City of Doral

Low Impact Development Master Plan

Draft Report

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1.0 EXECUTIVE SUMMARY

The City of Doral (City) was incorporated in 2003 and is located in the western-central portion of Miami-Dade County. The City is roughly bounded by NW 90th Street to the north, the Florida Turnpike to the west, State Road 836 (Dolphin Expressway) to the south, and State Road 826 (Palmetto Expressway) to the east. The City of Doral comprises a total area of approximately 15 square miles.

The preliminary estimated population for 2016 is 59,304. This represents an increase of approximately 6.7% from last year's population estimates (55,586). By 2020, the estimated population for the city is approximately 78,668 residents. Despite this growth, the City has ample inventory of planned dwelling units and vacant land to accommodate future growth through 2025. Beyond 2025, the City may experience reduced growth unless additional residential capacity is added through annexation and/or redevelopment.

Presently, the city is experiencing significant growth in residential and non-residential development. This includes a new downtown, several major mixed-use developments (PUDs and TND projects), commercial mixed-use projects, and redevelopment projects along Doral Boulevard and NW 58th Street.

This rapid land development and urbanization will have an impact on the natural urban hydrologic processes of surface water runoff patterns, infiltration, percolation to ground water, and evapotranspiration. Under predevelopment conditions, up to half of the annual rainfall infiltrates through the sandy soils and percolates downward where portions of it recharge the ground water. In contrast, developed areas can generate up to five times the annual runoff and only allow one-third the pre-development infiltration of natural areas.

This change will have a potential negative impact to the environment, which includes but is not limited to, soil erosion, increase in impervious areas, reduction in open space and recreational areas, reduction on ground water recharge, increase of potential flooding, and degradation in water quality. Minimizing these environmental impacts by reducing the overall imperviousness, applying new techniques, and using natural drainage features on site is one of the major goals of the City and an important design strategy to maintain the pre-development site hydrologic characteristics after development to the maximum extent practicable. This goal can be accomplished by applying various proven Low Impact Development (LID) planning strategies for storm water management.

The purpose of this project is to develop a LID Master Plan to assist the City in maximizing implementation of LID Integrated Management Practices. These practices will minimize impacts from anticipated new development and/or redevelopment projects. The Master Plan will also provide guidance for LID site planning, hydrologic analysis, and erosion and sediment control practices, as well as incentives for participation.

The scope of work to develop the Low Impact Development Master Plan was subdivided into the following key tasks:

- Task 1 – Project Coordination and Progress Meetings
- Task 2 – Data Collection and Evaluation
- Task 3 – Low Impact Development Site Planning
- Task 4 – Low Impact Development Hydrologic Analysis
- Task 5 – Low Impact Development Integrated Management Practices
- Task 6 – Low Impact Development Erosion and Sediment Control Management practices
- Task 7 – Public Involvement and Outreach Programs
- Task 8 – Low Impact Development Master Plan Report

In 2019, the City of Doral retained A.D.A. Engineering, Inc. (ADA) to update the 2016 LID Master Plan Report. Updates were based on input from the development community and City staff following meetings and public workshops.

The following sub-sections include a summary of the work completed under each task for the original 2016 Low Impact Development Master Plan.

1.1 Task 1 – Project Coordination and Progress Meetings

The City of Doral retained A.D.A. Engineering, Inc. (ADA) to provide the services identified below for the project entitled "Low Impact Development Master Plan" in accordance with City of Doral Continuing Professional Services Final Agreement RFQ#2014-24 dated March 2, 2015.

As part of this Task, ADA attended bi-monthly progress meetings to provide for general project coordination and work planning. The status of all ongoing tasks and City reviews were discussed at these meetings, as well as all issues related to draft deliverables and comments received from the City regarding such deliverables.

1.2 Task 2 – Data Collection and Evaluation

Data was requested and acquired from the various sources maintaining data within Miami-Dade County and the State of Florida, as well as from the City of Doral. The collected data was cataloged, evaluated, and utilized as needed to support the analyses and preparation of the Low Impact Development Master Plan Report. Data was requested and/or collected from the following entities:

- Miami-Dade County
- City of Miami Beach
- City of Orlando
- City of Sanford
- City of Tampa
- Alachua County
- Hillsborough County
- Orange County
- Pinellas County

- Sarasota County
- South Florida Water Management District
- Environmental Protection Agency
- Florida Department of Environmental Protection
- Florida Water Star Program

In addition to the data collected, ADA also performed a literature search of available documented data that was presented at the American Society of Civil Engineers (ASCE) and the Environmental and Water Resources Institute (EWRI) conference held in San Francisco, California in April 11–14, 2010. The documented research contained pertinent and applicable data related to LID management practices. The technical papers presented during this conference addressed a broad range of topics that are relevant to a sustainable approach to stormwater management using the LID technology. These topics include:

- LID and Sustainability
- Overcoming Institutional and Other Barriers to LID Implementation
- Codes, Regulations, Constraints, Guidelines
- Recent Monitoring / Performance Findings
- Computational Methods
- Advances in LID Best Management Practice (BMP) Design Methods – Lessons Learned
- Site Design Considerations
- LID Incentives for New Developments
- Watershed Retrofit with LID
- Education and Training Outreach
- Long-Term Performance, Maintenance

1.3 Task 3 – Low Impact Development Site Planning

Implementation of LID begins at the planning level of the site development or redevelopment process. One of the first steps in site planning involves taking inventory of the existing features on the site including topography, soil characteristics, flow paths, drainage features, building and stormwater infrastructure, impervious areas, open spaces, and vegetation. Through LID techniques, developments are designed to be integrated with these existing features and to retain or simulate the pre-development site conditions.

LID design techniques include both structural and non-structural hydrologic controls that compliment traditional stormwater treatment and conveyance systems by utilizing pre-development hydrological features to decentralize and micromanage stormwater runoff at its source. Throughout the site development process, alternative design options that include LID techniques or LID techniques combined with traditional stormwater management infrastructure are evaluated and integrated into the site plan to the greatest extent possible. The overall LID site planning development process includes:

- Identification and compliance with existing site planning regulations and ordinances,
- Assessment and inventory of pre-development site conditions,
- Development of the preliminary site plan,
- Minimization of directly connected impervious areas (DCIA),
- Evaluation and implementation of Best Management Practices (BMPs), these are LID management techniques employed to achieve the desired post-development hydrologic condition,
- Comparison of pre-development and post-development hydrology, and
- Completion of LID Site Plan.

The primary nonstructural LID site planning practices and considerations that appear to be most applicable to the City of Doral include the following:

1. Restoration and preservation of pre-development topography and soil profile
2. Preservation and use of native and local vegetation
3. Open space design and conservation
4. Minimization of total impervious areas
5. Reduction of DCIA

The primary structural LID BMPs and practices that appear to be most applicable to the City of Doral include the following:

- Bioretention Basins or Rain Gardens
- Tree Box Filters or Infiltration Planters
- Vegetated Swales
- Filter Strips or Vegetated Buffers
- Infiltration Trench
- Exfiltration Trench or French Drains
- Green Roofs/Rain Barrels or Cisterns
- Permeable Pavement
- Detention Ponds
- Parking Chambers

1.4 Task 4 – Low Impact Development Hydrologic Analysis

Conventional stormwater management techniques are typically sited at the most downstream end of the entire site (typically end of pipe control). The requirement is usually to provide the required water quality retention volume and maintain the post-development peak runoff rates in cubic feet per second (cfs) at or below the pre-development rates for a particular 24- or 72-hour design storm event. Under this approach, the peak runoff rate will not be increased; however, the post-development runoff volume is usually greater than the pre-development volume. This is because the typical drainage systems are designed to control the peak flow runoff rate, but overall the systems discharge a larger runoff volume because the flows are just discharged over a longer duration. For this reason, the recommended hydrologic analysis approach to assess LID BMPs is to implement a pre- versus post-development runoff volume approach using an average annual rainfall event. This approach is best suited to assess the structural LID BMPs because these type of BMPs are aimed to control or retain smaller rainfall events, which constitute about 80% of the annual amount of rainfall for a typical average year in south Florida.

The purpose of implementing an LID approach is to match pre-development conditions by compensating for losses of rainfall abstraction through maintenance of infiltration potential, evapotranspiration, and surface storage as well as increased travel time to reduce rapid concentration of excess runoff and impacts to downstream drainage systems such as the City’s drainage systems located within the City’s right-of-way areas.

The implementation of LID techniques aims to control smaller and more frequent rainfall events. These events are usually less than a 2-year return period, but generate most of the annual runoff from an urban watershed.

1.5 Task 5 - Low Impact Development Integrated Management Practices

Current site development or redevelopment projects must meet, at a minimum, the stormwater quality and flood protection requirements outlined by South Florida Water Management District (SFWMD), Miami-Dade County Department of Regulatory and Economic Resources (DRER), and City of Doral. The water quality requirement is to provide retention of one inch of runoff over the entire site or 2.5 inches over the impervious areas, whichever is greater. For flood protection, at a minimum, roads and parking areas must be built at or above the 5-year, 24-hour design peak stage, the post-development runoff rate cannot exceed the pre-development rate, and the building finish floor elevations must be set at or above the 100-year, 3-day design storm event or the Federal Emergency Management Agency (FEMA) flood elevation, whichever is greater.

Prior to this LID Master Plan, the City of Doral had no specific requirements for implementing LID techniques. As part of the LID Master Plan, the City now requires non-structural LID practices be implemented in new developments to the maximum extent practicable. If not practical, developers must demonstrate that the practices cannot be implemented because of site constraints, and not due to financial impacts. Developments incorporating LID techniques are required to adhere to the same ordinances, zoning regulations, water quality and quantity requirements, and land use designations as developments designed utilizing traditional stormwater management techniques.

1.6 Task 6 – Low Impact Development Erosion and Sediment Control Management Practices

The City of Doral participates as a co-permittee with Miami-Dade County in the National Pollution Discharge Elimination System (NPDES) program. The program is aimed at improving stormwater runoff water quality and control erosion from construction activities. The City of Doral must address specified activities and program compliance stated within the Annual Reports and NPDES permit conditions.

The application of LID concepts and the associated emphasis on minimizing the areas disturbed, as well as breaking up drainage areas into small manageable sub-catchment areas, is in agreement with the basic principles of erosion and sediment control. The application of LID technology can easily result in improved erosion and sediment control without significant additional effort.

An effective sediment and erosion control plan is essential for controlling stormwater pollution during construction. An erosion and sediment control plan is a site-specific plan that specifies the location, installation, and maintenance of best management practices to prevent and control erosion and sediment loss at a construction site.

1.7 Task 7 – Public Involvement and Outreach Programs

The City of Doral and the ADA Team implemented a pro-active Public Involvement and Outreach Program to educate the public and local land developers in the activities that were being performed to complete this LID Master Plan and to obtain feedback from the residents and land developers. The public involvement task included coordinating and conducting (2) workshops with the intent of providing a relaxed and comfortable venue where participants could focus on the LID Master Plan process and goals, solicit feedback, and discuss future improvements for the City.

Objectives of the community workshops included:

- Conducting an integrated Public Involvement and Community Outreach (public interaction) program;
- Engaging the community in an open, healthy dialogue about the project, emphasizing that the City of Doral bases the final decision on several criteria, and community input is important to them;
- Fostering understanding of the City of Doral's responsibility now and into the future with its LID Master Plan;
- Helping build communities based on environmental stewardship;
- Discussing ways of minimizing impacts on stakeholders and preventing opposition to future LID planning and design strategies;
- Communicate to stakeholders the need for implementing LID best management practices and how they benefit the community; and
- Explain the engineering and planning process to achieve environmental sustainable development.

In addition to the resident and developer workshops, individual meetings were held with elected officials. The LID Plan was also available for public inspection for more than six weeks in the City’s website. Thereafter, the project was presented to the Mayor and the City Council on October 28, 2016 at regular council meeting.

1.8 Conclusions and Recommendations

The rapid land development and urbanization taking place in the City of Doral will have an impact on the natural urban hydrologic processes of surface water runoff patterns, infiltration, percolation to ground water, and evapotranspiration. Low Impact Development takes an innovative approach to mitigating these impacts and seeks to retain runoff and treat stormwater pollution at the source. The purpose of the LID Master Plan is to provide the City of Doral with guidelines and recommendations to adopt integrated LID BMPs and green infrastructure practices in future development sites.

The City of Doral has one ordinance (Ord. No. 2013-37, § 2, 12-3-2014) for the incorporation of LID practices into building plans, project designs, and site plans. The ordinances mandate that LID practices be included as part of site development plan, and provide provisions for rainfall harvesting facilities. The current Site Planning Regulations are hereby recommended to be amended with the addition of a requirement for a hydrological assessment of the pre- versus post-development conditions, implementation of a Site LID Design Strategies Checklist document into the current permit application, and the addition of more substantial details for the implementation of LID requirements, as well as provisions for sites where LID techniques are technically infeasible.

In addition, it is recommended that provisions for long-term maintenance, monitoring, and enforcement be developed. Long-term maintenance and inspection plans are required for LID systems and the entity responsible for the maintenance and monitoring should be clearly defined. Site Planning Regulations should be evaluated to minimize the requirements for property setbacks, traffic distribution network widths, sidewalk widths, and right-of-way areas.

Based on the data previously collected and evaluated, non-structural and structural LID planning practices were identified that will naturally treat and retain stormwater for new developments and redevelopment sites. The site planning process should incorporate LID strategies in each step of the process. The recommended priority for managing and capturing stormwater runoff is infiltration, evapotranspiration, capture and use, and treatment through biofiltration/bioretention systems.

Based on a review of the current City of Doral LID ordinance and LID management practices, the City's current site development approach does not require any LID BMP implementation or provide any guidelines. In the City of Doral, there are no requirements for minimum vegetated/stormwater management space for commercial or residential land use development, the water quality retention requirement is the first 1 inch of runoff, and the stormwater management system is required to meet pre- versus post-development peak discharge flow only.

The City of Doral implements standard on-site practices for erosion and sediment control, which include inlet protection systems, silt fence, turbidity barriers, and temporary gravel construction entrances and exits. However, it is recommended that the City include other erosion control practices, such as soil stabilization and runoff control. The recommended measures effectively isolate the development site from surrounding properties and control sediment where it is produced, thus preventing its transport from the site. Diversions, berms, sediment traps, vegetative filters, and sediment basins are examples of practices to control sediment. Vegetative and structural sediment control measures are either temporary or permanent, depending on whether they will remain in use after development is complete. Generally, sediment is retained by (a) filtering runoff as it flows through an area and (b) impounding the sediment-laden runoff for the soil particles to settle. The most effective method to control sediment, however, is to prevent erosion

2.0 INTRODUCTION

2.1 Background

The City of Doral was incorporated in 2003 and is located in the western-central portion of Miami-Dade County. The City is roughly bounded by NW 90th Street to the north, the Florida Turnpike to the west, State Road 836 (Dolphin Expressway) to the south, and State Road 826 (Palmetto Expressway) to the east – see **Figure 2-1**. The City of Doral encompasses a total area of approximately 15 square miles.

