Harris County Low Impact Development & Green Infrastructure Design Criteria for Storm Water Management

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PART I

Background

This document is intended to provide a set of interim guidelines for the use of Low Impact Development (LID) and Green Infrastructure (GI) techniques. Over the last couple of years there has been an increased public interest in the regulatory adoption of LID and GI techniques, as a potential land development option to address drainage and storm water quality requirements. The Environmental Protection Agency has also required the adoption of such “region-appropriate practices” by November 1, 2011, as a part of the Harris County Public Infrastructure Department Architecture & Engineering Division (HCPID-AED) and Harris County Flood Control District (HCFCD) Storm Water Management Programs. This requirement is specifically located in the Bacteria Reduction Plan found in Section 12 of the Storm Water Management Program." (HCFCD, 2010 and HCPID-AED, 2010).

It is anticipated that these criteria will be in an interim form for at least 3 years after the date of adoption. During this interim period, design techniques will be reviewed and monitored for implementation success to determine how these interim criteria should be modified in the future. If at any time during this interim period HCPID-AED & HCFCD determine that a modification to the criteria is necessary, updates to this document will be issued. When such updates are issued they will affect all developments that have not yet had a pre-project meeting (See Section 2.2).

These criteria do not require a “conventional development” project to follow these LID requirements, nor do they intend for every project to be a LID project. However, these requirements shall apply to any new development or re-development project choosing to incorporate LID practices for the purpose of satisfying current HCPID-AED and/or HCFCD requirements for detention, infrastructure, stormwater quality, or other applicable requirements. Furthermore, it is intended that these guidelines should assist in the facilitation by Texas Commission on Environmental Quality (TCEQ) of Municipal Utility District (MUD) reimbursements for LID and GI elements.

Illustrations have been included in this document to aid in the understanding of the criteria. These illustrations are intended to provide visual reference to the concepts addressed in the criteria; however, they are not construction details and should not be used as such. The Integrated Management Practices used under this document are to be designed to meet the criteria as applicable to the development intended.

Final approval of the use of any LID techniques shall not include a maintenance responsibility for HCPID-AED, HCFCD, or any Harris County Precinct, unless specifically agreed to otherwise.

1 Introduction to Low Impact Development

Low Impact Development (LID) is a comprehensive land planning and engineering design approach with the goal of maintaining, as the minimum, the pre-development hydrologic regime in a watershed without solely using conventional development and detention basin techniques to satisfy drainage and flood mitigation requirements.

The term Green Infrastructure (GI) is synonymous with LID. Both terms describe an approach to infrastructure management that is cost-effective, sustainable, and environmentally friendly. GI, like LID management approaches and technologies, infiltrate, evapotranspire, capture and/or reuse storm water to maintain or restore natural hydrology. Integrated Management Practices (IMPs) are LID based practices that reduce stormwater runoff volume and pollutant loading from developed sites. IMPs function by slowing runoff, promoting infiltration, and utilizing evapotranspiration through plantings.

Principles of LID

- Conserve natural resources that provide valuable natural functions associated with controlling and filtering storm water.
- Minimize & disconnect impervious surfaces.
- Direct runoff to natural and landscaped areas conducive to infiltration.
- Use distributed small-scale controls or Integrated Management Practices (IMPs) to mimic the site's pre-project hydrology.
- Storm water education leads to pollution prevention.

1.1 LID Site Planning Concepts

Hydrologic goals and objectives should be incorporated into the site planning process as early as possible. The goal of LID site planning is to allow for full development of the property while maintaining pre-development hydrologic functions as opposed to solely comparing outfall rates. A few fundamental concepts that define the essence of low impact development technology must be integrated into the site planning process to achieve a successful and workable plan. These concepts are so simple that they tend to be overlooked, but their importance cannot be overemphasized. The steps to achieve LID include first minimizing the hydrologic impacts created by the site development through site design, and then providing controls to mitigate or restore the unavoidable disturbances to the hydrologic regime. These fundamental concepts are defined in the following sections:

- Using Hydrology as the Integrating Framework
- Controlling Storm Water at the Source
- Creating Multi-Functional Landscape and Infrastructure

1.1.1 Using Hydrology as the Integrating Framework

In LID technology, the traditional approach to site drainage is reversed to mimic the natural drainage functions. Instead of rapidly and efficiently draining the site, LID relies on various planning tools and control practices to preserve the natural hydrologic functions of the site. The application of LID techniques results in the creation of a hydrologically functional landscape, the use of distributed micromanagement practices, impact minimization, and reduced effective imperviousness. The process allows for maintenance of infiltration capacity, storage, and longer time of concentration.

Integration of hydrology into the site planning process begins by identifying and preserving sensitive areas that affect the hydrology, including streams and their buffers, floodplains, wetlands, steep slopes, high and low permeability soils, and woodland conservation zones. This process defines a development envelope, with respect to hydrology, which is the first step to minimizing hydrologic impacts. This development envelope may have the least hydrologic impact on the site while retaining important natural hydrologic features.

Integrating Hydrology

1. Identify sensitive areas that affect hydrology
2. Define the Development Envelope
3. Minimize total impervious area
4. Disconnect Impervious surfaces
5. Control and breakup impervious areas with IMPs

1.1.2 Controlling Storm Water at the Source

LID IMPs implemented on small drainage areas allow for a distributed control of storm water throughout the entire site. This process offers significant opportunities for maintaining the site's key hydrologic functions including infiltration/biofiltration, depression storage, and interception, as well as an increase in the time of concentration. The key to restoring the predevelopment hydrologic functions is to minimize and then mitigate the hydrologic impacts of land use activities closer to the source of generation. Natural hydrologic functions such as interception, depression storage, and infiltration/biofiltration are evenly distributed throughout an undeveloped site.

1.1.3 Creating Multi-Functional Landscape and Infrastructure

LID offers an innovative alternative approach to urban storm water management that uniformly or strategically integrates storm water controls into multifunctional landscape features where runoff can be micromanaged and controlled at the sources. LID may allow a variety of urban landscapes or infrastructure feature (roof, streets, parking, sidewalks, collection/conveyance systems and green space) to be designed to be multifunctional, incorporating detention, retention, filtration, or runoff use, where feasible.

PART II

2 Approval Process & LID-Based Project Criteria

A LID-based project is one which takes a comprehensive land planning and engineering design approach with the goal of maintaining, as the minimum, the pre-development hydrologic regime in a watershed without solely using conventional development and detention basin techniques. These projects will typically be characterized by the use of distributed IMPs, as described in Appendix A, rather than centralized pipe and detention basin approaches to meet these goals.

The LID analysis and design approach focuses on the following hydrologic analysis and design components:

- **Time of Concentration (Tc)**: Maintaining the pre-development Tc by minimizing the increase of the peak runoff rate after development by lengthening and flattening flow paths and reducing the length of the highly efficient conveyance systems.
- **Retention**: The storage of stormwater for an indefinite period of time. A retention feature does not have an outlet structure, but relies on infiltration, often supplemented by amended soils to improve the infiltration characteristics.
- **Detention**: The temporary storage of stormwater. A detention feature temporarily detains stormwater with an outlet that restricts the outflow to a pre-project development rate. For LID projects, the goal is to drain within 72 hours, unless pre-existing conditions are shown to take longer.
- **Change in Impervious Cover**: Minimizing changes in impervious areas and preserving more natural areas to reduce the storage requirements to maintain the predevelopment runoff volume.
- **Disconnection**: Distributing concentrated flow through landscape in a manner intended to promote slower velocities and infiltration.

2.1 Acceptable LID Practices

Table 1 below describes which LID IMPs will be acceptable for use in satisfying storm water quality and detention requirements.

Table 1. Acceptable LID IMPs for Storm Water Management and Mitigation Credit

IMP	Storm Water Quality	Detention	Time of Concentration
Bioretention & Engineered Soil	**X**	**X**	**X**
Vegetated Swale	**X**	**X**	**X**
Vegetated filter strip	**X**		**X**
Permeable Pavement	**X**	**X* (1)**	**X**
Tree Box Filter	**X**	**X**	**X**
Storm Water Planter	**X**	**X**	**X**

Green Roof	**X**		**X**
Disconnection	**X**		**X**
Soil Amendment	**X**		**X**
Rainwater Harvesting	**X*** (2)	**X*** (3)	

*(1) Voids within the permeable pavement itself can not be counted for detention, see section 3.6.1.
*(2) Acceptable for Storm Water Quality if re-used for irrigation or other non-potable uses.
*(3) Various LID practices will be considered, so long as sufficient volume reductions and the design approach are proven. Applies only to commercial sites and non-single family residential structures in limited circumstances, see section 3.4.1.

2.2 Pre –Project Meeting Requirements

Any person proposing to utilize LID IMPs shall have a pre-project meeting with HCPID-AED & HCFCD. The Harris County Permit Office is responsible for coordination of the meeting with HCPID-AED and HCFCD personnel.

Table 2. Pre-Project Review Meetings

Mandatory Pre-Project Meeting	Pre-project meetings with HCPID-AED and HCFCD will be mandatory for projects utilizing LID. The pre-project meeting is intended to ultimately expedite the review process. Consultants should prepare for these meetings with: • A list of proposed LID practices, with schematics and assumptions. • Exhibits of the project area with topographic information. • References in this Design Guide and/or the PCPM which relate to the project. In addition, this meeting will provide an opportunity for discussion of proposed hydrologic modeling methods. Once the conditions of the submittal have been defined at the pre-project meeting, future submittals will not be considered as variances and will advance through the approval system in the normal manner.
Agency Response to Pre-Project Meeting	Meeting minutes shall be provided by the development engineer and submitted for approval by HCPID-AED & HCFCD after the pre-project meeting that describes the LID processes to be used and the method of design of the LID systems. Any approvals issued will be valid for 2yrs and will not be transferable to others.

2.3 Detention and Hydrograph Requirements

Table 3: Detention and Hydrograph Requirements

Subject	HCFCD Requirements	HCPID-AED Requirements
Detention Criteria	The minimum detention rate for gravity drained detention basin systems is 0.55 ac-ft per acre. Any reductions to this rate will be based on approved hydraulic methodology based on low impact design techniques such as reduced impervious cover, increased time of concentration, etc. However, the minimum detention rate with approved low impact techniques is 0.35 ac-ft per acre. Acceptable low impact techniques and analysis methodology must be discussed and agreed upon at a pre-project meeting with HCFCD.	Minimum detention rate of 0.55 ac-ft per acre for outfalls into a Harris County maintained roadside ditch, and 50% of the required detention rate determined using the Harris County Infrastructure Regulations Section 6.03.2 for outfalls into a Harris County maintained storm sewer. Any reductions to this rate will be based on approved hydraulic methodology based on low impact design techniques such as reduced impervious cover, increased time of concentration, etc. Acceptable low impact techniques and analysis methodology must be discussed and agreed upon at a pre-project meeting with HCPID-AED.
Monitoring	HCPID-AED and/or HCFCD may be allowed to monitor, test, and/or inspect any LID IMP, and may choose to coordinate with the owner for the design elements the agencies might need for future monitoring by the agencies.	
Area Eligible for Low Impact Development	The portion of the drainage area within the project limits covered by an agreement for maintenance, repair, and rehabilitation of the facilities. LID Practices must be pre-approved at the mandatory pre-project meeting.	
Peak Flow	The LID design must show that the post-project condition has an equal or lower peak flow than the pre-project condition peak flow.	
Hydrologic Calculations and Acceptable Modeling Techniques	TBD at the required pre-project meeting. Techniques will be driven by project size (see section 2.3.1), although multiple methods may be accepted.	
Location Relative to Flood Risk Zone	Developments in a regulatory floodplain will abide by current floodplain regulations.	
Eligible LID Practices	Various LID practices will be considered, so long as sufficient volume reductions and the design approach are proven. In general, LID practices which can be shown to result in the following benefits will be considered: • Reduced impervious cover • Disconnected impervious cover • Increased time of concentration, including cumulatively over the entire development site. • Increased losses in effective rainfall through storage, interception, etc. • Dispersed storage • A factor of safety of 1.25 for engineered soil void space calculations is required.	

2.3.1 Threshold Acreages and Analysis Methodologies Requirements

The following design approaches must be considered for the respective size of the overall development. The standard of no adverse impact between pre-project and post-project will be held across all threshold acreages. Additionally, pre and post-project analyses must follow identical methodologies across all threshold acreages.

Table 4. Threshold Acreages and Analysis Methodology Requirements

Site Acreage	HCFCD Requirements*	HCPID-AED Requirements
Site ≤ 10 Acres	• No adverse impact for 2-Year, 10-Year, and 100-Year events. • Peak flow: Rational Method • NRCS TR-55 (Chapter 3) presents an acceptable method for calculating time of concentration (t_c). Other methods may be presented at the pre-project meeting. • End-of-pipe analysis: Compare Q_{exist} v. Q_{prop}, and meet minimum detention rate of 0.55 ac-ft per acre if an analysis is not performed. A comparison of pre and post-project t_c is an alternative method of analysis under the Rational Method.	• Same as HCFCD • End-of-pipe analysis: Compare $Q_{allocated}$ v. Q_{prop}, and meet minimum detention rate of 0.55 ac-ft per acre for outfalls into a Harris County maintained roadside ditch, and 50% of the required detention rate determined using the Harris County Infrastructure regulations section 6.03.2 for outfalls into a Harris County maintained storm sewer. A comparison of pre and post-project t_c is an alternative method of analysis under the Rational Method. $Q_{allocated}$ is to be determined by using Harris County Infrastructure Regulations sec 6.03.4
10 Acres < Site < 640 Acres	• No adverse impact for 2-Year, 10-Year, and 100-Year events. • Hydrologic Methodology (see PCPM for details). • Detailed routing may be required. • End-of-pipe analysis (see above).	• Same as HCFCD
Site ≥ 640 Acres	• No adverse impact for 2-Year, 10-Year, and 100-Year events. • Hydrologic Methodology (see PCPM for details). • Requires detailed routing • Analysis at end-of-pipe and at critical point(s) downstream.	• Same as HCFCD

* HCFCD Requirements listed in this document are supplemental to the criteria and procedures in the HCFCD 2010 Policy, Criteria, and Procedures Manual, they do not replace them.

