Accessed: May 2, 2017. Web address: http://www.concretepromotion.com/pervious_mix_design.html.
- Texas Commission on Environmental Quality. November 2015. Rules and Regulations for Public Water Systems.




## SECTION

Notes

1. Permeable Paver material shall be either brick paver per City of Fort Worth STD Specification 32 14 16 or permeable interlocking concrete paver per ASTM C936. All pavers shall be laid in an interlocking pattern for increased stability. Attention shall be paid to joint material to ensure uniform spacing is achieved for application that do not use interlocking pavers.

2. Thickness of brick paver shall be a minimum of 2.25" unless specified per City of Fort Worth STD Specification 32 14 16. Thickness of a permeable interlocking concrete paver shall be dependent on usage (minimum of 2.75" for vehicular use and 2.25" for pedestrian use).

3. Joint material shall either be sand per Section 4.6.1 or No. 8, 89, or 9 per ASTM C33. For interlocking concrete paver systems, open joints with no jointing material may be acceptable per manufacturer requirements. Open joints shall not exceed 1/2" openings per Texas Accessibility Standards.

4. Pavers shall have chamfered edges.

5. See Section 3 for full pavement section requirements for permeable pavers.

trwd Tarrant Regional Water District

TARRANT REGIONAL WATER DISTRICT

**Permeable Pavers**

REVISED: FEBRUARY 2018

**DM-DC 4.9.1**

This page intentionally left blank.

## SECTION 5

# Water Quality Requirements Specific to Zone 1 (Panther Island)

## 5.1 INTRODUCTION AND BACKGROUND

To cost-effectively meet water quality goals from stormwater runoff originating from Panther Island, TRWD is requiring revised procedures for selecting and implementing water quality practices in Zone 1 (maps of which are included in Appendix F). The Panther Island form-based code implemented by the City of Fort Worth is designed to provide for high-density, mixed use developments. While the practices and procedures for Zones outside of Panther Island could be applied in Zone 1, it would be much costlier to property owners and also place more restrictions on how an owner/operator/developer of a property could use their available footprint to achieve the needed water quality goals while meeting other requirements expressed by the form-based code as each developer would be trying to individually place and maintain stormwater quality practices on their property.

The water quality requirements for Zone 1 are designed to achieve the same results in pollutant removal as they would from Zone 2. However, by constraining the number of available water quality practices that can be used in Zone 1 and placing them predominantly in the public right-of-way instead. This results in several benefits to TRWD, TRVA, and owner/operator/developers of properties:

1) It improves consistency with the Panther Island Form-Based Code (which is designed in-part to maintain look and feel compatibility among the many properties that will be built on the Island).
2) It removes most of the responsibility for operating and maintaining any stormwater quality treatment system from the owner/operator of the property and shifts it to Public Improvement District (PID) planned for Panther Island.
3) Because the number of available practices is constrained for Zone 1, this greatly increases the efficiency of stormwater quality management, substantially lowers the aggregate footprint (square footage) needed for stormwater treatment, and substantially reduces the cost of stormwater treatment for developers.

## 5.2 REQUIREMENTS SPECIFIC TO ZONE 1

TRWD's requirements for Zone 1 (Panther Island) in many ways simplify the implementation of this manual. The following are the specific requirements and restrictions for Zone 1:

1) The vast majority of stormwater treatment will be operated and maintained by the aforementioned PID (those treatment practices within a public right-of-way);
2) Placement and type of practice required will be reviewed and approved by TRWD for Zone 1 in accordance with this manual. Placement and type of practice may be adjusted accordingly based on additional evaluation by TRWD and reflected in subsequent versions of this manual. Therefore, those working to comply with this manual are encouraged to make sure they are working with the most recent version of the manual.
3) Currently, only bioretention basins (sections 3.2.3.3.1 and 3.2.3.2) and permeable surfaces in the form of pervious pavers (Section 3.9) may be used in public right-of-way locations approved by TRWD. Predominantly these will be distributive bioretention basins (Section 3.2.3.2).
4) Because of groundwater conditions on the island, all practices must have underdrains to collect and convey treated stormwater to stormwater drainage infrastructure.
5) Because of groundwater conditions on the island, it is critical that all practices, especially bioretention, have positive-side waterproofing consistent ASTM Standards (see references). Because groundwater is shallow, the significant incursion of groundwater into biorientation facilities may cause plants to die from excess water around root systems.
6) Additional treatment of stormwater may be required by TRWD for installation, operation, and maintenance by property owner/operators where the risk of pollutant discharge is increased such as in any directly-connected impervious surface (an example would be parking-garage rooftops with drainage directly to the Panther Island waterway or canals and no treatment between the two).
7) Larger detention practices (serving a larger number of properties) may be prescribed by TRWD and implementation of any larger practices for stormwater treatment is at TRWD's sole discretion in coordination with TRVA and its implementation of the Panther Island form-based code.

Figure 5.1 shows the current distribution of stormwater practices in the public right-of-way by practice-type and is subject to revision by TRWD.

## 5.3 REFERENCES

The following references are useful in specifying either elastomeric sheet waterproofing or hot fluid-applied, rubberized asphalt waterproofing (two of the more common techniques used to prevent groundwater intrusion). Other references will be needed for design purposes.

ASTM International. ASTM C 1305: Test Method for Crack Bridging Ability of Liquid-Applied Waterproofing Membrane. West Conshohocken, PA: ASTM, 2008.

ASTM D 5329: Test Methods for Sealants and Fillers, Hot-Applied, for Joints and Cracks in Asphaltic and Portland Cement Concrete Pavements. 2009.

ASTM D 6622: Guide for Application of Fully Adhered Hot-Applied Reinforced Waterproofing Systems. 2001 (Reapproved 2009).

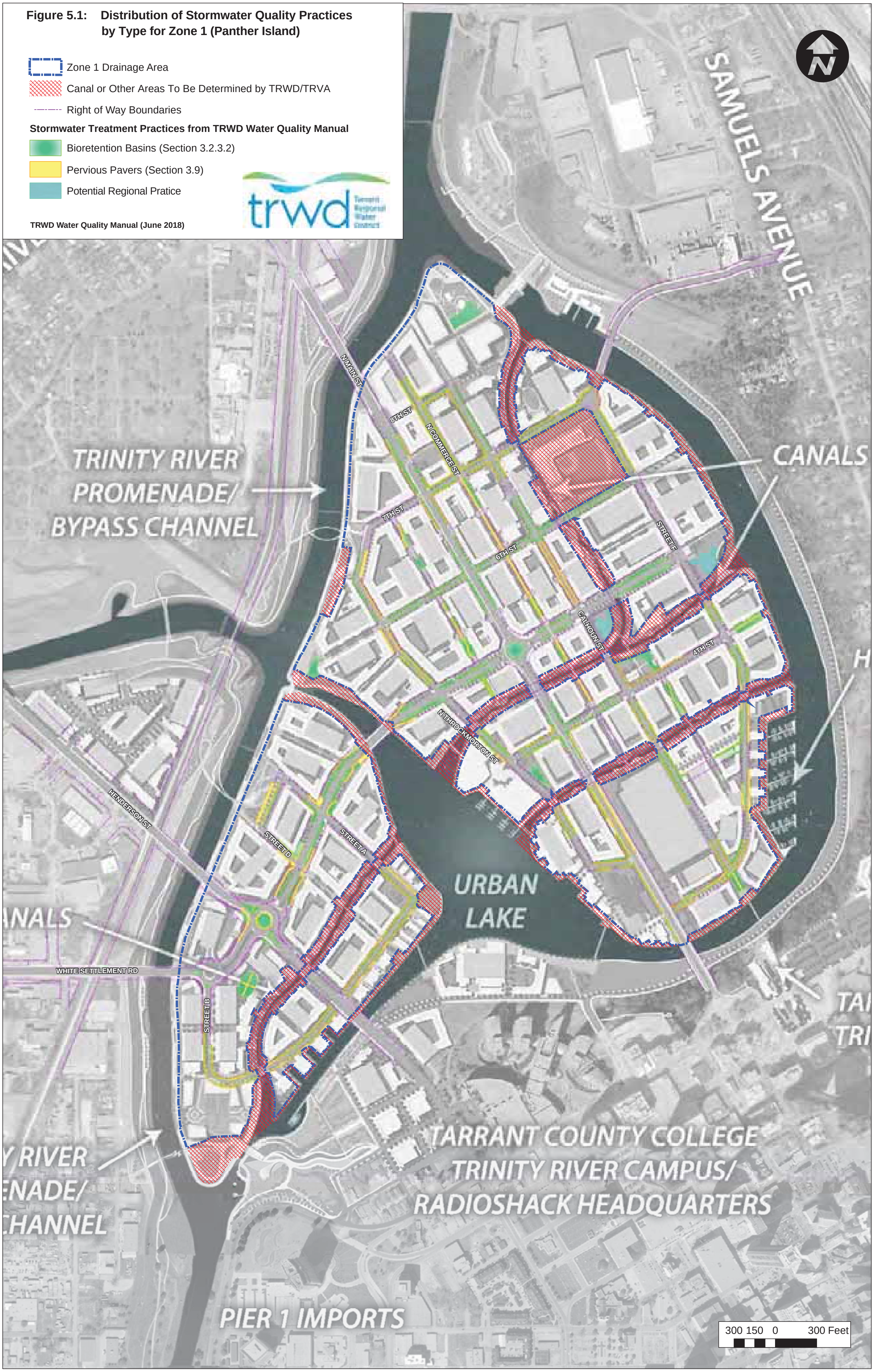
ASTM E 96/E 96M: Test Methods for Water Vapor Transmission of Materials. 2010.

Sealant, Waterproofing, and Restoration Institute. Below Grade Waterproofing Manual. Kansas City, MO: SWRI, 2000, (Available at www.swrionline.org)

ASTM International. ASTM D 5295: Guide for Preparation of Concrete Surfaces for Adhered (Bonded) Membrane Waterproofing Systems. West Conshohocken, PA: ASTM, 2000 (Reapproved 2006).

ASTM D 5898/D 5898M: Guide for Standard Details for Adhered Sheet Waterproofing. 1996 (Reapproved 2013).

**Figure 5.1: Distribution of Stormwater Quality Practices by Type for Zone 1 (Panther Island)**



# Appendix A

## Design Review Resources

This page intentionally left blank.

## APPENDIX A – DESIGN REVIEW RESOURCES

| | | Y or N | Notes |
|---|---|---|---|
| **Site Plan** | | | |
| Project Area | Does the plan set show the total project area and has the project area been defined correctly? | | |
| | Does the plan set include the drainage area for the BMP and has this been delineated correctly? | | |
| | Have all drainage plans and stormwater piping plans been included? | | |
| Water Quality Volume | Is the water quality volume calculated correctly? | | |
| | Has the BMP footprint and volume been calculated correctly to treat the entire water quality volume? | | |
| | Is flow diversion addressed? | | |
| **Site Activity Plan for BMP Projects** | | | |
| Runoff Management During Construction | Will the BMP facility be kept offline until construction is complete? Alternatively, the excavation can be used as a sediment trap during construction before filtration or other BMP media are placed in the basin. In that case, the bottom of the basin should not be excavated below 2-feet of the final grade. Engineer should authorize discharge of runoff into completed BMP facility. | | |
| | Will the upstream drainage areas be stabilized before installation of BMP components? | | |
| | Sediment accumulation in BMP must be promptly removed. Is this noted? | | |
| **BMP Design and Implementation** | | | |
| BMP Design Spreadsheets (Appendix E) | Have the necessary design sheets and specifications outlined in Sections 3 and 4 and Appendix E been completed and provided? | | |
| General BMP | Submittals include material certificates, aggregate gradation, contractor's qualifications, construction procedures, and quality control plan? | | |
| Maintenance | Facility Maintenance Agreement submitted? | | |
| | Facilities provided for maintenance access? | | |
| | Plan meets maintenance requirements? | | |
| | Is maintenance access provided for BMP facilities, including pre- and / or post-treatment? | | |

This page intentionally left blank.

# Appendix B

## BMP Fact Sheets

# Bioretention Basin

## Overview:

Bioretention basins are commonly used Best Management Practices (BMP) due to the effectiveness for pollutant load reduction and visual appeal. There are two main types of bioretention basins outlined in this manual: centralized and distributive. Centralized bioretention basins are intended for larger drainage areas and include a sedimentation forebay. Distributive bioretention basin can be implemented for drainage areas less than 1-acre. These are often placed adjacent to impervious surfaces to capture runoff directly. Bioretention basins utilize infiltration and filtration through soils and vegetation in depressed basins or landscape areas to provide both water quantity and water quality benefits. The vegetation, microbes, and soils in bioretention basins provide additional treatment and removal of pollutants from stormwater runoff.

*Rendering of Bioretention with Components (TRWD Developer Manual, 2018)*

## Benefits:

- Effective removal of suspended solids, heavy metals, adsorbed pollutants, nitrogen, phosphorous, and pathogens
- Based on soil conditions, groundwater levels, and geology, bioretention basins can be designed to provide groundwater recharge
- Flexible for use in urban retrofits or new development and can be used in both small and medium drainage basins
- Can be well integrated into landscaping and provide natural look and aesthetics

## Potential Constraints and Considerations:

- The design and construction of bioretention systems is critical to their performance
- Maintenance requirements may be time intensive and expensive
- Surface soil may require restoration or replacement if it becomes clogged (often after multiple years of operation)
- Plant materials and mulching require maintenance
- Effectiveness of BMP may be dependent upon site geology and soils, but an underdrain can be added if site soil infiltration capacity is insufficient. All aplications of this practice in Zone 1 (Panther Island) will require water proofing and underdrains due to high groundwater
- May be subject to drainage area size limitations

## Design Guidance:

All runoff from impervious surfaces should be directed towards BMPs. Important site parameters to be considered during design include the drainage area and the portion that is impervious, depth to the water table, permeability of soils, downstream water surface, and overall space required for the BMP. Bioretention basins can be designed using both centralized and distributed configurations, the main difference being the allowable drainage area and the inclusion of a sediment forebay. The water quality capture volume (WQV) should drain in less than 24-hours with a goal of 12-hours. The minimum components for a bioretention basin are as follows: stormwater inlet, pre- and post-treatment, energy dissipation, area protection (where necessary), BMP media, media barriers, landscaping, and outlets/piping. Refer to Section 4 of the TRWD Developer Manual for specific information on these components.


*Bioretention Basin with Components Labeled (CDM Smith, 2017)*

## Sizing Criteria:

The calculations below are from Section 3.2 of the TRWD Developer Manual. This table contains the main calculations for sizing the BMP. Reference Section 3.2 and Appendix E for the specific design calculations and criteria.

| Step | Parameter | Unit |
|---|---|---|
| **STEP 1** | **WATER QUALITY VOLUME** ($WQ_v = DA*[d_t/(12in/ft)]*43{,}560ft^3/ac$) | $ft^3$ |
| | Contributing Drainage Area (DA) | ac |
| | Capture Depth for 12 Hour or 24 Hour Drawdown Time ($d_t$) | in |
| **STEP 2** | **SEDIMENT FOREBAY VOLUME** (Vbc = 10%WQv) *(if required)* | $ft^3$ |
| **STEP 3** | **TOTAL AVAILABLE BIORETENTION STORAGE VOLUME** | $ft^3$ |
| | Top of ponding surface area ($SA_T$) | ft |
| | Bottom of ponding surface area ($SA_B$) | ft |
| | Ponding depth ($d_h$) | in |
| | Void ratio | - |
| | Storage aggregate depth (df) | in |
| **STEP 4** | **ORIFICE DIAMETER** ($d_o=2*(A_o/\pi)^{0.5}$) | in |
| | Max. discharge of WQv ($Q_o$) | $ft^3/s$ |
| | Drain time ($t_d$) | hr |
| | Orifice opening area ($A_o$) | $in^2$ |
| | Orifice coefficient (c) | - |
| | Average head ($H_{avg}$) | ft |

## Inspection and Maintenance Requirements:

Inspections help to ensure that the bioretention basin continues to operate effectively and as designed throughout its lifespan. Regular inspection also indicates when certain maintenance practices are necessary. Like inspection, regular maintenance keeps the BMP operating smoothly and prolongs, or eliminates, the need for intensive rehabilitation such as side slope restabilization or replacing of corroded pipes. The table below outlines the regular and as-needed maintenance practices for bioretention basins. Specific information on inspection and maintenance requirements can be found in Appendix D of the TRWD Developer Manual.