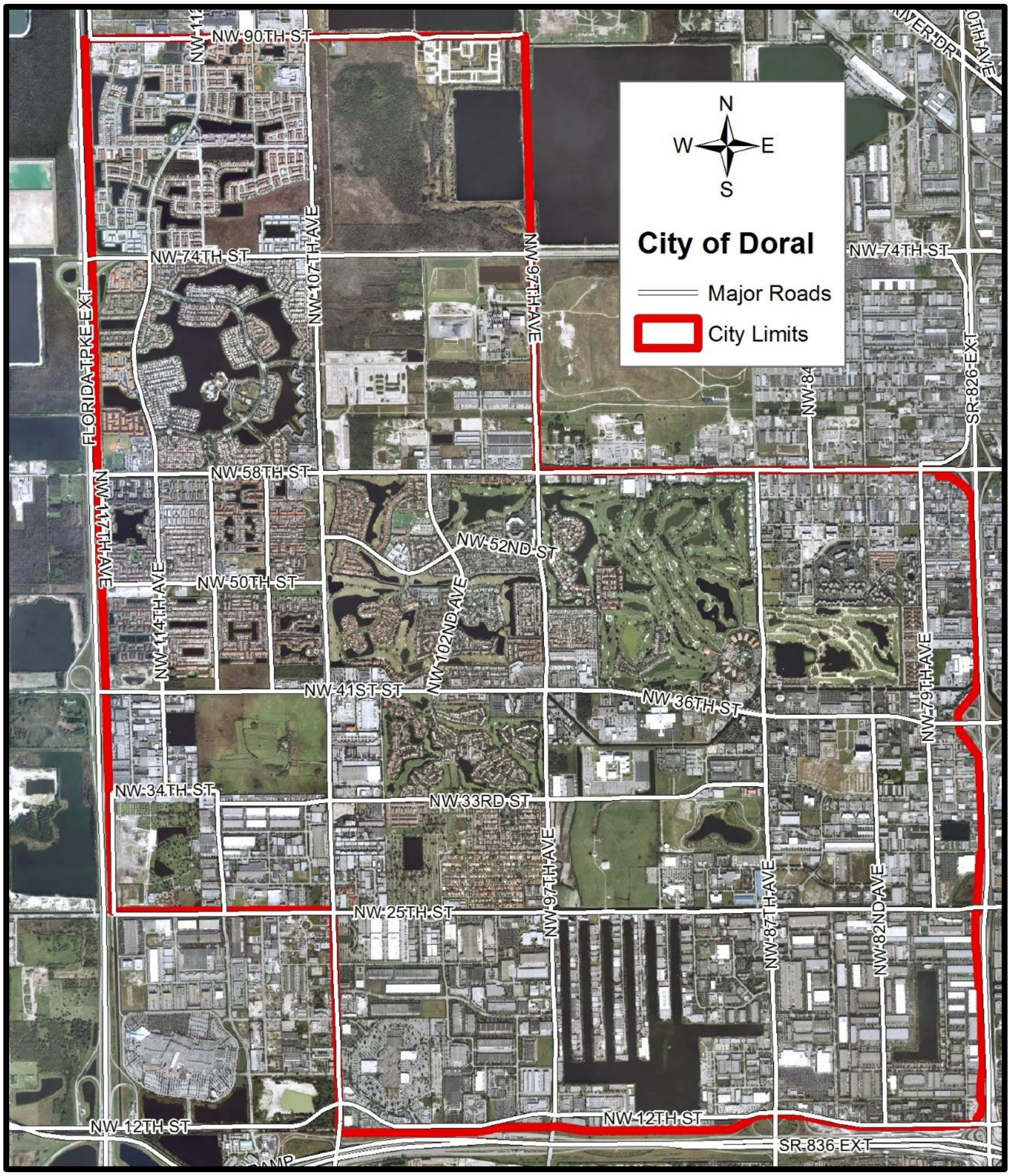


Figure 2-1 – Major Roads within the City of Doral

The City is located within the boundaries of the SFWMD, C-4 and C-6 Drainage Basins – see **Figure 2-2**. Both the C-4 Canal and C-6 Canal are SFWMD primary canals. These canals primarily flow from the Everglades conservation areas to Biscayne Bay. There are three main secondary canals which convey stormwater within the City: C-2 Extension Canal (Snapper Creek Canal) along NW 17th Avenue, Northline Canal located immediately north of NW 25th Street which discharges to the C-4 Canal, and Dressels Canal which connects to the FEC Canal. These canals are operated by Miami-Dade County.

The main conveyance in the C-4 Basin is the C-4 Canal (Tamiami Canal), and the main conveyance in the C-6 Basin is the C-6 Canal (Miami River). The City's primary and secondary drainage systems discharge to these two major watersheds. These watersheds are at their maximum hydraulic capacity and ultimately discharge to Biscayne Bay, an Outstanding Florida Waterbody. It is imperative that LID planning practices are implemented for future development and redevelopment to minimize impacts to these sensitive watersheds.

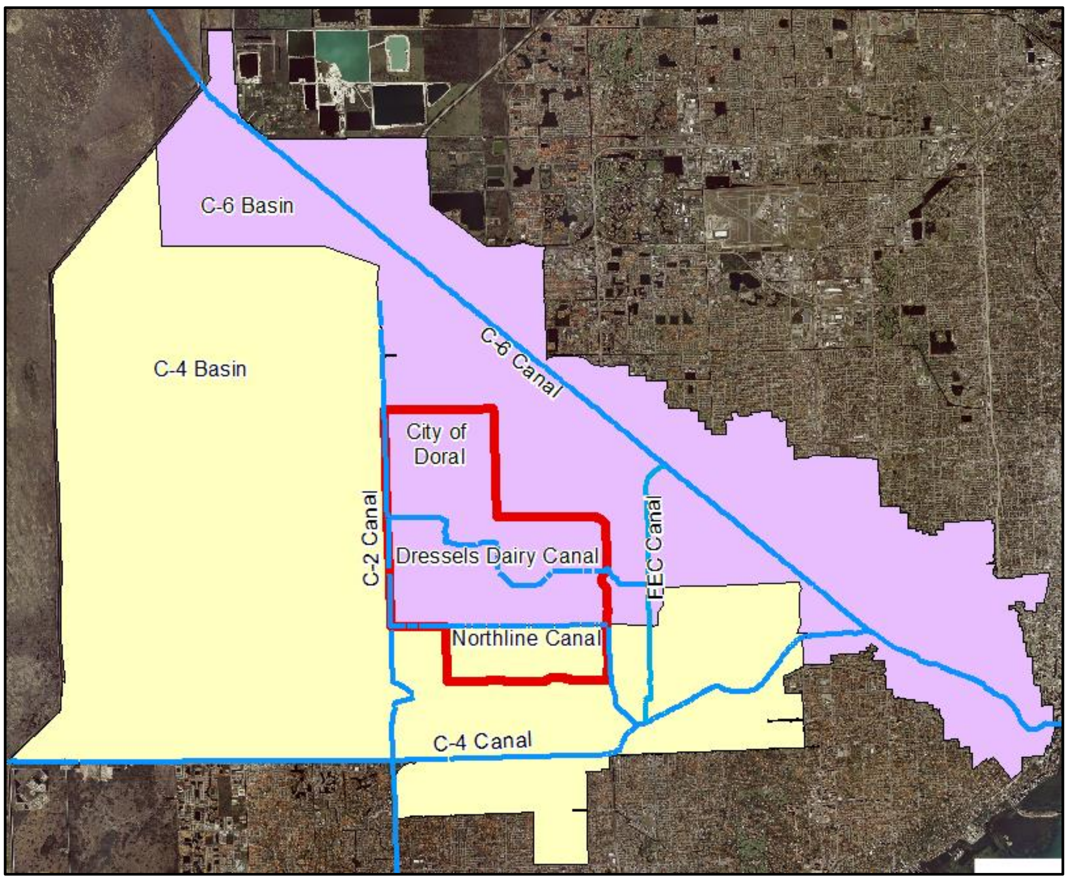


Figure 2-2 – SFWMD Canal Basins & City of Doral Limits

The City's residential, commercial/industrial, and mixed-use land uses account for approximately 83% of the City's total area based on the 2015 land use GIS shapefile available from the City – see **Table 2-1** for existing land use distribution.

Table 2-1 – Land Use Distribution within the City of Doral

Land Use	Area (sq. mi)	% of City
Residential	4.9	33%
Commercial / Industrial	6.1	41%
Parks	1.8	12%
Institutional / Public	0.8	5%
Mixed Use	1.3	9%
Total	**14.9**	**100.0%**

The City is currently one of the fastest growing young cities in the United States. It is anticipated that this will continue into the next three to five years as newly approved major mixed-use development projects such as Downtown Doral, Park Square, Grand Bay North and South, and Midtown will attract more people to the City. These development projects will generate between 8,000 and 9,000 new units between 2014 and 2025.

In addition, more than 1,000 hotel apartments are expected to be built from 2014-2020. The non-residential component is expected to generate over 1.0 million square feet of retail and 2.0 million square feet of office space. The City anticipates that the existing non-residential development estimates will change within the next five years because of changes in the real estate market for such uses. The City is also entering a redevelopment phase along major commercial corridors such as Doral Boulevard and NW 58th Street that will create more opportunities for more mixed-use development and commercial/retail uses.

This rapid land development and urbanization will have an impact on the natural urban hydrologic processes of surface water runoff patterns, infiltration, percolation to ground water, and evapotranspiration. Under predevelopment conditions, up to half of the annual rainfall infiltrates through the sandy soils and percolates downward where portions of it can recharge the ground water. In contrast, developed areas can generate up to five times the annual runoff and only allow one-third the pre-development infiltration of natural areas.

This change will have a potential negative impact to the environment, which includes but is not limited to, soil erosion, increase in impervious areas, reduction in open space and recreational areas, reduction on ground water recharge, increase of potential flooding, and degradation in water quality. Minimizing these environmental impacts by reducing the overall imperviousness, applying new techniques, and using natural drainage features on site is one of the major goals of the City and an important design strategy to maintain the pre-development site hydrologic characteristics after development as much as possible. This goal can be accomplished by applying various LID planning strategies for storm water management.

2.2 Low Impact Development Master Plan Purpose and Scope

The basic traditional engineering approach to storm water management conveys runoff rapidly from developed surface into man-made drainage structures designed to accommodate a large volume of storm water and pollutant to a discharge area. In contrast, LID takes a different approach than conventional stormwater management by using the natural environment within the sites being developed or redeveloped to recreate as much as possible the predevelopment natural hydrologic processes and reduce the disruptive effects of urban runoff patterns.

The purpose of this project is to develop a LID Master Plan to assist the City in maximizing implementation of LID Integrated Management Practices (IMPs). These practices will minimize impacts from anticipated new development and/or redevelopment projects. The Master Plan will also provide guidance for LID site planning, hydrologic analysis, and erosion and sediment control practices, as well as incentives for participation. As part of the Master Plan development, a Public Outreach Program was implemented to educate the residents and developers regarding the benefits of implementing LID practices and obtain input from these stakeholders to build consensus on the final recommendations of the LID Master Plan.

A.D.A. Engineering, Inc. (ADA) was contracted by the City of Doral to complete the LID Master Plan for the City, in accordance with City of Doral Continuing Professional Services Final Agreement (RFQ#2014-24) dated March 2, 2015. The LID Master Plan was subdivided into eight tasks with the final task consisting of preparing the final LID Master Plan Report. The results and findings of each primary task were summarized in five task specific Technical Memorandums (TM). The Technical Memorandums prepared as part of this LID Master Plan are as follows:

- Technical Memorandum No. 1 – Data Collection and Evaluation
- Technical Memorandum No. 2 – Low Impact Development Site Planning
- Technical Memorandum No. 3 – Low Impact Development Hydrologic Analysis
- Technical Memorandum No. 4 – Low Impact Development Integrated Management Practices
- Technical Memorandum No. 5 – Low Impact Development Erosion and Sediment Control Management Practices
- Final Low Impact Development Master Plan Report

The scope of work to develop the Low Impact Development Master Plan was subdivided into the following key tasks:

- Task 1 – Project Coordination and Progress Meetings
- Task 2 – Data Collection and Evaluation
- Task 3 – Low Impact Development Site Planning
- Task 4 – Low Impact Development Hydrologic Analysis
- Task 5 – Low Impact Development Integrated Management Practices
- Task 6 – Low Impact Development Erosion and Sediment Control Management Practices
- Task 7 – Public Involvement and Outreach Programs
- Task 8 – Low Impact Development Master Plan Report

The following sub-sections include a summary of the work completed under each of these tasks, and detailed descriptions are included in **Section 2.0** through **Section 8.0** of the Final Low Impact Development Master Plan Report.

In 2019, the City of Doral retained A.D.A. Engineering, Inc. (ADA) to update the 2016 Low Impact Development Master Plan Report. Updates were based on input from the development community and City staff following meetings and public workshops. Updates have been integrated into the Low Impact Development Master Plan report, and include added detail and analysis methodologies for Best Management Practices (BMPs), as well as examples of implemented BMPs within the City. In addition, the hydrologic/hydraulic model used in the sample analyses was converted from ICPR3 to ICPR4.

2.2.1 Task 1 – Project Coordination and Progress Meetings

The City of Doral retained A.D.A. Engineering, Inc. (ADA) to provide the services identified below for the project entitled "Low Impact Development Master Plan" in accordance with City of Doral Continuing Professional Services Final Agreement RFQ#2014-24 dated March 2, 2015.

As part of this Task, ADA attended bi-monthly progress meetings to provide for general project coordination and work planning. The status of all ongoing tasks and City reviews will be discussed at these meetings, as well as all issues related to draft deliverables and comments received from the City regarding such deliverables.

2.2.2 Task 2 – Data Collection and Evaluation

The purpose of this task, *Technical Memorandum No. 1 - Data Collection and Evaluation*, was to request and collect readily available data that would support the development of the LID Master Plan. ADA reviewed the data collected and assessed its relevance for inclusion as a part of this project.

As part of this task, ADA performed a literature search of currently available LID practices and standards. In addition, ADA performed an inter-municipal research on already implemented LID techniques with the purpose to identify LID practices that are best applicable and beneficial to the South Florida environment and hydrology.

The collected data was cataloged, evaluated, and utilized as necessary to support the analyses and preparation of the subsequent Technical Memorandums and the final LID Master Plan Report.

2.2.3 Task 3 – Low Impact Development Site Planning

The purpose of this task, *Technical Memorandum No. 2 - Low Impact Development Site Planning*, was to evaluate the City's current Site Planning Regulations and identify areas where the current regulations could be amended and modified to include sustainable LID practices.

As part of this TM, the data collected as part of TM1, Data Collection and Evaluation, non-structural and structural LID planning practices most applicable to the City were identified to naturally treat and retain stormwater from new development and redevelopment sites, and provide incentive for implementing environmentally sensitive site planning and design. This TM also documented the advantages and disadvantages of each of the LID practices identified

2.2.4 Task 4 – Low Impact Development Hydrologic Analysis

The purpose of this task, *Technical Memorandum No. 3 - Low Impact Development Hydrologic Analysis,* is to identify and document the hydrologic analysis procedures to be implemented in analyzing the structural LID BMPs identified and explained in detail in TM#2 Site Planning.

As part of this TM, the recommended computation procedures were documented and included an example of a recently permitted development project to illustrate the application of these procedures. The example includes the same development with and without LID BMPs to document the benefits provided by the LID BMPs.