2.4 Storm Water Quality Treatment

LID-based projects of one acre or larger, or those which are part of a larger plan of common development which exceed one acre, shall have a Storm Water Quality (SWQ) Permit and the accompanying Storm Water Quality Management Plan (SWQMP). The Maintenance Plan incorporated into the SWQMP must meet or exceed the maintenance requirements indicated in these criteria for the LID practices utilized. Single-family residential projects of one acre or less in size are exempt from this requirement.

Table 5: Storm Water Quality Treatment Requirements

Site Acreage	Requirements
Site $\geq$ 1 Acre	• Treatment of the first 1" of runoff • Storm Water Quality Permit required. • Storm Water Quality Management Plan (SWQMP) required.

3 LID IMP Design Criteria

3.1 Disconnection of Roof Runoff & Impervious Surfaces

Disconnection of impervious surfaces is encouraged to maximize the function of the LID practices. This method is used to increase time of concentration and promote infiltration, thereby helping to improve water quality. More detailed information can be found in Appendix A.

3.2 Vegetated Filter Strip

A vegetated Filter Strip is a band of dense vegetation, usually grass, planted between a pollution source (e.g., roadway, rooftop downspout, etc.) and a downstream receiving water body or conveyance. The filter strips function by slowing runoff, trapping sediment and pollutants, and in increasing the ability to infiltrate a portion of the runoff into the ground. More detailed information can be found in Appendix A.

3.2.1 Requirements

- The longest flow path to a filter strip, without the installation of energy dissipaters and/or flow spreaders, should not exceed 75 feet for impervious ground cover and 150 feet for pervious ground cover.

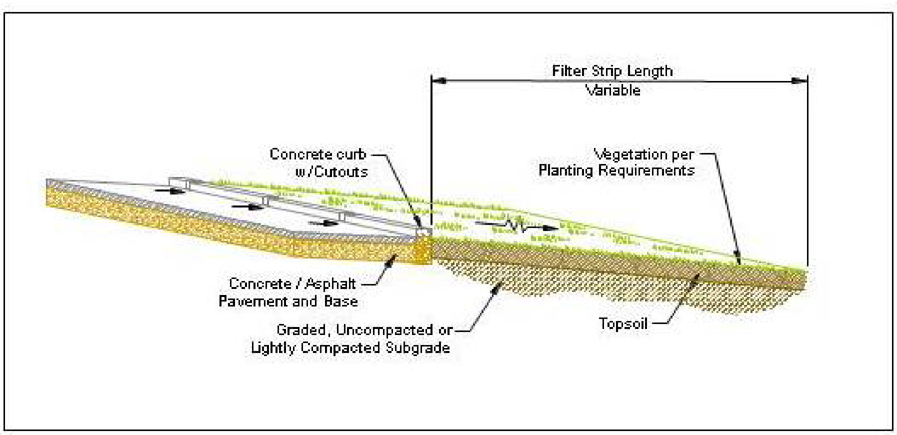


Figure 1. Vegetated Filter Strip (Perspective Cutaway View)

3.3 Vegetated Swale

Vegetated Swales are broad, shallow channels designed to convey and filter storm water runoff while slowing runoff and removing gross pollutants. They handle runoff from small drainage areas at low velocities.

3.3.1 Requirements

- The bottom and sides of the swale must be vegetated. Surface ponding in a vegetated swale must not exceed 24 hours, however a longer time frame may be considered to match existing conditions hydrograph.
- Public safety and integrity of adjacent structures must be evaluated when considering ponding depth and duration.
- See section 4.1.2 for swales used in Roadways.

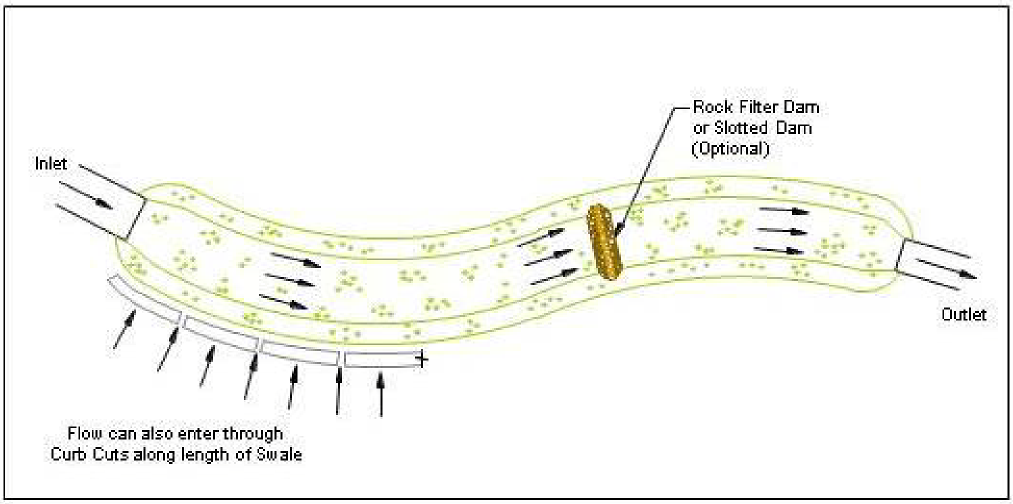


Figure 2. Vegetated Swale (Perspective Cutaway View)

3.4 Rainwater Harvesting

Rainwater harvesting systems, including cisterns, rain barrels, and underground storage systems are designed to capture roof runoff for reuse. Cisterns reduce the runoff volume only when the cistern is empty and may not reduce the peak flow rate for small, frequently occurring storms. These systems can help provide a means for water storage to serve irrigation purposes and may factor into a water conservation plan. More detailed information can be found in Appendix A.

3.4.1 Requirements

- Acceptable for water quality and detention on the commercial site or non-single family residential structures.
- Development of a water budget shall be conducted to show how volume is made available for detention.
- Storage capacity must be designed to assure capacity is available in multiple rain events.
- Not typically accepted for detention purposes.

3.5 Bioretention Systems

Bioretention is a water quality and water quantity control practice using the chemical, biological and physical properties of plants, microbes and soils for biofiltration and the removal of pollutants from storm water runoff. Bioretention Cells, or Rain Gardens, are vegetated depressions, filled with an engineered soil media which provides biofiltration for removal of pollutants, increases time of concentration, may provide detention and prevents long-term storm water surface ponding. More detailed information can be found in Appendix A.

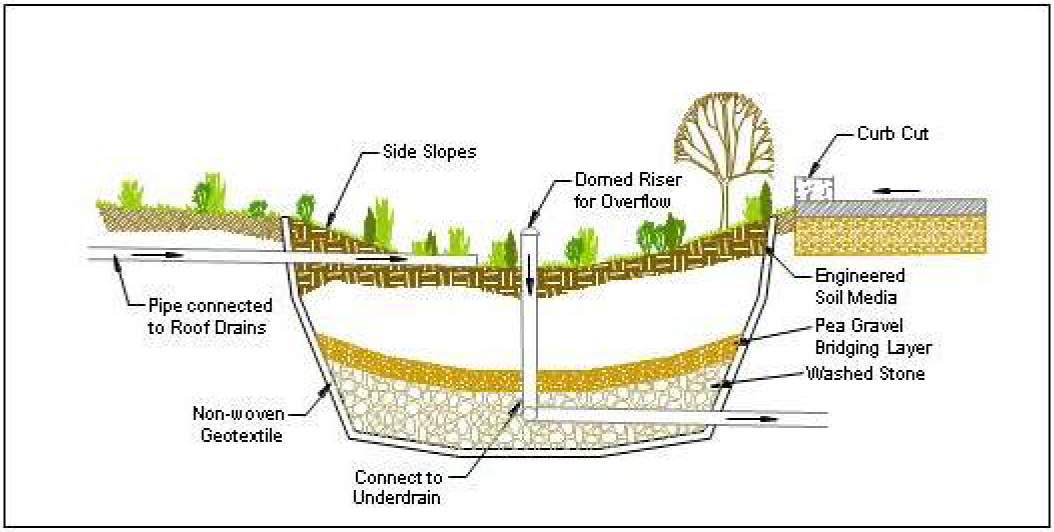


Figure 3. Bioretention Cell/Rain Garden (Section View)
Note: Soil media, type, size, and quantity to be determined in the individual designs.

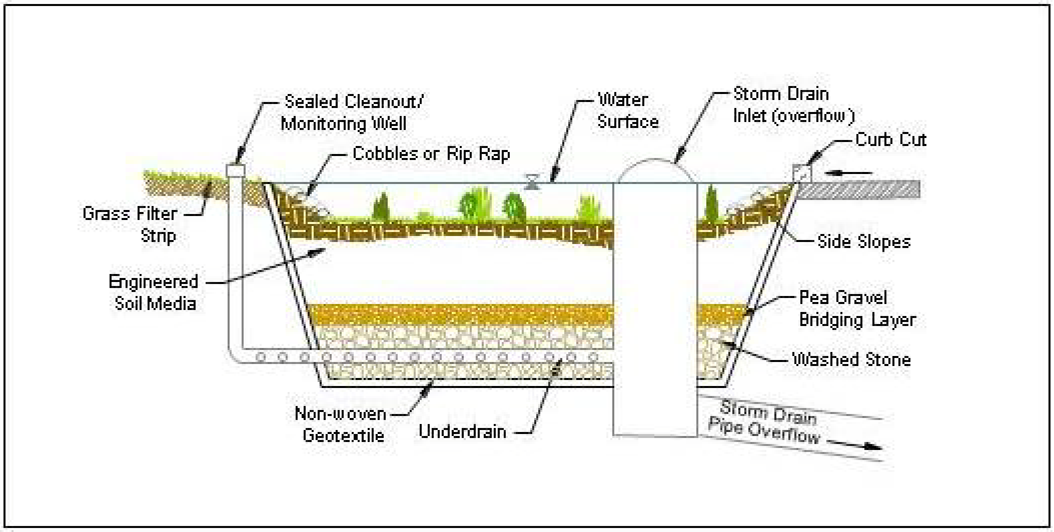


Figure 4. Bioswale (Section View)
Note: Soil media, type, size, and quantity to be determined in the individual designs.

3.5.1 Requirements

Table 6. Bioretention System Components

BIORETENTION SYSTEM COMPONENT	REQUIREMENT	PURPOSE OF COMPONENT
Geotextile Filter Fabric	required	Separate Engineered Soil Media from in situ soils. (Not to be used as separation layer between Engineered Soil Media and drainage aggregate surrounding underdrain.)
Engineered/Amended Soil Media	required	Provide high infiltration rates, safety factor of 2 for design infiltration rate and suitable substance for proposed vegetation. Provides water quality enhancement to intercepted runoff. Design infiltration rate based on size of drainage area, size of infiltration zone, underdrain inflow capacity, and treatment of the first 1" of runoff. A factor of safety of 2 should be applied in order to offset potential degradation of flow rate. See appendix B for testing requirements.
Vegetation	required	Provides water quality benefits, increased runoff storage and infiltration support as well as root absorption, erosion protection and evapotranspiration.
Bridging Aggregate	required	Aggregates used as 'bridging materials to create a separation layer between Engineered Soil Media and underdrain aggregate.
Aggregate	required	Surrounds the underdrain and provides increased volume/area capacity available to the storage component of the swale.
Underdrain	required*	Provides a secondary conveyance component to a standard bioretention swale design. May also incorporate added retention volume/storage for rainwater recycle. Underdrain must be sized to accommodate inflow and assuming 50% blockage of orifices by aggregate. *Required, unless in situ soils are proven viable for direct infiltration.
Observation/Cleanout Standpipe	required	Installed at both ends of the system and at all bends, and at 50' intervals, if run exceeds 100'. Made of min. 6" PVC pipe and capped.
Positive Overflow	required	Safely convey excessive runoff from extreme storm events. Grate must be sloped or otherwise designed to prevent clogging by mulch and debris.
Storage Chamber Products	not required	Provides the highest volume/area capacity available to the storage component of the bioretention swale.
Outfall Structure	required	Controls the rate of flow off the project site and maintains the extreme event discharge requirements.
Surface Ponding	required	Maximum surface ponding depth of 2ft for the 2yr event and 4ft for the 100yr event. Ponding duration not to exceed 24 hours. Ponding depth & duration shall be discussed at the pre-project meeting.

3.5.2 Sizing a Bioretention System

For a Bioretention System with an underdrain, the calculations for Water Quality Volume (Vwq) and Required Surface Area (Af) are as follows:

$$Vwq = (P / 12) * A$$

Where,

- Vwq = water quality volume in Cubic Feet
- P = depth of runoff to treat (1" under these guidelines)
- A = drainage area in Square Feet

$$k = (i * 24) / 24$$

Where,

- k = coefficient of permeability of engineered soil bed
- i = infiltration rate of engineered soil media in inches per hour

$$Af = Vwq * Df / [k * (H + Df) (Tf)]$$

Where,

- Af = required surface area of Engineered Soil Media in Square Feet
- Vwq = water quality volume in Cubic Feet
- Df = engineered soil media depth in Feet (typically 1.5 – 2.0)
- H = maximum ponding depth over Engineered Soil Media in Feet
- Tf = Drawdown time in Days

3.5.3 Engineered Soil Media

The infiltration rate of Engineered Soil Media in a bioretention facility must be designed to treat the first 1" of runoff volume from the drainage area it serves. In order to minimize maintenance needs and insure performance, the Design Infiltration Rate (inches per hour) must account for potential future degradation and therefore, must provide a minimum safety factor of 2.

For quality control purposes, the supplier of the Engineered Soil Media must provide a certificate which indicates the infiltration rate of the media on delivery to the project site. An in situ test must be conducted on site after engineered soil media is placed and settled to insure that the design infiltration rate is met or exceeded. This test shall be conducted using a field Infiltrometer as outlined in Appendix B.

The separation of the Engineered Soil Media and the aggregate surrounding the underdrain below it must be handled with care. Historically, geotextile fabrics (typically nonwoven) have been used as a separation layer; however, these are highly susceptible to clogging which renders the bioretention system inoperable. Fabric separation layers shall be avoided.