***Regular Maintenance***

| MAINTENANCE ACTION | FREQUENCY |
|---|---|
| Mow grassy areas | Annually or more frequently during growing season |
| Prune excessive vegetation/ branches | Annually or more frequently during growing season |
| Replant annuals | Before corresponding growing season |
| Clearing trash, debris, and foliage | Monthly |

***As-Needed Maintenance***

| INSPECTION ISSUE | FREQUENCY |
|---|---|
| Standing water after design storm event and drawdown time | Check the inlet/outlet for clogging. Clear if present. Check for excessive fines/hard-packing on the surface |
| Foul odors or insects such as mosquitos | Promote insect predators and/or prevent stagnant water |
| Inlet/outlets clogged with debris | Clear out accumulated debris. Install debris screens. |
| Accumulated sediment/debris | Dredge or remove accumulated sediment or debris to design elevations. Vacuum clogged permeable surfaces. |
| Poor vegetative health / invasive species | Replant vegetation and remove invasive species, taking care not to spread seeds/ spores. |
| Excessive or overgrown vegetation | Prune the excessive/overgrown vegetation. |
| Banks/slopes eroded | Repair banks/slopes such that they match design slopes. Install energy dissipaters or flow diversions. |
| Signs of channeling or worn paths | Mow or possibly regrade. |
| Pipe corrosion | Replace piping. Consider different material or covering the pipe with a corrosion resistant coating. |

## Pollutant Removal Effectiveness:

| POLLUTANT | REMOVAL EFFECTIVENESS* |
|---|---|
| Sediment | High |
| Nutrients | Moderate |
| Trash | High |
| Metals | High-Moderate |
| Bacteria | High |
| Oil and Grease | High |
| Organics | Moderate |

*(SARA, 2013; iSWM, 2014; and TCEQ, 2005)*
**Removal effectiveness varies dependent on infiltration capacity and design*

***References or Future Reading:***
*"Complying with the Edwards Aquifer Rules: Technical Guidance on Best Management Practices". July 2005. TCEQ. RG-348. Accessed September 2017. < http://www.storm-tex.com/wp-content/uploads/2016/04/TCEQ_RG-348.pdf >.*
*"iSWM Technical Manual: Site Development Controls". (2014). North Central Texas Council of Governments. Accessed September 2017. < http://iswm.nctcog.org/Documents/technical_manual/Site_Development_Controls_9-2014.pdf >.*
*Roach, V. (CDM Smith). March 6, 2017. "Green Infrastructure Design in Your CSO Long Term Control Plan". NJ Water Environment Association: Winter Technology Transfer Seminar. New Jersey. Presentation. Accessed September 2017.*
*"San Antonio River Basin Low Impact Development Technical Design Guidance Manual". (2013). San Antonio River Authority. Accessed September 2017. < https://www.sara-tx.org/wp-content/uploads/2015/05/Full-LID-Manual.pdf >.*
*"Tarrant Regional Water District Developer Manual". (2018). Tarrant Regional Water District (TRWD).*

trwd Tarrant Regional Water District

# Constructed Wetlands

## Overview:

Constructed Wetlands, also referred to as stormwater wetlands, are designed to permanently hold water and increase detention time between storm events for improved treatment. This Best Management Practice (BMP) requires more land than other BMPs and a constant source of influent water. However, constructed wetlands can be an excellent option for improving water quality. Constructed wetlands employ complementary mechanisms (i.e. physical and biological) to effectively treat stormwater inflow. The slow, sinuous flow and extended detention time promotes particle settling and plant uptake. Because this BMP is not intended for infiltration, its stormwater runoff volume reduction is minimal, except through evaporation and evapotranspiration. As such, constructed wetlands are ideal at the end of a storm-to-stream sequence for final treatment before discharge into a stream. Constructed wetlands can provide site aesthetics and provide habitat for local wildlife.

## Benefits:

- Well suited for removal of particulate matter and some dissolved contaminants (TCEQ, 2005)
- Provides an aesthetically pleasing space for the surrounding community
- Provides wildlife habitat (see note below on bacterial indicator loads)
- Effective for large tributary areas

## Potential Constraints and Considerations:

- Requires continuous source of base flow (i.e. stormwater and dry weather inflow or make-up water inflow)
- Potential significant maintenance costs and large amounts of sediment removal to prevent pond stagnation, floating debris, scum, algal blooms, and unpleasant odor (TCEQ, 2005).
- Potential accumulation of salts and scum that can be discharged during large storm events
- Proper design must be used to prevent habitat for undesirable insects such as mosquitos
- May not be appropriate for locations with high groundwater levels due to potential for contamination
- Overgrowth and sediment accumulation may reduce hydraulic capacity
- Wildlife are a potential source of bacteria indicator loads

*(iSWM, 2014; EPA, 2009)*

## Design Guidance:

All runoff from impervious surfaces should be directed towards the BMP. Important site considerations during design include the drainage area and the proportion of which is impervious, depth to the water table, permeability of soils, downstream water surface, and overall space required for the BMP. A long, sinuous flow path promotes pollutant removal. A micropool has been added at the outlet to improve maintenance and provide additional treatment before discharge. The water quality volume (WQV) should drain within 24 hours. The minimum components for a constructed wetland include, a stormwater inlet, pre- and post-treatment, energy dissipation, area protection, landscaping, and outlets/piping. Refer to Section 4 of the TRWD Design Manual for specific information on these components.

*Constructed Wetland Rendering (TRWD Design Manual, 2018)*

## Sizing Criteria:

The calculations below are from Section 3.3 of the TRWD Design Manual. This table contains the main calculations for sizing the BMP. Reference Section 3.3 and Appendix E for the specific design calculations and criteria.

| | | |
|---|---|---|
| STEP 1 | WATER QUALITY VOLUME ($WQ_v = DA*[d_t/(12in/ft)]*43,560ft^3/ac$) | $ft^3$ |
| | Contributing Drainage Area (DA) | ac |
| | Capture Depth for 24 Hour Drawdown Time ($d_t$) | in |
| STEP 2 | Sediment Forebay Volume ($V_{fb}$ = 0.1in per impervious acre of drainage area) | $ft^3$ |
| | Impervious Drainage Area ($A_{imp}$) | $ft^2$ |
| STEP 3 | Basin Volume ($V_B = V_P + V_S$) | $ft^3$ |
| | Permanent Pool Volume ($V_P$) = 100% $WQ_v$ | $ft^3$ |
| | Surcharge Pool Volume ($V_S$) = 120% $WQ_v$ | $ft^3$ |
| STEP 4 | Orifice Diameter ($d_o=2*(A_o/\pi)^{0.5}$) | in |
| | Max. discharge of $WQ_v$ ($Q_o$) | $ft^3/s$ |
| | Drain time ($t_d$) | hr |
| | Orifice coefficient (c) | - |
| | Average head ($H_{avg}$) | ft |
| | Orifice opening area ($A_o$) | $in^2$ |

## Inspection and Maintenance Requirements:

Inspections help to ensure that the constructed wetland continues to operate effectively and as designed throughout its lifespan. Regular inspection also indicates when certain maintenance practices are necessary. Like inspection, regular maintenance keeps the BMP running smoothly and prolongs, or eliminates, the need for intensive rehabilitation such as side slope restabilization or replacing of corroded pipes. The table below outlines the regular and as-needed maintenance practices for constructed wetlands. Specific information on inspection and maintenance requirements can be found in Appendix D of the TRWD Design Manual.

***Regular Maintenance***

| MAINTENANCE ACTION | FREQUENCY |
|---|---|
| Clear trash, debris, weeks, and foliage | Monthly or as needed |
| Mow grassy areas | Annually, but monthly during growing season |
| | Before corresponding growing season |
| Prune excessive vegetation / branches | Annually, but monthly during growing season |
| Replant Annuals | Before corresponding growing season |

*Constructed Wetland (CDM Smith, 2017)*

***As-Needed Maintenance***

| INSPECTION ISSUE | FREQUENCY |
|---|---|
| Standing water after drawdown period | Check the inlet/outlet for clogging. |
| Foul odors or insects such as mosquitos | Retrofit BMP to prevent stagnant water |
| Inlet/outlets clogged with debris | Clear out accumulated debris. Install debris screens. |
| Accumulated sediment/ debris higher than limit | Dredge or remove accumulated sediment or debris to design elevations. Vacuum clogged permeable surfaces. |
| Poor vegetative health / invasive species | Replant vegetation and remove invasive species, taking care not to spread seeds/spores. |
| Excessive or overgrown vegetation | Prune the excessive/overgrown vegetation. |
| Banks/slopes eroded | Repair banks/slopes such that they match design slopes. Install energy dissipaters or flow diversions. |
| Signs of channeling or worn paths | Assess drainage conditions. Consider regrade. |
| Broken or missing area protection | Repair or replace area protection. |
| Pipe corrosion | Replace piping. If reoccurring issue, consider different material or covering the pipe with a corrosion resistant coating. |

## Pollutant Removal Effectiveness:

| POLLUTANT | REMOVAL EFFECTIVENESS* |
|---|---|
| Sediment | High |
| Nutrients | Medium to High |
| Trash | High |
| Metals | Medium |
| Bacteria | High** |
| Oil and Grease | High |
| Organics | High** |

**(SARA Manual, 2013; Clary, J. 2017)*
*** Wetlands or other BMPs with wildlife habitat can have high internal loads of bacterial indicators, nutrients, and organics*


***References or Future Reading:***

*"Complying with the Edwards Aquifer Rules: Technical Guidance on Best Management Practices". July 2005. TCEQ. RG-348. Accessed September 2017. < http://www.storm-tex.com/wp-content/uploads/2016/04/TCEQ_RG-348.pdf >.*
*"iSWM Technical Manual: Site Development Controls". (2014). North Central Texas Council of Governments. Accessed September 2017. < http://iswm.nctcog.org/Documents/technical_manual/Site_Development_Controls_9-2014.pdf >.*
*Clary, J. et al. "International Stormwater BMP Database 2016 Summary Statistics: Final Report". (2017). The Water Environment & Reuse Foundation. Accessed September 2017. < http://www.bmpdatabase.org/Docs/03-SW-1COh%20BMP%20Database%202016%20 Summary%20Stats.pdf >.*
*"San Antonio River Basin Low Impact Development Technical Design Guidance Manual". (2013). San Antonio River Authority. Accessed September 2017. < https://www.sara-tx.org/wp-content/uploads/2015/05/Full-LID-Manual.pdf >.*
*"Stormwater Wet Pond and Wetland Management Guidebook". February 2009. EPA. EPA 833-B-09-001.*
*"Tarrant Regional Water District Developer Manual". (2018). Tarrant Regional Water District (TRWD).*


trwd Tarrant Regional Water District

# Extended Dry Detention Basins

## Overview:

Extended dry detention basins are a type of Best Management Practice (BMP) used for temporary storage of stormwater during small to moderate storm events. This BMP is designed to provide flood control by mitigating or regulating runoff while the extended storage promotes particle settling. Extended dry detention basins can be combined easily with other water quality treatment BMPs for holistic stormwater management and are meant for larger drainage areas. Unlike wet ponds and constructed wetlands, extended dry detention basins should drain completely after a storm and remain dry between storm events.

*Extended Dry Detention Basin, City of Lenexa, KS*

## Benefits:

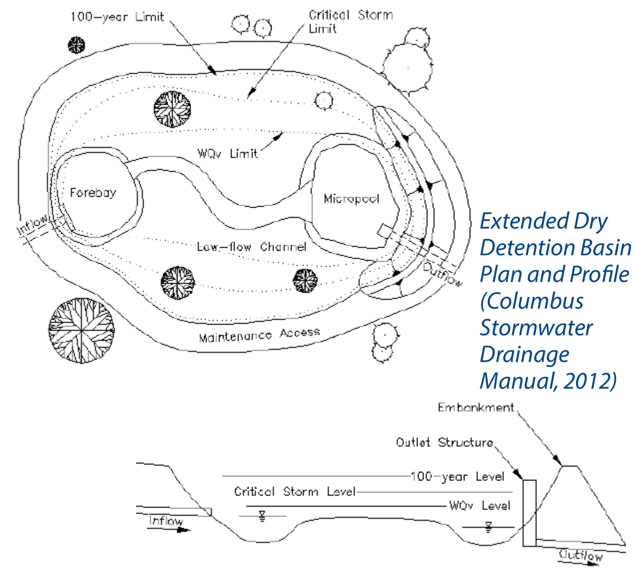
- Easily incorporated into a sequence of BMPs for holistic treatment of stormwater
- Provides temporary stormwater storage to mitigate downstream flooding
- Effective for larger drainage areas
- Can be used for recreation between storm events
- Relatively low cost compared to other BMPs such as wet ponds due to less excavation
- Requires less stringent maintenance than other BMPs which maintain permanent pools throughout the year
- If properly prevented, less chance of harboring pests such as mosquitoes than other BMPs with permanent pools of water

## Potential Constraints and Considerations:

- Limited effectiveness for some pollutants. Coordinate with other BMPs where possible or include pre- / post-treatment
- Water quality treatment is limited to small to moderate storm events

## Design Guidance:

The first step in design is to accurately delineate the drainage area of the BMP. Next, all runoff from impervious surfaces should be directed towards the BMP. Important site considerations during design include the drainage area and the portion of which is impervious, depth to the water table, permeability of soils, downstream water surface, and overall space required for the BMP. Micropools should be included at the outlet for maintenance and water quality benefits. The water quality volume (WQv) should drain within 40 to 48 hours. The minimum components for an extended dry detention basin include, a stormwater inlet, pre- and post-treatment, energy dissipation, area protection, landscaping, and outlets/piping. Refer to Section 4 of the TRWD Developer Manual for specific information on these components.




*Extended Dry Detention Basin Plan and Profile (Columbus Stormwater Drainage Manual, 2012)*

*Rendering of an Extended Dry Detention Basin and Components After a Storm (TRWD Developer Manual, 2018)*

## Sizing Criteria:

The calculations below are from Section 3.6 of the TRWD Developer Manual. This table contains the main calculations for sizing the BMP. Reference Section 3.6 and Appendix E for the specific design calculations and criteria.

| | | | |
|---|---|---|---|
| **STEP 1** | **Water Quality Capture Volume** | $(WQ_v = A_D*[d_t/(12in/hr)]*43{,}560ft^3/ac)$ | $ft^3$ |
| | Contributing Drainage Area ($A_D$) | | ac |
| | Capture Depth for 48 Hour Drawdown Time ($d_t$) | | in |
| **STEP 2** | **Sediment Forebay Volume** | $(V_{fb} = 10\%WQ_v)$ | $ft^3$ |
| **STEP 3** | **Basin Volume** | $(V_B = 100\% WQ_v)$ | $ft^3$ |
| **STEP 4** | **Orifice Diameter** | $(d_o=2*(A_o/\pi)^{0.5})$ | in |
| | Max. discharge of WQv ($Q_o$) | | $ft^3/s$ |
| | Drain time (td) | | hr |
| | Orifice opening area ($A_o$) | | $in^2$ |
| | Orifice coefficient (c) | | - |
| | Average head ($H_{avg}$) | | ft |

## Inspection and Maintenance Requirements:

Inspections help to ensure that the extended dry detention basin continues to operate effectively throughout its lifespan. Regular inspection also indicates when certain maintenance practices are necessary. Like inspection, regular maintenance keeps the BMP running smoothly and prolongs, or eliminates, the need for intensive rehabilitation such as side slope restabilization or replacing of corroded pipes. The table below outlines the regular and as-needed maintenance practices for extended dry detention basins. Specific information on inspection and maintenance requirements can be found in Appendix D of the TRWD Developer Manual.

***Regular Maintenance***

| MAINTENANCE ITEMS | FREQUENCY |
|---|---|
| Clear trash, debris, weeks, and foliage | Monthly or as needed |
| Mow lawn | Annually, but monthly during growing season |
| Replant Annuals | Before corresponding growing season |

***As-Needed Maintenance***

| INSPECTION ISSUE | FREQUENCY |
|---|---|
| Standing water after drawdown period | Check the inlet/outlet for clogging. Check for excessive fines/hard-packing on the surface |
| Foul odors or insects such as mosquitos | Retrofit BMP to prevent stagnant water |
| Inlet/outlets clogged with debris | Clear out accumulated debris |
| Accumulated sediment/debris higher than limit | Dredge or remove accumulated sediment. Vacuum clogged permeable surfaces. |
| Poor vegetative health / invasive species | Replant vegetation and remove invasive species. |
| Excessive or overgrown vegetation | Prune the excessive/overgrown vegetation. |
| Banks/slopes eroded | Repair banks/slopes such that they match design slopes. Install energy dissipaters or flow diversions if reoccurring issue. |
| Signs of channeling or worn paths | Mow or possibly regrade. |
| Broken or missing area protection | Repair or replace area protection. |
| Pipe corrosion | Replace piping. Consider different material or cover the pipe with a corrosion resistant coating. |

## Pollutant Removal Effectiveness:

| POLLUTANT | REMOVAL EFFECTIVENESS* |
|---|---|
| Sediment | Medium |
| Nutrients | Low to Medium |
| Trash | High |
| Metals | Medium |
| Bacteria | Medium to High |
| Oils and Grease | No Data |
| Organics | Low |

*(iSWM, 2014; TCEQ, 2005; International Stormwater BMP Database, 2017)*
**nutrient, metals, and organics removal when bound to sediments that are removed*

***References or Future Reading:***
*"Complying with the Edwards Aquifer Rules: Technical Guidance on Best Management Practices". July 2005. TCEQ. RG-348. Accessed September 2017. < http://www.storm-tex.com/wp-content/uploads/2016/04/TCEQ_RG-348.pdf >.*
*Extended Dry Detention Basin. "Green Infrastructure". (no year pub.). City of Lenexa, Kansas. Image. Accessed September 2017. < http://www.lenexa.com/government/departments____divisions/rain_to_recreation/learn_more/green_infrastructure/ >.*
*"Facilities". Stormwater Partners. Image. Accessed January 2018. < http://www.stormwaterpartners.com/facilities/index.html >.*
*"iSWM Technical Manual: Site Development Controls". (2014). North Central Texas Council of Governments. Accessed September 2017. < http://iswm.nctcog.org/Documents/technical_manual/Site_Development_Controls_9-2014.pdf >.*
*"San Antonio River Basin Low Impact Development Technical Guidance Manual". (2013). San Antonio River Authority. 1st edition. Accessed September 2017. < https://www.sara-tx.org/wp-content/uploads/2015/05/Full-LID-Manual.pdf >.*
*"Columbus Stormwater Drainage Manual". (2012). The City of Columbus: Division of Sewerage and Drainage. Accessed September 2017. < https://www.columbus.gov/uploadedFiles/Public_Utilities/Document_Library/Publications/Sewer/StormwaterDrainageManual.pdf >.*
*"Tarrant Regional Water District Developers Manual". (2018) Tarrant Regional Water District (TRWD).*
*"BMP Database Tool: Texas BMPs." (2016). International Stormwater BMP Database. Accessed August 2017. <http://bmpdatabase.org/retrieveBMPs.asp>*

trwd Tarrant Regional Water District

# Permeable Surfaces

## Overview:

Permeable surfaces are a type of Best Management Practice (BMP) that treats stormwater sheet flow over what would alternatively be conventional impervious surfaces. This type of stormwater BMP consists of permeable pavers, porous concrete, porous asphalt, and grassed-modular grid systems. The TRWD Developer Manual (DM) only covers the use of permeable pavers. Permeable pavers can be used to replace or in place of impervious surfaces and to temporarily store water in the storage aggregate layer. The overall performance of permeable surfaces is variable based on design, duration of use, and frequency of maintenance.