2.2.5 Task 5 – Low Impact Development Integrated Management Practices

The purpose of this task, *Technical Memorandum No. 4 - Low Impact Development Integrated Management Practices,* is to provide the City with detailed descriptions, application standards, standard details, and recommend operation and maintenance of these BMPs. Also, provide recommendations to promote incentives to encourage environmentally sustainable site planning using these LID practices. ADA provided recommended regulation language to be implemented in the current LID Regulations to allow for innovating engineering and planning principles.

2.2.6 Task 6 – Low Impact Development Erosion and Sediment Control Management Practices

The purpose of this task, *Technical Memorandum No. 5 - Low Impact Development Erosion and Sediment Control Management Practices,* is to evaluate the City's current construction phase soil erosion and sediment control standards and identify areas where the current regulations can be amended and modified to include sustainable soil erosion and sediment control LID practices.

ADA used the data collected as part of Task 2 to identify supplemental or refined LID construction phase soil erosion and sediment control practices to be incorporated by the City. The recommended regulation language to be implemented in the current LID regulations to allow for innovative soil erosion and engineering implementation principles are documented and included in this report.

2.2.7 Task 7 – Public Involvement and Outreach Programs

The City of Doral and the ADA Engineering Team implemented a Public Involvement and Outreach program to educate the public and local land developers in the activities that were being performed to complete this LID Master Plan and to obtain feedback and input from the residents and developers. The public involvement task included coordinating and conducting one (1) Resident Workshop and one (1) Developer Workshop with the intent of providing a venue where participants could understand the LID Master Plan process and goals, solicit feedback, discuss future improvements, and develop a positive rapport with community stakeholders.

Some of the objectives of the Resident Workshop included:

- Foster an understanding of the City of Doral's implementation of LID Integrated Management Practices, the benefits to the community, and the engineering process;
- Minimize impact on businesses and stakeholder opposition to the proposed protocols;
- Communicate to stakeholders the need for implementation of LID site planning, hydraulic analysis, and erosion control practices;
- Engage the community in an open, healthy dialogue about the project, convey that the City of Doral bases the final decision on several criteria, and that community input is an important part of those criteria.

Attachment A includes a summary of the Resident and Developer Workshops.

3.0 DATA COLLECTION AND EVALUATION

The data collection task required collecting available data from entities in the State of Florida that have implemented or have experience with LID management practices. Data was requested and/or collected from the flowing entities:

- Miami Dade County
- City of Miami Gardens
- City of Miami Beach
- City of Orlando
- City of Sanford
- City of Tampa
- Alachua County
- Hillsborough County
- Orange County
- Pinellas County
- Sarasota County
- South Florida Water Management District
- Environmental Protection Agency
- Florida Department of Environmental Protection
- Florida Water Star Program

The following information was requested:

- LID management practices to naturally treat and retain stormwater from new developments and redevelopment sites,
- Structural and non-structural BMPs implemented,
- Incentives provided for implementing environmentally sensitive site planning and design, and
- Performance/feedback from LID practices implemented.

Attachment B includes a matrix of all entities contacted. This matrix includes point of contact, data requested, and status of request.

3.1 ASCE/EWRI Conference

As part of the data collection, ADA also performed a literature search of available documented data that was presented at the American Society of Civil Engineers (ASCE) and the Environmental and Water Resources Institute (EWRI) conference held in San Francisco, California in April 2010. The documented research contained pertinent and applicable data related to LID management practices. The technical papers presented during this conference addressed a broad range of topics that are relevant to a sustainable approach to stormwater management using the Low Impact Development technology. These topics include:

- LID and Sustainability

- Overcoming Institutional Barriers and Other Barriers to LID Implementation
- Codes, Regulations, Constraints, Guidelines
- Recent Monitoring / Performance Findings
- Computational Methods
- Advances in LID BMP Design Methods – Lessons Learned
- Site Design Considerations
- LID Incentives for New Developments
- Watershed Retrofit with LID
- Education and Training Outreach
- Long-Term Performance, Maintenance

Attachment C provides the following ASCE/EWRI key technical papers which were selected to support the development of this LID Master Plan:

- *ASCE-EWRI Permeable Pavement Technical Committee – Introduction of Committee Goals and Chapter 1 of Guidelines "Design Considerations Common to All Permeable Pavements".* Bethany E. Eisenberg
- *Considerations in Selecting a (Bio)Filtration Media to Optimize Lifespan and Pollutant Removal*. Shirley E. Clark and Robert Pitt.
- *Pervious Asphalt Roads and Parking Lots: Stormwater Design Configurations*. A. L. Broadsword and C. A. Rhinehart,
- *Pervious Pavement Systems in Florida – Research Results*. Manoj B. Chopra, Erik Stuart, and Martin P. Wanielista.
- *The Urban Green BioFilter: An Innovative Tree Box Applications.* James H. Lenhart, Scott A. deRidder, and Vaikko Allen.
- *A Non-Dimensional Modeling Approach for Evaluation of Low Impact Development from Water Quality to Flood Control*. T. Andrew Earles, James Guo, Ken MacKenzie, Jane Clary, and Shannon Tillack.
- *Comparison of BMP Infiltration Simulation Methods*. Jenny Zhen, Mow-Soung Cheng, John Riverson, and Jenny Zhen.
- *Planning-Level Cost Estimates for Green Stormwater Infrastructure in Urban Watersheds.* M. J. Vanaskie, R. D. Myers, and J. T. Smullen.
- *LID, LEED and Alternative Rating Systems – Integrating Low Impact Development Techniques with Green Building Design.* Laura Prickett and Jill Bicknell.
- *Evaluation of Roadside Filter Strips, Dry Swales, Wet Swales, and Porous Friction Course for Stormwater Treatment.* R. J. Winston, W. F. Hunt, and J. D. Wright.
- *Expanding the International Stormwater BMP Database Reporting, Monitoring, and Performance Analysis Protocols to Include Low Impact Development (Part 1).* Jane Clary, Marcus Quigley, Andrew Earles, Jonathan Jones, Eric Strecker, and Aaron Poresky.
- *Low Impact Development Benefits of Level Spreader – Vegetative Filter Strip Systems*. Ryan J. Winston and William F. Hunt.

The technical papers provided by ASCE/EWRI were evaluated for relevance to the application of non-structural and structural LID planning practices for the natural treatment and retention of stormwater at new development and redevelopment sites. The papers also gave insight into the incentives provided for implementing environmentally sensitive site planning and design practices. From a collection of 50 technical papers presented at the conference, 12 of the most relevant to the topics were selected for review.

3.2 Miami-Dade County

Miami-Dade County Planning Department provided information related to the recently updated Comprehensive Development Master Plan (CDMP). The amendments adopted on October 2, 2013 include many of the principles of LID management practices, sustainability and green building, and information on policies related to specific aspects of LID. The CDMP can be accessed at http://www.miamidade.gov/planning/cdmp-adopted.asp.

3.3 Pinellas County

In 2006 Pinellas County became the first jurisdiction in the State of Florida to be designated a Green Local Government by the Florida Green Building Coalition (FGBC). LID management practice programs contribute to the County's sustainability commitment in a time when the current redevelopment trends are increasing rapidly and reaching a state of build-out. Redevelopment in Pinellas County represents a particularly suitable opportunity for implementing LID practices on a lot-by-lot level. Some examples of LID practices that apply to individual lots include green roofs, cisterns or rain barrels, micro-irrigation, bioretention systems, and pervious pavers.

3.4 Sarasota County

Although LID stormwater management practices are not mandatory in Sarasota County, they encourage the use of LID practices, where possible, to help meet its water resource objective. The LID Manual developed is expected to be adopted by the Sarasota County Board of County Commissioners, and to be incorporated by reference into the Sarasota County ordinance. The manual can be found at https://www.scgov.net/WaterServices/Pages/LowImpactDevelopment.aspx.

This manual supports Sarasota County's goal of applying the LID concept and design where feasible to enhance existing stormwater management measures and reduce the adverse impacts of land development projects on the county's natural resources. The main LID management practices targeted include:

- Stormwater Reuse
- Bioretention
- Green Roofs
- Swales
- Compost Filters
- Tanks / Vaults
- Porous Pavements
- Soil Amendments

- Fertilizer Control / Drip Irrigation
- Florida Friendly Yards
- Curb Elimination
- Disconnected Impervious Areas
- Reduced Street Width
- Cisterns and Rain Barrels

3.5 South Florida Water Management District (SFWMD)

The SFWMD provided information related to the topics recently discussed at the Regional Integration Workshop held in Ft. Lauderdale in October 2014. The workshop focused primarily on addressing sea level rise and implementation of structural and non-structural BMPs. In addition, the following topics were covered more in depth:

- Installation of flap gates at ocean outlets to minimize storm surge backwater effects
- Shifting from a gravity-drained system to pumped drainage (i.e. municipal pumping)
- Lowering pre-storm water levels (pre-storm drawdown)

3.6 Environmental Protection Agency (EPA)

Existing LID design and guidelines studies were available via the *Water and Pollution and Prevention Control* website. This website contains supporting documentation for implementation, design and guidance manuals for LID management practices. The following data was acquired through the EPA LID portal (http://water.epa.gov/polwaste/green/):

- Case Studies Analyzing the Economic Benefits of Low Impact Development and Green Infrastructure Programs.
- Reducing Stormwater Costs through Low Impact Development Strategies and Practices
- Low Impact Development Design Strategies: An Integrated Design Approach
- Low Impact Development Urban Design Tools
- Low Impact Development Manual
- Field Evaluation of Permeable Pavements for Stormwater Management

3.7 Florida Department of Environmental Protection (FDEP)

The FDEP and the Water Management Districts are developing statewide stormwater treatment rules to address growing concerns about nutrient over-enrichment of Florida's surface waters, groundwater, and springs. This rule is a significant step forward in the control of nutrient loadings from stormwater discharges. The draft rule and Applicant's Handbook can be found at http://www.dep.state.fl.us/WATER/wetlands/erp/rules/stormwater/index.htm.

The Applicant's Handbook applies to the design of stormwater treatment systems authorized pursuant to Chapter 373, F.S. that do not serve agricultural or silvicultural activities. These Stormwater Treatment Systems include the following structural and non-structural BMPs:

- Retention Basin
- Exfiltration Trench
- Underground Storage and Retention Systems
- Underground Retention Vault/Chamber Systems
- Swales
- Vegetated Natural Buffers
- Pervious Pavement Systems
- Green Roof/Cistern System
- Wet Detention Systems
- Managed Aquatic Plant Systems (MAPS)
- Stormwater Harvesting
- Wetland Stormwater Treatment Trains
- Underdrain Filtration Systems
- Natural Area Conservation
- Site Reforestation
- Disconnecting DCIA
- Florida-Friendly Landscaping
- Rural Subdivisions

3.8 Low Impact Development Center

- The Low Impact Development Center (http://lowimpactdevelopment.org/index.htm) was established in 1998 to develop and provide information dedicated to research, development, and training for water resources and natural resource protection issues. The Center focuses on furthering the advancement of Low Impact Development technology.

3.9 Florida Water Star Program

Florida Water Star (http://floridawaterstar.com) is a water conservation certification program for developments. It was developed by St. John's River Water Management District in 2006 and became a statewide program in 2012. SFWMD works in conjunction with the Florida Water Star Program.

3.10 Data from Other Sources

Data collected from other sources was based on research of available web-data portals and ADA's own data catalogs. Data collected pertinent to LID management practices, flood protection targets, and design criteria from these sources were evaluated on a case-by-case basis to determine the relevance for the development of this LID Master Plan.

4.0 LOW IMPACT DEVELOPMENT SITE PLANNING

The traditional engineering approach to storm water management is to convey runoff away from the development site into man-made drainage structures designed to accommodate a large volume of stormwater. In contrast, Low Impact Development uses the natural, pre-development features of the site to maximize on-site infiltration, storage, and treatment of runoff while reducing the disruptive effects of urban runoff patterns. Benefits of implementing LID BMPs include:

- Maintain natural infiltration of stormwater
- Reduce the discharge of specific pollutants into local waterways
- Provide more aesthetically pleasing developments
- Reduce the flood impacts in the City stormwater system.
- Provide a wide range of economic and ecological benefits to the City and County through infrastructure savings
- Lower water management and treatment costs
- Promote potable water conservation
- Integration of water use and land use planning.

Revision. Implementation of the LID begins at the site planning level of the site development or redevelopment process. One of the first steps in site planning involves taking inventory of the existing features on the site including topography, soil characteristics, flow paths, drainage features, building and stormwater infrastructure, impervious areas, open spaces, and vegetation. Through LID techniques, developments are designed to be integrated with these existing features and to retain or simulate the pre-development site conditions.

LID design techniques include both structural and non-structural hydrologic controls that compliment traditional stormwater treatment and conveyance systems by utilizing pre-development hydrological features to decentralize and micromanage stormwater runoff at its source. Throughout the site development process, alternative design options that include LID techniques or LID techniques combined with traditional stormwater management infrastructure are evaluated and integrated into the site plan to the greatest extent possible. The overall LID site planning development process includes:

1. Identification and compliance with existing site planning regulations and ordinances,
2. Assessment and inventory of pre-development site conditions,
3. Development of the preliminary site plan,
4. Minimization of DCIA (Directly Connected Impervious Areas),
5. Evaluation and implementation of Integrated Management Practices, these are LID management techniques employed to achieve the desired post-development hydrologic condition,
6. Comparison of pre-development and post-development hydrology, and
7. Completion of LID Site Plan.

4.1 Non-Structural LID Site Planning Practices

When managed improperly, stormwater runoff contributes to water pollution, flooding, erosion, and groundwater recharge deficits. Implementation of LID techniques serve to manage stormwater runoff through the restoration and preservation of the natural drainage features present at the development site by applying runoff source control. The application of LID techniques throughout the site planning process reduces the use of traditional conveyance materials, such as steel and concrete, and often results in a more aesthetically pleasing site, lower development and maintenance costs and additional recreational resources. Nonstructural LID practices use native and natural features of the pre-development site to attenuate peak runoff and overall runoff volume. Implementation of nonstructural LID practices improve water quality and increase groundwater recharge within the development site.

The primary nonstructural LID site planning practices and considerations most applicable to the City of Doral are the following:

- Restoration and preservation of pre-development topography and soil profile
- Preservation and use of native and local vegetation
- Open space design and conservation
- Minimization of total impervious areas
- Reduction of DCIA

The following sections provide the purpose, implementation, and benefits of the above nonstructural LID concepts.

4.1.1 Preservation of Site Topography and Soil Profile

Traditional site development typically requires adding grading fill material to create new drainage contours and infrastructure foundations. The drainage contours are traditionally designed to direct drainage away from the site into a pipe network with an end-of-pipe treatment system. The topography of the site, including the natural slopes and depressions, define the natural flow path of stormwater runoff. With LID, the natural flow path is preserved and incorporated into the site plan as an existing open conveyance system where possible.

The soil profile includes the hydrologic soil groups, depth, extent, and infiltration capacity present throughout the site. The soil types present should be delineated within the site plan. Once delineated, the soil profiles should guide the placement of impervious areas, open or vegetated space, and stormwater management features. Locations of soil groups with low hydrologic function, such as clays and disturbed soils, are ideal for placement of buildings, parking areas, roadways, ponds, and other impervious structures. Areas with highly permeable soil groups are ideal for implementing LID stormwater management features relying on infiltration of runoff. Once the soil profiles have been established, construction activities must limit soil compaction in the areas of soils with higher permeability to protect the natural soil characteristics.