Instead, a thin layer (or two) of appropriately sized aggregates should be utilized as a "bridging" layer (sometimes called a "choker" course or "separator lens"). A layer of pea gravel will typically provide this bridge. Essentially, this practice relies on the largest 15% of the Engineered Soil Media "bridging" with the smallest 15% of the underdrain aggregate particles. Commonly used in United States Golf Association (USGA) greens construction, this method is simple, highly effective and not susceptible to clogging (USGA, 2004).

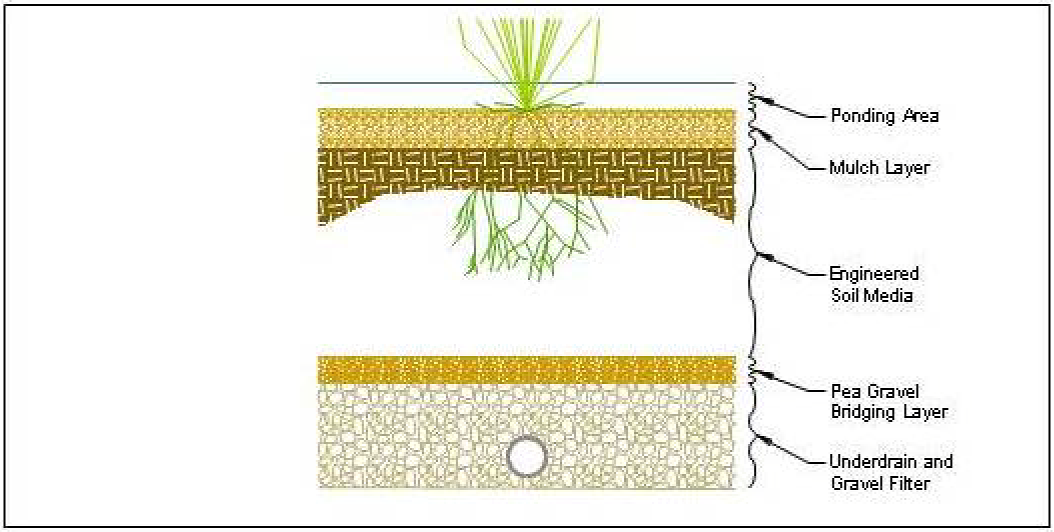


Figure 5. Bridging Engineered soil and underdrain system

3.5.4 Underdrain

Underdrain structures, including subsurface detention or storage structures which are used under Bioretention systems must have a total opening area which exceeds the expected flow capacity of the underdrain itself.

$$Q_{perforations} = C * A \sqrt{2gh} / B$$

Where,

- g = Acceleration due to gravity (32.2 ft/S^2)
- A = total area of orifice (units??)
- h = maximum depth of water above the pipe (units??)
- C = orifice coefficient
- B = blockage factor (2)

This aggregate layer surrounding the underdrain should consist of washed aggregate ½"-1½" in diameter. Holes in underdrain pipe shall consist of the minimum required area calculated above with a minimum hole diameter of ¼".

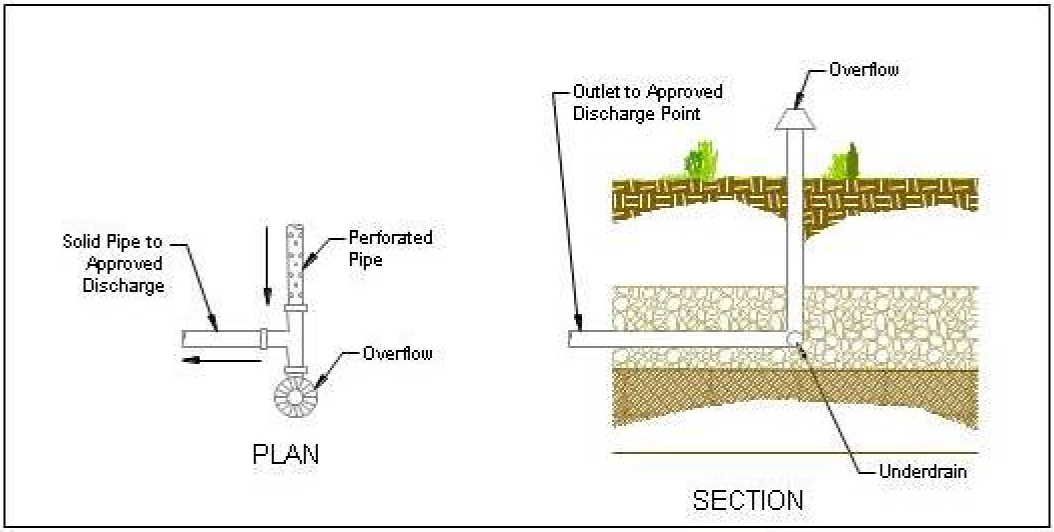


Figure 6. Underdrain (Plan & Section View)

3.5.5 Observation/Cleanout Standpipe

An observation/cleanout standpipe must be installed to the underdrain in every Bioretention Cell/Rain Garden or Bioswale. The standpipe will serve two primary functions: 1) it will indicate how quickly the bioretention IMP dewaters following a storm; and 2) it provides a maintenance port. The cleanout standpipe must be located at the upper end of the structure and be capped above the maximum ponding level elevation. It must consist of a rigid, non-perforated PVC pipe, 4 -6 inches in diameter. A cleanout must be installed at both ends of the system and at any bends.

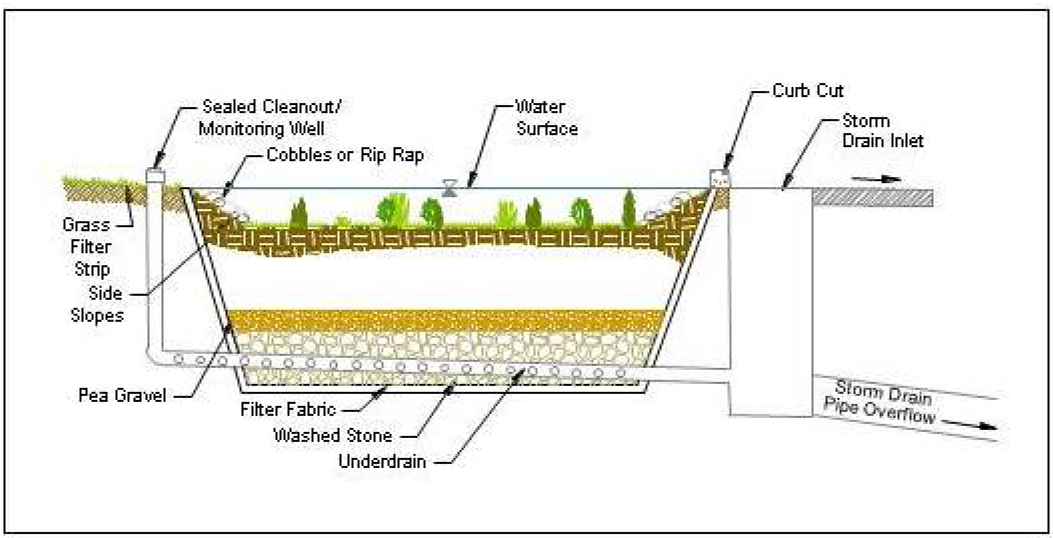


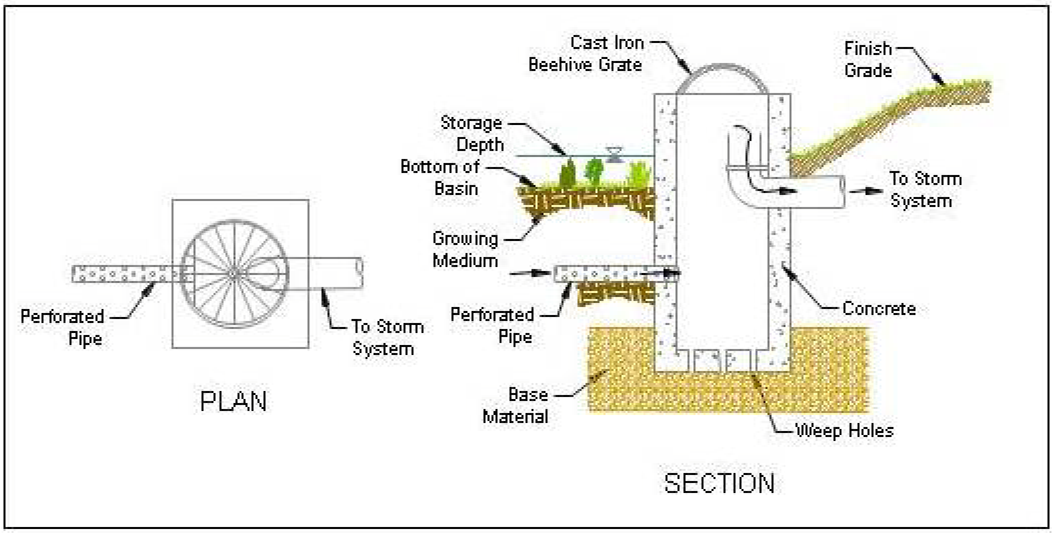
Figure 7. Observation/Cleanout Standpipe

If the Bioretention facility exceeds 100 feet in length; additional cleanouts must be installed in series every 50 feet. The top of the cleanout must be capped with a screw, or flange type cover to discourage vandalism and tampering.

3.5.6 Positive Overflow

Positive overflow options include:

- A domed riser may be installed to ensure positive, controlled overflow from the system. Once water ponds to a specified depth, it will begin to flow into the riser through a grate, which is typically domed to prevent clogging by mulch or debris.
- An inlet structure with sloped grate may also be installed to ensure positive, controlled overflow from the system. Once water ponds to a specified depth, it will begin to flow into the inlet. A sloped face will prevent clogging by mulch or debris.



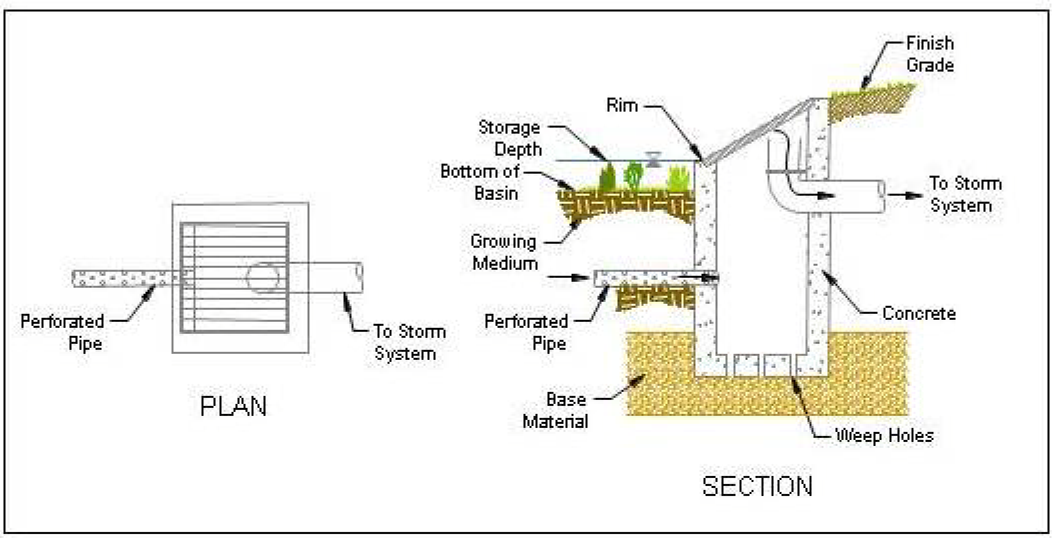


Figure 8. Positive Overflow Options (Section View)

3.6 Permeable Pavement

Permeable pavement includes a wide range of paved or load-bearing surfaces that allow water to pass rapidly through the surface and into the sub-grade that serves as a reservoir, a filter bed, and a load-bearing layer. Permeable pavement provides additional initial interception and captures pollutants.

3.6.1 Requirements

- Permeable pavement systems must be designed to incorporate an underdrain, or a subsurface detention or retention system with the capacity to drain the surface of the system within 24 hours.
- Storage in aggregate or underground structures may be located beneath the paving system to provide detention volume, but these systems must include a liner.
- Permeable pavements are not allowed on driveway aprons, or public streets.
- Voids in the permeable concrete itself may not be counted as detention volume.

3.7 Tree Box Filter

Tree box filters are bioretention systems enclosed in concrete boxes or other sub-surface structures that drain runoff from paved areas via a standard storm drain inlet structure. They consist of a precast concrete (or other) container, a mulch layer, bioretention media mix, observation and cleanout pipes, under-drain pipes, a street tree or large shrub, and a grate cover.

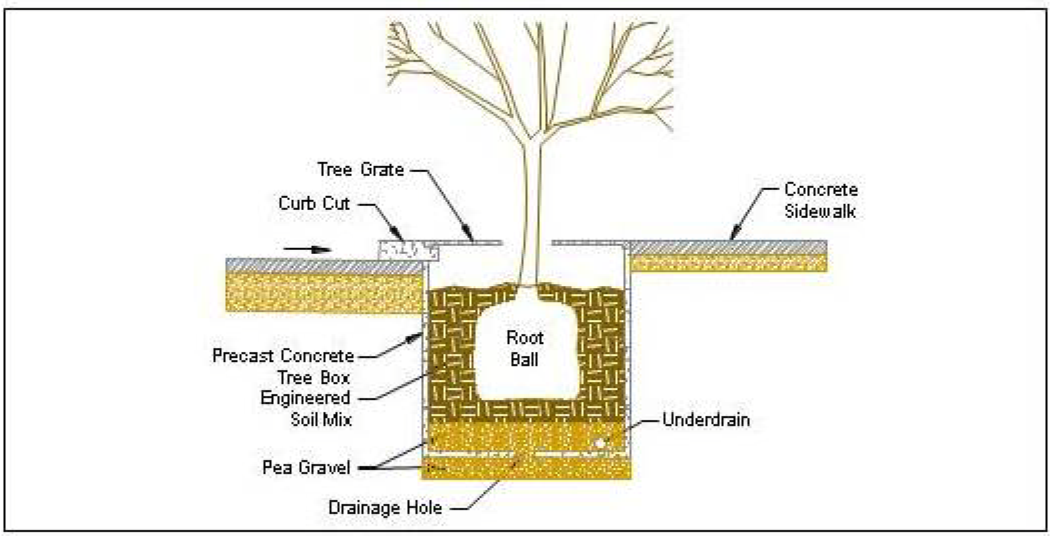


Figure 9. Tree Box Filter

3.7.1 Requirements

- The ponding area in Tree Box Filters shall be designed with a maximum ponding depth of 24" and to drain ponded water within 24 hours.
- Plants can also be selected from those that would be used in traditional bioretention systems (See Appendix A).
- An underdrain pipe is required to drain the feature.
- A maximum of 75% of the void space volume may be counted for detention.
- Pre-manufactured systems must be installed in accordance with the manufacturer's instructions.