*Permeable pavers and porous concrete sidewalk (CDM Smith, 2017)*

*Permeable pavers – aggregate joints (S. Landgren, 2011)*

## Benefits:

- Permeable pavers are easily adapted to site layout plan
- Can be effective at reducing runoff rate and volume instead of traditional impervious areas
- Can reduce stormwater infrastructure footprint requirements of downstream BMPs
- Promotes dual-purpose usage of pavement as a transportation surface and water treatment media
- Can be used to reduce stormwater pollutants loading to downstream surface waters

## Potential Constraints and Considerations:

- Regular maintenance required to prevent clogging of porous media by sediment, which may result in reduced pollutant removal effectiveness (SARA Manual, 2013)
- Permeable surfaces have potential to compress and lose permeability when installed in areas subject to heavy vehicle loads.
- Restricted to surfaces with minimal slopes
- Restricted to grades of 5% or less. 2% or less is recommended.

*Permeable pavers and rain gardens (Harroch, W., et al., 2017)*

## Design Guidance:

The first step is accurate delineation of the drainage area of the BMP. Important site considerations during design include the drainage area and the portion of which is impervious, depth to the water table, permeability of soils, downstream water surface, and overall space required for the BMP. When delineating the drainage area and considering use of permeable pavers, the recommended ratio of treated drainage area to permeable pavers surface area is 1.5 to 1. The water quality capture volume (WQv) should drain completely between 12 hours to 48 hours after the storm event. The minimum components for permeable pavers are as follows: area protection, BMP media, media barriers, outlets/piping, and permeable surfaces. Refer to Section 4 of the TRWD DM for specific information on these components.

*Rendering of permeable pavers with components after a storm (TRWD DM, 2018)*


*Pervious Pavement, National Association of City Transportation Officials*

## Sizing Criteria:

The calculations below are from Section 3.8 of the TRWD Developer Manual. This table contains the main calculations for sizing the BMP. Reference Section 3.8 and Appendix E for the specific design calculations and criteria.

| | | | |
|---|---|---|---|
| **STEP 1** | **Water Quality Capture Volume** | ($WQ_v = DA*[d_t/12 * 43{,}560 ft^3/ac)$ | $ft^3$ |
| | Contributing Drainage Area (DA) | | ac |
| | Capture Depth for 24 Hour Drawdown Time ($d_t$) | | in |
| **STEP 2** | **Required Permeable Surface Area** | ($SA_P = DA/1.5$) | $ft^2$ |
| **STEP 3** | **Orifice Diameter** | ($d_o = 2*(A_o/\pi)^{0.5}$) | in |
| | Max. discharge of WQv ($Q_o$) | | $ft^3/s$ |
| | Drain time ($t_d$) | | hr |
| | Orifice opening area ($A_o$) | | $in^2$ |
| | Orifice coefficient (c) | | - |
| | Average head ($H_{avg}$) | | ft |

## Inspection and Maintenance Requirements:

Inspections help to ensure that the permeable pavers continue to operate effectively and as desgined throughout their lifespan. Regular inspection also indicates when certain maintenance practices are necessary. Like inspection, regular maintenance keeps the BMP running smoothly and prolongs, or eliminates, the need for intensive rehabilitation such as side replacing pavers. The table below outlines the regular and as-needed maintenance practices for permeable pavers. Specific information on inspection and maintenance requirements can be found in Appendix D of the TRWD DM.

***Regular Maintenance***

| MAINTENANCE ITEMS | FREQUENCY |
|---|---|
| Clear trash, debris, and foliage | Monthly or as needed |
| Vacuum sweeping | Annually |

***As-Needed Maintenance***

| INSPECTION ISSUE | ACTION |
|---|---|
| Pooling of water over surface course 48 hours after storm event | Additional vacuum sweeping when dry |
| Significant deterioration of surface course or pavers and structural integrity of pavement, inlets/ outlets, and observation wells | Possible replacement of surface course, pavers, inlets/outlets, and observation well components depending on severity |
| Inlet/outlets clogged with debris | Clear out accumulated debris. If needed and not installed previously, install debris screens. |
| Pipe corrosion | Replace piping. If reoccurring issue, consider different material or covering the pipe with a corrosion resistant coating. |

## Pollutant Removal Effectiveness:

| POLLUTANT | REMOVAL EFFECTIVENESS* |
|---|---|
| Sediment | High |
| Nutrients | Low** |
| Trash | High |
| Metals | Medium |
| Bacteria | High |
| Oil and Grease | Medium |
| Organics | Low |

**(SARA, 2013; International Stormwater BMP Database, 2017)*
*** Removal occurs when associated with retainment of nutrient- and metal-bound sediments or filtering oil/grease on underlying soil media.*

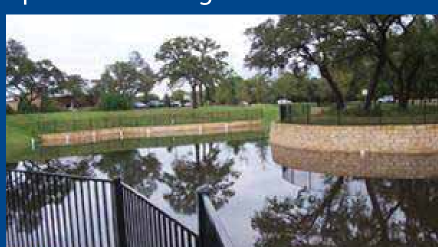

***References or Future Reading:***

*Harrouch, W., Roach, V., and M. Dodson (CDM Smith). October 23, 2017. "Turning Ultra Urban Into Ultra Green for CSO Control in the Bronx". Main Stormwater Conference. Portland, Maine. Presentation. Accessed September 2017.*
*"iSWM Technical Manual: Site Development Controls". (2014). North Central Texas Council of Governments. Accessed September 2017. < http://iswm.nctcog.org/Documents/technical_manual/Site_Development_Controls_9-2014.pdf >.*
*Landgren, S. "Hartford, CT Green Capitals Project". (2011). CDM Smith. Photograph.*
*"Pervious Pavement". (no year). National Association of City Transportation Officials. Accessed September 2017. < https://nacto.org/publication/urban-street-design-guide/street-design-elements/stormwater-management/pervious-pavement/ >.*
*Roach, V. (CDM Smith). March 6, 2017. "Green Infrastructure Design in Your CSO Long Term Control Plan". NJ Water Environment Association: Winter Technology Transfer Seminar. New Jersey. Presentation. Accessed September 2017.*
*"San Antonio River Basin Low Impact Development Technical Design Guidance Manual". (2013). San Antonio River Authority. Accessed September 2017. < https://www.sara-tx.org/wp-content/uploads/2015/05/Full-LID-Manual.pdf >.*
*"Tarrant Regional Water District Developer Manual". (2018). Tarrant Regional Water District (TRWD).*
*"Tennessee Permanent Stormwater Management and Design Guidance Manual". December 2014. Tennessee Department of Environment and Conservation. 1st ed. Accessed September 2017. < https://app.box.com/s/pdl1afehg00s1wwqa94d8qmizyptxw3i/file/25367692645 >.*

# Retention & Irrigation Basin

## Overview:

Retention/irrigation basins are a Best Management Practice (BMP) used to collect stormwater runoff with the intention of using it for irrigation of appropriate landscape areas. Unlike other BMPs such as extended dry detention basins or wet basins, retention/irrigation basins use mechanical components such as pumps, wet wells, and an irrigation system. Retention/irrigation basins typically are used in large contributing drainage areas, but site selection must be balanced with available landscape area to irrigate. This BMP relies on the infiltration capacity of the irrigated areas to discharge the full captured water quality volume (WQv). While the sediment forebay removes the majority of the suspended solids, collected water is treated further through infiltration and plant uptake in the irrigated area.



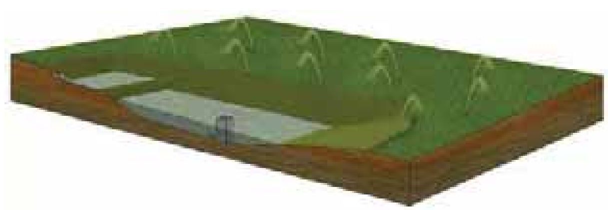
*Retention irrigation pond (City of Austin Watershed Protection Department, TX)*

## Benefits:

- Excellent pollutant removal through filtration of sediments, pollutant-bound sediments, oils, greases, and other organics as well as uptake of nutrients and some metals by vegetation when properly designed, constructed, and maintained
- Beneficial for areas that do not have much rainfall because it can reduce irrigation demand on groundwater
- Can provide indirect groundwater recharge through infiltration

## Potential Constraints and Considerations:

- Maintenance requirements and costs to keep the irrigation system operational are potentially high (TCEQ, 2005)
- Must match the amount of irrigated land to the captured stormwater volume
- Potential for groundwater contamination if inadequate soil coverage over irrigated areas (TCEQ, 2005; iSWM, 2014)
- This system requires mechanical components such as pumps, irrigation system, and electrical power which adds additional cost to the BMP



*Retention/irrigation basin and components rendering after storm event (TRWD Developer Manual, 2018)*

## Design Guidance:

First, accurately delineate the drainage area of the BMP. Next, all runoff from impervious surfaces should be directed towards the BMP. Important site considerations during design include the drainage area and the portion of which is impervious, depth to the water table, permeability of soils, downstream water surface, and overall space required for the BMP. Retention/irrigation basins range from dry-concrete basins to vegetated basins with a permanent pool. Stored water drains to a wet well outside of the basin and is then pumped to irrigate a landscaped area. The minimum components for an extended dry detention basin include, a stormwater inlet, pre- and post-treatment, energy dissipation, area protection, landscaping, and outlets/piping. Refer to Section 4 of the TRWD Developer Manual for specific information on these components. Retention/irrigation basins also require wet wells, pumps, and an irrigation system.

*Retention basin, outlet, and inlet structure (Kannan, 2014)*

## Sizing Criteria:

The calculations below are from Section 3.5 of the TRWD Developer Manual. This table contains the main calculations for sizing the BMP. Reference Section 3.5 and Appendix E for the specific design calculations and criteria.

| | | |
|---|---|---|
| STEP 1 | **Water Quality Capture Volume** ($WQ_v = DA*[d_t/(12in/hr)]*43{,}560ft^3/ac$) | $ft^3$ |
| | Contributing Drainage Area (DA) | ac |
| | Capture Depth ($d_t$) | in |
| STEP 2 | **Sediment Forebay Volume** ($V_{fb}$ = 0.1in per impervious acre of drainage area) | $ft^3$ |
| | Impervious Drainage Area ($A_{imp}$) | $ft^2$ |
| STEP 3 | **Retention Basin Volume** ($V_{RB}$ = 100% $WQ_v$ or 2.2WQv if includes a permanent pool) | $ft^3$ |
| STEP 4 | **Orifice Diameter** ($d_o=2*(A_o/\pi)^{0.5}$) | in |
| | Max. discharge of WQv ($Q_o$) | $ft^3/s$ |
| | Drain time ($t_d$) | hr |
| | Orifice opening area ($A_o$) | $in^2$ |
| | Orifice coefficient (c) | - |
| | Average head ($H_{avg}$) | ft |
| STEP 5 | **Irrigation Area** ($A_i=[(12in/ft)WQ_v]/[60r]$) | in |
| | Soil permeability (r) | in/hr |

## Inspection and Maintenance Requirements:

Inspections help to ensure that the retention/irrigation basin continues to operate effectively and as designed throughout its lifespan. Regular inspection also indicates when certain maintenance practices are necessary. Like inspection, regular maintenance keeps the BMP running smoothly and prolongs, or eliminates, the need for intensive rehabilitation such as side slope restabilization or replacing of corroded pipes. The table below outlines the regular and as-needed maintenance practices for retention/irrigation basins. Specific information on inspection and maintenance requirements can be found in Appendix D of the TRWD Developer Manual.

***Regular Maintenance***

| MAINTENANCE ITEMS | FREQUENCY |
|---|---|
| Clear trash, debris, weeks, and foliage | Monthly or as needed |
| Mow lawn | Annually, but monthly during growing season |
| Prune excessive vegetation / branches | Annually, but monthly during growing season |

***As-Needed Maintenance***

| INSPECTION ISSUE | ACTION |
|---|---|
| Standing water after design storm event and drawdown time | Check the inlet/outlet for clogging. Clear if necessary. Check for excessive fines/hard-packing on the surface. |
| Foul odors or insects such as mosquitos | Retrofit BMP to prevent stagnant water |
| Inlet/outlets clogged with debris | Clear out accumulated debris. |
| Accumulated sediment/debris higher than limit | Dredge or remove accumulated sediment or debris to design elevations. |
| Poor vegetative health / invasive species | Replant vegetation and remove invasive species. |
| Excessive or overgrown vegetation | Prune the excessive/overgrown vegetation. |
| Banks/slopes eroded | Repair banks/slopes. Install energy dissipaters or flow diversions. |
| Signs of channeling or worn paths | Mow or possibly regrade. |
| Broken or missing area protection | Repair or replace area protection. |
| Pipe corrosion | Replace piping. Consider different material or covering the pipe with a corrosion resistant coating. |
| Pump/Irrigation Equipment Failure | Replace or repair equipment. |

## Pollutant Removal Effectiveness:

| POLLUTANT | REMOVAL EFFECTIVENESS* |
|---|---|
| Sediment | High |
| Nutrients | Medium to High** |
| Trash | High |
| Metals | High |
| Bacteria | High |
| Oil and Grease | No Data |
| Organics | No Data |

** (iSWM, 2014)*
*** Depends on vegetation in the retention ponds for nutrient uptake*

***References or Future Reading:***
*"Complying with the Edwards Aquifer Rules: Technical Guidance on Best Management Practices". July 2005. TCEQ. RG-348. Accessed September 2017. < http://www.storm-tex.com/wp-content/uploads/2016/04/TCEQ_RG-348.pdf >.*
*"iSWM Technical Manual: Site Development Controls". (2014). North Central Texas Council of Governments. Accessed September 2017. < http://iswm.nctcog.org/Documents/technical_manual/Site_Development_Controls_9-2014.pdf >.*
*Kannan, N., Jeong, J., Arnold, J., Gosselink, L. "Hydrologic Modeling of a Retention Irrigation System". (2014). American Society of Civil Engineers: Journal of Hydrologic Engineering: 19(5). Accessed September 2017. < http://ascelibrary.org/doi/full/10.1061/(ASCE)HE.1943-5584.0000867 >.*
*"Retention Irrigation Ponds". The City of Austin: Watershed Protection Department. Image. Accessed January 2018. < https://austintexas.gov/content/1361/FAQ/2483 >.*
*"Tarrant Regional Water District Developer Manual". (2018). Tarrant Regional Water District (TRWD).*

# Sand and Media Filters

## Overview:

Sand and media filters are a versatile, well-established structural Best Management Practice (BMP) that provides treatment of stormwater runoff by filtration through sand or other filtration media. To improve treatment effectiveness, sand and media filters are paired with a pre-treatment BMP to remove large debris and sediment from the runoff inflow. This BMP is easily incorporated into new developments or adapted for retrofits in re-development sites. The sand and media filters are suitable for relatively large, highly impervious drainage areas.

*Surface Sand Filter Seneca Best Management Practice. DEP Montgomery County, MD.*

## Benefits:

- Offer design flexibility and can be implemented in urban retrofits or new development projects
- Effective in the removal of suspended solids, oil and grease, heavy metals, and particle-bound nutrients and pathogens
- Can be used to reduce peak runoff rates for relatively frequent storms
- Can incorporate deeper ponding depths of up to 5-feet to limit the required footprint

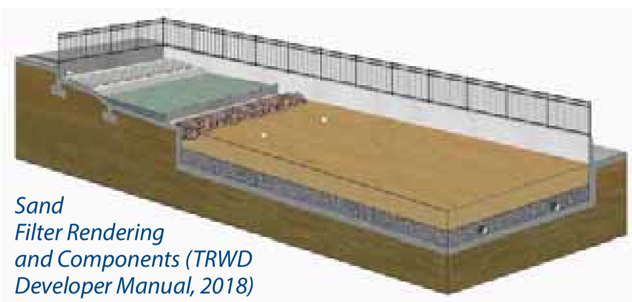
## Potential Constraints and Considerations:

- Sand filters in basins with heavy sediment loads are subject to clogging and require more frequent maintenance to maintain optimal filtration rate
- Frequent trash removal may be required for sites with high traffic volume
- Can lack aesthetic appeal
- Stagnant water due to clogging and /or inadequate maintenance may create breeding habitat for nuisance conditions

*Example of Surface Sand Filter (Bender Wells Clark Design, SARA, 2013)*

## Design Guidance:

First, delineate the drainage area of the BMP. Next, all runoff from impervious surfaces should be directed towards the BMP. Important site considerations during design include the drainage area and the portion of which is impervious, depth to the water table, permeability of soils, downstream water surface, and overall space required for the BMP. Sand and media filters include multiple chambers: a sediment forebay or sedimentation chamber, and a filtration chamber. If the drainage area is less than 2 acres, then a vegetated filter strip or grass swale can be used in lieu of a sediment forebay. The depth of the filtration basin must be balanced with the frequency of required maintenance. The deeper the filtration basin, the more frequent the maintenance. The water quality volume (WQv) in the sand and media filter should drain in 24 hours. The minimum components for the sand and media filter is as follows: stormwater inlet, pre- and post-treatment, energy dissipation, area protection, BMP media, media barriers, landscaping, and outlets/piping. Refer to Section 4 of the TRWD Developer Manual for specific information on these components.