To better preserve the pre-development topography and native soil characteristics, instead of using traditional slab-on-grade construction for building foundations, which require alteration of the natural contours and soil conditions of the site, an alternative construction method should be used when possible. For example, constructing buildings using stem wall construction, or pier and beam for raised floor foundations instead of slab-on-grade. **Figure 4-1** provides an example of a type of pier and beam foundation. Both alternative construction methods create a crawlspace below the foundation and minimizes the amount of excavation required which dramatically limits disturbance of the pre-development site.

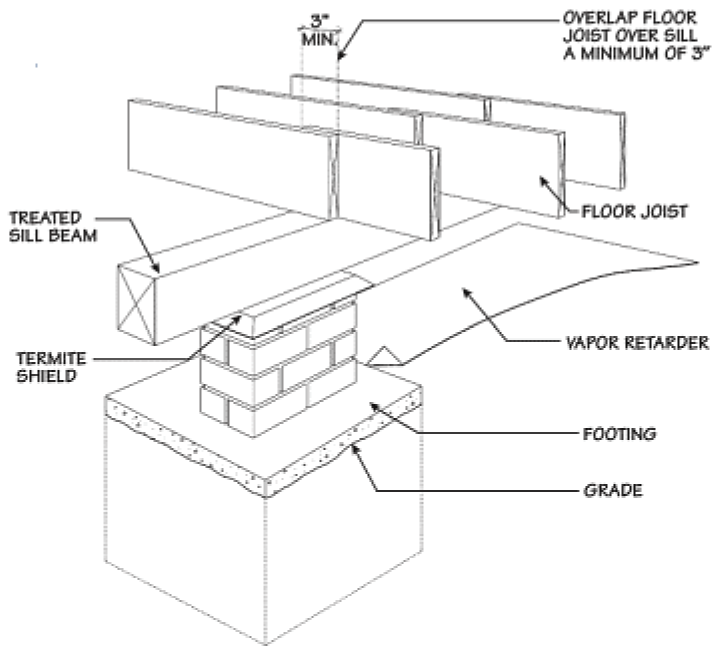


Figure 4-1 – Interior Detail of Example Pier

If the natural properties of the soil are modified during construction through compaction or other activities, soil amendment is recommended, and may be required. Soil amendment involves changing the soils chemical or physical properties through the addition of other materials, or through mechanical means such as tilling or aeration. As an LID practice, soil amendment is used to increase the infiltration capacity, storage capacity, or pollutant removal capacity of the soil, to add the nutrients needed for vegetation, and to stabilize sandy soils. For example, the addition of compost to compacted soils can increase the porosity and the permeability of the soil. It should be noted that soil amendment is not able to fully restore the natural characteristics of compacted soils. As such, the most effective way to preserve the soil profile is to limit construction activities, including vehicle and equipment travel, within areas identified to have highly permeable soils.

Additional preservation of site topography and soil profile LID practices include:

- Selective grading and clearing

- Minimize soil disturbance and compaction
- Soil Amendment
- Reduce construction on highly permeable soils
- Locate new buildings, parking, and ponds in areas that have lower hydrologic function, such as clayey or disturbed soil

4.1.2 Preservation and use of Native and Local Vegetation

The pre-development site inventory and assessment includes the vegetation present on the site. Both Florida native and exotic plant species should be inventoried and taken into account when designing the initial site plan with existing vegetation buffers around bodies of surface water preserved. Vegetation prevents erosion, reduces pollution levels, increases infiltration by decreasing runoff velocities, intercepts rainfall, and increases evapotranspiration rates. Traditional site development includes clearing onsite vegetation, which disturbs native soils, and introduces new vegetation that requires a greater amount of water and nutrients to become established compared to the pre-development vegetation present on the site. Preserving pre-development vegetation on the site and using Florida native vegetation creates a longer-lasting landscape and reduces the effort and cost of maintenance.

Through the use of hydrozones, plants are grouped into zones throughout the site based on nutrient demands and sunlight and water requirements. When designed and implemented, hydrozones minimize water, fertilizer, and pesticide use throughout the development. Whenever feasible, trees and native plants present on the site should be preserved and incorporated into the site design. The use of turfgrass should be limited to recreational areas, swales, and areas in need of erosion control that cannot be provided using other types of native ground cover.

When included in the site design, the type of turfgrass used should be specific to the environmental conditions of the planting area. The *Florida-Friendly Landscaping Guide to Plant Section & Landscape Design* provides landscape design strategies, planning worksheets, and a list of plants recommended within the four regions of Florida. The *Florida-Friendly Landscaping Pattern Book* provides sample plants and designs based on site conditions specific for USDA hardiness zones in South Florida. Both handbooks can be found at http://fyn.ifas.ufl.edu/. Vegetation types and species extracted from the *Florida-Friendly Landscaping Pattern Book* are provided in **Attachment D**. The tables provide specific examples of plants, flowers, and grass types recommended for South Florida, grouped by plant type, characteristics, and sun/shade requirements.

Preservation of native and local vegetation LID practices include:

- Preservation and incorporation of conservation areas and wetland habits
- Removal of exotic vegetation (recommended when greater than 5%)
- Retention of existing native vegetation
- Introducing native vegetation appropriate to existing site conditions
- Conservation of existing Tree Canopy

- Limit use of turfgrass and select turfgrass species with characteristics matching existing site conditions

4.1.3 Open Space Design and Conservation

Once the inventory and assessment of the site topography, soil profiles, and vegetation have been completed and delineated, the next step in the LID site plan is to design and outline the placement of open space and infrastructure such as roadways, sidewalks, lot layouts, buildings, driveways, and parking spaces. Open space includes existing or designed pervious areas, such as natural areas, recreational areas, common use areas, and buffer zones. When planning the layout of the site, employ the LID strategies of preserving the existing topography, soil zones with positive drainage benefits, and native plant communities by maximizing the area designed for open space. Larger open space areas and open spaces with smaller borders provide the maximum benefit for both stormwater management and wildlife.

Open spaces can be utilized for alternative LID stormwater management strategies that reduce the impact of the site development on the watershed. Open spaces maximize overland sheet flow with longer flow paths that reduce runoff velocities, increase residence times, and provide space for planting native vegetation. One method that maximizes the open space available is placing buildings with the cluster design approach. The cluster design approach increases the number of buildings or units per acre, which reduces overall infrastructure and development costs.

The Central Broward Water Control District requires a minimum of 25% open space for residential areas. In Alachua County the minimum required open space is 20% for residential and 50% for rural areas. It is recommended that the City of Doral adopt local zoning ordinances and building codes to include an open space requirement and to provide flexibility in the development design to encourage implementation of open space. Based on the conditions of the City and on common practices of other municipalities, it is recommended that 25% open space be required for new residential developments and for existing developments that are expanded or undergo substantial changes. A minimum requirement of 15% open space is recommended for commercial/industrial developments.

Additional open space design and conservation LID practices include:

- Increase (or augment) the amount of vegetation on the site.
- Maximize use of open swale systems
- Maximize overland sheet flow
- Avoid total site clearing
- Reduce fill and grade operations

4.1.4 Minimization of Total Impervious Areas

The greatest sources of impervious areas are the traffic distribution network and building rooftops. Alternative roadway layouts that implement shorter roadway lengths, such as the loops and lollipops layout, can reduce the overall roadway surface by 26% compared to implementation of the traditional grid layout. In some cases, the use of the T-shaped turn-about instead of the more common cul-de-sac design can decrease the roadway area needed, without adversely affecting the desired traffic access. Throughout the design of the traffic distribution network, pavement lengths and widths should be minimized to the extent that safety consideration allow.

When designing parking lots, use the smallest space dimensions with the fewest number of spaces, and use pervious areas for overflow parking needed for seasonal or rare events. Drainage from the impervious areas should be designed to direct runoff to vegetated, pervious areas such as swales or bioretention islands before entering a conventional pipe conveyance system.

Buildings should be designed to maximize the ratio of square footage to roof area. The application of high density development strategies will reduce the stormwater runoff per building and decrease the total impervious area compared to low-density developments with the same number of units. High-density development strategy also has less impact on the overall watershed and can improve the water quality of runoff generated on the site.

Additional minimization of total impervious areas LID practices include:

- Alternative roadway, sidewalk, parking lot, and driveway design standards to minimize imperviousness
- Minimize width and lengths of traffic distribution networks
- Implement pervious shoulders and right-of-way areas
- Limit the installation of sidewalks to one side of roadways

4.1.5 Reduction of Directly Connected Impervious Areas

Once the preliminary site plan has been developed which minimizes the total impervious area, preserves the sites natural hydrological characteristics and vegetation, and maximizes the areas of open space, the site plan should be evaluated to disconnect the unavoidable impervious areas. Stormwater runoff should be directed to flow into natural areas, vegetated buffer zones, and soils with favorable infiltration. The flow from large impervious areas should be broken up into smaller drainage areas with the flow directed to stabilized vegetated areas.

LID systems are composed of several incremental structural and nonstructural hydrologic controls. By disconnecting impervious areas from directly discharging into the offsite discharge system, the need for costly stormwater conveyance and treatment systems are reduced. Instead of large runoff volumes being drained into centralized basins and piped long distances to traditional end-of-pipe treatment facilities, runoff from individual roof tops is separated and treated using small basins located adjacent to the structure. Runoff from paved roads and parking areas are also separated using structural LID controls, and the flow paths are directed to vegetated areas located within and adjacent to the impervious area. By reducing DCIA, the negative impacts of a component failure have significantly less negative impact on the overall site and is often less costly to repair.

LID practices that reduce DCIA include:

- Direct drainage to stabilized vegetated areas.
- Site layout to break up flow directions from large paved surfaces
- Disconnect roof drains and drain to vegetated areas
- Site development to encourage sheet flow through vegetated areas (Locate impervious areas so that they drain to permeable areas)

4.2 Structural LID Practices and Stormwater Management

Structural LID practices use of a wide array of simple, cost-effective techniques that focus on site-level hydrologic control. LID projects should strive to obtain or improve the same hydrologic and hydraulic conditions that were present before development by maintaining runoff conveyance patterns, infiltration and treatment capacity, total stormwater runoff volume controls.

After completion of the preliminary site planning and minimization of DCIA, the next step in the LID Site Plan is evaluation and implementation of Integrated Management Practices (IMPs). IMPs are LID management techniques employed to achieve the desired post-development hydrologic condition. Ideally, LID IMPs technologies are located at the runoff source, on level ground, and within individual lots of the development. LID IMPs eliminate the need for a large centralized system to control the entire runoff of the development. Aside from the main characteristics of these low impact IMPs of providing quantity and quality control and enhancement, IMPs must provide:

- Groundwater recharge through infiltration or exfiltration into the soil.
- Retention or detention of runoff for permanent storage or for later release.
- Pollutant settling and entrapment by conveying runoff slowly through vegetated swales and natural buffer strips.
- Aesthetic value to the property which enhances a sense of community lifestyle.
- Satisfaction of local government requirements for green or vegetated buffer space by implementing multiple landscaped areas within each lot.

The most effective type of design for maximum on-lot stormwater runoff control consists of placing source controls in series, this is especially effective at reducing volume and peak flow rates. **Attachment E** provides an overview and comparison matrix of the most common LID IMPs utilized in South Florida which have the greatest applicability for the City of Doral. The matrix in **Attachment E** includes the advantages, disadvantages, space requirements, maintenance frequency and approximate cost extent, and proximity to building foundation.

The primary structural LID BMPs and practices that appear to be most applicable to the City of Doral include the following:

- Bioretention Basins or Rain Gardens
- Tree Box Filters or Infiltration Planters
- Vegetated Swales
- Filter Strips or Vegetated Buffers
- Infiltration Trench
- Exfiltration Trench or French Drains
- Green Roofs/Rain Barrels or Cisterns
- Permeable Pavement
- Detention Ponds
- Parking Chambers

4.2.1 Bioretention Basins or Rain Gardens

Bioretention basins are small landscaped basins, on-lot, which hold and infiltrate stormwater. These are intended to manage and provide water quality treatment by using a conditioned planting soil bed and materials to filter the stored runoff. It is recommended that landscaped areas only use native species (see **Attachment D** for recommended species) to promote water conservation, benefits to native wildlife, aesthetic benefits to neighborhoods, and increase in property values. The major components of Bioretention Basins or Rain Gardens systems include:

- Pretreatment area (optional – required for significant volumes)
- Ponding area
- Ground cover layer
- Plant Material and planting soil
- In situ soil
- Inlet and outlet controls
- Maintenance

This approach is very flexible as a method of runoff source control for stormwater in residential developments, parking lot islands, and landscaped areas in commercial or public areas. In cases where soil permeability does not benefit infiltration, underdrains can carry the filtered water downstream through the Bioretention basin. An example of a typical Bioretention basin is shown in **Figure 4-2**.

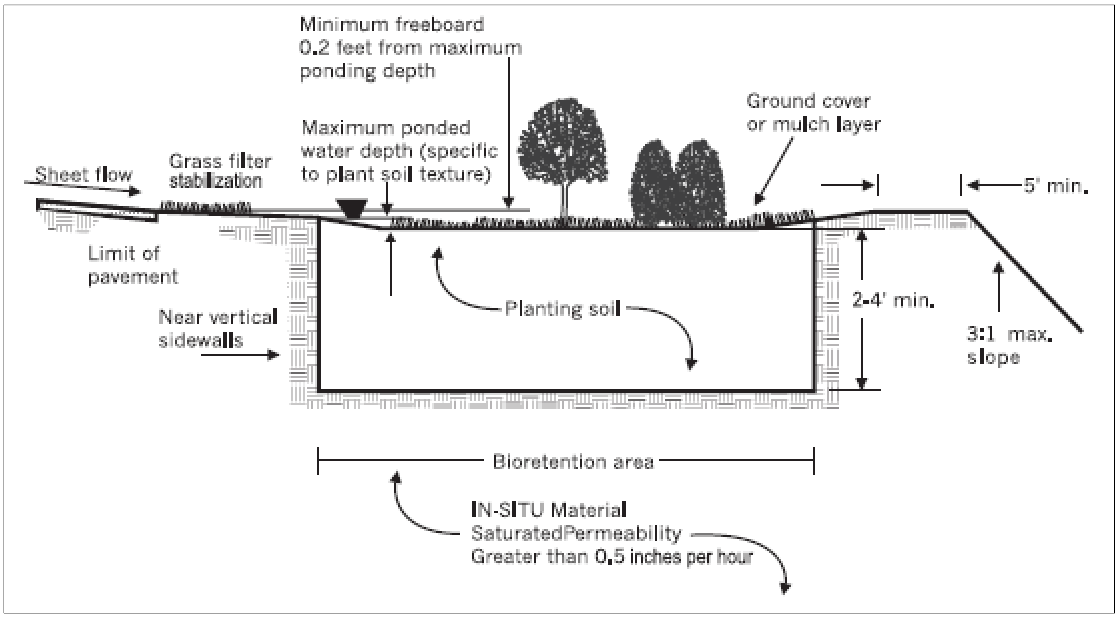


Figure 4-2 – Typical Bioretention Basin Cross-section

A summary of design considerations for evaluating the suitability of Bioretention basins or Rain Gardens are summarized in **Table 4-1**.