3.8 Storm Water Planter Box

Storm Water Planters, also known as flow through planters, are also bioretention systems in enclosed in concrete structures. They can be designed to drain runoff from paved areas via curb inlet structures or pipes, or they can be located under roof drain downspouts for treatment of roof runoff.

3.8.1 Requirements

- Storm Water Planters shall be designed with an underdrain pipe.
- Waterproofing shall be incorporated into the designs of Storm Water Planters sited near buildings and other structures.
- The ponding area in Storm Water Planters shall be designed with a maximum ponding depth of 24" and to drain ponded water within 24 hours.
- Plants can also be selected from those that would be used in traditional bioretention systems.
- Pre-manufactured systems must be installed in accordance with the manufacturer's instructions

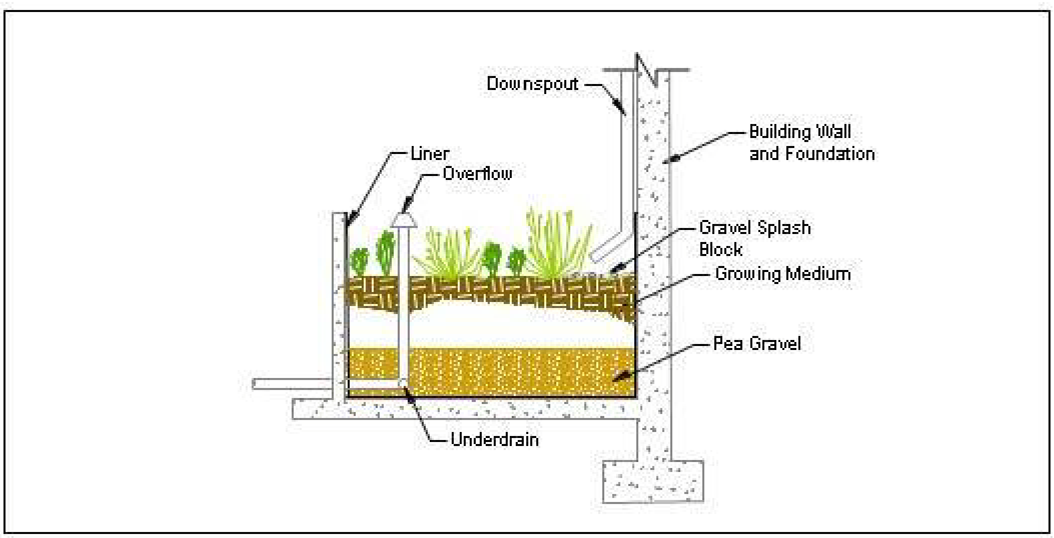


Figure 10. Storm Water Planter Box (Section View)

3.9 Green Roof

A green roof is a vegetated roofing system. Green roofs typically consist of a number of layers: a waterproofing membrane, a drainage system, root protection, growing media (soil) and vegetation. Green roofs provide numerous environmental benefits and offer a valuable tool for integrated storm water management.

3.9.1 Requirements

Green roofs can provide an acceptable storm water quality treatment on the commercial site or non-single family residential structures.

4 LID Design Essentials for Specific Project Types

4.1 Roadways

Harris County Public Infrastructure Division standards for public roads which implement LID practices include those detailed in this section.

4.1.1 General Roadway Criteria for Public Streets

Table 7. General Roadway Requirements

Consideration	Requirements
LID Features	• Pervious asphalt or pervious concrete will not be used for the roadway pavement. • Generally, Impacts must be restrained to the road ROW; i.e. no off site detention or mitigation would be required. LID features should be able to fit in the MTFP ROW (i.e. 100ft) • Roadway safety cannot be compromised. • Maintenance intensive features are not acceptable. • LID features cannot be placed beneath travel lanes (median openings acceptable). • All LID features will be incorporated within the Public Right of way, or within a dedicated easement. • Designs must provide safe conveyance of the 100 year event.
Culvert Sizes	• Culverts must meet minimum size standard of 18”. However, a restrictor on upstream end may be allowed if needed for hydraulic reasons. The minimum restrictor size shall be 6”.
Construction Management	• This critical element for successful implementation must be addressed in the design.
Hydrology	• See Section 2.3
Maintenance	• In general, maintenance costs should not be increased to a point that offsets the capital cost savings of the LID design approach. • Design maintenance is to be minimized by landscape choices

	and other decisions that may impact maintenance requirements. (Ideally it would be limited to once or twice per year vegetative maintenance.) Requirements should be clearly spelled out in the design. • See Required Maintenance in other sections.

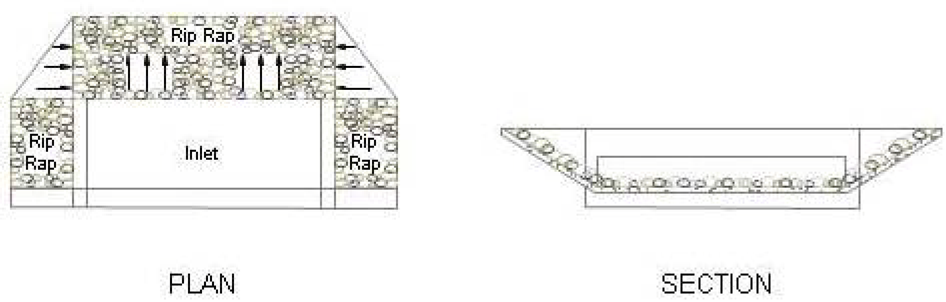


Figure 11: False inlet (preferred)

4.1.2 Criteria for Vegetated Swales in Roadways

Table 8. Criteria for Vegetated Swales in Roadways

Consideration	Requirements
Overflow & Safety	• Overflow weir or structures are required, and must accommodate the extreme event. • Overflow inlet grates must be designed to minimize blockage. • Overflow bypass should occur at design maximum ponding depth. • Crossovers may be depressed up to 6" to act as 100 year event overflow weirs, provided crossover is not associated with a major thoroughfare intersection. • Utilize standard minimum curb heights as an option to prevent traffic from entering the swale. • Acceptable inlet styles are those which do not impinge on safety requirements and account for the potential for being clogged with debris, such as: ▪ False inlet (preferred) ▪ Curb Cut with recessed flume opening, if top surface bridged. ▪ Horizontally slotted curb at street grade, if sufficiently long. • Inflow inlets to Bioswale should be dropped 3" to assist in capturing sediment before it reaches the Engineered Soil Media and be sufficiently long so as to prevent flow restrictions caused by vegetation.
Water Quality	• Vegetated Swales may act as a pretreatment system for water quality, but alone will not meet the water quality requirement to treat the first 1" of runoff.
Detention	• Maximum side slope at 4:1, unless approved by the County Engineer.

	• Maximum water depth for the 2yr event shall not exceed 2 feet. • Maximum water depth for the 100yr event shall not exceed 4 feet, and one traffic lane in each direction shall remain passable. • In the design, plan for left turn lanes so that this volume is excluded. • Culverts must meet minimum size standard of 18”. However, a restrictor on upstream end may be allowed if needed for hydraulic reasons. Minimum restrictor size is 6”. • Water shall not pond for more than 24 hours (max). • Maintain the requirement for no adverse impact during an extreme event. • If the design includes taking credit for storing storm water within the voids of engineered soils then appropriate modeling techniques should be used to account for this.
Utilities	• Shallow depth of typical LID features may offer beneficial design options with respect to utilities beneath them, but may in some circumstances, limit the use of Bioswales at the outer edges of the ROW.
Vegetation	Vegetation shall be selected based on the following criteria: • Hardiness in the design condition, evapotranspiration rate, pollutant removal, maintenance requirements and cost. • Ornamental plant massing should be utilized only where non-standard maintenance capacity exists (‘adopt-a-mile’ programs, garden club, HOA affiliations, etc.) and grouped to allow for efficient maintenance procedures. • Where maintenance issues are most critical, specify grass-only landscape plans. • Vegetation capable of wet and dry conditions. • Construction timing and seasonal considerations should be considered in the specification of plant material, and erosion control measures.

4.1.3 Criteria for Bioswales in Roadways

Table 9. Criteria for Bioswales in Roadways

Consideration	**Requirements**
General	• See criteria above (Table 8) for Vegetated Swales. • Bioswales by definition incorporate engineered soils and biofiltration of water to an underdrain, storm sewer, or detention structure (see 3.5.2). • Bioswales must infiltrate water through engineered soils to treat the first 1” of runoff. Runoff above this specified amount may bypass into the storm sewer system.
Engineered Soils	• Engineered soil must be a designed mix, submitted for approval, but the minimum effective infiltration rate for engineered soils must be designed for at least thirty inches per hour (30”/hr), with a factor of safety of 2. Therefore the actual design capacity of the soil is to be 60”/hr to meet the 30”/hr criteria with safety factor. • Use of mulch should be limited to the use of aged, shredded hardwood bark mulch (not floatable) used only in biofiltration areas of limited size • In situ testing of Engineered Soil Media must be performed to verify that infiltration rate meets specified rate. Failure to meet the design infiltration rate will result in removal and replacement of the media.

4.1.4 Swale Slope-Depth Ratios: Based on a 30' Median

Table 10. Swale Slope Depth Ratios

Slope	Max Depth from Top of Curb	Max Depth 100yr Event	Max Depth 10 yr Event
6:1	2.5	2.2	2.0
5:1	3.0	2.7	2.5
4:1	3.7	3.4	3.0

Note: for the 100-year event, one lane in each direction shall remain passable with a maximum water depth of 4 feet. For events up to the 10 year, the water shall remain below the gutter line with a maximum water depth of 3 feet. Deeper bioswales may require evaluation for the appropriate level of vehicle control or channelization techniques.

4.2 Commercial Development

4.2.1 Location and Maintenance of LID IMPs

If there are no publicly owned facilities on the commercial site, LID practices shall be maintained by the property owner. As they are part of the Storm Water Quality Permit for the site, they shall be maintained as the Storm Water Quality Management Plan dictates. This maintenance generally consists of familiar landscape maintenance and pavement sweeping activities.

4.3 Suburban Residential Development

4.3.1 Location and Maintenance of LID IMPs

For residential subdivision development, all LID IMPs shall be located within a public Right of Way and/or easement maintained by a governmental entity, i.e. Municipal Utility District, etc. As they are part of the Storm Water Quality Permit for the site, they shall be maintained as the Storm Water Quality Management Plan dictates.

4.3.2 Maintenance Declarations

The responsible governmental entity, i.e. Municipal Utility District, etc., must make a "Maintenance Declaration" as to the intent to construct and maintain the LID IMPs. The declaration shall be filed in the real property records, and the file number referencing such declarations shall be located on the subject plat under "notes". An example declaration is located in Appendix C.

4.3.3 Pavement Width

Any proposed deviations from the approved criteria for pavement width and geometry must be discussed with HCPID at the Pre-project meeting and approved by HCPID.

4.3.4 Detention in Roadside Ditches

Storm water detention within roadside ditches may be allowed provided that the detention, roadside ditch, and drainage features adjacent to the roadway are maintained by another governmental entity other than Harris County, i.e. a Municipal Utility District, etc.

Appendix A
LID IMPs General Reference Material

1 LID Integrated Management Practices (IMP)

Although the LID toolbox is virtually unlimited, the practices described below are believed to be the most likely to be used in this area, in combination or alone, to achieve the goals of a LID-based project design. The table below presents the variety of runoff management functions provided by LID IMPs.

Table 11. LID IMP Runoff Management Functions

IMP	Effect or Function					
	Slow Runoff	Filtration	Retention	Detention	Evaporation	Water Quality
Disconnection	X	X				X
Soil Amendment		X				X
Vegetated Filter Strip	X	X			X	X
Vegetated Swale	X	X		X	X	X
Rainwater Harvesting			X	X		X
Bioretention	X	X		X	X	X
Permeable Pavement	X	X		X	X	X
Tree Box Filter	X			X		X
Storm Water Planter	X	X		X	X	X
Green Roof	X				X	X

1.1 Disconnection

Roofs, roads, and driveways account for a large percentage of post-development imperviousness. These surfaces influence storm water quality and runoff volume by facilitating the rapid transport of storm water and collecting pollutants from rainfall, automobiles, and additional sources. Disconnecting storm water can be achieved through identifying the source of runoff and how it will be managed once disconnection occurs. Disconnection is ideal for most single-family developments, but can also be applied to many development sites, including larger office parks and retails centers. This IMP can help reduce total volume and peak rates of runoff when runoff is directed to other IMPs. Disconnection can help reduce runoff volume and peak rates; to the extent that it is absorbed via amended soils or captured in rain gardens otherwise it is only slowed down before reaching the receiving conveyance system.

Taking steps to increase the permeability of soils can also play a valuable role in disconnection. Tilling and amending soils with compost or other amendments can increase permeability and enhance vegetative growth, both of which can assist in the reduction of volume and peak rates.