*Sand Filter Rendering and Components (TRWD Developer Manual, 2018)*

## Sizing Criteria:

The calculations below are from Section 3.1 of the TRWD Developer Manual. This table contains the main calculations for sizing the BMP. Reference Section 3.1 and Appendix E for the specific design calculations and criteria.

| Step | Item | Equation | Unit |
|---|---|---|---|
| **STEP 1** | **Water Quality Capture Volume** | $WQ_v = DA*[d_t/12*43{,}560ft3/ac)$ | $ft^3$ |
| | Contributing Drainage Area (DA) | | ac |
| | Capture Depth for 24 Hour Drawdown Time ($d_t$) | | in |
| **STEP 2** | **Sediment Forebay Volume** | $V_{fb} = 25\%WQ_v$ | $ft^3$ |
| **STEP 3** | **Surface Area of Filtration Chamber** | $A_f = WQ_v/[kT_f]$ *where k=3.5ft/day* | $ft^3$ |
| | Filtration chamber drain time ($T_f$) | | days |
| **STEP 4** | **Total Available Sand Filter Water Quality Storage Volume** | | $ft^3$ |
| | Surface area top of basin ponding storage ($SA_T$) | | $ft_2$ |
| | Surface area bottom of basin ponding storage ($S_{AB}$) | | $ft_2$ |
| | Depth of ponding ($H_f$) | | ft |
| | Depth of storage aggregate ($H_{agg}$) | | ft |
| | Void ratio | | - |
| **STEP 5** | **Sand Filter Chamber Total Depth** | $H_t = [H_f/(12in/ft)]+H_m$ | ft |
| | Filter media depth ($H_f$) | | in |
| | Filtration chamber depth ($H_m$) | | ft |
| **STEP 6** | **Orifice Diameter** | $d_o=2*(A_o/\pi)^{0.5}$ | in |
| | Max. discharge of WQv ($Q_o$) | | $ft^3/s$ |
| | Drain time ($t_d$) | | hr |
| | Orifice opening area ($A_o$) | | $in^2$ |
| | Orifice coefficient (c) | | - |
| | Average head ($H_{avg}$) | | ft |

## Inspection and Maintenance Requirements:

Inspections help to ensure that the sand and media filters continue to operate effectively and as designed throughout their lifespan. Regular inspection also indicates when certain maintenance practices are necessary. Like inspection, regular maintenance keeps the BMP running smoothly and prolongs, or eliminates, the need for intensive rehabilitation such as media replacement. The table below outlines the regular and as-needed maintenance practices for sand and media filters. Specific information on inspection and maintenance requirements can be found in Appendix D of the TRWD Developer Manual.

***Regular Maintenance***

| MAINTENANCE ITEMS | FREQUENCY |
|---|---|
| Clearing trash, debris, and foliage | Monthly or as needed |

***As-Needed Maintenance***

| INSPECTION ISSUE | ACTION |
|---|---|
| Standing water after drawdown time | Check the inlet/outlet for clogging. Clear if necessary. |
| Foul odors or insects such as mosquitos | Retrofit BMP to prevent stagnant water |
| Inlet/outlets clogged with debris | Clear out accumulated debris. |
| Accumulated sediment/debris | Dredge or remove accumulated sediment or debris. |
| Surface media spent | Replace the top of the surface media |
| Broken or missing area protection | Repair or replace area protection. |
| Pipe corrosion | Replace piping. If reoccurring issue, consider different material or covering the pipe with a corrosion resistant coating. |

## Pollutant Removal Effectiveness:

| POLLUTANT | REMOVAL EFFECTIVENESS* |
|---|---|
| Sediment | High |
| Nutrients | Low to Moderate |
| Trash | High |
| Metals | Medium to High |
| Bacteria | Medium to High |
| Oil and Grease | High |
| Organics | Medium to High |

*(SARA, 2013; iSWM, 2014; and TCEQ, 2005)*
** removal effectiveness varies dependent on infiltration capacity and design*
*** Sources have ranged from low removal to high removal*

***References or Future Reading:***
*"Complying with the Edwards Aquifer Rules: Technical Guidance on Best Management Practices". July 2005. TCEQ. RG-348. Accessed September 2017. < http://www.storm-tex.com/wp-content/uploads/2016/04/TCEQ_RG-348.pdf >.*
*"iSWM Technical Manual: Site Development Controls". (2014). North Central Texas Council of Governments. Accessed September 2017. < http://iswm.nctcog.org/Documents/technical_manual/Site_Development_Controls_9-2014.pdf >.*
*"San Antonio River Basin Low Impact Development Technical Design Guidance Manual". (2013). San Antonio River Authority. Accessed September 2017. < https://www.sara-tx.org/wp-content/uploads/2015/05/Full-LID-Manual.pdf >.*
*"Tarrant Regional Water District Developer Manual". (2018). Tarrant Regional Water District (TRWD).*
*Young, G.K., et al. 1996. "Evaluation and Management of Highway Runoff Water Quality". U.S. Department of Transportation. Federal Highway Administration: Office of Environment and Planning. Publication No. FHWA-PD-96-032.*

trwd Tarrant Regional Water District

# Vegetated Filter Strips and Grass Swales

## Overview:

Vegetated Filter Strips (VFS) and Grass Swales can be used to treat stormwater runoff from low density impervious areas or along linear impervious surfaces, such as roadways or sidewalks. VFS are linear strips of natural, grass vegetation extended over a gentle slope which use the biological and physical properties of the vegetation and infiltration to remove sediment and other pollutants in sheet flow runoff. Grass swales are grass-lined ditches that can be used to convey and treat shallow concentrated flow. These Best Management Practices (BMPs) should not be used as a stand-alone BMP for developments and can be used as pre- or post-treatment along with other water quality BMPs.

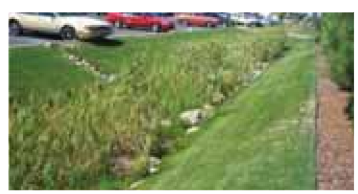
*Grass Swale (Dominican College-DEC, NY, 2007)*

## Benefits:

- VFS and grass swales are relatively simple and low cost to design and construct
- Both can be used for pretreatment and reduction of sediment from stormwater
- Both have simple, aesthetically pleasing qualities and provide landscaping opportunities
- Low maintenance requirements
- VFS and grass swales are effective along linear, narrow, impervious surfaces and are easily distributed around a site

## Potential Constraints and Considerations:

- May not be suitable for industrial sites or large drainage areas, unless used to convey sub-areas as replacement for storm sewers
- VFS requires sheet flow across vegetated areas
- Require mild slopes to allow vegetation to provide filtration and to maintain low velocities
- Application in arid areas is limited because of the need for dense vegetation
- Does not provide sufficient attenuation of peak flows, unless check dams or other storage mechanisms are installed to the grass swale



*Vegetated Grass Swale (Dott Architecture, 2010)*

## Design Guidance:

*Grass Swale (Niskayuna Business Park-DEC, NY, 2005)*

First, delineate the drainage area of the BMP. Next, all runoff from impervious surfaces should be directed towards the BMP(s). Important site considerations during design include assessment of the impervious portion of the drainage area, depth to the water table, permeability of soils, downstream water surface, and overall space required for the BMP. VFS typically have one gentle side slope where the sheet flow runoff is treated. Grass swales are more channelized, having shallow side slopes on both sides of the channel perpendicular to the longitudinal flow path. VFS and grass swales can be enhanced by constructing check dams along the flow path to store and treat the stormwater for an extended period. Water should not pool in these BMPs. If check dams are installed, then the ponding behind the dams must drain within 48 hours. The minimum components for VFS and grass swales are as follows: stormwater inlet, pre- and post-treatment, energy dissipation, area protection, BMP media, media barriers, landscaping, and outlets/piping. Refer to Section 4 of the TRWD Developer Manual for specific information on these components.

## Sizing Criteria:

The criteria below are from Section 3.7 of the TRWD Developer Manual. This table contains the main calculations for sizing the BMP. Reference Section 3.7 and Appendix E for the specific design calculations and criteria.

| | |
|---|---|
| **STEP 1** | **WATER QUALITY CAPTURE VOLUME** |
| | Grass Swale: Contributing Drainage Area (DA) less than 5ac? |
| | VFS: Length of contributing drainage area in direction of flow less than 75-feet? |
| **STEP 2** | **UPSTREAM OR DOWNSTREAM BMP? IF NOT, JUSTIFICATION?** |
| **STEP 3** | **INFLOW PARAMETERS** |
| | Grass Swale: Less than 4 inches of sheet flow? |
| | Grass Swale: Energy dissipation at the inlet to reduce channelized water velocities to < 1-ft/s? |
| | VFS: Less than 2 inches of sheet flow? |
| **STEP 4** | **VFS OR GRASS SWALE PARAMETERS** |
| | Grass swales: Longitudinal slope less than 4% with max. water velocity less than 1-ft/s? |
| | Grass swale: Side slopes no steeper than 3:1 (horizontal:vertical) and channel bottom between 2-feet and 6-feet? |
| | VFS: Flow path at least 15-feet with 2% to 6% longitudinal slope and transverse slope less than 2%? |
| | VFS: Minimum of 12-inches of soil cover and dense vegetative cover? |
| **STEP 5** | **CHECK DAM PARAMETERS** |
| | Does it drain within 48-hours? |
| | Dam has max. height of 12-inches with 3:1 side slopes? |

## Inspection and Maintenance Requirements:

Inspections help to ensure that the VFS and the grass swales continue to operate at their designed effectiveness throughout their lifespan. Regular inspection also indicates when certain maintenance practices are necessary. VFS and grass swales require less maintenance than other BMPs, but consistent inspection and maintenance keeps the BMP running smoothly and prolongs, or eliminates, the need for intensive rehabilitation such as side slope restabilization. The table below outlines the regular and as-needed maintenance practices for VFS and grass swales. Specific information on inspection and maintenance requirements can be found in Appendix D of the TRWD Developer Manual.

***Regular Maintenance***

| MAINTENANCE ITEMS | FREQUENCY |
|---|---|
| Clear trash, debris, weeds, and foliage | Monthly or as needed |
| Mow lawn | Annually, but monthly during growing season |

***As-Needed Maintenance***

| INSPECTION ISSUE | ACTION |
|---|---|
| Standing water after drawdown time | Check for excessive fines/hard-packing on the surface |
| Foul odors or insects such as mosquitos | Retrofit BMP to prevent stagnant water |
| Inlet/outlets clogged with debris | Clear out accumulated debris. |
| Accumulated sediment/debris higher than limit | Dredge or remove accumulated sediment or debris. |
| Poor vegetative health / invasive species | Replant vegetation and remove invasive species. |
| Excessive or overgrown vegetation | Prune the excessive/overgrown vegetation. |
| Banks/slopes eroded | Repair banks/slopes such that they match design slopes. Install energy dissipaters or flow diversions. |
| Signs of channeling or worn paths | Mow or possibly regrade. |
| Pipe corrosion | Replace piping. If reoccurring issue, consider different material or covering the pipe with a corrosion resistant coating. |

## Pollutant Removal Effectiveness:

| POLLUTANT | REMOVAL EFFECTIVENESS |
|---|---|
| Sediment | Medium to High |
| Nutrients | Low to Medium |
| Trash | Low to Medium |
| Metal | Low to Medium |
| Bacteria | Low* |
| Oil and Grease | Medium to High |
| Organics | Medium to High |

*(SARA, 2013; iSWM, 2014)*

** Removal effectiveness will vary based on removal mechanism (i.e. adsorption to sediment or vegetation or infiltration)*


***References or Future Reading:***

*"Dominican College Dry Swale." (2007). New York State Department of Environmental Conservation. Accessed September 2017. < http://www.dec.ny.gov/lands/59332.html >.*

*"iSWM Technical Manual: Site Development Controls". (2014). North Central Texas Council of Governments. Accessed September 2017. < http://iswm.nctcog.org/Documents/technical_manual/Site_Development_Controls_9-2014.pdf >.*

*"Niskayuna Busiess Park Dry Swale." (2005). New York State Department of Environmental Conservation. Accessed September 2017. < http://www.dec.ny.gov/lands/59335.html >.*

*"San Antonio River Basin Low Impact Development Technical Design Guidance Manual". (2013). San Antonio River Authority. Accessed September 2017. < https://www.sara-tx.org/wp-content/uploads/2015/05/Full-LID-Manual.pdf >.*

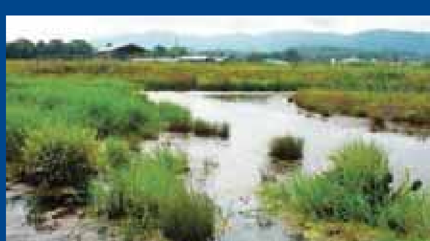
*"Sustainable practices for landscape design: vegetated swales". (2010). Dott Architecture. Accessed September 2017. < https://dottarchitecture.com/2010/06/03/sustainable-practices-for-landscape-design-vegetated-swales/ >.*

*"Tarrant Regional Water District Developer Manual". (2018). Tarrant Regional Water District (TRWD).*

# Wet Basins

## Overview:

Wet basins are a Best Management Practice (BMP) designed to retain stormwater between runoff events to allow the retained volume to be treated for an extended period. These BMPs are also known as wet ponds, stormwater ponds, or retention ponds. They are similar to extended dry detention basins, but this BMP maintains a permanent pool throughout the year. Wet basins remove pollutants from the surcharge primarily through particle settling and plant uptake of nutrients. This BMP is not intended for infiltration. Therefore, the stormwater runoff volume reduction is minimal, except through evaporation and evapotranspiration. Wet basins require large amounts of space and contributing drainage area. A source of inflow is needed to maintain a permanent pool throughout the year.



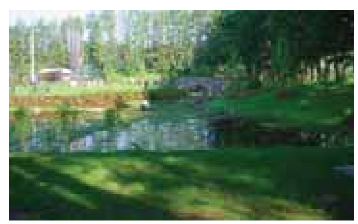
*Wet basin (Tennessee Permanent SW Mgmt and DGM, 2014)*

## Benefits:

- Well suited for removal of particulate matter and some dissolved contaminants (TCEQ, 2005)
- Provides an aesthetically pleasing space for the surrounding community
- Provides wildlife habitat. See note below on bacterial indicator loads
- Effective for large tributary areas

## Potential Constraints and Considerations:

- Requires continuous source of base flow (i.e. stormwater inflow or make-up water inflow)
- Potential significant maintenance costs and large amounts of sediment removal to prevent pond stagnation, floating debris, scum, algal blooms, and unpleasant odor (TCEQ, 2005).
- Potential accumulation of salts and scum that can be discharged during large storm events



*Wet basin (CDM Smith, 2017)*

- Proper design must be used to prevent habitat for undesirable insects such as mosquitos
- May not be appropriate for locations with high groundwater levels due to potential for contamination
- Overgrowth and sediment accumulation may reduce hydraulic capacity

## Design Guidance:

*Wet basin multi-stage outlet (SARA Manual, 2013)*

First, delineate the drainage area of the BMP. Next, all runoff from impervious surfaces should be directed towards the BMP. Important site considerations during design include assessment of the portion of which is impervious, depth to the water table, permeability of soils, downstream water surface, and overall space required for the BMP. The wet basin does not vary in depth as much as the constructed wetland, though, 15% of the total surface area of the basin must be made up of a littoral zone, or safety bench. Like the constructed wetland, it has a micropool at the outlet for additional treatment before discharge. The water quality volume (WQv) should drain within 12 hours. The minimum components for a wet basin include, a stormwater inlet, pre- and post-treatment, energy dissipation, area protection, landscaping, and outlets/piping. Refer to Section 4 of the TRWD DM for specific information on these components.

*Rendering of a wet basin after a storm (TRWD DM, 2018)*

## Sizing Criteria:

The calculations below are from Section 3.4 of the TRWD DM. This table contains the main calculations for sizing the BMP. Reference Section 3.4 and Appendix E for the specific design calculations and criteria.

| Step | Calculation | Unit |
|---|---|---|
| **STEP 1** | **Water Quality Capture Volume** $(WQ_v = DA*[d_t/(12in/hr)]*43{,}560ft^3/ac)$ | $ft^3$ |
| | Contributing Drainage Area (DA) | ac |
| | Capture Depth for 12 Hour Drawdown Time ($d_t$) | in |
| **STEP 2** | **Sediment Forebay Volume** ($V_{fb}$ = 0.1in per impervious acre of drainage area) | $ft^3$ |
| | Impervious Drainage Area ($A_{imp}$) | $ft^2$ |
| **STEP 3** | **Basin Volume** $(V_B = V_P + V_S)$ | $ft^3$ |
| | Permanent Pool Volume ($V_P$) = 100% $WQ_v$ | $ft^3$ |
| | Surcharge Pool Volume ($V_S$) = 120% $WQ_v$ | $ft^3$ |
| **STEP 4** | **Orifice Diameter** $(d_o=2*(A_o/\pi)^{0.5})$ | in |
| | Max. discharge of WQv ($Q_o$) | $ft^3/s$ |
| | Drain time ($t_d$) | hr |
| | Orifice opening area ($A_o$) | $in^2$ |
| | Orifice coefficient (c) | - |
| | Average head ($H_{avg}$) | ft |

## Inspection and Maintenance Requirements:

Inspections help to ensure that the wet basin continues to operate as designed and effectively throughout its lifespan. Regular inspection also indicates when certain maintenance practices are necessary. Like inspection, regular maintenance keeps the BMP running smoothly and prolongs, or eliminates, the need for intensive rehabilitation such as side slope restabilization or replacing of corroded pipes. The table below outlines the regular and as-needed maintenance practices for wet basins. Specific information on inspection and maintenance requirements can be found in Appendix D of the TRWD DM.