Table 4-1 – Bioretention Basins and Rain Garden Design Considerations

Parameter	Consideration
Treatment Area	Individual lots in subdivisions or common areas, other landscaped areas and retrofit projects. Minimum surface area of 50 – 200 sq. ft. Minimum length to width ratio 2:1.
Pretreatment Area	Required when significant volume is anticipated from parking lots and commercial areas (i.e. grass buffer strip or vegetated swale).
Proximity to building Foundation	Minimum distance of 10 feet down gradient.
Soils	Infiltration rates < 0.1 in/hr require underdrains or soil augmentation.
Topography	May be difficult in areas with slopes > 10%.
Depth of Water Table	Not suitable if difference between seasonal high water table and bottom of Bioretention area is < 2 feet.
Groundcover Area	3 inches of mature mulch recommended.
Planting Soil	Depth = 4 feet / Clay content ≤ 10%. Soil mixture to include sand, loamy sand, and sandy loam.
Inlet and outlet control	Non-erosive flow velocities (0.5 ft/sec)
Plant Material	Minimum 3 native species. (see **Attachment D**)
Maintenance	Routine landscape – 5-7% of construction cost. Mulch should be replaced annually. Ornamental rocks such as lava rock can reduce maintenance cost of rock

	Accumulated trash and sediment must be cleaned out. Infiltration capacity must be inspected (Total drawdown time 72-hr).
Hydrologic Design	Determine by State or Local agency

4.2.2 Tree Box Filters or Infiltration Planters

Tree box filters or infiltration planters are a small scale variation of Bioretention basins. As the name implies, tree boxes use trees and infiltration planters use plants other than trees. The two basic types are: 1) a filter, or 2) detention boxes. The box performs as a filter if the bottom is open and stormwater is discharged through infiltration or the box acts as a detention box when the bottom is closed. In the detention box, the filtered stormwater flows into an underdrain and is discharged to another LID BMP or pipe system. Each consists of a ponding area or container filled with a layer of mulch, planting soil, and plants or trees.

As with bioretention basins, native species of trees and plants should be used (see **Attachment D**) to promote water conservation, provide benefits to the native habitat, add aesthetic value to the site, and reduce the heat island effect. Plants reduce the volume of runoff and can enhance the quality of discharge or infiltrated water by amending the soil to assist in removing a particular pollutant present in the area. They are appropriate for new projects and can be retrofitted into existing stormwater systems. An example of a typical Tree Box Filter is shown in **Figure 4-3**.

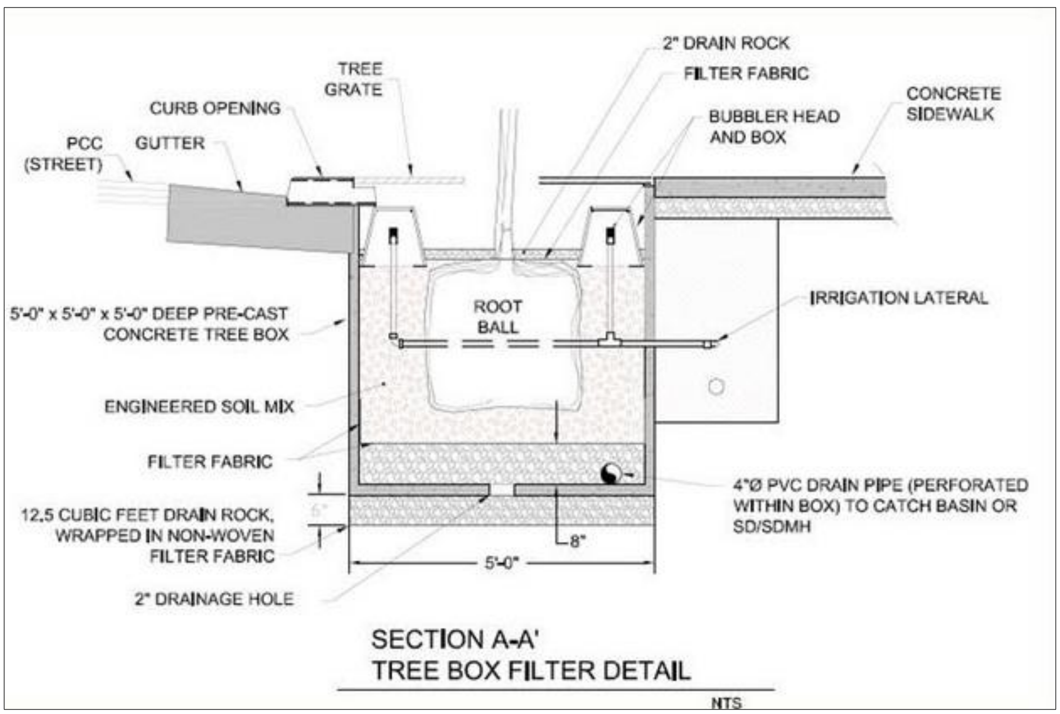


Figure 4-3 – Typical Tree Box Filter

A summary of design considerations for evaluating the suitability of Tree Box Filters and Infiltration Planters are summarized in **Table 4-2**.

Table 4-2 – Design Considerations for Tree Box Filters and Infiltration Planters

Parameter	Consideration
Treatment Area	New Developments or retrofit into existing stormwater systems
Pretreatment Area	N/A
Proximity to building Foundation	Minimum distance of 10 feet down gradient if infiltration permitted. If located closer boxes should be contained with impermeable structures & with an underdrain.
Soils	Reduction of soil will directly impact the potential size of the tree. Avoid soil compaction. 12-inch drainage rock depth under the soil with a 2-inch minimum depth of drainage rock above drainage hole
Topography	N/A
Depth of Water Table	N/A
Groundcover Area	Bark mulch should be placed 4 inches deep. Pea gravel should be placed 2 inches deep.
Planting Soil	Typically amended to facilitate vigorous plant growth and not restrict performance requirements. Organic matter improves moisture retention and microbial action.
Inlet and outlet control	Curb cuts may be used as entry points of runoff Grating (surrounding pavement is graded towards box).
Plant Type and Species	See **Attachment D**.
Maintenance	Routine landscape. Maintaining the health of the plants, pruning and addition of mulch semi-annually. Trash and debris removal may be required based on location. If plant material dies, it must be replaced as part of regular maintenance.
Hydrologic Design	Determine by State or Local agency

4.2.3 Vegetated Swales

Vegetated swales are commonly used to transport stormwater runoff away from roadways and right-of-way areas. Swales reduce or eliminate the need for standard curb and gutter and pipe systems. Swales optimize stormwater drainage systems by reducing stormwater runoff, and provide many benefits including attenuation of peak flow rates and runoff velocities. Vegetated swales are classified as either dry or wet.

Dry swales provide water quantity and water quality control by facilitating stormwater infiltration of all or a portion of design treatment volumes. Wet Swales use residence time and natural growth to reduce peak discharge and provide water quality treatment before discharge to another LID BMP or pipe system. Permeability of the soil determines whether a dry swale or wet swale is used. An example of a Vegetated Conveyance Swale is shown in **Figure 4-4**.

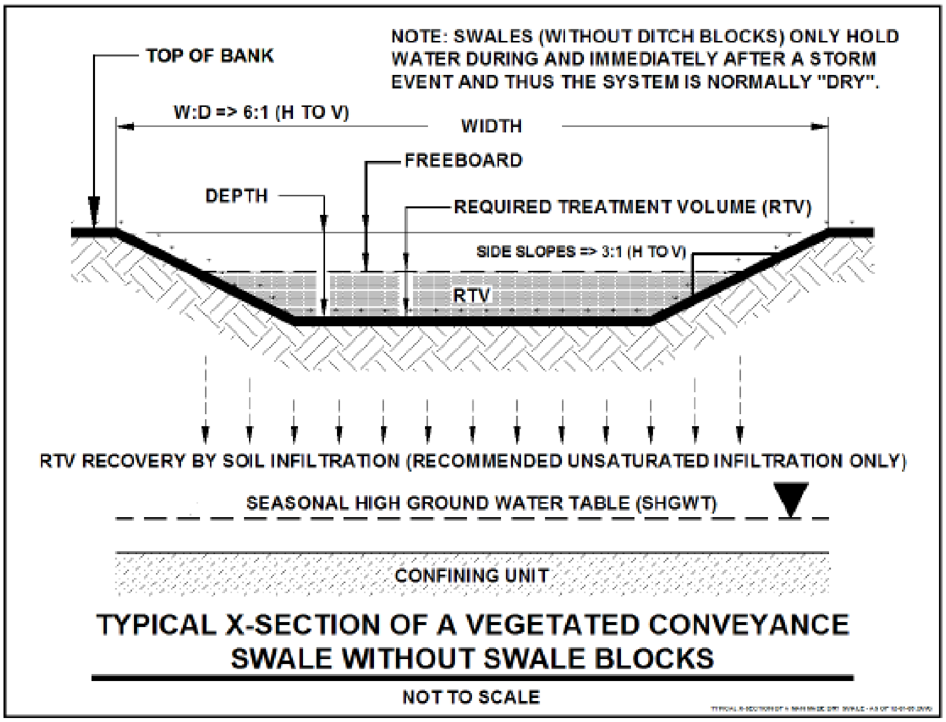


Figure 4-4 – Typical Cross-section of a Vegetated Conveyance Swale without Swale Blocks

A summary of design considerations for evaluating the suitability of Vegetated Swales are summarized in **Table 4-3**.

Table 4-3 – Design Considerations for Vegetated Swales

Parameter	Consideration
Treatment Area	Along roadways and right-of-way areas. Linear retention swales or conveyance swales. Top width to depth ratio of cross section ≥ to 6:1 or side slopes ≤ to 3H:1V
Pretreatment Area	N/A
Proximity to building Foundation	Minimum distance of 10 feet down gradient.
Soils	Permeability will determine whether dry or wet swale can be used. The minimum infiltration rate through the vegetation and soil shall be at least 1 inch per hour. Avoid soil compaction.
Topography	Trapezoidal or parabolic shape recommended
Depth of Water Table	Bottom of swale must be at least 2 feet above seasonal high water table.
Groundcover Area	Design to account for soil erosion potential, soil percolation, slope, slope length, and drainage area to prevent erosion and reduce pollutant concentration.
Planting Soil	Typically planted or has stabilized vegetation suitable for soil stabilization, stormwater treatment, and nutrient uptake.

Parameter	Consideration
Inlet and outlet control	Curb elimination, curb cuts, or curb replacements with raised knobs allow rainwater to enter vegetated swales.
Plant Material	See **Attachment D**.
Maintenance	Routine landscape. Inspected and maintaining to preserve adequate infiltration capacity in the soil. Trash and debris removal may be required based on location. Can become clogged with sediment deposits, overgrowth of alga, or overloading of oil and grease. Inspections should look for healthy vegetated slopes, erosion problems, blockage of flow path or any other damage.
Hydrologic Design	Determine by State or Local agency

4.2.4 Filter Strips or Vegetated Buffers

Filter strips or vegetated buffers are constructed or naturally occurring vegetated zones between pollutant sources and downstream receiving water bodies. The strips or buffers slow runoff, reduce peak discharge, allow for infiltration, and reduce stormwater volume. These types of structural LID practices should be used as a component of a broader management system and are not intended to be the sole stormwater treatment system in residential areas. In some instances, they are recommended for treatment of runoff from backyards of residential developments.

Vegetated buffers are typically composed of undisturbed native vegetation. If planted, only a diverse variety of native species should be used (See **Attachment D**). An example of a Vegetated Buffer is shown in **Figure 4-5**.

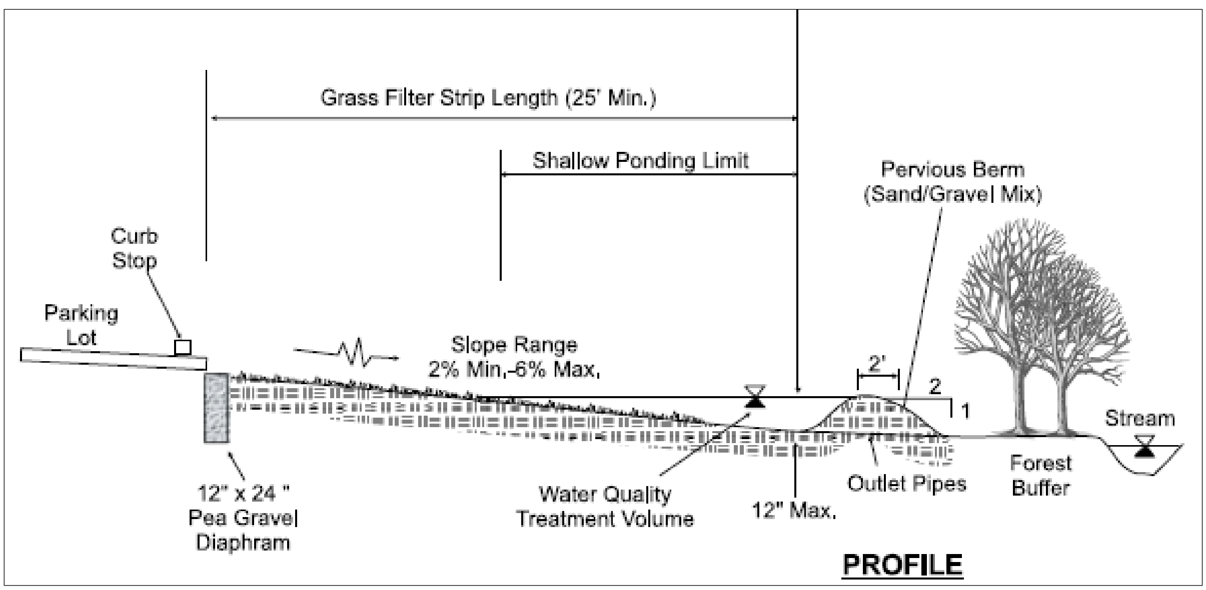


Figure 4-5 – Typical Profile of a Filter Strip

A summary of design considerations for evaluating the suitability of Vegetated Buffers or Filter Strips are summarized in **Table 4-4**.

Table 4-4 – Design Parameters for Vegetated Buffers and Filter Strips

Parameter	Consideration
Treatment Area	Closed growing vegetation (natural or planted). Between pollutant source and downstream receiving water body. Sensitive areas (waterbodies, wetlands, erodible soils). Runoff from backyards of residential developments. Minimum dimensions recommended are 25 feet and maximum is 100 feet parallel to flow direction. The length perpendicular to the runoff must be at least as long as the contributing runoff area.
Pretreatment Area	Should be used as a part of a treatment train to reduce stormwater volume and pollutant
Proximity to building Foundation	Natural areas adjacent to rear-lots that have good infiltration potential.
Soils	The minimum infiltration rate through the vegetation and soil shall be at least 1 inch per hour.
Topography	Maximum slope shall not be greater than 6:1
Depth of Water Table	Seasonal high groundwater table shall be at least two feet below the bottom of the vegetated natural buffer. Unless appropriate design demonstrates is suitable for the specific site conditions.
Groundcover Area	Design to account for soil erosion potential, soil percolation, slope, slope length, and drainage area to prevent erosion and reduce pollutant concentration.
Planting Soil	Undisturbed native species, if planted See **Attachment D.**
Inlet and outlet control	Erosion control measures should be used to prevent erosion and sedimentation.
Plant Type and Species	Undisturbed native vegetation, if planted See **Attachment D.**
Maintenance	Inspection of sheetflow and infiltration of the required treatment, generally 24 to 72 hours after a storm. Must be inspected annually. Check damage by foot or vehicular traffic or encroachment by adjacent property owners. Inspect health and density of vegetation. Routine landscape if needed.
Hydrologic Design	Determine by State or Local agency

4.2.5 Infiltration Trench

Infiltration trenches consist of shallow excavated areas filled with rock material to create a subsurface reservoir layer. They store stormwater runoff until it can be infiltrated into the surrounding soil over a period of 72 hours. They are very adaptable making them ideal for small urban drainage areas. When filter strips and grassed swales are used in combination as a form of pretreatment, infiltration trenches area highly effective at removing all targeted pollutants from stormwater runoff.