1.1.1 Disconnecting Roof Runoff

Minimize storm water volume by disconnecting roof leaders. In addition to directing runoff to vegetated areas, runoff may also be discharged to non-vegetated IMPs, such rain barrels, and cisterns for storm water irrigation and water planning purposes. Disconnection of small runoff flows can be accomplished in a variety of ways:

- Encourage shallow sheet flow through vegetated areas.
- Direct roof leader flow into BMPs designed specifically to receive and convey rooftop runoff.
- Direct flows into stabilized vegetated areas, including swales and bioretention areas.
- Rooftop runoff may also be directed to onsite depression storage areas.
- The entire vegetated "disconnection" area should have a maximum slope of five percent.
- Roof downspouts or curb cuts should be at least 10 feet away from the nearest connected impervious surface to discourage "re-connections."
    - Limit the contributing impervious area to a maximum of 1,000 sq. ft. per discharge point.
    - Limit the contributing rooftop area to a maximum of 1,000 sq. ft. per downspout, where pervious area receiving runoff must be at least twice this size.

1.1.2 Disconnecting Impervious Surfaces

Reductions in peak flows may be gained by redirecting and dissipating concentrated flows from impervious areas onto vegetated surfaces. Strategies for accomplishing this include: directing flows from small swales to stabilized vegetated areas; breaking up flow directions from large paved surfaces; and encouraging sheet flow through vegetated areas.

1.2 Vegetated Swale

Vegetated Swales are broad, shallow channels designed to convey and filter storm water runoff while slowing runoff and removing gross pollutants. They handle runoff from small drainage areas at low velocities. The bottom and sides of the swale are vegetated, with side vegetation at a height greater than the maximum design depth.

Storm water runoff is conveyed along the length of the low slope channel, and the vegetation traps sediments, decreases the velocity of overland flows, and reduces erosion. Vegetated Swales treat runoff by filtering sediments and associated pollutants through the vegetation, and by infiltration into underlying soils if in situ soils are conducive to infiltration.

Check dams are typically used in Vegetated Swales to act as flow spreaders, inducing sheet flow along the swale. They may also be used as a storm water detention mechanism, to encourage sedimentation and to reduce runoff velocity. Vegetated Swales can be used to convey and treat runoff from parking lots, buildings, roadways, and residential, commercial, industrial, and municipal land uses. They can also be used as pretreatment devices for other structural treatment controls.

1.3 Vegetated Filter Strip

A vegetated Filter Strip is a band of dense vegetation, usually grass, planted between a pollution source (e.g., roadway, rooftop downspout, etc.) and a downstream receiving water body or conveyance. They function by slowing runoff, trapping sediment and pollutants, and in some cases infiltrating a portion of the runoff into the ground. Filter strips are a sensible and cost- effective storm water management pretreatment option applicable to a variety of development sites including roads and highways. Given that vegetation is the key functional component of a vegetated filter strip, due consideration must be given to the ability of the in-situ soil to support healthy vegetative growth conditions.

1.3.1 Soil Amendment

The 'sponge' effect of in situ soils in Vegetated Filter Strips may be significantly improved when tilled and amended with compost to enhance pollutant removal, reduce surface ponding time and slow runoff by enhancing vegetative cover. Soil amendments may also be selected to adjust pH to levels supportive of vegetative growth, provide necessary nutrients and minerals, and increase water access and availability characteristics among other benefits. Check dams are typically used in Vegetated Swales to act as flow spreaders, inducing sheet flow along the swale. They may also encourage sedimentation and reduce runoff velocity. Surface ponding in a Vegetated Swale must not exceed 24 hours.

Vegetated Swales can be used to convey and treat runoff from parking lots, buildings, roadways, and residential, commercial, industrial, and municipal land uses. They can also be used as pretreatment devices for other structural treatment controls.

1.3.2 Vegetation Considerations

Given that vegetation is the key functional component of a vegetated swale, due consideration must be given to the ability of the in-situ soil to support healthy vegetative growth conditions. A soil profile which has been cut to create the swale will often expose soils which are not capable of supporting growth without significant, ongoing use of fertilizers which is unlikely to be carried out over the long term. A substantial layer of topsoil retained from the site during the grading phase or imported, and placed over the cut slopes, may alleviate the problem. Vegetation is not restricted to grasses, but regardless of the plant material selected, native plants are preferred. A soil analysis is highly recommended for any Vegetated Swale design, to determine what, if any, amendments may be needed to encourage and ensure proper vegetative growth.

1.3.3 Maintenance Requirements

Proper maintenance includes mowing/pruning, weed control, removal of trash and debris, and reseeding of non-vegetated areas/replacement of plant material. Inspect Vegetated Swales at least twice annually for damage to vegetation, erosion, and sediment accumulation. Sediments should be removed when depths exceed 3 inches. If hazardous materials spill and contaminate soils in vegetated swales, the affected soils should be removed, properly disposed of, and replaced.

1.4 Rainwater Harvesting

Cisterns and rain barrels are designed to capture roof runoff for reuse. Cisterns reduce the runoff volume and may reduce the peak flow rate for small, frequently occurring storms. Cisterns or rainwater catchment systems can provide a storm water management solution where impervious surfaces are unavoidable and site constraints limit the use of other LID practices. Such situations may include highly urbanized areas (such as downtown centers), or dense housing developments without adequate space for storm water infiltration or detention, or where soil and groundwater conditions do not permit infiltration. In addition to storm water management benefits, rainwater catchment systems can be utilized as a sustainable building approach to reduce a development's dependence on municipal water supplies.

There are several management and maintenance factors for the rain water catchment system that should be considered including the fact that the storage capacity needs to be available to catch the next storm event's flow. For example, if the water in the storage tank is only used for landscape irrigation and the need for irrigation water during a period of extended rainfall is minimal, the tank may fill after the first few storms and overflow during subsequent storms. Therefore, rainwater catchment systems that are only used for landscape irrigation may not be effective for storm water management during the rainy season. Development of a water budget should be conducted for maximum efficiency and is required to demonstrate how rainwater harvesting is used to reduce the storm water detention requirement.

1.5 Bioretention Systems (Bioretention Cell, Rain Garden, Bioswale)

Bioretention is a terrestrial-based (up-land as opposed to wetland), water quality and water quantity control practice using the chemical, biological and physical properties of plants, microbes and soils for biofiltration and the removal of pollutants from storm water runoff. Bioretention Cells or Rain Gardens are vegetated depressions, filled with an engineered soil media which provides biofiltration for removal of pollutants, increases time of concentration, may provide detention and prevents surface ponding of storm water. The Bioswale is linear version of a Bioretention Cell and has similar design considerations, requirements and attributes. Bioswales are typically designed for primary or secondary conveyance as well as its bioretention and biofiltration benefits.

1.5.1 Design Considerations

A typical bioretention system design includes a depressed ponding area (at a grade below adjacent impervious surfaces), an engineered soil mix, and an underdrain or underground detention or water harvesting system.

Bioretention facilities are typically excavated to a minimum depth of 1 to 3 feet, Excavation depth is typically based on depth to the seasonal high groundwater table, outfall depth considerations and volume to be captured. Deeper excavation allows for additional storage in the engineered soil, gravel layers, underdrain or underground detention/storage structures. Unless the system is being constructed without an underdrain, a layer of geotextile filter fabric or an impermeable liner (if surrounding infrastructure dictates) should be placed along the sides and bottom of the excavation to separate the engineered soils from the existing site soils.

Engineered soil media occupies the remaining excavated space above the underdrain system, leaving room for the desired amount of surface ponding. The area is then mulched and planted with shrubs, perennials, grasses, and small trees. When shrubs and flowers are used as the plant material, a 2 to 3 inch layer of mulch is used on top of the media. The mulch acts as a pretreatment device to protect the underlying media and helps to retain some water in the media for the health of the plant.

Generally runoff is ponded to a maximum depth of approximately 12-24 inches and then gradually filters through the engineered soil media, where it is retained in the porous soils, utilized by plants, evapotranspired, and either infiltrated into the underlying soils (when applicable), or drained into an underdrain or underground storage system over a period of hours. The Bioretention system should be designed so that surface ponding does not exceed 24 hours.

The layout of a Bioretention system should be determined based on site constraints such as location of utilities, underlying soil conditions, existing vegetation and drainage patters. The plant selection and layout should consider aesthetics, maintenance, native versus non-native, invasive species, and regional landscaping practices**.** It should be noted that ideal plants for a typical Bioretention system are drought and inundation tolerant.

An important design factor to consider when applying Bioretention to development sites is the scale at which it will be applied. Typical system scales are:

- Bioretention Cells or Rain Gardens are small, distributed practices designed to treat runoff from small areas. Inflow is typically sheet flow, or can be concentrated flow with energy dissipation.
- Bioretention Basins are larger systems treating parking lots and/or commercial rooftops, or other large areas, usually in commercial or institutional areas. Inflow can be either sheet flow or concentrated flow. Bioretention basins may also be distributed throughout a residential subdivision for instance, but in this case they should be located in common area or within drainage easements, to treat a combination of roadway and lot runoff.
- Urban Bioretention structures include systems such as Tree Filters, Curb Extensions, and Planter Box Filters.

1.5.2 Engineered Soil Media

The infiltration rate of Engineered Soil Media in a bioretention facility must be designed to treat the first 1” of runoff volume from the drainage area it serves. In order to minimize maintenance needs and insure performance, the Design Infiltration Rate (inches per hour) must account for potential future degradation and therefore, must provide a minimum safety factor of 2.

The Engineered Soil Media shall be placed and graded using low ground-contact pressure equipment or by excavators and/or backhoes operating on the ground adjacent to the bioretention facility. No heavy equipment shall be used within the perimeter of the bioretention facility before, during, or after placement of the media. The Engineered Soil Media shall be placed in horizontal layers not to exceed 12 inches for the entire area of the bioretention facility. It shall be compacted by saturating the entire area of the bioretention facility after each lift is placed until water flows from the underdrain. Water for saturation shall be applied by spraying or sprinkling. An appropriate sediment control device shall be used to treat any sediment-laden water discharged from the underdrain. Final grading of the Engineered Soil Media shall be performed after a 24-hour settling period.

For quality control purposes, the supplier of the Engineered Soil Media must provide a certificate which indicates the infiltration rate of the media on delivery to the project site. An in situ test must be conducted on site after engineered soil media is placed and settled, to insure that it meets the design infiltration rate. This test shall be conducted using a field Infiltrometer, as outlined in Appendix B.

The Engineered Soil Media depth should be determined based on the mature root depth of the selected vegetation, (typically between 18 and 24 inches). Trees and larger shrubs may require a greater soil depth.

1.5.3 Mulching

Once the plants are in place, the entire bioretention facility shall be mulched to a uniform thickness of 3 inches. Well aged (minimum age of 6 months) shredded hardwood bark mulch is the only acceptable mulch.

1.5.4 Flow Inlet

The flow entrance of the Bioretention facility is an important component of the bioretention. The best method of capturing and treating runoff is to allow the water to sheet flow into the facility over grassed areas. This is not always possible, especially where site constraints or space limitations impede such an approach. A remedy to this problem is to provide flow inlets that can reduce the velocity of the water. In the case of parking lot landscape islands, curb cuts protected with energy dissipaters such as landscape stone can be used. It is important to note that entrances of this type will tend to become obstructed with sediment and trash that settles out at lower velocities. This is not a problem as long as routine parking lot maintenance is performed. The trapped sediment along the curbline provides a convenient location for parking lot sweeping. On occasion, accumulated sediment and debris should be removed from the flow entrance area if the accumulation is obstructing flow into the facility itself.

Erosion control and energy dissipation features should always be provided where concentrated runoff enters bioretention systems (e.g. cobbles or riprap beneath a curb-cut opening or a splash block beneath a roof drain downspout). In addition:

- Vegetated swales or filter strips can be added to the design to provide pretreatment (e.g. for sediment reduction).
- Trench drains can accept runoff from impervious surfaces and convey it to a bioretention facility. The trench drain may discharge to the surface of the system or may connect directly to an aggregate infiltration bed beneath.

- Curbs can be used to direct runoff from an impervious surface along a gutter to a low point where it flows into the bioretention system through a curb cut. Curb cuts may be depressed curbs, full height curbs with openings cast or cut into them or may be “false” inlets, designed to look like a traditional curb inlet.

1.5.5 Underdrain

The role of an underdrain in the bioretention facility is to ensure proper drainage for the plants and to ensure proper infiltration rates occur so as to avoid standing water for extended periods. Underdrains are configured in many different ways and typically include a washed gravel/stone "blanket" encompassing a horizontal, perforated discharge pipe or other perforated drainage system. A pea gravel separation layer as described above can be used between the under drain's aggregate blanket and the Engineered Soil Media to protect the underdrain from blocking. Underdrains keep the soil at an adequate aerobic state, allowing plants to flourish.

Underdrain structures, including subsurface detention or storage structures which are used under Bioretention systems must have a total opening area which exceeds the expected flow capacity of the underdrain itself.

To estimate the capacity of flows through the perforations, orifice flow conditions are assumed and a sharp-edged orifice equation can be used. First, the number and size of perforations needs to be determined (typically from the manufacturer's specifications) and used to estimate the flow rate into the pipes using the head of the Engineered Soil Media depth plus the ponding depth. Second, it is conservative but reasonable to use a blockage factor to account for partial blockage of the perforations by the drainage layer media. A safety factor of two is required.

This aggregate layer surround the underdrain should consist of washed aggregate ½"-1½" in diameter. Placement of the gravel over the underdrain must be done with care. Avoid dropping the gravel high levels from a backhoe or front-end loader bucket. Spill directly over underdrain and spread manually.

Underdrains must discharge into an adequate conveyance system. The underdrain system should be sized to support the flow rate of the engineered soils and the volume of water entering. Discharge from the underdrain can be routed to a down gradient storm drain pipe or channel or another IMP device. The underdrain system should have a vertical solid section that extends above the surface of the ponding area in the basin to provide a monitoring well and clean out access port.

In some cases, a liner may be necessary to avoid infiltration into surrounding soils and/or groundwater. Examples include facilities located in Brownfields, or in close proximity to structures or roadbeds, or in areas where there is outdoor storage or use of chemicals or materials within the drainage area that could threaten groundwater quality if a spill were to occur.