***Regular Maintenance***

| MAINTENANCE ITEMS | FREQUENCY |
|---|---|
| Clear trash, debris, weeks, and foliage | Monthly or as needed |
| Mow lawn | Annually, but monthly during growing season |
| Prune excessive vegetation / branches | Annually, but monthly during growing season |
| Replant Annuals | Before corresponding growing season |

***As-Needed Maintenance***

| INSPECTION ISSUE | ACTION |
|---|---|
| Standing water after design storm event and drawdown time | Check the inlet/outlet for clogging. Clean if necessary. |
| Foul odors or insects such as mosquitos | Retrofit BMP to prevent stagnant water |
| Inlet/outlets clogged with debris | Clear out accumulated debris. |
| Accumulated sediment/debris higher than limit | Dredge or remove accumulated sediment or debris to design elevations. Vacuum clogged permeable surfaces. |
| Poor vegetative health / invasive species | Replant vegetation and remove invasive species, taking care not to spread seeds/ spores. |
| Excessive or overgrown vegetation | Prune the excessive/overgrown vegetation. |
| Banks/slopes eroded | Repair banks/slopes such that they match design slopes. Install energy dissipaters or flow diversions if reoccurring issue. |
| Signs of channeling or worn paths | Mow or possibly regrade. |
| Broken or missing area protection | Repair or replace area protection. |
| Pipe corrosion | Replace piping. If reoccurring issue, consider different material or covering the pipe with a corrosion resistant coating. |

## Pollutant Removal Effectiveness:

| POLLUTANT | REMOVAL EFFECTIVENESS* |
|---|---|
| Sediment | High |
| Nutrients | Medium to High |
| Trash | High |
| Metals | Medium |
| Bacteria | High** |
| Oil and Grease | High |
| Organics | High |

**(SARA Manual, 2013); Clary, J. 2017)*
*** Wetlands or other BMPs with wildlife habitat can have high internal loads of bacterial indicators*

**References or Future Reading:**
*"Complying with the Edwards Aquifer Rules: Technical Guidance on Best Management Practices". July 2005. TCEQ. RG-348. Accessed September 2017. < http://www.storm-tex.com/wp-content/uploads/2016/04/TCEQ_RG-348.pdf >.*
*"iSWM Technical Manual: Site Development Controls". (2014). North Central Texas Council of Governments. Accessed September 2017. < http://iswm.nctcog.org/Documents/technical_manual/Site_Development_Controls_9-2014.pdf >.*
*Clary, J. et al. "International Stormwater BMP Database 2016 Summary Statistics: Final Report". (2017). The Water Environment & Reuse Foundation. Accessed September 2017. < http://www.bmpdatabase.org/Docs/03-SW-1COh%20BMP%20Database%202016%20Summary%20Stats.pdf >.*
*"San Antonio River Basin Low Impact Development Technical Design Guidance Manual". (2013). San Antonio River Authority. Accessed September 2017. < https://www.sara-tx.org/wp-content/uploads/2015/05/Full-LID-Manual.pdf >.*
*"Tarrant Regional Water District Developer Manual". (2018). Tarrant Regional Water District (TRWD).*
*"Tennessee Permanent Stormwater Management and Design Guidance Manual". December 2014. Tennessee Department of Environment and Conservation. 1st ed. Accessed September 2017. < https://app.box.com/s/pdl1afehg00s1wwqa94d8qmizyptxw3i/file/25367692645 >.*

This page intentionally left blank.

# Appendix C

## Planting Palettes

This page intentionally left blank.

## Herbaceous Species - Grasses

Cereal Rye
*Secale cereale L.*

Bermudagrass
*Cynodon dactylon*

Buffalo Grass
*Buchloe dactyloides*

Blue Grama
*Bouteloua gracilis*

Little Bluestem Grass
*Schizachyrium scoparium*

Side Oats Grama /
*Bouteloua curtipendula*

Big Bluestem
*Andropogon gerardii*

Green Sprangletop
*Leptochola dubia*

Herbaceous Species - Grasses

Eastern Gamagrass
*Tripsacum dactyloides*

Sand Dropseed
*Sporobolus cryptandrus*

Prairie Wildrye
*Elymus canadensis*

Switchgrass
*Panicum virgatum*

Sand Lovegrass
*Eragrostis trichodes*

Indiangrass
*Sorghastrum nutans*

Western Wheatgrass
*Pascopyrum smithii*

Cane Bluestem
*Bothriochloa barbinodis*

Texas Cupgrass
*Eriochloa sericea*

Herbaceous Species - Grasses

| | | |
|---|---|---|
|  |  |  |
| Curly Mesquite<br>*Hilaria belangeri* | White tridens<br>*Tridens albescens* | Bushy Bluestem<br>*Andropogon glomeratus* |
|  |  |  |
| Halls Panicum<br>*Panicum hallii* | Broomsedge Bluestem<br>*Andropogon virginicus* | Regal Mist Gulf Muhly<br>*Muhlenbergia capillaris 'Regal Mist'* |
|  |  |  |
| Lindheimer Muhly<br>*Muhlenberia lindheimeri* | Cherokee Sedge<br>*Carex cherokeensis* | Emory's Sedge<br>*Carex emoryi* |

Herbaceous Species - Grasses

| | | |
|---|---|---|
|  |  |  |
| Inland Sea Oats<br>*Chasmanthium latifolium* | Witchgrass<br>*Panicum cappillare* | Virginia Wildrye<br>*Elymus virginicus* |
|  | | |
| Texas Bluegrass<br>*Poa arachnifera* | | |

## Herbaceous Species – Perennials

American Basketflower
*Centaurea americana*

Illinois Bundleflower
*Desmanthus illinoensis*

Clasping Coneflower
*Dracopis amplexicaulis*

Plains Coreopsis
*Coreopsis lanceolate*

Blackeyed Susan
*Rudbeckia hirta*

Scarlet Sage
*Salvia coccinea*

Cutleaf Daisy
*Engelmannia peristenia*

Pink Evening Primrose
*Oenothera speciosa*

Maximilian Sunflower
*Helianthus maximiliani*

## Herbaceous Species – Perennials

Giant Goldenrod
*Solidago gigantea*

Texas Bluebonnet
*Lupinus texensis*

Indian Blanket
*Gaillardia pulchella*

Lemon Mint
*Monarda citriodora*

Purple Prairie Clover
*Dalea purpurea*

White Prairie Clover
*Dalea candida*

Partridge Pea
*Chamaecrista fasciculata*

Gayfeather
*Liatris spicata*

Tall Goldenrod
*Solidago altissima*

Herbaceous Species – Perennials

Texas Yellow Star
*Lindheimera texana*

Zexmenia / *Wedelia acapulcensis var. hispida*

Aromatic Aster / *Symph-yotrichum oblongifolium*

Gregg's Mistflower
*Conoclinium greggii*

Mealy Blue Sage
*Salvia farinacea*

Turk's Cap
*Malvaviscus drummondii*

Tall Aster / *Symphyotrichum praealtum var. Praealtum*

Joe Pye Weed
*Eupatorium fistolosum*

Cardinal Flower
*Lobelia cardinalis*

Herbaceous Species - Perennials

Louisiana Iris
*Iris ser. Hexagonae*

Halberdleaf Hibiscus
*Hibiscus laevis*

Dwarf Tickseed
*Coperopsis tinctoria*

Late Boneset
*Eupatorium serotinum*

Cinnamon Fern
*Osmunda cinnamomea*

Royal Fern
*Osmunda regalis*

Texas Bluebells
*Eustoma grandiflora*

Common Milkweed
*Aesclepias syriaca*

Obedient Plant
*Physostegia virginiana*

Herbaceous Species - Perennials

| | | |
|---|---|---|
|  |  |  |
| Butterfly Weed *Asclepias tuberosa* | Purple Coneflower *Echinacea purpurea* | Texas Gayfeather / *Liatris puncata var. mucronatum* |
|  | | |
| Autumn Sage *Salvia greggii* | | |

Shrubs

Dwarf Yaupon Holly
*Ilex vomitoria 'Nana'*

Pale Leaf Yucca
*Yucca pallida*

Cast Iron Plant
*Aspidistra elatior*

American Beautyberry
*Callicarpa americana*

Dwarf Palmetto
*Sabal minor*

Dwarf Waxmyrtle
*Morella cerifera var. pumilla*

Common Buttonbush
*Cephalanthus occidentalis*

## Ornamental Trees

Oklahoma Redbud / *Cercis canadensis 'Oklahoma'*

Texas Redbud / *Cercis canadensis 'Texensis'*

Mexican Redbud / *Cercis canadensis 'Mexicana'*

Reverchon Hawthorn
*Crataegus reverchonii*

Eve's Necklace
*Sophora affinis*

Shantung Maple
*Acer truncatum*

Possumhaw
*Ilex decidua*

Yaupon Holly - Male
*Ilex vomitoria*

Yaupon Holly - Female
*Ilex vomitoria*

## Ornamental Trees

Southern Waxmyrtle
*Myrica cerifera*

Wafer Ash
*Ptelea trifoliata*

Trees

Texas Ash
*Fraxinus albicans*

Slippery Elm
*Ulmus rubra*

Bald Cypress
*Taxodium distichum*

Montezuma Cypress
*Taxodium mucronatum*

Pond Cypress
*Taxodium ascendens*

Cedar Elm
*Ulmus crassifolia*

Green Ash
*Fraxinus pennsylvanica*

Pecan
*Carya illinoensis*

Common Persimmon
*Diospyros virginiana*

Trees

Bur Oak
*Quercus macrocarpa*

Chinkapin Oak
*Quercus muhlenbergii*

Shumard Oak
*Quercus shumardii*

Live Oak
*Quercus virginiana*

## Aquatic Plants – Perennials and Grasses


Yellow Waterlily
*Nymphaea mexicana*


Fragrant Waterlily
*Nymphaea odorata*


Spatterdock
*Nuphar luteum*


Sweetflag
*Acrous calumus*


Caric Sedge
*Carex spp.*


Square Stem Spikerush
*Elocharis quadrangulata*


Swamp Sunflower
*Helianthus angustifolius*


Soft Rush
*Juncus effusus*


Rice Cut Grass
*Leersia oryzoides*

Aquatic Plants – Perennials and Grasses

Green Arum
*Peltandra virginica*

Smart Weed / *Polygonum hydropiperoides*

Pickerelweed
*Pontederia cordata*

Pickerelweed
*Pontederia lanceolata*

Lance-leaf Arrowhead
*Saggitaria landifolia*

Duck Potato
*Saggitaria latifolia*

Lizard's Tail
*Saururus cernuus*

Three-square
*Scirpus americanus*

Giant Bulrush
*Scirpus californicus*

## Aquatic Plants – Perennials and Grasses

Softstem Bulrush
*Scirpus validus*

Virginia Chain Fern
*Woodwardia virginica*

This page intentionally left blank.

# Appendix D

## Design Component Inspection and Maintenance

This page intentionally left blank.

# APPENDIX D - DESIGN COMPONENT INSPECTION AND MAINTENANCE

This appendix discusses the inspection and maintenance items for each BMP to help maintain desired removal rates over the lifetime of the BMP. The following tools are intended to provide quick references and checklists that a Contractor, an Inspector, and an Operator could use to ensure that construction and operational use complies with this Manual. It is recommended to discuss these items during the pre-construction meeting.

## INSPECTIONS

### Construction Inspections

During construction, the BMPs must be installed according to design and installation procedures provided in this manual and outlined in the SWPPP. The site activity plan should cover the construction schedule, the runoff management plan, the site access plan, and the site utilization plan.

Contractor should be aware of final inspection requirements defined in the SWPPP, as well as local requirements for BMPs. **Table D-1** lists inspection items for construction inspection(s) and final construction inspection. During the pre-construction meeting, the Inspector and the Contractor should discuss these items and the other inspections required throughout the Construction Schedule.

When reporting the inspection activity, include the inspection date, the condition of the BMP components, any maintenance activity performed, and any notes for future maintenance.

**Table D-1 Construction Inspection Items** **Date Performed** ____________

| Construction Site Inspection (include any maintenance activity performed and notes for future maintenance) | | Condition? (Good, Fair, or Poor) | Notes |
|---|---|---|---|
| BMP condition | Inlets and outlets clear of debris | | |
| | Sediment accumulation level within BMP (BMP should not be used for stormwater collection or conveyance until construction is complete) | | |
| | Trash and debris accumulation within BMP | | |
| | Fallen leaves, weeks, and dead or diseased plans removed and replaced | | |
| | Condition of BMP media | | |
| | Condition of basin structure (erosion, damage, etc.) | | |
| | Mulch condition (if used on-site) | | |
| Vegetation Establishment | Sufficient watering | | |
| | Plant condition / survival | | |
| | Inspections by certified arborists performed | | |
| BMP implementation | BMP has positive grade from inlet to outlet | | |
| | BMP constructed consistent with design | | |
| Construction Activities | Owner / Contractor to coordinate with trades and subcontractors to prevent vehicle travel across bioretention footprint | | |
| | Excess materials to be temporarily stockpiled in approved areas | | |
| | Material storage areas are protected | | |
| | Excavation areas are protected from heavy equipment to prevent compaction of soils within BMP footprint | | |
| | BMP areas to be protected from use, wear and damage during construction period. | | |
| Final Inspection Items | Underdrains operational and clear | | |
| | Observation wells operational and clear | | |
| | Clean-outs operational and clear | | |
| | Stockpiled materials removed | | |
| | Bioretention soils covered with mulch and / or vegetation | | |
| Records | Detailed monthly records kept on site | | |

## Post-Construction Inspection

The post-construction inspection and monitoring period covers the lifespan of the BMP from immediately after construction/establishment period to the decommissioning of the BMP. **Table D-2** lists inspection items for post-construction inspection(s) after the BMPs are in operation. Several of the inspection items include a frequency. The others should be inspected on a regular basis during other inspections and after storm events. The Inspectors should use the following timeline for ensuring that the BMPs are operating at their designed parameters.

When reporting the inspection activity, include the inspection date, the condition of the BMP components, any maintenance activity performed, and any notes for future maintenance.

## Table D-2 Post-Construction Inspection Items

**Date Performed** ____________________

| Inspection Items (include any maintenance activity performed and notes for future maintenance) | | Condition? (Good, Fair, or Poor) | Notes |
|---|---|---|---|
| All BMPs | Foul odors or insects such as mosquitos | | |
| | Inlet/outlets clogged with debris | | |
| | Condition of BMP media | | |
| | Condition of basin structure (erosion, damage, etc.) | | |
| | Mulch condition (if used on-site) | | |
| | Accumulated sediment/debris in forebay or channel higher than limit | | |
| | Trash and debris accumulation within BMP | | |
| | Underdrains operational and clear | | |
| | Observation wells operational and clear | | |
| | Clean-outs operational and clear | | |
| | Broken or missing area protection | | |
| | Signs of channeling or worn paths | | |
| | Standing water after design drawdown subsequent to a storm event (for BMPs without permanent pools) (after storm events) | | |
| | Poor vegetative health / invasive species (quarterly to bi-annually) | | |
| | Fallen leaves, weeks, and dead or diseased plans removed and replaced | | |
| | Banks/slopes eroded (bi-annually to annually and after large storm events) | | |
| | Pipe corrosion (bi-annually to annually) | | |
| | Surface media spent (bi-annually to annually) | | |
| | Excessive or overgrown vegetation (Annually) | | |
| Permeable Surfaces | Significant deterioration of surface course or pavers and structural integrity of pavement, inlets, and observation wells (bi-annually to annually) | | |
| Retention and Irrigation Basin | Pump/Irrigation Equipment Failure (bi-annually to annually) | | |
| Records | All submittals (including as-builts) submitted by owner to TRWD | | |
| | Detailed monthly records kept on site | | |

# MAINTENANCE

Maintaining BMPs should be performed on a regular basis and as needed based on the results of inspections. The following subsections will list the action and the frequency at which these maintenance items should be performed.

## Regular Maintenance

Regular maintenance is necessary for continued performance throughout the lifetime of the BMP. Maintenance items in this category include mowing of lawns, pruning of branches, clearing debris and foliage, and vacuum sweeping. **Table D-3** lists these types of maintenance activities and the frequency at which they should be performed.

**Table D-3 Regular Maintenance Requirements**

| Maintenance Items | Frequency | Notes |
|---|---|---|
| Clear trash, debris, weeks, and foliage | Monthly or as needed | |
| Manufactured Treatment Devices | Based on manufacturer specifications | Need to be maintained on a regular basis based on specifications |
| Mow, trim, and / or maintain vegetation | Annually or monthly based on safety. Monthly or more frequently during growing season | Any BMPs with landscaping. Don't mow vegetation too low and reduce the effectiveness of the vegetation |
| Prune excessive vegetation / branches | Annually, but monthly during growing season | |
| Replant Annuals | Before corresponding growing season | Incorporate plants that do not or rarely need to be replanted |
| Vacuum sweeping | Annually | Critical for permeable pavers |

**As-Needed Maintenance**

As-needed maintenance are actions that should be performed resulting from an inspection. These actions include clearing accumulated sediments in forebays, vacuuming clogged surfaces, replanting vegetation, replacing corroded inlets/outlets, and restoring bank slopes. The following table lists the inspection item and the action required to fix the issue. These activities are performed as-needed, typically following the inspection timeline.