Concerns of over groundwater contamination, soil permeability, and clogging at the site inflict restrictions on the use of infiltration trenches. Examples of conditions where infiltration trenches may not be appropriate to use include:

- Sites with low soil permeability
- Industrial locations where contaminated or toxic spills may occur
- Sites with unstable soils
- High groundwater table
- Sites with contaminated groundwater
- Excessively permeable soils as pollutants may affect groundwater quality
- Terrain with steep slopes

To prevent infiltration trenches from becoming plugged over time, sediment must be removed before stormwater enters the trench. It is important to consider other forms of pretreatment such as vegetated filter strips or grassed swales to remove and filter sediment upstream of the infiltration trench. Refer to **Attachment D** for suitable, native vegetation types to use. An example of an Infiltration Trench is shown in **Figure 4-6**.

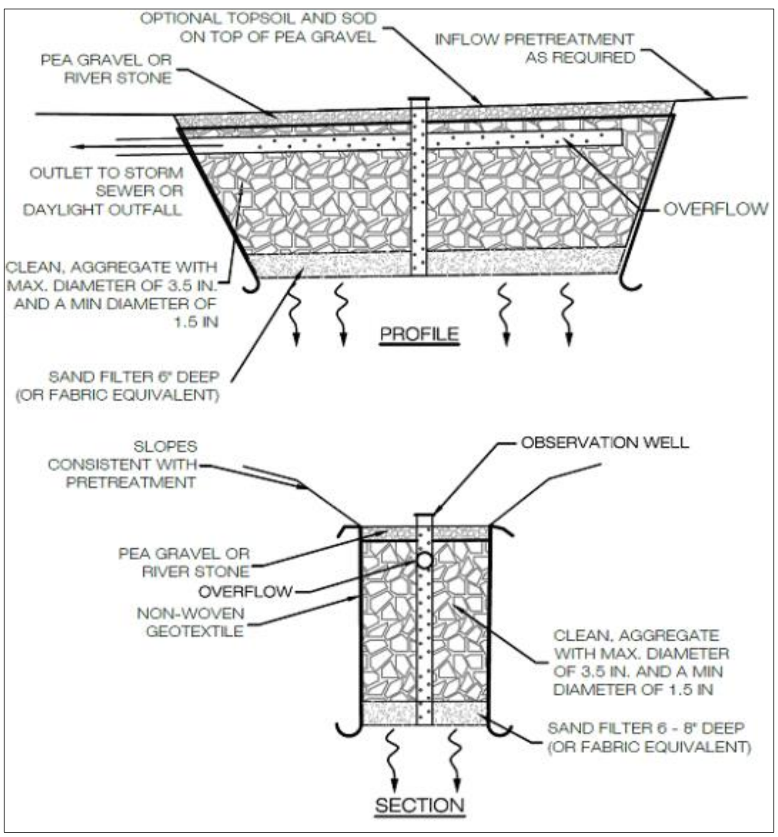


Figure 4-6 - Typical Profile & Section View of an infiltration Trench

A summary of design considerations for evaluating the suitability of Infiltration Trenches is provided in **Table 4-5**.

Table 4-5 – Design Parameters for Infiltration Trenches

Parameter	**Consideration**
Treatment Area	Small urban areas. Parking lots, recreational areas. Minimum surface area range: 8 – 20 sq.ft Minimum length to width ratio: 2:1
Pretreatment Area	Other form of pretreatment is ideal. Vegetated filter strips or grassed swales.
Proximity to building Foundation	Minimum distance of 10 feet down gradient.
Soils	The minimum infiltration rate through the vegetation and soil shall be at least 1 inch per hour.
Topography	May be difficult in areas with steep slopes
Depth of Water Table	Not suitable if difference between seasonal high water table and bottom of Trench area is < 2 ft
Backfill	Clean aggregate > 1 ½”, <3”, surrounded by engineering filter fabric
Planting Soil	Pretreatment
Inlet and outlet control	Non-erosive flow velocities (0.5 ft/sec). Overflow system must be identified.
Plant Material	Pretreatment native species. (see **Attachment D**)
Maintenance	Periodic monitoring Accumulated trash and sediment must be cleaned out. Infiltration capacity must be inspected (Total drawdown time 72-hr).
Hydrologic Design	Determine by State or Local agency

4.2.6 Exfiltration Trenches or French Drain

Exfiltration trenches, or French drains are the most commonly used stormwater system in South Florida. These systems consist of at least one catch basin or inlet that leads to a perforated or slotted pipe contained in a bed of aggregate filter media. They can be placed below paved surfaces or at the bottom of retention areas and discharge to the surrounding native soils. Advantages of exfiltration trench systems include:

Advantages:

- Requires relatively low construction cost
- Occupies relatively minimal ground space
- Provides pollutant and sediment treatment

Disadvantages:

- Requires periodic cleaning and maintenance
- Not for use in areas of contamination
- Requires permeable soils
- Debris and sediment may clog perforated pipe

Figure 4-7 shows a typical longitudinal profile and cross section of an exfiltration trench. The effectiveness of exfiltration trenches is dependent on the soil hydraulic conductivity, groundwater table elevations, and available topographic elevations. Exfiltration trenches are deemed viable when soil hydraulic conductivity is greater than $1x10^{-5}$ cfs/ft^2/ft of hydraulic head and the average October elevation in Miami Dade County is at least one to two feet below the control elevation.

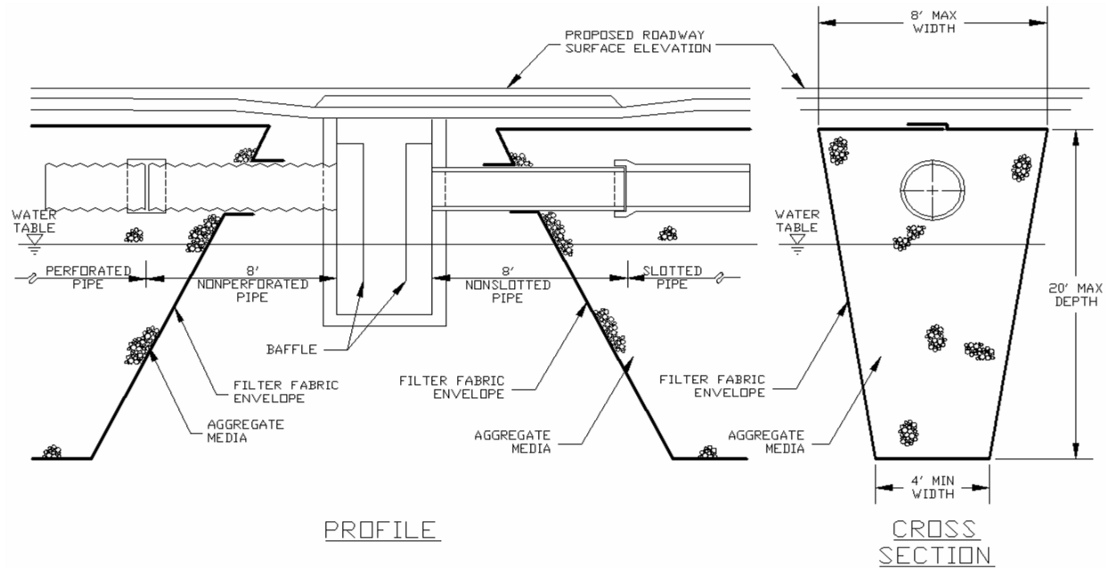


Figure 4-7 - Typical Exfiltration Trench

A summary of design considerations for evaluating the suitability of Infiltration Trenches are summarized in **Table 4-6**.

Table 4-6 – Design Parameters for Exfiltration Trenches (French Drains)

Parameter	Consideration
Treatment Area	Urban areas with limited surface space available, parking lots, recreational areas.
Pretreatment Area	Other form of pretreatment is ideal. Vegetated filter strips or grassed swales.
Proximity to building Foundation	Minimum distance of 10 feet down gradient.
Soils	Minimum soil hydraulic conductivity of $1x10^{-5}$ cfs/ft^2/ft
Topography	May be difficult in areas with steep slopes
Depth of Water Table	Pipe invert should be at or above the water table whenever possible
Backfill	No. 57 Stone ¾"-1", surrounded by engineering filter fabric
Inlet and outlet control	Control elevation determined by groundwater table, or lowest pipe inlet elevation. May be a self-contained system. If not self-contained, weir or control structure required.
Maintenance	Periodic monitoring

Parameter	Consideration
	Accumulated trash and sediment must be cleaned out. Baffles are not required, but recommended to prevent clogging the perforated pipe.
Hydrologic Design	Determine by State or Local agency

4.2.7 Green Roofs or Rain Barrels/Cisterns

Green roofs and rain barrels are roof water management devices that collect stormwater and provide retention storage volume above-ground and underground. The runoff collected can later be used for non-potable activities including irrigation, toilet flushing, or industrial processes. The most common above-ground systems are rain barrels which are low-cost, effective, and easily maintained. Underground systems are composed of a pipe to divert runoff to the cistern, an overflow system for when the cistern is full, and a pump and a distribution system to transport the non-potable water for the intended use.

Rain barrels and cisterns also provide an opportunity for water conservation and a reduction in water utility costs. An example of a rain barrel and cistern system is shown in **Figure 4-8**.

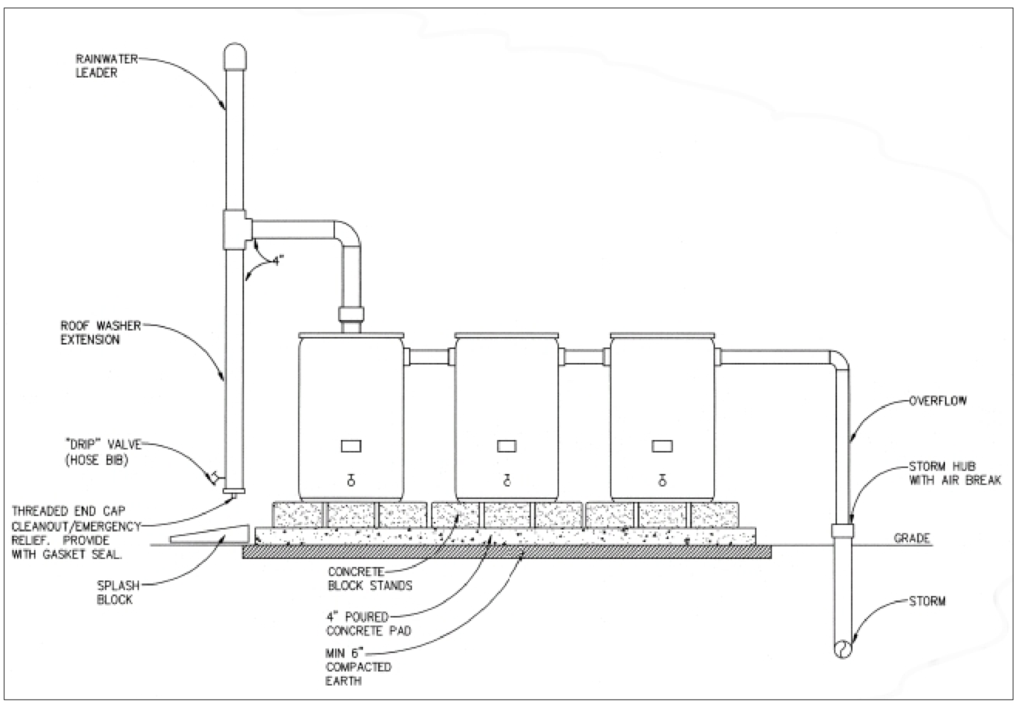


Figure 4-8 - Typical Profile of a Rain Barrel System

A summary of design considerations for evaluating the suitability of Rain Barrels and Cisterns are summarized in **Table 4-7**.

Table 4-7 – Design Considerations for Rain Barrels and Cisterns

Parameter	Consideration
Treatment Area	Rooftops and other small impervious areas. Size of Rain Barrels is a function of rooftop surface area & the inches of rainfall to be stored. Premanufactured residential cisterns come in sizes ranging from 100 to 1,400 gallons.
Pretreatment Area	Filter screens should be used on gutters to prevent clogging of debris.
Proximity to building Foundation	Beneath each downspout.
Soils	N/A
Topography	N/A
Depth of Water Table	N/A
Groundcover Area	N/A
Planting Soil	N/A
Inlet and outlet control	Downspout & gutters.
Plant Material	N/A
Maintenance	Should be located for easy maintenance & replacement. Inspect and repair/replace treatment area components.
Hydrologic Design	Determine by State or Local agency

4.2.8 Permeable Pavement

Permeable pavement, unlike traditional pavements that are impermeable, allow water to pass through reducing the volume and peak of stormwater runoff. Some types can mitigate pollutants by allowing stormwater to percolate through the pavement and enter the soil below. Permeable surfaces include modular paving systems (concrete pavers, modular grass or gravel grids) or poured-in-place pavement (porous concrete, permeable asphalt). They work best on flat surfaces or with gentle slopes. Recent studies on the design, longevity and infiltration characteristics of pervious pavement systems are available on the University of Central Florida's website http://stormwater.ucf.edu/

Pervious pavement systems are retention system that should be used as part of a treatment train to reduce stormwater volume and pollutant load from parking lots and similar areas. One of the major advantage of using these type of systems is that it reduces impervious areas and increases usable land/developable space. The treatment efficiency is based on the amount of the annual runoff volume infiltrated, which depends on the available storage volume within the pavement system, the soil permeability, and the ability of the system to readily recover this volume. Ideal locations are parking lots, driveways, sidewalks and areas with light traffic (<100 cars/day). An example of a pervious pavement system is shown in **Figure 4-9**.