1.5.6 Positive Overflow

A positive overflow, via the surface or subsurface, is required to safely convey excessive runoff from extreme storm events. Bioretention systems should include design features that allow flows from relatively large storm events to either bypass the system or overflow to a conventional storm drain structure such as a channel, a curb and gutter system, or a storm drain overflow inlet. Off-line designs are an option and are best accomplished when only one inlet is present in the bioretention system. Once the bioretention facility is full, the high flows would bypass the inlet. Bypass flows or overflows can also be routed to another downstream storm water treatment system such as a vegetated swale or an extended detention basin.

1.5.7 Required Maintenance

One of the major advantages of a bioretention system over any underground BMP is that inspection is easy since the system is in full view to inspect the health of the plants and amount of debris or sedimentation that has accumulated. Once plants are established, only minimal plant maintenance and occasional removal of sediment and debris is necessary. Mulch should be replaced on an annual basis. Other considerations include:

- Upon installation and during the first year, Bioretention systems should be inspected monthly for potential erosion and/or extended ponding.
- Key inspection/maintenance areas include inlet and overflow areas for potential erosion, the ponding area for trash and debris, and the Observation/Cleanout Standpipe for potential early signs of stagnant water in the system if an underdrain system is included.
- Inspections can be reduced to a semi-annual schedule once the system has proven to work properly and vegetation is well established.
- An evaluation of the health of the plants, trees and shrubs should be conducted biannually.
- Pruning, weeding and trash removal should be conducted as necessary.
- Mulch replacement is generally required every year.
- If ponding is observed to exceed 24 hours, particularly during the primary mosquito breeding season (June through October), the reason for the extended ponding should de determined and mitigated.
- If a spill occurs and hazardous materials contaminate soils in landscape detention areas, the affected materials should be removed immediately and the appropriate engineered soil media and materials replaced as soon as possible.

1.6 Permeable Pavement Systems

Permeable pavement includes a wide range of paved or load-bearing surfaces that allow water to pass rapidly through the surface and into the sub-grade that serves as a reservoir, a filter bed, and a load-bearing layer. Permeable pavement decreases the runoff volume and peak flow rate and captures pollutants. These systems allow for infiltration of storm water while providing a stable load-bearing surface for walking and driving. Porous pavement detention can be used as a substitute for conventional pavement, but should be limited to parking areas and low traffic volume roadways where little to no truck traffic is anticipated.

Example applications include residential street parking lanes, parking stalls in commercial or retail parking lots, overflow parking areas, maintenance walkways/trails, emergency vehicle and fire access lanes, stopping lanes on divided highways, equipment storage areas, and patios. Permeable pavements may not currently be used on residential driveways or major thoroughfares.

Permeable pavement treats rainfall that falls directly on the surface, as well as runoff from adjacent impervious areas. These systems contain void spaces to provide infiltration of runoff into their underlying engineered porous materials and then into existing site soils. Generally, underlying engineered materials consist of clean sands or gravels separated from existing site soils by a synthetic filter fabric. Underlying engineered materials detain and filter pollutants prior to infiltration into underlying soils or discharge to a conventional storm drain system through an underdrain system. With these systems, it is important to note that the load-bearing sub-grade must be sufficiently thick to support the design load from the intended use and provide storage for volume or detention control. Porous paving systems can preserve natural drainage patterns, enhance groundwater recharge and soil moisture, and can help establish and maintain roadside vegetation. Although a good substitute for conventional concrete and asphalt in certain applications such as parking lots or long private driveways, porous paving systems are not suitable in high-traffic areas.

All installations of permeable pavement systems should be carried out according to manufacturer's specifications. There are several types of Permeable Pavement systems, including:

- Open Celled Block Pavers
- Open Jointed Block Pavers
- Porous Asphalt Pavement
- Porous Concrete Pavement
- Porous Turf
- Porous Gravel
- Open-Celled Plastic Grids

1.6.1 Underdrain

Permeable pavement systems must be designed to incorporate an underdrain/subsurface detention or retention system with the capacity to drain the surface of the system within 24 hours. Storage in aggregate or underground structures may be located beneath the paving system to provide additional detention volume, but these systems must be lined with an impermeable liner.

1.6.2 Required Maintenance

The overall maintenance goal is to avoid clogging of the void spaces. Remove accumulated debris and litter as needed. Inspect Permeable Pavement systems several times during the first few storms to insure proper infiltration and drainage. After the first year, inspect at least once a year.

Permeable pavements and materials should be cleaned with a vacuum-type street cleaner at least twice a year to prevent clogging of the pervious surface. Hand held pressure washers can be effective for cleaning the void spaces of small areas with some pavement systems and should follow vacuum cleaning. Maintenance personnel must be instructed not to seal or pave with non-porous materials.

Vegetated paving systems require careful vegetative maintenance to insure the health and viability of the vegetation.

1.7 Tree Box Filter

Tree box filters are bioretention systems enclosed in concrete boxes or other sub-surface structures that drain runoff from paved areas via a standard storm drain inlet structure. They consist of a precast concrete (or other) container, a mulch layer, bioretention media mix, observation and cleanout pipes, under-drain pipes, a street tree or large shrub, and a grate cover. The filters are installed below grade at the curb line. For low to moderate flows, storm water enters the tree box inlet, percolates through the media, and exits through an underdrain into the storm drain. For high flows, storm water bypasses the tree box filter once it becomes full and flows directly to the downstream curb inlet. As an engineered media-based filter, tree box filters remove pollutants through the same physical, chemical, and biological processes as traditional bioretention systems. Under normal conditions, pretreatment is not necessary. Most of the general design standards noted previously for bioretention systems also apply to tree box filters. Tree box filters should generally be designed per the bioretention system design criteria and engineered media testing requirements.

1.8 Storm Water Planter Box

Storm Water Planters, also known as flow through planters, are also bioretention systems in enclosed in concrete structures. They can be designed to drain runoff from paved areas via curb inlet structures or pipes, or they can be located under roof drain downspouts for treatment of roof runoff. They should be designed with an underdrain pipe. Waterproofing should be incorporated into the designs of Storm Water Planters sited near buildings and other structures.

Most of the general design standards noted above for bioretention systems also apply to storm water planters. For example, the ponding area in Storm Water Planters should be designed with a maximum ponding depth of no more than 12-24" and to drain ponded water within 24 hours. Plants can also be selected from those that would be used in traditional bioretention systems.

1.9 Green Roof

A green roof is a vegetated roofing system. Green roofs typically consist of a number of layers: a waterproofing membrane, a drainage system, root protection, growing media (soil) and vegetation. Green roofs provide numerous environmental benefits and offer a valuable tool for integrated storm water management.

Green roofs may cover all or part of a building's roof. Green roofs retain rainfall from small, frequently occurring storms through storage in the soil. In turn, this water is lost to evaporation or transpiration by plants. For larger storms, the runoff volume and peak flow rate is reduced because of percolation and temporary storage in the soil. Green roofs improve water quality through a variety of physical, biological and chemical processes in the soil.

Structurally, there are two types of green roofs: extensive and intensive. Extensive green roofs are lightweight vegetated roofs typically consisting of 4-8 inches of growth media (or soil), planted with hardy, drought-tolerant species to minimize additional irrigation, maintenance, cost and weight. They typically require supplemental irrigation to support growth during initial establishment of vegetation and during extended dry periods. Modular green roof systems are available that can come pre-planted in ready-to-install blocks. Alternatively, intensive green roofs can be designed to support lawns, trees, and create a useable outdoor garden space; often referred to as roof gardens. While these amenities do not preclude environmental benefits of green roofs, they do require extra structural support, cost, and have functional goals in addition to storm water management objectives. They also typically require supplemental irrigation systems.

1.9.1 Required Maintenance

Upon installation, the green roof system should be inspected monthly for the first year and after each large storm event for erosion, plant survival, proper drainage, and waterproofing. Inspections can be reduced to a quarterly schedule once the green roof system has proven to work properly and vegetation is established. If necessary, irrigate in short bursts only (3-5 minutes) to prevent runoff. Irrigation frequencies should be established by the designer using an automated system. Clean out drain inlets as needed. Weeding and mulching may be necessary during the establishment period, depending on the planting design. Replace or fill in vegetation as needed. Inspect soil levels semi-annually to ensure plant survival and rainfall absorption.

2 LID Landscaping Design

Landscaping is a critical component of bioretention because of the natural ability for plant material to treat pollutants in urban storm water. The integration of landscaping also sets bioretention apart from other integrated management practices by allowing the storm water practice to be distributed throughout the site - closer to the pollution sources - while improving the site aesthetics. With the proper landscaping application of bioretention, most people interacting with the built environment will tend to admire the sites aesthetics and not even be aware that storm water management exists on the site.

Key factors in the design of bioretention facilities are careful selection of plant materials that can tolerate highly variable hydrologic changes and an overall planting plan that ecologically and aesthetically blends the facility into the landscape. Designing for ease of maintenance is also a critical element of any landscape plan.

Consider interactions with adjacent plant communities including the potential to provide links to wildlife corridors. Adjacent plant communities should be evaluated for compatibility with any proposed bioretention area species. Nearby existing vegetated areas dominated by non-native invasive species pose a threat to adjacent bioretention areas. Invasive species typically develop into monocultures by out-competing other species. Mechanisms to avoid encroachment of undesirable species include providing a soil breach between the invasive communities for those species that spread through rhizomes and providing annual removal of seedlings from wind borne seed dispersal. It is equally important to determine if there is existing disease or insect infestations associated with existing species on site or in the general area that may affect the bioretention plantings.

2.1 Soil Amendment

The 'sponge' effect of in situ soils may be significantly improved when tilled to depth of at least 6" and incorporating at minimum of 2" of compost within the root zone to improve soil quality, plant viability and soil hydraulic conductivity, which enhances time of concentration, provides enhanced pollutant removal and reduces surface ponding time. This practice is typically utilized for Vegetated Swales and Vegetated Filter Strips, but should be strongly considered for general landscape and turf areas.

Prior to soil amendment, existing soils must be sampled and evaluated to determine amendment quantities and plan the amending process. In addition to compost, soil analysis may reveal the need for other soil amendments, such as lime, gypsum and specific nutrients.

Compost shall be mature, stable, weed free, and produced by aerobic decomposition of organic matter. The product must not contain any visible refuse or other physical contaminants, substances toxic to plants, or over 5% sand, silt, clay or rock material by dry weight. The moisture level shall be such that no visible water or dust is produced when handling the material.

The results of compost analysis shall be provided by the compost supplier. Before delivery of the compost, the supplier must provide the following documentation:

- feedstock percentage in the final compost product
- a statement that the compost meets federal and state health and safety regulations
- a statement that the composting process has met time and temperature requirements

- a copy of the lab analysis, less than four months old, performed by a Seal of Testing Assurance Certified Laboratory verifying that the compost meets the physical requirements as described.

Compost shall uniformly be applied over the entire area to a depth of two (2) inches, and incorporated into the soil to a minimum depth of six (6) inches. Where tree roots or other natural features limit the maximum depth of incorporation, compost quantities should be adjusted. Required volume of compost may be estimated using the following approximation: one (1) inch compost spread over 1000 square feet = three (3) cubic yards. The Designer may specify different compost application rates depending upon soil conditions.

2.2 Mulching

Once the plants are in place, the entire bioretention facility shall be mulched to a uniform thickness of three (3) inches. Well aged (minimum age of six [6] months) shredded hardwood bark mulch is the only acceptable mulch.

2.3 Plant Species Selection

The role of plant species in the bioretention concept is to bind nutrients and other pollutants by plant uptake; to remove water through evapotranspiration; and to create pathways for infiltration through root development and plant growth. Root growth provides a media that fosters bacteriologic growth, which in turn develops a healthy soil structure. A variable plant community structure is preferred to avoid monoculture susceptibility to insect and disease infestation and to create a microclimate, which ameliorates urban environmental stresses including heat and drying winds. Parking lot island bioretention is particularly susceptible to extended dry conditions. A layered planting scheme will help discourage weeds as well as creating suitable microclimates. There are many potential side benefits to the use of planting systems other than water quality and quantity treatment. Planting systems, if designed properly, can improve the value of the site; provide shade and wind breaks; improve aesthetics; support wildlife; and absorb noise.

3 Landscape Maintenance

All landscape treatments require maintenance. Landscapes designed to perform storm water management functions are not necessarily more maintenance intensive than highly manicured conventional landscapes. A concave lawn requires the same mowing, fertilizing and weeding as a convex one and less irrigation after rain is filtered into the underlying soil. Sometimes infiltration basins may require a different kind of maintenance than conventionally practiced.

Typical maintenance activities include periodic inspection of surface drainage systems to ensure clear flow lines, repair of eroded surfaces, adjustment or repair of drainage structures, soil cultivation or aeration, care of plant materials, replacement of dead plants, replenishment of mulch cover, irrigation, fertilizing, pruning and mowing. Landscape maintenance can have a significant impact on soil permeability and its ability to support plant growth. Most plants concentrate the majority of their small absorbing roots in the upper 6 inches of the soil surface if the surface is protected by a mulch or forest litter. If the soil is exposed or bare, it can become so hot that surface roots will not grow in the upper 8 to 10 inches. The common practice of removing all leaf litter and detritus with leaf blowers creates a hard crusted soil surface of low permeability and high heat conduction. Proper mulching of the soil surface improves water retention and infiltration, while protecting the surface root zone from temperature extremes.

In addition to impacting permeability, landscape maintenance practices can have adverse effects on water quality. Because commonly used fertilizers and herbicides are a source of organic compounds, it is important to keep these practices to a minimum, and prevent over watering. Over watering can be a significant contributor to run off and dry weather flows. Watering should only occur to accommodate plant health when necessary. When well-maintained and designed, landscaped concave surfaces, bioretention systems, vegetated swales and other LID IMPs can add aesthetic value while providing the framework for environmentally sound, comprehensive storm water management systems.

4 Putting LID into practice

4.1.1 Collaborative Design

Successful sustainable design is inherently a collaborative process. Collaboration by integrated design teams representing all the key areas of the design, permitting, construction, and development process must work together to insure an ideal outcome. While this has become standard operating procedure in green building, it has not always translated into site development.

This Guide, and the collaborative permitting process which it informs, seeks to insure a process in which all parties benefit from the opportunities to learn as we determine the best adaptations, applications and implementations of Low Impact Development and Green Infrastructure practices in our community.