### Table D-4 As Needed Maintenance Requirements

| Inspected Issue | Required Action | BMPs |
|---|---|---|
| Pooling of water over surface course 48 hours after storm event | Additional vacuum sweeping when dry | Permeable Surfaces |
| Significant deterioration of surface course or pavers and structural integrity of pavement, inlets/outlets, and observation wells | Possible replacement of surface course, pavers, inlets/outlets, and observation well components depending on severity | Permeable Surfaces |
| Banks/slopes of impervious surface eroding such that it contributes high sediment loads to the permeable pavers | Stabilize or replace banks/slopes to minimize sediment loads to permeable pavers | Permeable Surfaces |
| Standing water after design storm event and drawdown time | Check the inlet/outlet for clogging. Clear if true. After water drains and basin, filter, or swale is dry, check for excessive fines/hard-packing on the surface | All BMPs |
| Foul odors or insects such as mosquitos | Retrofit BMP to promote insect predators and/or prevent stagnant water (e.g. fountain/sprinkler for permanent water or clear clogging for temporary water storage BMPs) | All BMPs |
| Inlet/outlets clogged with debris | Clear out accumulated debris. If needed and not installed previously, install debris screens. | All BMPs |
| Backflow prevention devices operating effectively | Inspect and maintain backflow prevention devices as necessary | All BMPs with backflow prevention system |
| Accumulated sediment/debris higher than limit | Dredge or remove accumulated sediment or debris to design elevations. Ensure that the accumulation marker is situation properly. Vacuum clogged permeable surfaces. | All BMPs |
| Poor vegetative health / invasive species | Replant vegetation and remove invasive species, taking care not to spread seeds/spores. | All Vegetated BMPs |
| Excessive or overgrown vegetation | Prune the excessive/overgrown vegetation. Reinstate or establish a routine pruning. | All Vegetated BMPs |
| Surface media spent | Replace the top of the surface media | Sand/Media Filters |
| Banks/slopes eroded | Repair banks/slopes such that they match design slopes. Install energy dissipaters or flow diversions if bank/slope erosion is a reoccurring issue. | All BMPs |
| Signs of channeling or worn paths | Mow or possibly regrade. | All BMPs with Grass Banks/Channels |
| Broken or missing area protection | Repair or replace area protection. | All BMPs |
| Underdrains and distribution pipes | Use observation wells and clean outs to identify clogged underdrains and to perform maintenance and clear out the underdrain system. | All BMPs with underdrains |
| Pipe corrosion | Replace piping. If reoccurring issue, consider different material or covering the pipe with a corrosion resistant coating. | All BMPs |
| Check valves | Inspect and maintain for proper operation | All BMPs |
| Pump/Irrigation equipment failure | Replace or repair equipment. | Retention and Irrigation Basin |
| Hydrodynamic separators and manufactured pre- and post-treatment devices | Inspect and maintain based on the manufacturer specifications. | Pre- and Post-Treatment Devices |

This page intentionally left blank.

# Appendix E

## BMP Spreadsheets

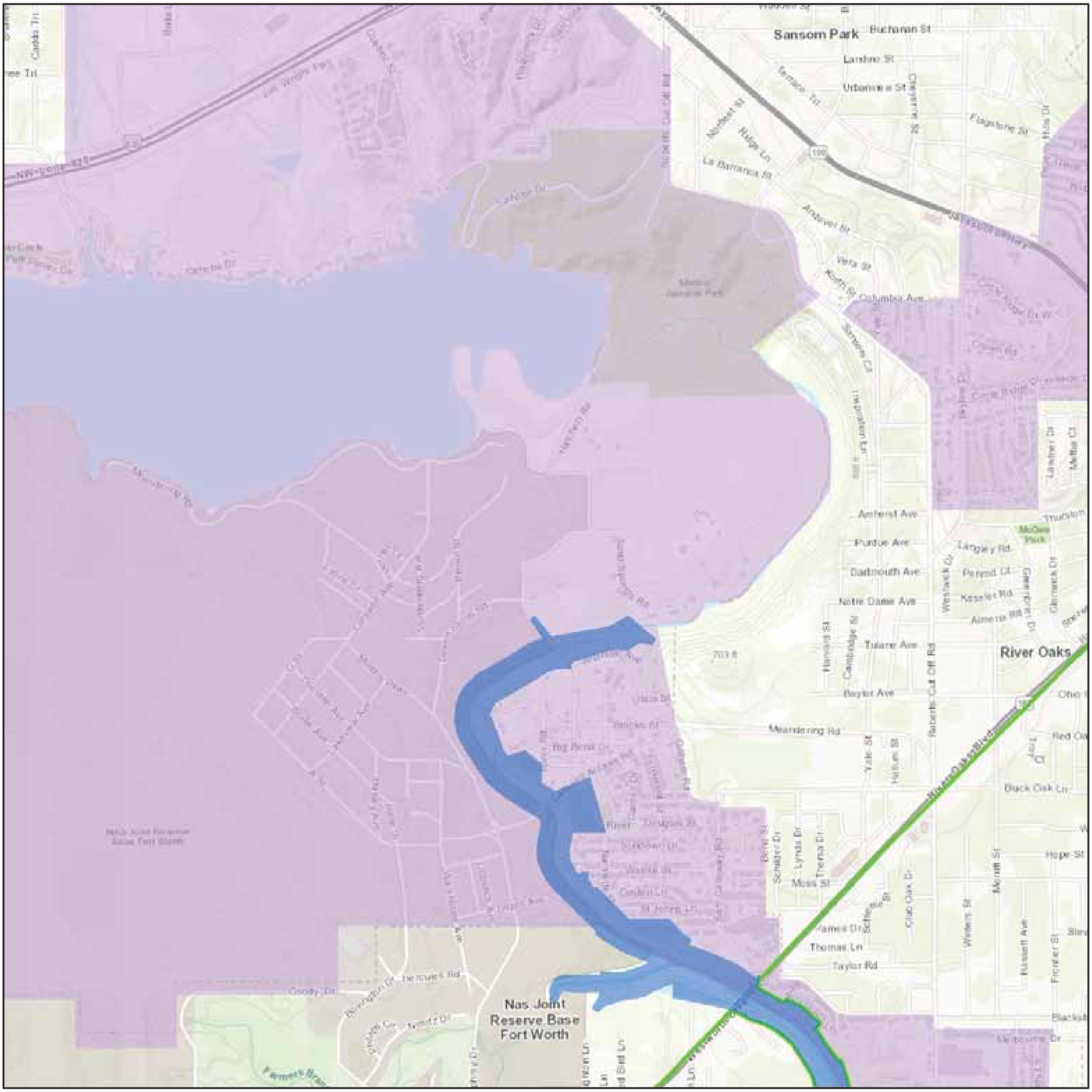
(Provided Electronically)

This page intentionally left blank.

# Appendix F

## Zone Maps

This page intentionally left blank.

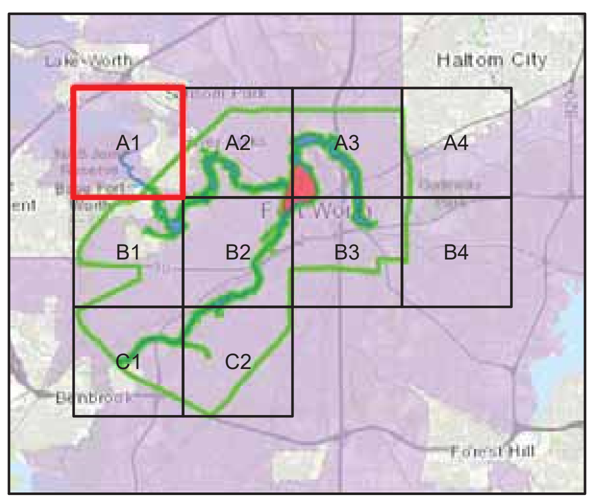


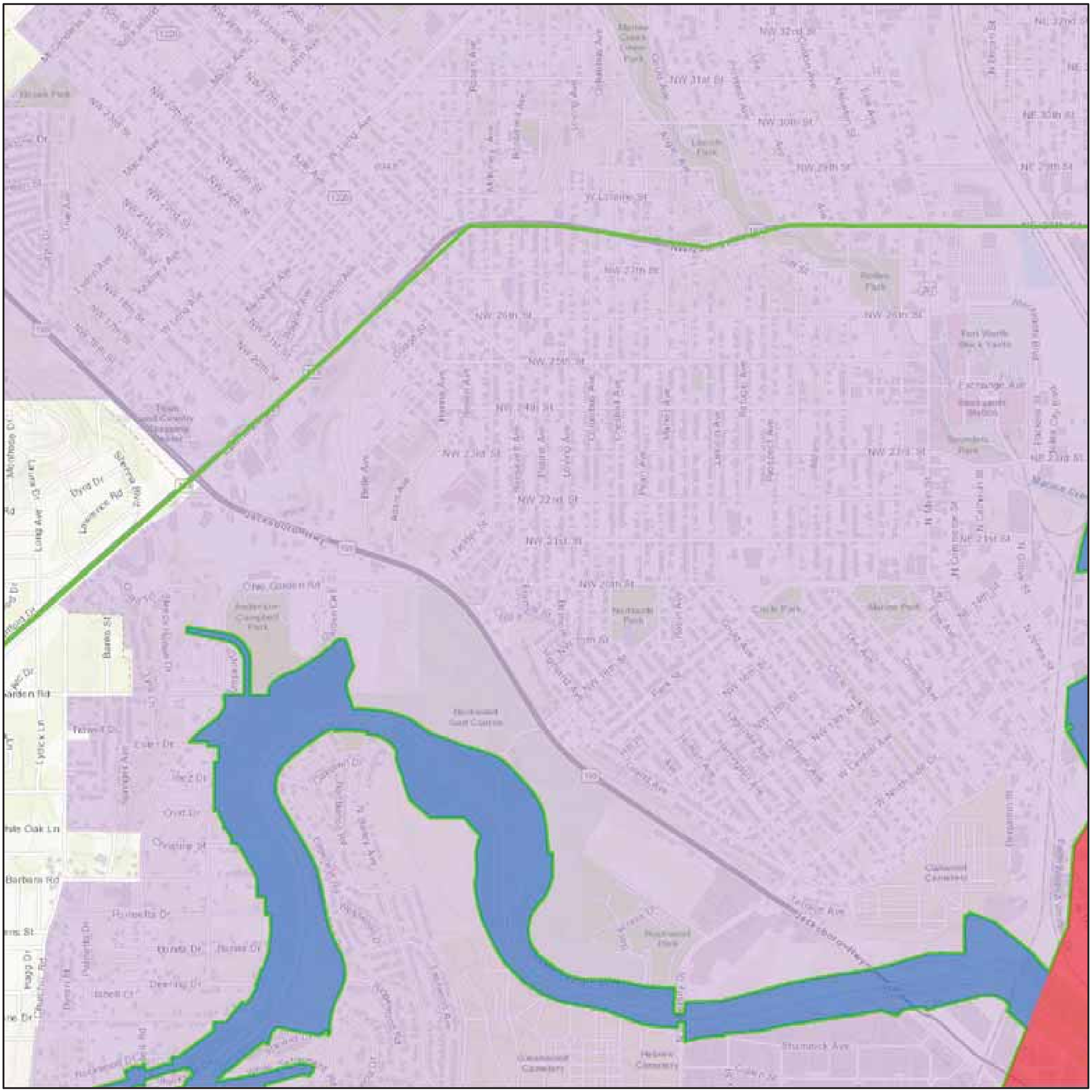

# Legend

- Zone 1 - Panther Island
- Zone 2 - Floodway Corridor
- Zone 3 – Water Quality Zone (Conceptual)
- Zone 4 - City of Fort Worth

# A1

0 1,200 2,400
Feet



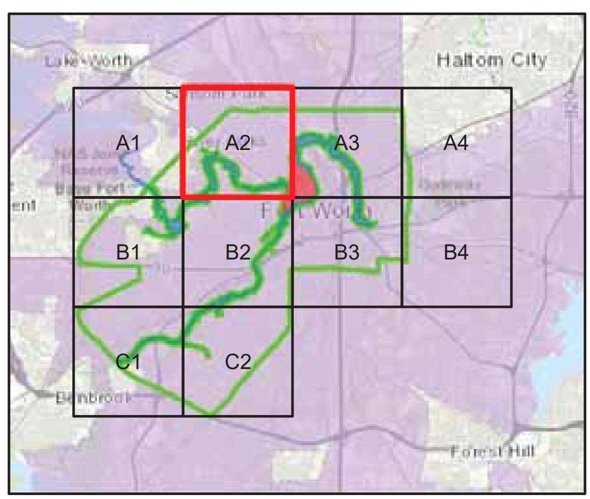


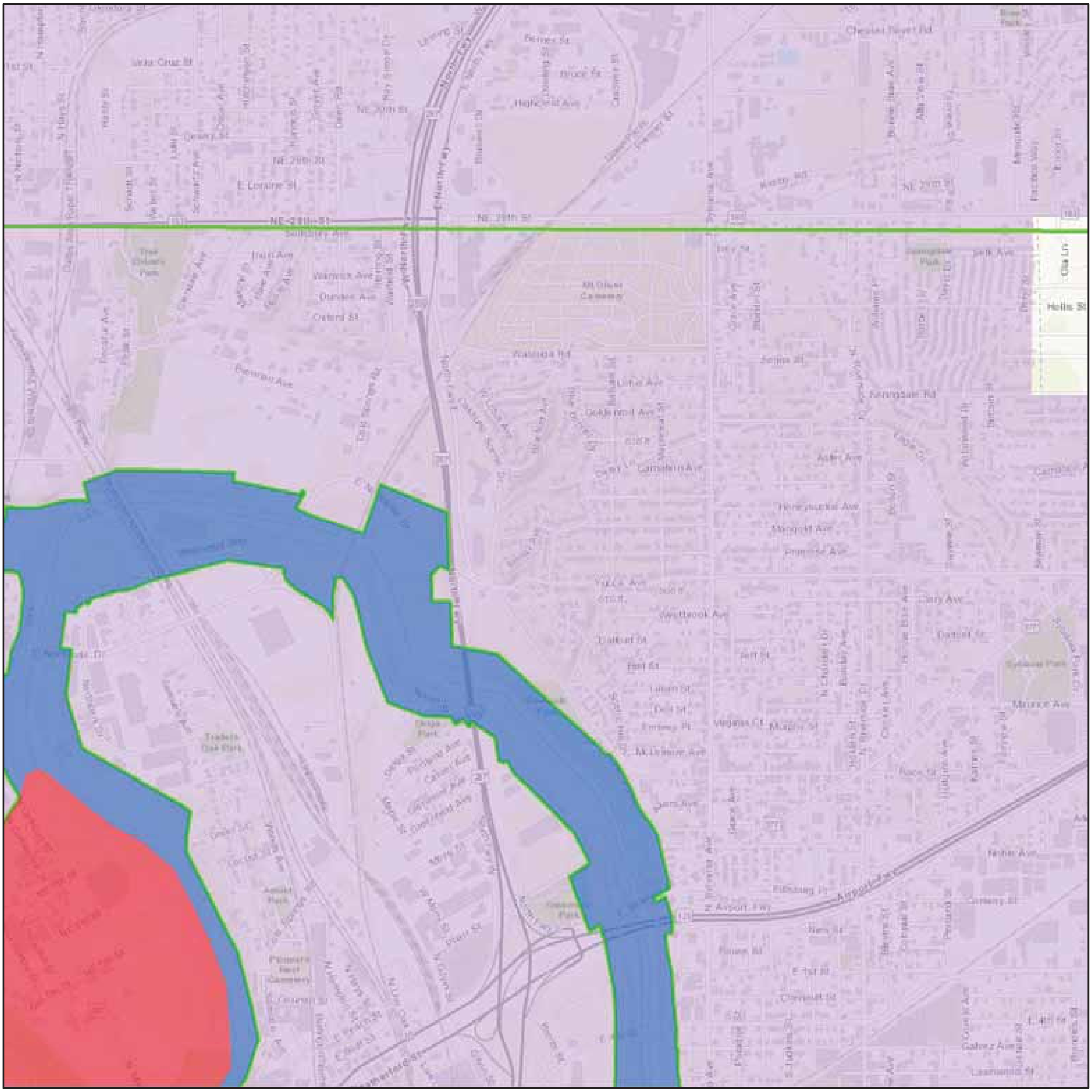
**Legend**

- Zone 1 - Panther Island
- Zone 2 - Floodway Corridor
- Zone 3 – Water Quality Zone (Conceptual)
- Zone 4 - City of Fort Worth