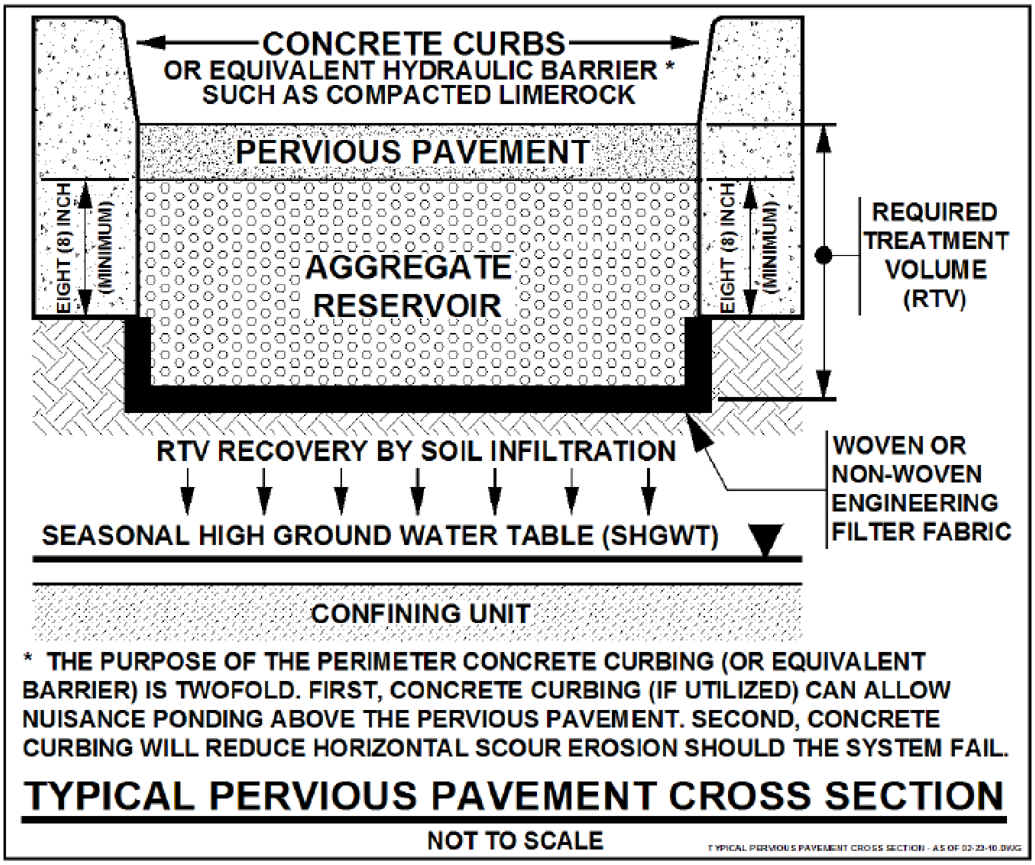


Figure 4-9 - Typical Pervious Pavement Cross-section

A summary of design considerations for evaluating the suitability of implementing pervious pavement is summarized in **Table 4-8**.

Table 4-8 – Pervious Pavement Design Considerations

Parameter	Consideration
Treatment Area	Parking lots, driveways, sidewalks and areas with light traffic. Avoid areas with high potential for hazardous material spills. Should consider potential for tripping hazards in areas used by pedestrians.
Pretreatment Area	Should be used as a part of a treatment train to reduce stormwater volume and pollutant
Proximity to building Foundation	Distance to foundation >10’ down-gradient and >100’ up-gradient without liner, septic systems, >100’ from water supply wells
Soils	Permeability rate >0.5 inch/hr
Topography	May be difficult in areas with steep slopes. Should not exceed 1.04%.
Depth of Water Table	Present challenges in shallow seasonal high groundwater tables and shallow confining units, >3’ recommended, if impermeable liner present >1’ recommended
Groundcover Area	Pervious surface.

Parameter	Consideration
Planting Soil	Pervious walks and bicycle paths must be placed over native upland soils or clean fill. For redevelopments, must be placed over rehabilitated soils.
Inlet and outlet control	Except for pervious walks and bike paths, curbing, edge constraint or other equivalent hydraulic barrier will be required to a minimum depth of 8 inches beneath the bottom of the pavement to prevent scouring from horizontal movement of water.
Plant Material	Native species. (see **Attachment D**)
Maintenance	Periodic vacuum sweeping is recommended annually and whenever the vertical hydraulic conductivity is less than 2.0 inches per hour or less than the permitted design percolation rate. Repair near edge constrains or overflows, and assure contributing area is stabilized and not a source of sediments.
Hydrologic Design	Determine by State or Local agency

4.2.9 Detention Ponds

Dry detention ponds detain a portion of urban runoff for a short period of time (24-hours after a storm) using a fixed opening to regulate outflow at a specified rate and allowing solids and associated pollutants time to settle out. Dry detention volume shall be provided equal to 75% of the amounts computed for wet detention. These systems in general are effective in removing total suspended solids but have low treatment efficiency for nutrients. They are normally dry between storm events. Sitting requirements call for a minimum of one foot from control elevation to the bottom of the detention zone. Therefore, constructing dry detention ponds on wetlands and floodplains should be avoided. Where drainage areas are greater than 250 acres and ponds are being considered, inundation of upstream channels may be of concern.

Wet detention ponds are designed to maintain a permanent pool of water and temporarily store urban runoff until it is released at a controlled rate. Hydraulic holding times are relatively short, such as hours or days. These systems are more efficient in removing soluble pollutants (nutrients) than dry detention due to the biological activity in the vegetation and water column. Enhanced designs include a forebay to trap incoming sediment where it can be easily removed. A littoral zone can also be established around the perimeter of the pond. SFWMD requires 20% Littoral Zone by area or 2.5% of the total basin area drainage to the pond, whichever is less.

For wet detention systems, the bleed-down volume is defined between the elevation of the overflow weir and control elevation and shall be the first one inch of runoff from the contributing area, or the total runoff of 2.5 inches' times the percentage of imperviousness, whichever is greater. The control elevation is the normal water level for the pond and it is established at the higher elevation of either the normal wet season tailwater elevation or the seasonal high groundwater table minus six inches. The maximum stage above the control elevation for providing bleed-down volume shall not exceed 18 inches unless alternative design is appropriate for the specific site conditions.

The permanent pool size shall be sized to provide a resident time that achieves the required nutrient removal efficiency. Resident time shall be based upon annual rainfall volumes. Maximum depth shall be no greater than 12 feet. The maximum allowable permanent pool depth as it relates to the aerobic zone is directly related to the anticipated algal productivity within the pond.

To ensure proper drainage, aerobic functioning and aeration, and regular vegetative health inspections are needed. Also, regular maintenance should be performed to remove sediment, trash and debris. Ideal locations of wet detention ponds include downstream of catchment and runoff, usually constructed at the lowest point of the site.

An example of a typical wet detention system cross section is shown in **Figure 4-10**.

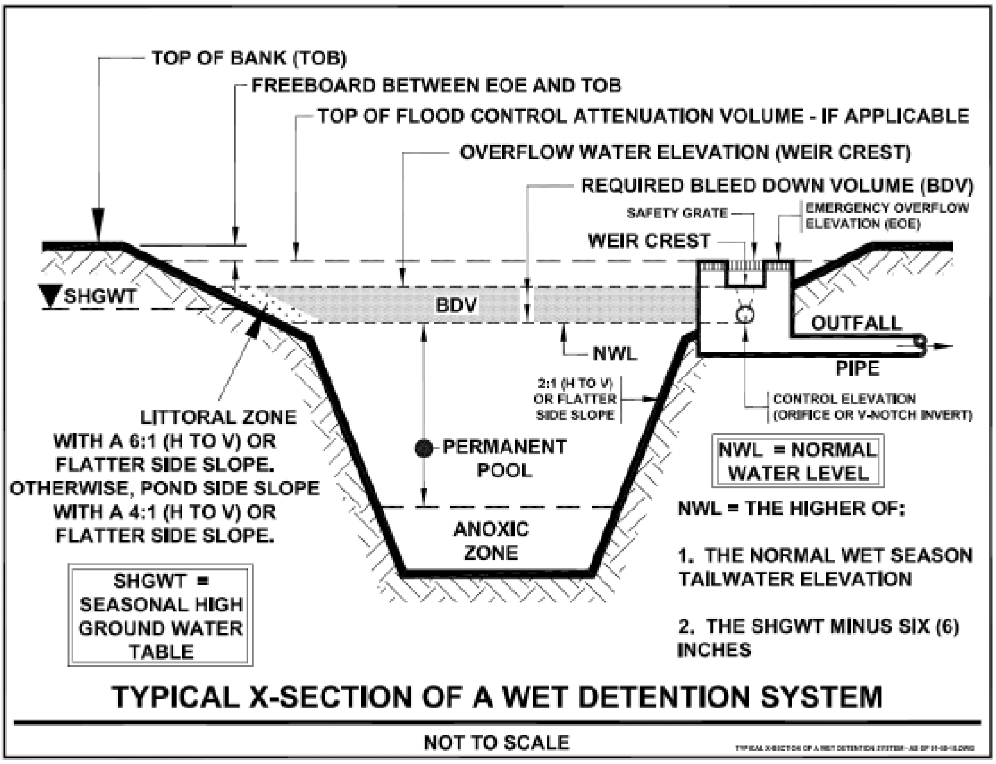


Figure 4-10 - Typical Cross-section of a Wet Detention System

A summary of design considerations for evaluating the suitability of implementing a wet detention system is summarized in **Table 4-9**.

Table 4-9 – Detention System Design Considerations

Parameter	Consideration
Treatment Area	Detention ponds are designed to slowly release a portion of the collected stormwater runoff through an outlet structure. Most significant component is the storage capacity of the permanent pool.

Parameter	Consideration
Pretreatment Area	Provide removal of both dissolved and suspended pollutants by taking advantage of physical, chemical, and biological processes. Can be implemented also as a part of a BMP treatment train.
Proximity to building Foundation	Distance to foundation >10', septic systems >20', public roadway >15', drinking water wells >100' is recommended
Soils	Can be used with almost all soil types. If soil permeability >2.5 in/hr, full treatment prior to the pond is recommended.
Topography	Pond slopes shall be restricted from public access or have slopes that are no steeper than 4:1. Deeper areas of the pond must maintain side slopes no steeper than 2:1.
Depth of Water Table	Moderate to high water table condition
Groundcover Area	Side slopes shall be stabilized by vegetation or other materials to minimize erosion and sedimentation of the pond.
Planting Soil	Managed Aquatic Plant Systems (MAPS) are aquatic plant-based BMPs. Littoral Zones shall be gently slopes (6:1) or flatter. 20% Littoral Zone by area or 2.5% of the total basin area drainage to the pond, whichever is less. Pond level shall be below 18 inches above control elevation to ensure vegetation can survive. Planting is recommended to meet 80% coverage requirement (MAPS) with no more than 10% consisting of exotic or nuisance species.
Inlet and outlet control	Outlet structure generally includes a drawdown device (orifice, "V" or square notch weir) set to establish a normal water control elevation and slowly release the bleed down volume.
Plant Material	Native species. (see **Attachment D**)
Maintenance	Ensure proper drainage, aerobic functioning and aeration. Vegetative regular inspections are needed to prevent erosion of side slopes and around inflow and outflow structures. Remove sediment, trash and debris. Inspect for potential mosquito breeding problems. Inspect littoral zone to assure invasive vegetation is not becoming established.
Hydrologic Design	Determine by State or Local agency

Design of wet detention ponds with various BMP features can improve their water quality benefits. Two BMPs that could add water quality benefit to wet retention ponds are floating wetlands and enhanced stormwater ponds. Details about the pond enhancements are explained below.

Floating Wetlands

Floating wetlands consist of aquatic plants attached to floating mats or other support material[19]. The biological processes related to the root systems of the plants utilize dissolved nutrients from the water, and thus work to remove dissolve nutrients in ponds. **Figure 4-11** shows an example of a floating wetland BMP implementation.

Figure 4-11 – Floating Wetland Mat[19]

Enhanced Stormwater Ponds

Enhanced stormwater ponds are wet ponds that are more elaborate than simple rectangular wet ponds with grassy slopes. Features of enhanced stormwater ponds enhance the abilities of the pond to have greater sedimentation and pollutant removal capabilities. Features such as shoreline vegetation, a spectrum of depths, and sedimentation forebays create treatment trains that have greater hydrologic benefits than standard treatment ponds. **Figure 4-12** shows a rendering of an enhanced stormwater pond.

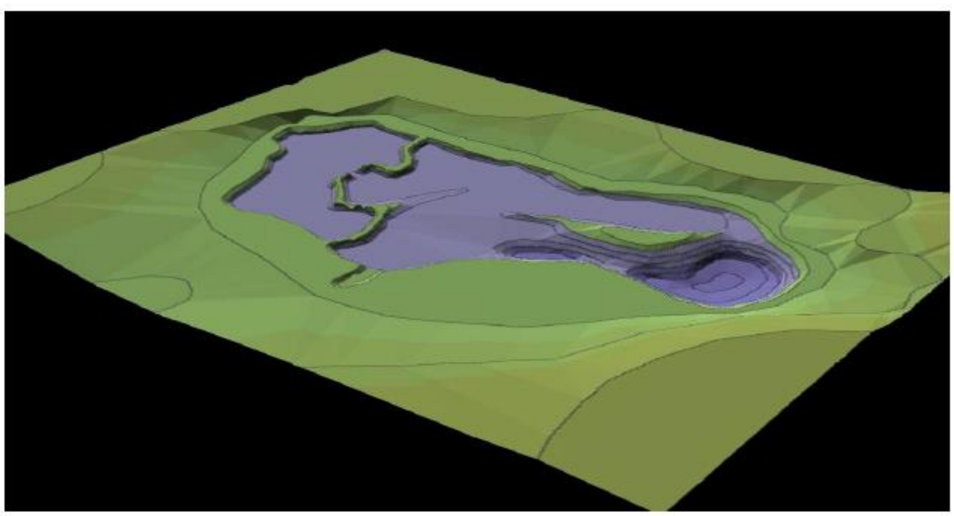


Figure 4-12 – Rendering of Enhanced Stormwater Pond[19]

4.2.10 Retention Ponds

Retention systems rely on absorption of runoff to treat urban runoff discharges. Water is percolated through soils, where filtration and biological action remove pollutants. Systems that rely on soil absorption require a deep layer of permeable soils at separation distances of at least 1 foot between the bottom of the structure and seasonal groundwater levels. Retention volumes shall provide equal to 50% of the above amounts computed for wet detention systems. Using retention systems in a watershed will help preserve or restore predevelopment hydrology, increase dry weather base flow, and reduce bank fill flooding frequency. Where groundwater requires protection, retention systems may not be appropriate.

Dry retention basins are depressed areas where incoming urban runoff is temporarily stored until it gradually filtrates into the surrounding soil. These would gradually drain down to maintain aerobic conditions that favor bacteria which aid in pollutant removal and to ensure the basin is ready to receive the next storm. Runoff entering the basin is sometimes pretreated to remove coarse sediment that may clog the surface soil pore on the basin floor. Concentrated runoff should flow through a sediment trap, or a vegetated filter strip may be used for sheet flow.

The required treatment volume to achieve the necessary efficiency shall be determined based on the percentage DCIA and the weighted curve number for non-DCIA areas. To avoid degradation of retention basin infiltration capacity specific construction practices should be implemented these include:

- Prevent unnecessary vehicular traffic to avoid soil compaction
- Excavation shall be done by lightweight equipment to minimize soil compaction
- Entire basin bottom must be deep raked and loosened for optimal infiltration once the basin has been excavated to final grade

Maintenance for regular trash and intermittent sediment removal should be performed, pollutants accumulate in soil and may require amendments and to be clean out. Ideal locations include downstream of catchment and runoff, and upstream from off-site stormwater management systems.

An example of a typical dry retention system cross section is shown in **Figure 4-13**.