4.2 Construction

The effectiveness of LID systems is a function of the design and the construction techniques employed. Of these two parameters, construction is perhaps more critical at achieving quality results. Poor construction techniques will cause the best designed IMP to fail prematurely, usually from sedimentation and/or clogging.

4.2.1 Training

It is very important that contractors, vendors, and inspectors be properly trained in the design specification and construction requirements for all LID practices employed. The success of many LID techniques depends on accurately following the grading plan; the use of proper materials and the appropriate location of practices. Due to the complexities of the practice, it may be necessary for vendors, contractors, and permit personnel to participate in training classes. For example, the design and construction of bioretention cells requires the knowledge of several disciplines including engineering, landscape architecture, and soil science to ensure the proper design and construction of the project.

4.2.2 Communication

LID uses innovative techniques, unique strategies and various combinations of practices. Consequently, each development results in a unique design with its own set of issues and challenges. It is vital that everyone involved in the LID project (contractors, vendors, design engineers, and inspectors) understands the unique details of the LID project. A pre-construction meeting is the most useful approach to ensure that the project goals and issues are effectively communicated. Ideally the contractor, vendor, design engineer, and inspector should hold a meeting to go over the plans and discuss all aspects of the project. During the pre-construction meeting, the inspector may evaluate the proposed sequence of construction, sediment control requirements, and indicate when inspection points during construction of the LID practices are required as identified in the design manual.

Throughout the construction process, there must be effective communication. No construction project takes place without unforeseen problems and the need to make some field adjustments. Proper lines of communication must be in place throughout the construction phase between the general contractor, site engineer, inspector, and permit staff to address required changes. Designers must also make it a priority to make construction sequencing and details conspicuous on plans.

4.2.3 Erosion and Sediment Control

Proper erosion and sediment control during construction is vital for LID practices. If existing vegetation is to be used for treatment (bioretention, swales or buffers), then these areas must be protected from sedimentation. Areas that may be used for biofiltration must be protected to prevent sediment from clogging soils with silts and clays. Preventing damage from sedimentation is less expensive than cleaning or rehabilitating an area.

4.2.3.1 Storm Water Pollution Prevention (SWPPP) During Construction

The clearing, grubbing and scalping (mass clearing or grading) of excessively large areas of land at one time promotes erosion and sedimentation problems. On the areas where disturbance takes place the site designer should consider staging construction, temporary seeding and /or temporary mulching as a technique to reduce erosion. Staging construction involves stabilizing one part of the site before disturbing another. In this way the entire site is not disturbed at once and the duration of soil exposure is minimized. Temporary seeding and mulching involves seeding or mulching areas that would otherwise lie open for long periods of time. The time of exposure is limited and therefore the erosion hazard is reduced. Two methods of sediment control are typically applied to bioretention facilities as follows.

The first method (most typical) is to direct all drainage away from the locations of IMPs to avoid excessive sedimentation. Flow can be directed away from the bioretention IMP by utilizing silt fencing materials, wattles and temporary diversion swales

The second method of erosion and sediment control design allows the area proposed for the bioretention IMP to be used as a temporary sediment control structure. If a sediment control structure is to become a bioretention IMP, the sediment materials shall be removed prior to constructing the bioretention IMP and placing the Engineered Soil Media.

4.2.4 Tree Protection

Care must be taken to protect tree conservation areas during construction. Tree conservation areas are ineffective if the trees die shortly after the project is completed.

In order to effectively protect trees, it is important to consider the following during any construction process:

- All types of construction equipment can cause mechanical injury to roots, trunks, or branches. This can weaken a tree's resistance to a number of diseases and insect infestation. Trees should be clearly marked and given wide clearance. Excavation around trees should not be within the drip line of the tree.
- Soil compaction squeezes the air and water out of the soil making it difficult for a tree to absorb oxygen and water. No construction equipment should be allowed to run over the roots within the drip line of the tree.
- Grading practices that deposit soil over the roots of trees eventually suffocates those roots. More than an inch or two of soil over the roots is enough to potentially suffocate the roots of trees and compromise the health of the tree. Measures can be taken to improve soil aeration around tree roots if it is necessary to add fill within the critical root zone (see Figure 6-1).
- Grading practices that divert too much runoff to a mature stand of trees can result in damage. As a tree matures its ability to adapt to changes decreases. Additionally, if a stand of trees is located in a normally dry area that suddenly becomes very wet, the additional water may kill the trees. An arborist should be consulted these situations to determine the trees' tolerance to a change in hydrology.
- A tree protection plan with written recommendations for the health and long-term welfare of the trees during the pre-construction, demolition, construction, and post-construction development phases, should be developed. The tree protection plan should include specifics about avoiding injury, information about treatment for damage and specifics about required inspections of protected trees. The tree protection plan should also provide information about caring for damaged trees.

4.2.5 Construction Sequencing

Construction sequencing is important to avoid problems while constructing LID projects. Proper sequencing decreases the likelihood of damage to the BMP during construction and helps to ensure optimal performance of each IMP. Each LID practice is somewhat different, therefore information should be provided to the contractor on the proper sequencing. The construction drawings should clearly state the designer's intentions and an appropriate sequence of construction should be shown on the plans. This sequence should then be the topic of a detailed discussion at the pre-construction meeting (that must include the on-site responsible construction personnel) and then enforced by an appropriate inspection program throughout the construction period.

Conservation areas must be identified and protected before any major site grading takes place. Most of the engineered LID practices (bioretention, infiltration trenches, and infiltration swales) should be constructed at the end of the site development process, and preferably when most of the site is stabilized. Any LID practice that relies on filtration or infiltration must be protected throughout the construction phase from sedimentation and should not be activated until the contributing drainage area is stabilized. For example, bioretention systems should be constructed at the time of final grading and landscaping, and/or these areas should be protected from sedimentation until the drainage routes to the facility are stabilized.

4.2.6 Maintenance

As with any stormwater management technique, maintenance is essential with LID BMPs to ensure that the designed stormwater benefits continue. Post-construction inspections and maintenance are important to ensure that each technique is functioning effectively. Annual inspections are recommended, with more frequent inspections during the first year to ensure that vegetation is thriving.

Inspection and maintenance of structural LID practices such as cisterns, vegetated roofs, permeable pavements, infiltration structures, and manufactured proprietary devices should follow state or local stormwater minimum standards, as well as manufacturer's recommendations for maintenance or repair. Any under-drains or outfall structures should be inspected on a regular basis and cleaned out or repaired as necessary. The primary maintenance requirement for vegetative LID structural and non-structural practices is inspection and periodic repair or replacement of the treatment area's components. This often includes the maintenance of the vegetative cover (pruning), replacing mulch, removing weeds, and possibly removing sediment to preserve the practice's hydraulic properties. For many LID practices, this generally involves little more than the routine periodic landscape type maintenance. Maintenance requirements are further discussed above in sections associated with specific LID technique.

To ensure continued long-term maintenance, all affected landowners should be made aware of their individual or collective maintenance responsibilities through legal instruments such as maintenance agreements and maintenance easements that convey with the property. Outreach materials, such as LID brochures or facts sheets that explain the function of practices and the anticipated maintenance responsibilities for homeowners, should be included in settlement or homeowner association documents. The developer should prepare a maintenance plan that provides clear guidance and instructions to the property owner property manager or property owners association about the annual maintenance needs of each LID technique.

Appendix B
Harris County Standard Operating Procedure for Determining In Situ Hydraulic Performance of High Flow Rate Bioretention Media

Objective

Provide as-built confirmation of proper installation and hydraulic performance, to meet Harris County minimum 30"/hour Infiltration rate requirements, of bioretention media on newly-placed bioretention systems. This procedure measures the entire media profile under saturated conditions to insure a reliable and accurate result.

Example Site Test Layout and Design Schematic

For bioretention systems with a surface area less than 50 m^2 (538 ft2), in situ hydraulic testing should be conducted at three points that are spatially distributed. For systems with a surface area greater than 50 m^2, an extra monitoring point should be added for every additional 100 m^2 (1076 ft2). (Values are based on recommendations from the Facility for Advancing Water Biofiltration.)

Testing should be performed on the perimeter since this is the area most likely to be impacted by sediment in the runoff.

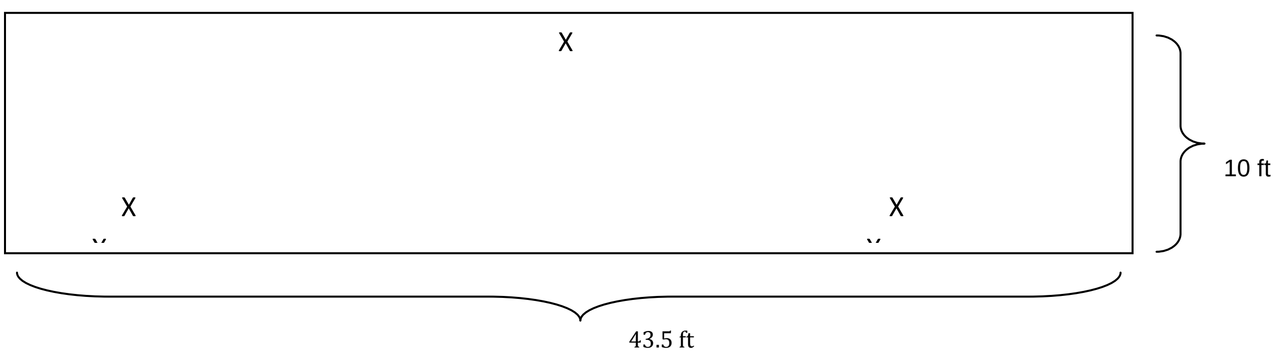


Figure 1. Site Layout

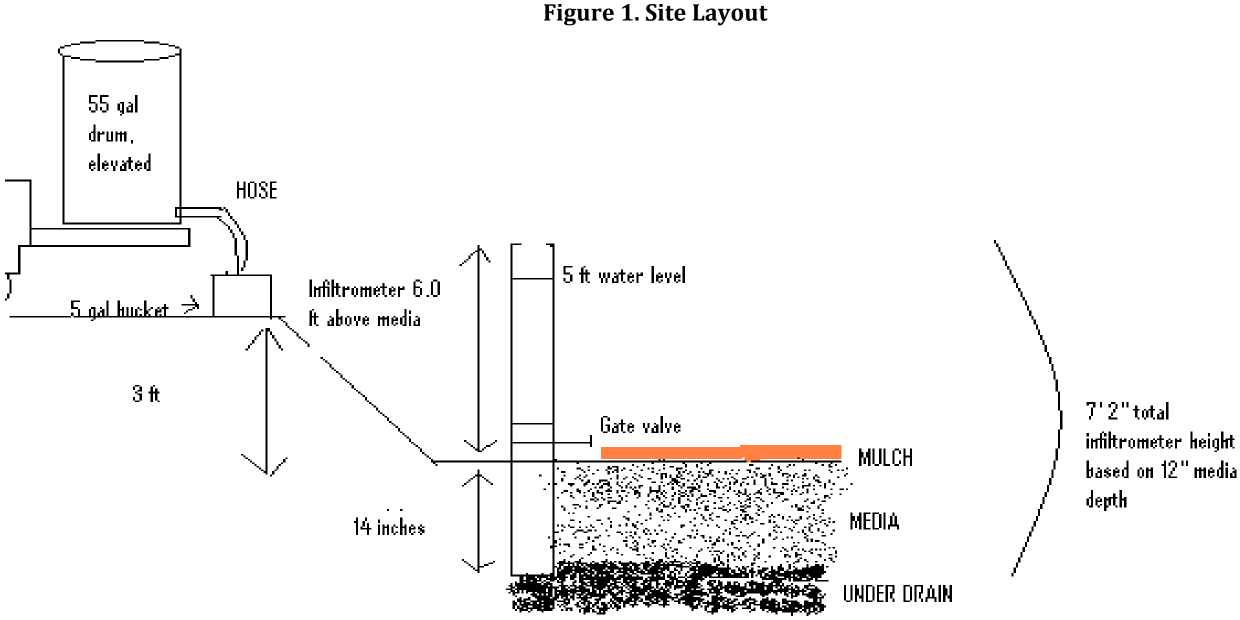


Figure 2. Example Design Schematic

Equipment Description

The components of this test apparatus are readily accessible, inexpensive and lightweight.

Infiltrometer Components:

- X inches long x 6 inch ID schedule 40 white PVC pipe with 2 inch beveled ending and 2 opposite holes drilled one inch from top sized for rebar
- (X = media depth + 2 inch pipe into UD + 3 inch pipe above media; ex: for a 12 inch media depth you would need 17 inch pipe)
- 24 inch piece of rebar for insertion through 2 drilled holes for removal of pipe from media after test
- 5 ft long x 6 inch ID schedule 40 clear PVC cylinder
- 6 inch gate valve with pull handle designed to fit schedule 40 PVC
- Tube of silicone caulking

Hammering Components:

- 4 inch thick by 8 inch wide by 24 inch long pressure treated wood board
- 5# to 10# sledge hammer

Water Storage Components:

- 5 gallon clear gradated bucket (in gallons)
- Two 55 gallon sealed plastic drums with the following:
  - at least 1 bung hole (screw cap in lid) to prevent air lock in each drum
  - plastic barb with gasket placed at bottom of each drum for water discharge
  - plastic shut off valve placed at end of hose to control flow at test location
  - garden hose connector attached to barb in drums to control flow and connect hose
  - garden hose with screw-on shut off valve at flow end
- An acceptable alternative to this is a simple low-cost water supply system.

Other Materials

- Water
- Manhole lifter or crow bar for use on rebar to remove pipe from media after test completion
- Light weight oil or petroleum jelly with dry wipes for application
- Level
- Stopwatch
- Rake/shovel
- Measuring tape
- Large stones (~2 inch; see Figure 6)
- Flashlight
- Clipboard with pencil and Table 1 from this document

Assembly:
Insert 5 ft long x 6 inch clear PVC cylinder into topside opening of gate valve. Apply silicone caulking to outside area where cylinder and gate valve meet. Smooth out caulking to create leak proof seal. Let dry according to directions on tube.