# A2

0 1,200 2,400
Feet



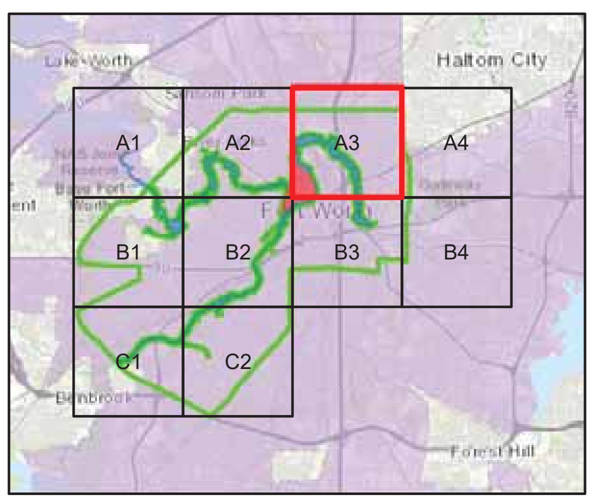


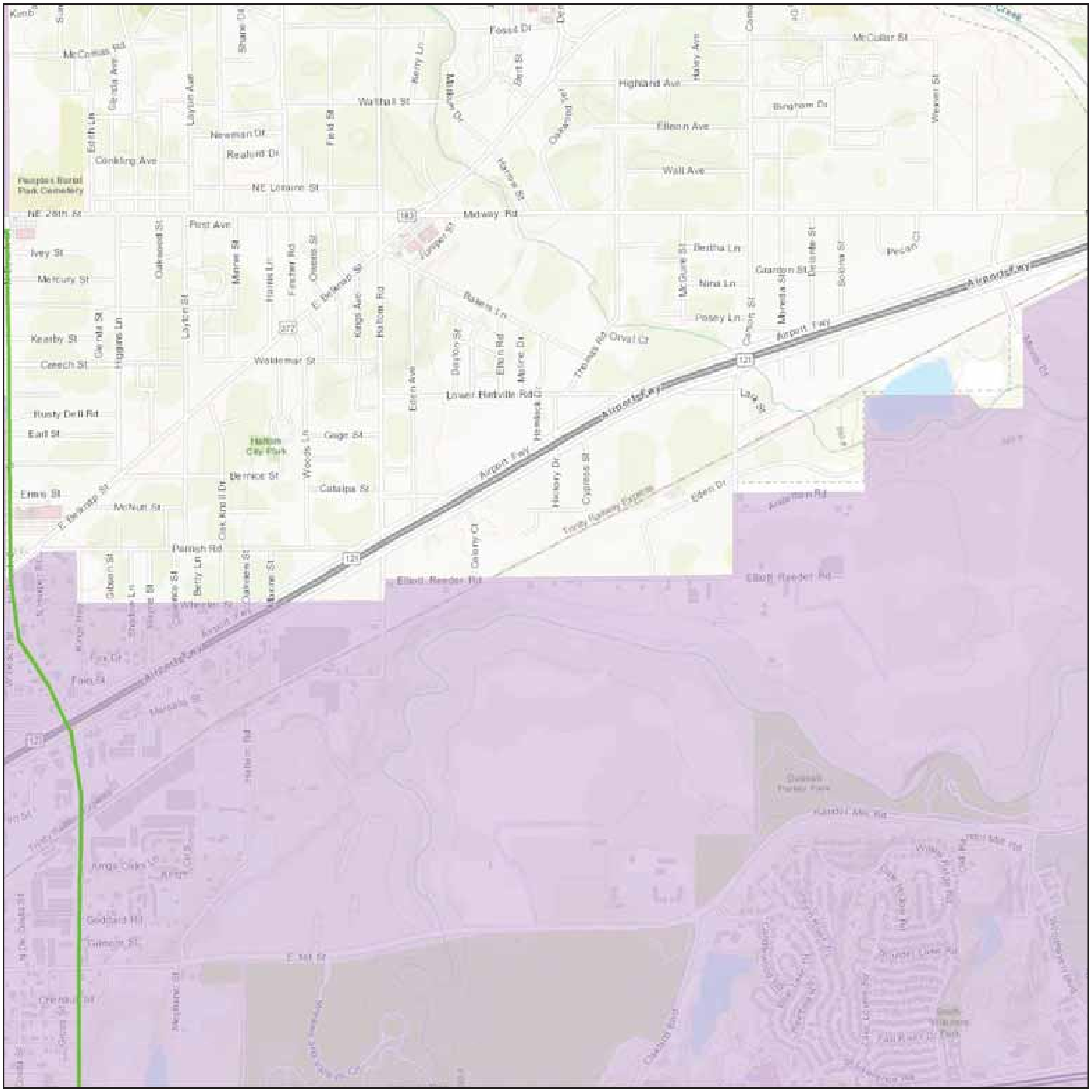
## Legend

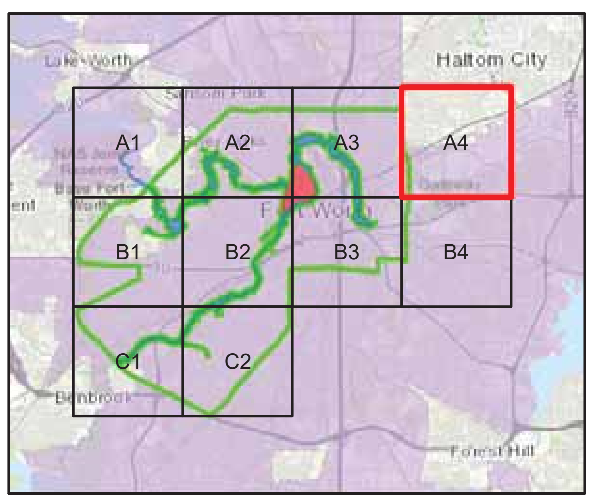
- Zone 1 - Panther Island
- Zone 2 - Floodway Corridor
- Zone 3 – Water Quality Zone (Conceptual)
- Zone 4 - City of Fort Worth

# A3

0 1,200 2,400
Feet







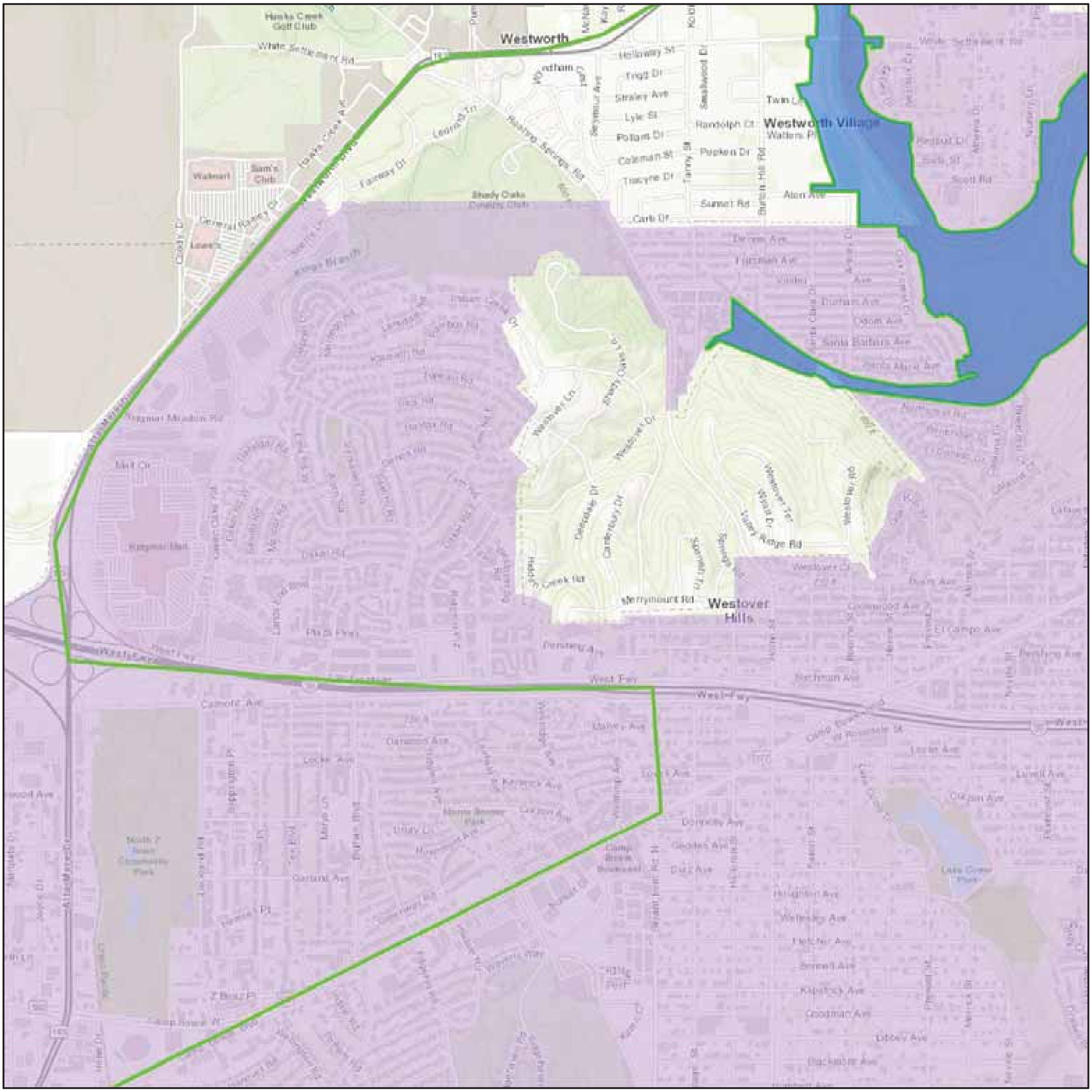

## Legend

- Zone 1 - Panther Island
- Zone 2 - Floodway Corridor
- Zone 3 – Water Quality Zone (Conceptual)
- Zone 4 - City of Fort Worth

**A4**

0 1,200 2,400
Feet

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong),

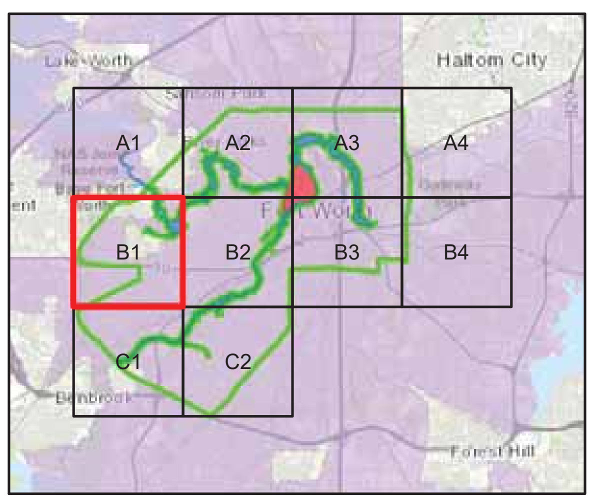


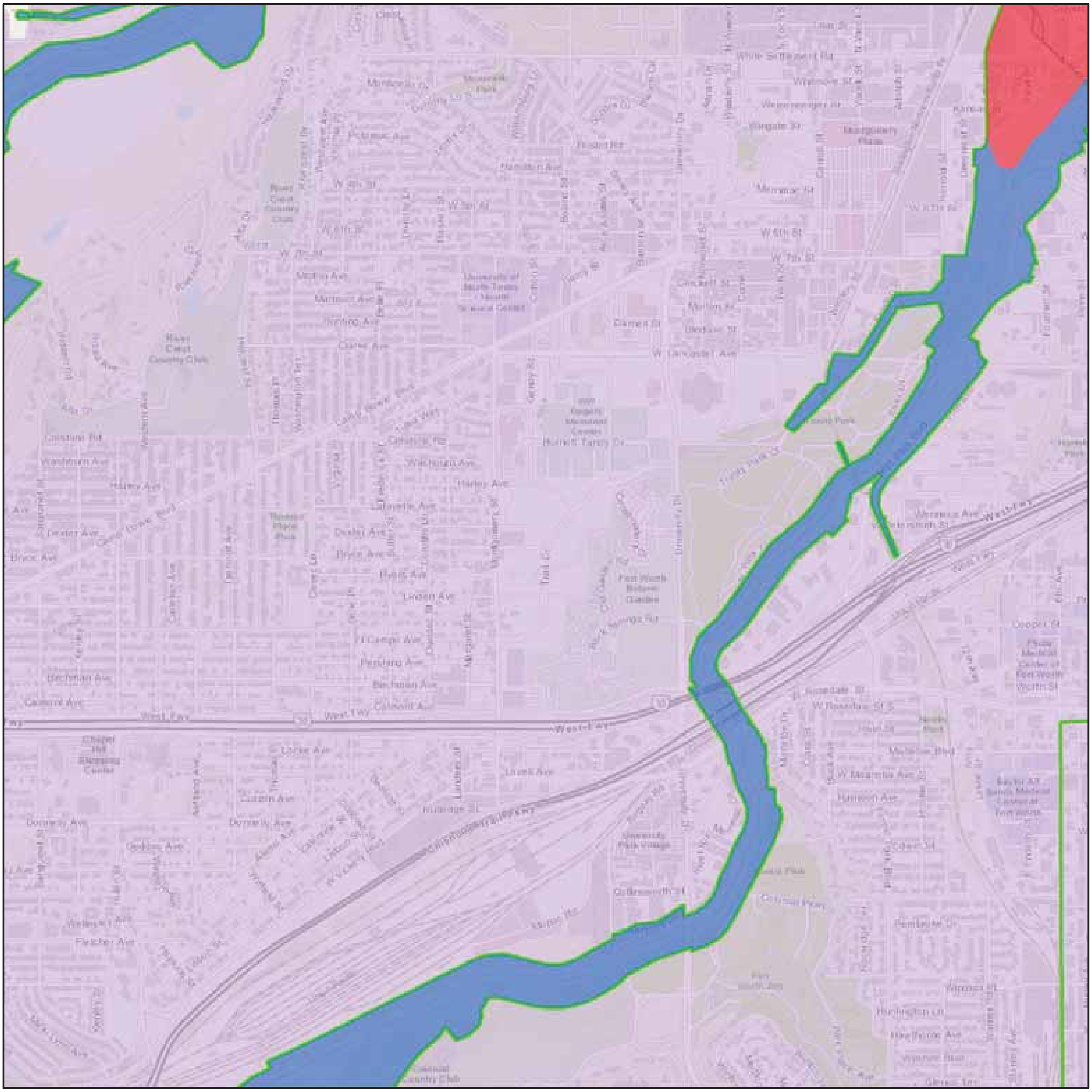

# Legend

- Zone 1 - Panther Island
- Zone 2 - Floodway Corridor
- Zone 3 – Water Quality Zone (Conceptual)
- Zone 4 - City of Fort Worth

**B1**

0 1,200 2,400
Feet



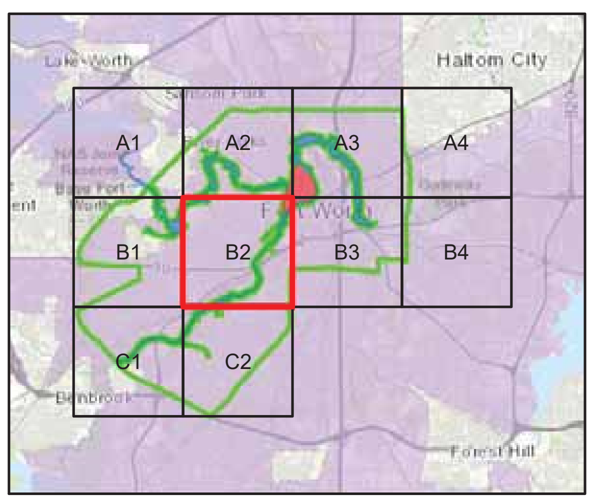


## Legend

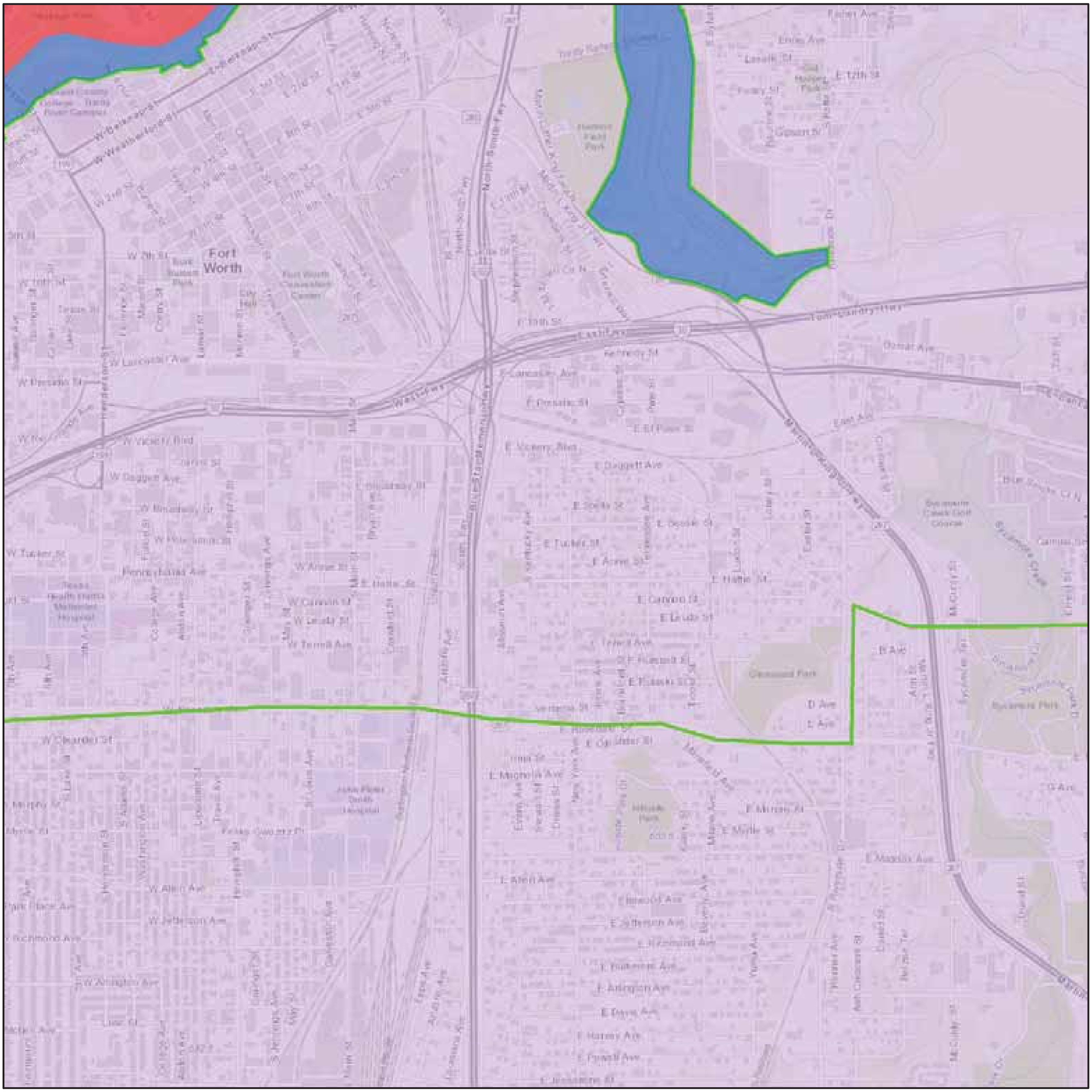
- Zone 1 - Panther Island
- Zone 2 - Floodway Corridor
- Zone 3 – Water Quality Zone (Conceptual)
- Zone 4 - City of Fort Worth