Test Methodology

1. Carefully scrape away any surface covering (e.g. mulch, gravel, leaves) without disturbing the soil filter media surface.

2. In an area near the test location, confirm media profile depth by using a shovel to dig to under drain stone and place measuring tape in hole to determine depth from top of under drain stone to top of media bed. A flash light may be needed to ensure the under drain stone has been reached before a depth measurement is taken.
3. At the test location which has been cleared of mulch, locate the six (6) inch wide white PVC pipe (beveled end down) on the surface of the media. Ensure testing is not too close to vegetation. Place the wooden board over the pipe and then gently pound with the sledge hammer on top of the board (Figure 3). Hammer the PVC pipe into the entire media profile based on the depth previously determined until it is approximately 3 inches above the media (Figure 4). Check with level to insure that the pipe is plumb. Note: It is important that the pipe is driven in slowly and carefully to minimize disturbance of the filter media profile. The media may slightly move downward in the pipe during hammering, but not more than 1 inch, and will not significantly affect hydraulic performance.

Figure 3: Hammer pipe into media

Figure 4: Pipe installed in media

4. If top of pipe is less than 3 inches from media surface, remove media around outside of pipe so that the pipe is 3 inches from the media bed. This will allow the gate valve coupling to properly slide onto the pipe.
5. Remove board and rub lightweight oil/petroleum jelly on outside of PVC pipe above media (Figure 5).
6. Place 2 inch dissipater stones into pipe (Figure 6).

Figure 5. Oil application

Figure 6. Dissipater stones

7. Slide gate valve with clear PVC cylinder down onto the media PVC pipe (Figure 7). Note: Disregard black coupling on clear pipe as well as pipe plug in Figure 7.

8. Measure from the original surface of the media within the column to the 1ft, 2 ft, 3 ft, 4 ft and 5 ft gradations, and mark them on the clear PVC cylinder (Figure 8). The 1 ft and 5 ft marks are the critical marks, since the timed fall of the water level between these two intervals represent the pass/fail criteria for the test. (The time at other intervals between 1ft and 5 ft may be recorded for additional information, but will not be used in the pass/fail criteria).

Figure 7. Infiltrometer placement

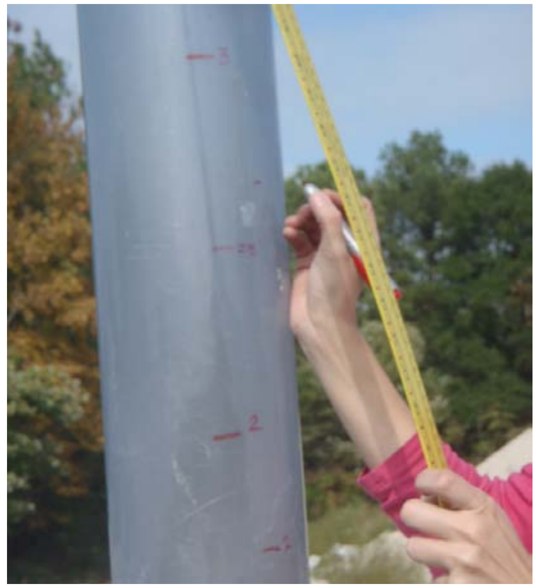


Figure 8. Gradation of clear pipe

9. Fill a 5 gallon bucket with 3 gallons from the filled 55 gallon drum. Leave cap off of drum at test site to prevent airlock. Alternative water supply sources are acceptable.
10. Ensure the gate valve to the infiltrometer is closed. Fill with the 3 gallons of water (Figure 9). To create a saturated condition, an initial wetting of the media using the infiltrometer is conducted by opening up the gate valve completely. The gate valve should be slowly opened by tapping gently on the handle to prevent, a sudden high flow of water which might disturbance of the media surface by. Pulling open by hand tends to force the valve open too quickly.

Figure 9. Filling infiltrometer with water

11. After the water level disappears from the clear column, a drain down time of 25 minutes is allowed to ensure free water has drained from the system. The media is now at field capacity (fully saturated).
12. After 25 minutes, ensure the gate valve is closed. Fill the 5 gallon bucket with water and continue to fill the column until water level reaches the very top of the clear pipe. Water is then re-introduced by opening the gate valve slowly by tapping the handle gently. The stopwatch should be started when the falling water level reaches the 5 ft gradation, and recorded subsequently at every 1 ft gradation. The stopwatch time must be stopped when the water level reaches the 1 ft mark.
13. Pass/fail criteria is based on maximum drawdown times (Table 1), relative to media depth. For example, a media profile depth of 18 inches should not exceed a drawdown time of 27 minutes and 0 seconds between the 5 ft and 1 ft gradations.

Table 1. Maximum Time Criteria Based on Media Depth

Media Depth (inches)	Maximum Drawdown Time (min:sec)
6	8:00
7	9:48
8	11:30
9	13:18
10	15:00
11	16:42
12	18:18
13	19:54
14	21:24
15	22:54
16	24:18
17	25:42
18	27:00
19	28:18
20	29:30
21	30:42
22	31:54
23	33:00
24	34:06
25	35:12
26	36:12
27	37:12
28	38:12
29	39:06
30	40:00
31	40:54
32	41:42
33	42:30
34	43:24

35	44:06
36	44:54
37	45:36
38	46:18
39	47:00
40	47:42
41	48:24
42	49:00
43	49:36
44	50:12
45	50:48
46	51:24
47	52:00
48	52:30

Appendix C
Maintenance Declaration

MAINTENANCE DECLARATION

Low Impact Development & Green Infrastructure Design Criteria for Storm Water Management

This Maintenance Declaration (this "Declaration") is made as of the ___ day of __________, 20__, by ____________***[INSERT NAME OF OWNER OF PROPERTY COVERED BY APPLICABLE PLAT]***_______ ("Owner").

RECITALS

A. Owner is a _______***[INSERT TYPE OF ENTITY]***___ and has the legal authority to construct {water, sewer, and drainage facilities, road facilities and related road improvements, and recreational and landscaping improvements} (Specify those that apply) within the Property (hereinafter defined). .

B. Owner owns that certain real property described on **Exhibit A** attached to this Declaration and incorporated herein for all purposes (the "Property").

C. In accordance with the Low Impact Development & Green Infrastructure Design Criteria for Storm Water Management (the "LID Criteria"), certain enhancements to public improvements are required. Owner intends to submit to Harris County, Texas (the "County") for approval a plat covering the Property (the "Plat"), which, among other things, includes enhancements to certain public improvements to be constructed within the Plat boundaries pursuant to the LID Criteria as are identified below (collectively, the "Enhancements").

D. Owner desires to declare its obligation to construct and maintain the Enhancements.

NOW, THEREFORE, Owner hereby declares that, upon acceptance of the Plat by the County and construction of the Enhancements, Owner will be responsible for all maintenance for the following Enhancements [*check as applicable*]:

□ Drainage, including ditches, swales and storm sewers

□ Storm water quality and drainage features, including green infrastructure and low impact development practices

□ Water and sanitary sewer lines

□ Upgraded crosswalks and intersections

□ Pedestrian underpasses and overpasses

□ Conduit

□ Recreational improvements

□ Enhanced landscaping

□ Lighting improvements (excluding traffic signals)

□ Other ____
____

□ Other ____
____

□ Other ____
____

This Declaration shall be governed by, construed and interpreted in accordance with, and enforceable under, the laws of the State of Texas.

IN WITNESS WHEREOF, Owner has caused this Declaration to be executed as of the date and year first set forth above.

[INSERT NAME OF OWNER]

____
(name and title of Owner's representative)

ATTEST:

____
(add in if appropriate)

Add standard notary acknowledgement

Attachment:
Exhibit A – Description of Property
After recording, return to: ***[insert Owner's address]***

Appendix D
References

USGA Recommendations for a Method of Putting Green Construction, 2004 USGA

WSUD Engineering Procedures: Stormwater, 2005, Melbourne Water

Stormwater Management Guidance Manual Version 2.0, City of Philadelphia

Low Impact Development Guidance Manual, City of Wilmington, North Carolina

Town of Huntersville Water Quality Design Manual, 2008, Mecklenburg County Water Quality Program

Low Impact Development Technical Guidance Manual for Puget Sound, 2005, Puget Sound Action Team & Washington State University Pierce County Extension

Seattle Right of Way Improvements Manual, City of Seattle

Bioretention.com website

Low Impact Development Handbook, 2007, County of San Diego

Low Impact Development Center, Inc. website

San Mateo County Sustainable Green Streets and Parking Lots Design Guidebook, 2009 San Mateo County

HCFCD, 2010. HCFCD Storm Water Management Program (SWMP). TPDES Permit No. WQ0004685000. Revised October 31, 2010.

HCFCD, 2010. HCFCD Policy, Criteria, & Procedure Manual. Revised December 2010.

HCPID, 2010. HCPID Storm Water Management Program (SWMP). TPDES Permit No. WQ0004685000. Revised October 31, 2010.

Appendix E
Resources

San Mateo County Sustainable Green Streets and Parking Lots Design Guidebook, First Edition, January 2009 (http://www.flowstobay.org/ms_sustainable_guidebook.php)

The Low Impact Development Center, Inc. (http://www.lowimpactdevelopment.org)

Low Impact Development Urban Design Tools Website (http://www.lid-stormwater.net/index.html)

Runoff Reduction Method, Virginia Department of Conservation & Recreation (http://www.princegeorgescountymd.gov/Government/AgencyIndex/DER/ESG/manuals.asp)

USGA Recommendations for a Method of Putting Green Construction (http://www.usga.org/course_care/articles/construction/greens/USGA-Recommendations-For-A-Method-Of-Putting-Green-Construction(2)/)

WSUD Water Sensitive Urban Design Program (http://www.wsud.org)

WSUD Engineering Procedures: Stormwater, 2005, Melbourne Water (http://wsud.melbournewater.com.au/)

Stormwater Management Guidance Manual Version 2.0, City of Philadelphia (http://www.phillyriverinfo.org/WICLibrary/PSMGM%20V2.0.pdf)

Low Impact Development Guidance Manual, City of Wilmington, North Carolina (http://www.nhcgov.com/planningandinspections/Documents/LID%20Manual.pdf)

Town of Huntersville Water Quality Design Manual, 2008, Mecklenburg County Water Quality Program (http://www.huntersville.org/Planning%20Info/Huntersville%20Design%20Manual%20January%201,%202008%20Version.pdf)

Low Impact Development Technical Guidance Manual for Puget Sound, 2005, Puget Sound (http://www.psparchives.com/publications/our_work/stormwater/lid/LID_manual2005.pdf)

Seattle Right of Way Improvements Manual, City of Seattle (http://www.seattle.gov/util/About_SPU/Drainage_&_Sewer_System/GreenStormwaterInfrastructure/index.htm)

Bioretention.com website (http://www.bioretention.com)

Low Impact Development Handbook, 2007, County of San Diego (http://www.co.san-diego.ca.us/dplu/docs/LID-Handbook.pdf)

Appendix F
Acknowledgments

This Guide represents a commitment by Harris County "to enhance, enable and integrate sustainable use of land and water for our area's continued growth and economic vitality." This is in fact the mission statement of the Houston Land/Water Sustainability Forum, in which both Harris County Public Infrastructure Division and Harris County Flood Control have played a significant role since the it's inception.

The direct impetus for the LID & Green Infrastructure Design Guide was the success of a Forum-sponsored Low Impact Development Design Competition, in which a broad range of participants from the local design community were asked to create a project design using these practices, in one of three categories: Green Roadway, Suburban Residential and Urban Redevelopment. The projects were real, in fact one was an existing Harris County road slated for expansion, and the data on which the designs were based was the same information any owner would have provided to a design team.

The results of the competition were twofold. First, there was a profound recognition by the participants of the value, validity and benefits for all parties in widespread adaptation and adoption of these practices. Second, was a groundswell of interest in getting new projects which utilize them permitted smoothly and without the delays which might otherwise accrue to permitting a new style of development which take such fundamentally different approach than the traditional development for which current rules and regulations were designed.

Rewriting regulations can be a time consuming process. Recognizing that taking advantage of the enthusiasm for adopting these practices, which have proven so beneficial elsewhere, and moving forward with LID-based projects meant removing the obstacles to permitting them. During the summer of 2010, under the auspices of the Houston Land/Water Sustainability Forum, a series of three day-long collaborative workshops were held specifically to examine the obstacles to permitting LID-based projects, exploring how LID practices could be adapted to meet the intent of current rules and developing guidelines for the permitting process. This process examined the primary development categories of Suburban Residential, Green Roads, Commercial and General Site Design, as well as Urban Infill and Redevelopment.

Participants in this process included key permitting, storm water, and development regulatory staffers, and leadership, from Harris County Public Infrastructure Division, Harris County Flood Control and the City of Houston. The design community was represented by the firms whose teams placed in the finals of the design competition and included civil and transportation engineers, planners, landscape architects and architects. Representatives from the Houston Council of Engineering Companies, the American Society of Landscape Architects and American Association of Civil Engineers and developers associated with the Greater Houston Builders Association also contributed.

Appendix G
Acronyms

BMP	Best Management Practice
EPA	Environmental Protection Agency
GI	Green Infrastructure
HCFCD	Harris County Flood Control District
HCPID-AED	Harris County Public Infrastructure Department Architecture & Engineering Division
HOA	Homeowners Association
IMP	Integrated Management Practice
LID	Low Impact Development
MTFP ROW	Major Thoroughfare and Freeway Plan Right Of Way
MUD	Municipal Utility District
PCPM	Policy Criteria and Procedures Manual (HCFCD)
Q	Peak Discharge
$Q_{allocated}$	Allocated Discharge
Q_{exist}	Existing Discharge
Q_{prop}	Proposed Discharge
ROW	Right Of Way
SWPPP	Storm Water Pollution Prevention Plan
SWQ	Storm Water Quality
SWQMP	Storm Water Quality Management Plan
Tc	Time of Concentration
TC&R	Time of Concentration and Storage Coefficient (from HCFCD PCPM)
TCEQ	Texas Commission on Environmental Quality
USGA	United States Golf Association
WQ_v	Water Quality Volume