**B2**

0 1,200 2,400
Feet




Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong),

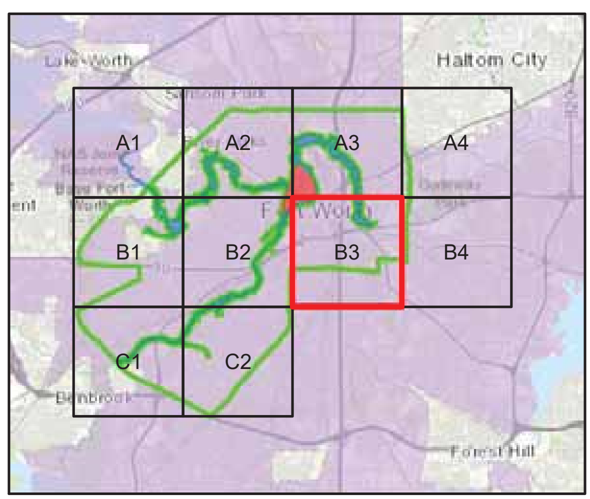


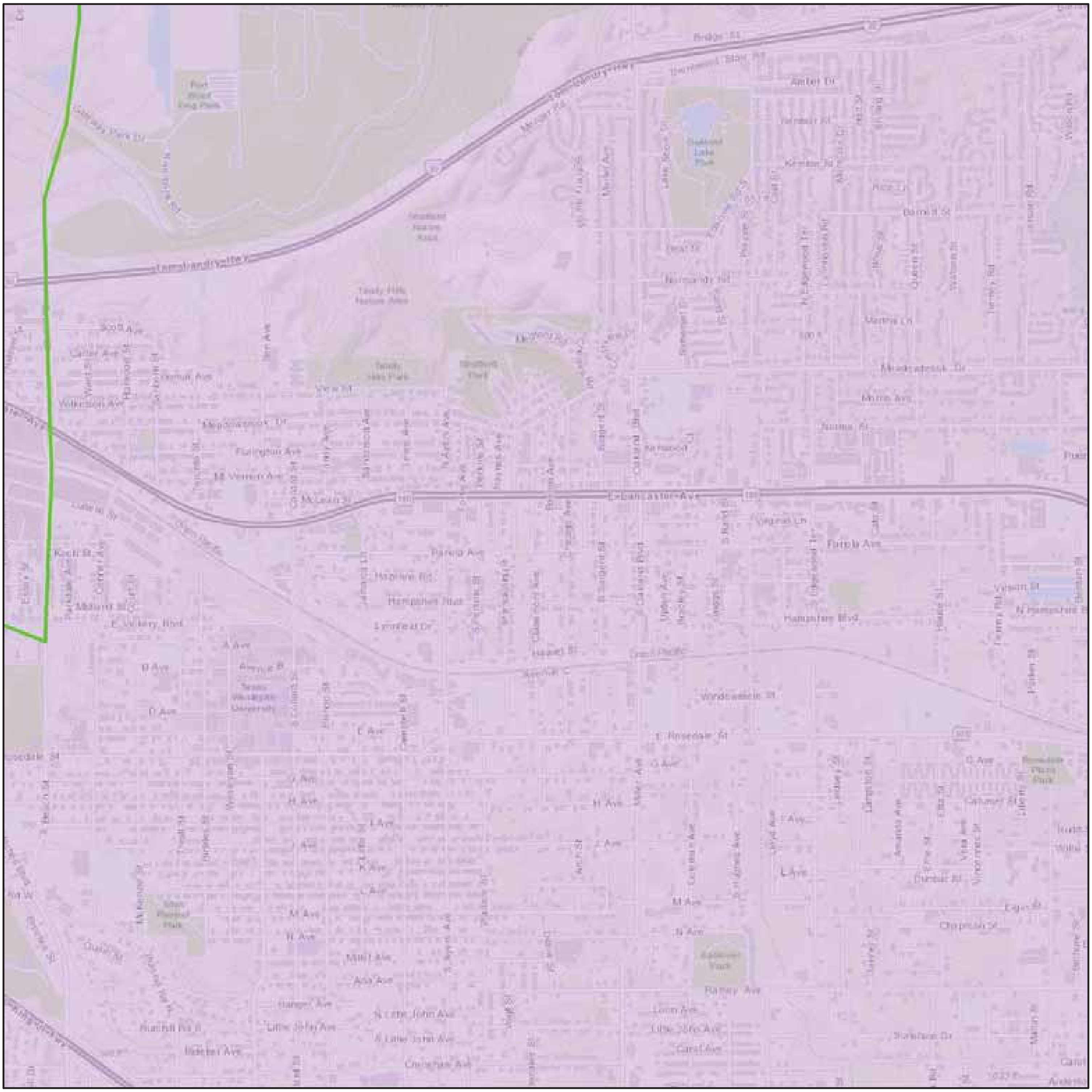

**Legend**

- Zone 1 - Panther Island
- Zone 2 - Floodway Corridor
- Zone 3 – Water Quality Zone (Conceptual)
- Zone 4 - City of Fort Worth

**B3**

0 1,200 2,400
Feet



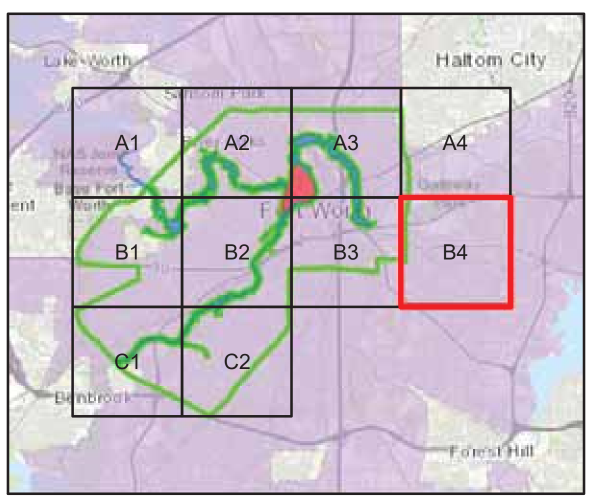


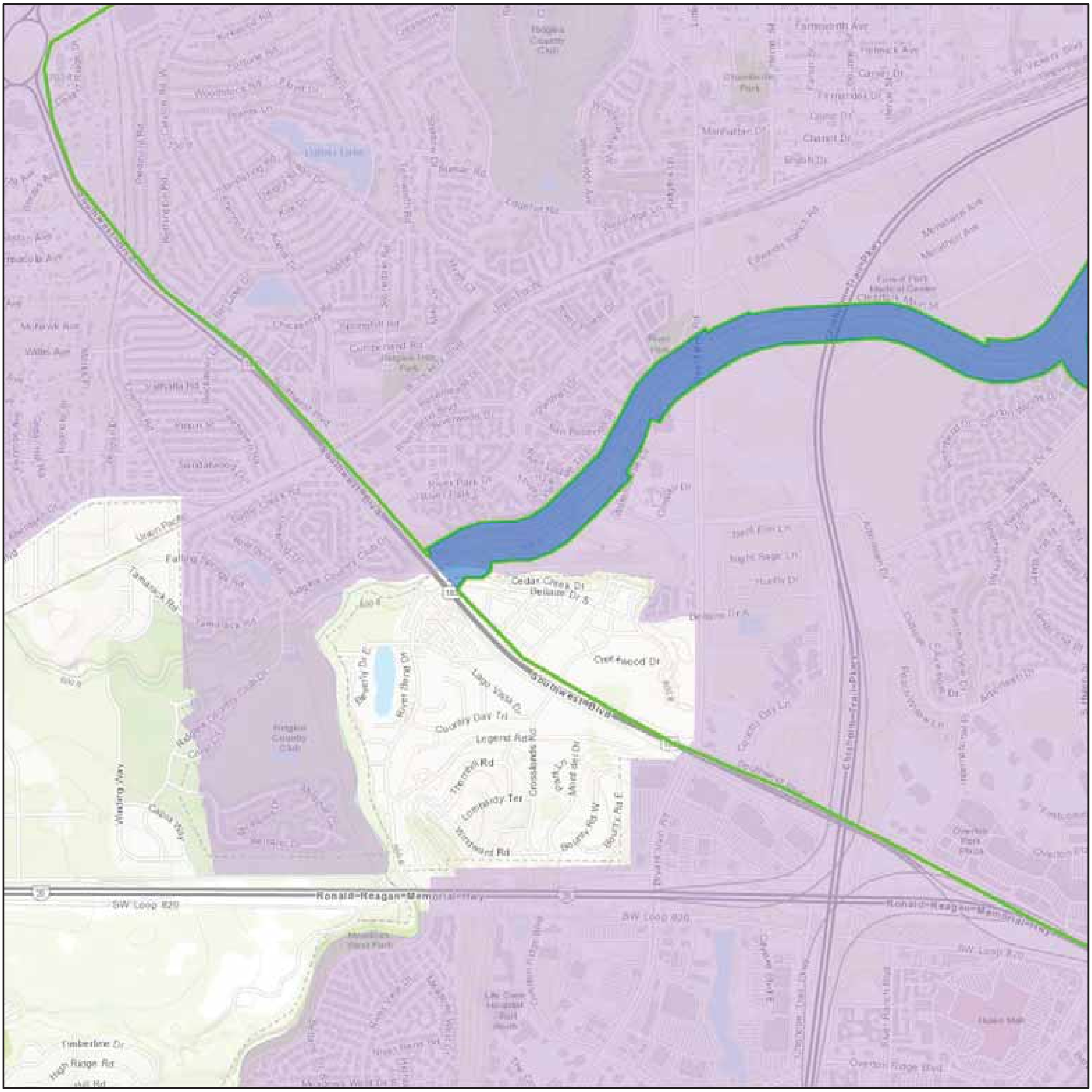
**Legend**

- Zone 1 - Panther Island
- Zone 2 - Floodway Corridor
- Zone 3 – Water Quality Zone (Conceptual)
- Zone 4 - City of Fort Worth

# B4

0 1,200 2,400
Feet



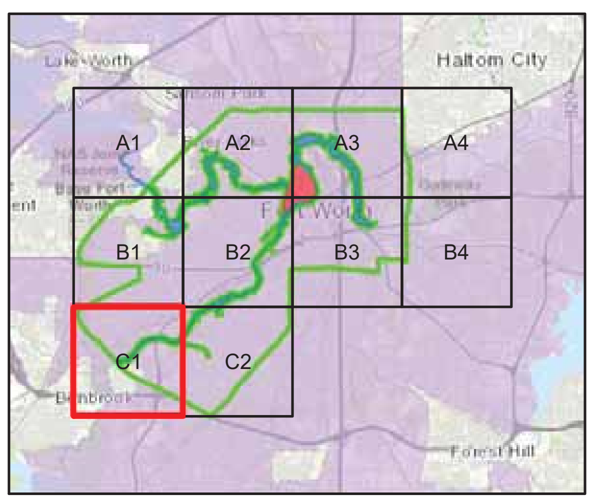



**Legend**

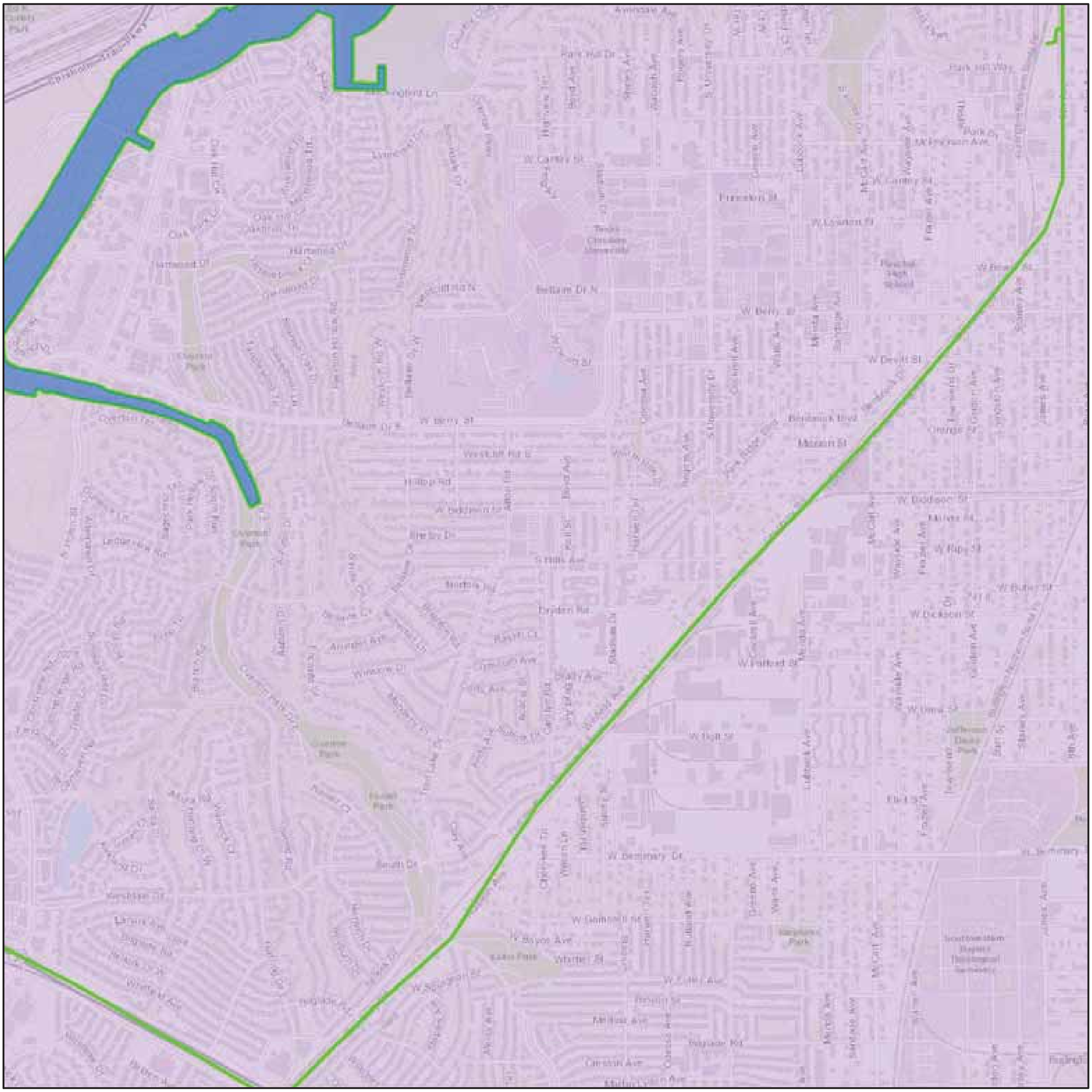
- Zone 1 - Panther Island
- Zone 2 - Floodway Corridor
- Zone 3 – Water Quality Zone (Conceptual)
- Zone 4 - City of Fort Worth

## C1

0 1,200 2,400
Feet




Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong),

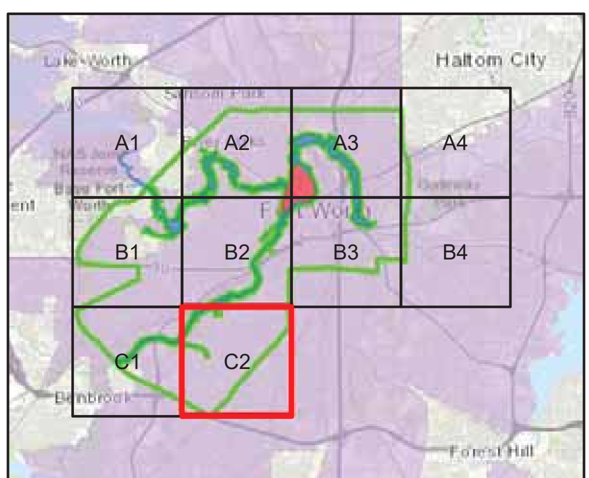


## Legend

- Zone 1 - Panther Island
- Zone 2 - Floodway Corridor
- Zone 3 – Water Quality Zone (Conceptual)
- Zone 4 - City of Fort Worth

**C2**

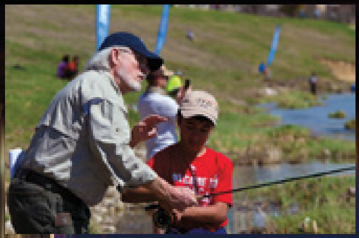
0 1,200 2,400
Feet

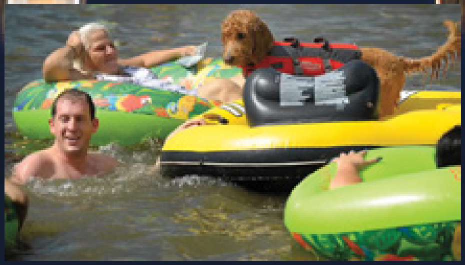


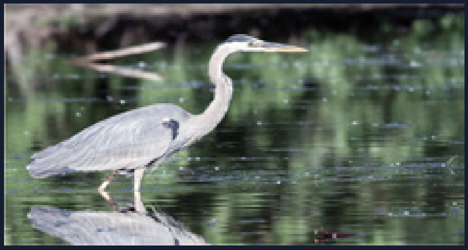

Service Layer Credits: Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong),

This page intentionally left blank.

trwd
Tarrant Regional Water District







CDM Smith

LANDSCAPE ARCHITECTS
CCA Caye Cook & Associates

NCIMM National Center for Infrastructure Modeling and Management