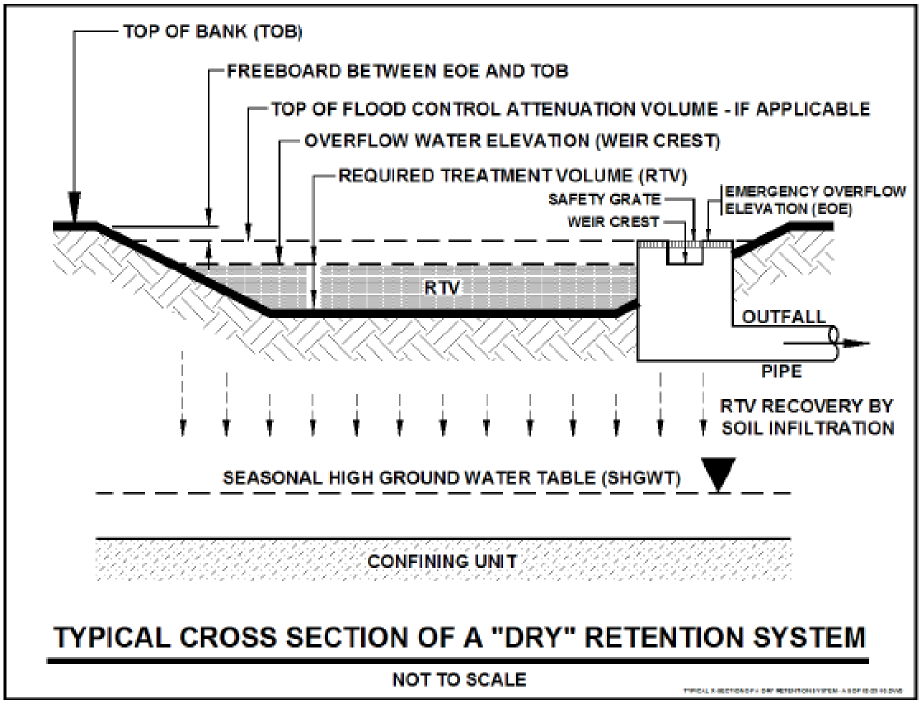


Figure 4-13 – Typical Cross-section of a Dry Retention System

A summary of design considerations for evaluating the suitability of implementing a dry retention system is summarized in **Table 4-10**.

Table 4-10 – Retention System Design Considerations

Parameter	Consideration
Treatment Area	Must have the capacity to retain required treatment volume without a discharge and without considering soil storage. Constructed or natural depression areas, typically flat with turf, natural ground cover or other appropriate vegetation to promote infiltration and stabilize basin slopes. Side slopes of 1:4 are recommended. Bottom slopes of 2% or zero are recommended to maximize infiltration.
Pretreatment Area	Stormwater pollutants such as suspended solilds, oxygen demanding materials, heavy metals, bacteria, some varieties of pesticides, and nutrients are removed as runoff percolates through the soil profile.
Proximity to building Foundation	Distance needs to be determined onsite prior to construction to prevent any adverse effects to building foundations, septic systems, or wells. Shall not be constructed within 50 feet of public or private potable water supply well.
Soils	Turf, natural ground cover or other appropriate vegetation.
Topography	Typically flat
Depth of Water Table	Seasonal high ground water table shall be at least 1 foot beneath the bottom of the retention basin.

Parameter	Consideration
	Unless alternative design is appropriate for the specific site condition.
Groundcover Area	Sides and bottom shall be stabilized with permanent vegetative cover, or pervious material to prevent erosion and sedimentation.
Planting Soil	Vegetation roots help maintain soil permeability. Grass needs to be mowed and grass clippings removed to reduce internal nutrient loadings.
Inlet and outlet control	Non-erosive velocities should be maintained to avoid resuspension of settled out solids.
Plant Material	Native species. (see **Attachment D**)
Maintenance	Remove accumulated sediments from retention basin bottom and inflow and outflow pipes. Remove trash and debris, trash racks and other components to prevent flooding and impeding flow. Maintain healthy vegetative cover to prevent erosion in the basin bottom, side slopes or around inflow and outflow structures.
Hydrologic Design	Determine by State or Local agency

Design of wet retention ponds with various BMP features can improve their water quality benefits. Two BMPs that could add water quality benefit to wet retention ponds are floating wetlands and enhanced stormwater ponds. Details about the pond enhancements are explained in **Section 4.2.9** above.

4.2.11 Parking Stormwater Chambers

Parking stormwater chambers are underground retention or detention systems. The stormwater chambers consist of underground pipes, vaults, or other water storage structure that captures stormwater runoff from an inlet or catch basin. The system is designed to retain stormwater runoff throughout the storm event or infiltrates the surrounding soil. In the case of non-perforated structures, after the storm event, the stormwater is released through an outlet structure that is designed to discharge at predevelopment rates. **Figure 4-14** shows an example configuration of a parking stormwater chamber.

Underground chambers are used for new developments in which land cost are high and/or there is limited land available for above-ground stormwater management infrastructure. The chamber system is contained within the site and ensures no net increase in post development peak runoff. However, the chambers do not provide any stormwater treatment, so additional water quality treatment practices are required. Chamber systems typically have a service life of 50 years depending on the construction material, but they are challenging to maintain and clean.

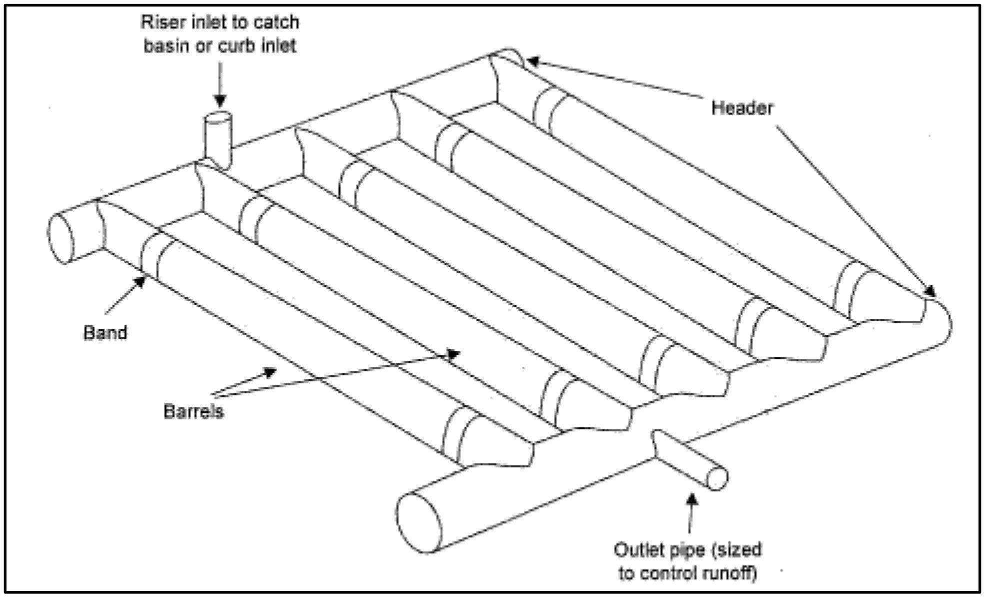


Figure 4-14- Example configuration of Parking Stormwater Chamber

A summary of design considerations for evaluating the suitability of implementing a dry retention system is summarized in **Table 4-10**. The size, shape, and characteristics of the site will determine the design of the system and if pipes or storage structures are utilized.

Table 4-11 – Parking Stormwater Chamber Design Considerations

Parameter	Consideration
Treatment Area	Urban areas with limited surface space available or high land costs.
Pretreatment Area	A separate form of pretreatment is required.
Proximity to building Foundation	Determined by material of system and access for maintenance and cleaning. Cannot be located under buildings.
Construction Material	Concrete is only used for rectangular vaults and pipes in continuous space without angles. HDPE and CMP pipes can have irregular and angled spaces, and requires minimum spacing between pipes, however they can corrode depending on soil conditions.
Soils	If system uses perforated pipes, the minimum soil hydraulic conductivity is $1x10^{-5}$ $cfs/ft^2/ft$. Soil condition must be tested to ensure CMP and HDPE pipes will not be corroded.
Depth and Area of Excavation	Depth of excavation must be deep enough to contain and provide stability for the system. Aluminum pipes require greater excavation depth than concrete pipes of the same diameter.
Fill Material	Concrete pipes do not require fill for stability, aluminum and HDPE pipes require more fill above for stability.
Depth of Water Table	Pipe invert should be at or above the water table whenever possible and is required if using HDPE pipes.
Inlet and outlet control	Control elevation determined by groundwater table, or lowest pipe inlet elevation. Weir or other control structure required.
Maintenance	Periodic monitoring. Accumulated trash and sediment must be cleaned out. Baffles are not required, but recommended to prevent clogging if using perforated pipe.
Hydrologic Design	Determine by State or local agency

5.0 LID HYDROLOGIC ANALYSIS

A hydrologic/hydraulic evaluation is used to determine the amount of surface water storage (retention) and/or infiltration (groundwater recharge) is needed for a particular development to control the peak runoff rate and overall volume of runoff generated during storm events. Conventional stormwater treatment require post-development peak runoff rates to be maintained at, or below, the pre-development rates for the 24- or 72-hour design storm event. This usually results in an overall larger volume of stormwater runoff being discharged for a longer duration. Consequently, a pre- versus post-development runoff volume approach, using an average annual rainfall event, is recommended for the evaluation and assessment of structural LID practices. This approach is particularly appropriate for the evaluation of structural LID BMPs because they are typically designed to control or retain smaller rainfall events, which constitute approximately 80% of the annual rainfall in South Florida.

5.1 Key Hydrologic Principles

The key hydrologic principles required for the analysis and design of low impact development sites and BMPs include:

- annual precipitation and design storm events,
- rainfall abstractions,
- surface runoff, and
- groundwater recharge.

Annual precipitation and design storm event data are used for site planning and stormwater design. The key parameters used are the total depth of rainfall, intensity of the event, and duration of the event. In Miami-Dade County, the 5-, 10-, 25- and 100-year return periods are the storm events used for development design.

Rainfall abstractions occur when rainfall is evaporated, transpired, infiltrated, or otherwise retained within a site, and does not contribute to surface runoff, or offsite discharge. Infiltration of stormwater through soil is typically the greatest source of rainfall abstraction. Most site developments create and/or increase the amount of impervious area, which decreases the amount of rainfall abstraction, and results in a more rapid accumulation of rain water on land surfaces and an increase of the offsite stormwater runoff.

Rainfall abstraction is quantified by the depth of water that does not contribute to a site's surface runoff. When natural areas are developed, the alteration of site runoff characteristics is likely to cause an increase in the volume, velocity, and frequency of runoff flows. These modified runoff flow conditions contribute to flooding, a reduction in the capacity of the City's drainage systems, accelerated erosion, and a reduction in groundwater recharge. According to the *Low-Impact Development Hydrologic Analysis* from Prince George County, MD in 1999, rainfall accounts for 10 to 30 percent of the total annual rainfall volume of a natural, undeveloped site. Depending on the level of development and the site planning methods used, development of the site can increase the surface runoff from the site to over 50 percent of the annual runoff volume. **Figure 5-1** shows the runoff variability with increased impervious surfaces.

Groundwater recharge is the percolation of surface runoff into the groundwater. A significant reduction or loss of groundwater recharge leads to the lowering of the groundwater water table and a reduction of the base flow within streams, canals, and well-fields. Lowering of the groundwater table greatly increases the likelihood of salt water intrusion and promotes the migration of contaminants.

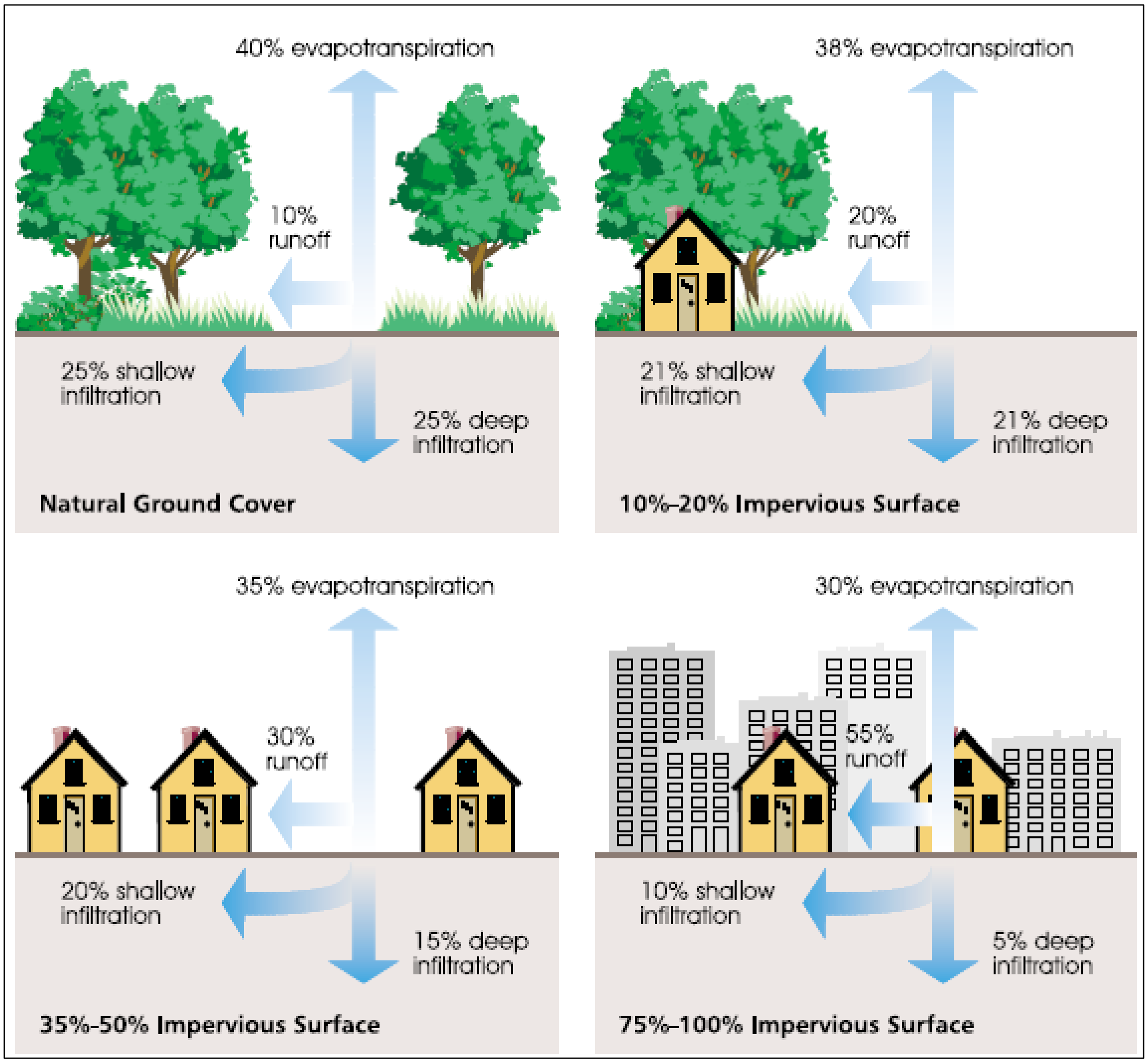


Figure 5-1 – Surface Runoff Variability with Increased Impervious Surfaces

LID techniques emulate the pre-development retention and infiltration functions of the development site through runoff volume control, peak runoff rate control, and water quality control. Implementation of LID practices preserve or increase rainfall abstraction volumes through maintenance of the site's infiltration, evaporation, transpiration, and storage potentials. In addition, LID practices aim to lengthen the travel time of surface runoff, which reduces the rapid concentration of surface runoff and lessens the load on the City's drainage system.

5.2 Hydrologic Evaluation

Hydrologic evaluation of a development site predicts the volume and flow rate of surface water generated during different storm events based on the developments topography, geology, and amount of impervious area. Appropriate LID techniques are then selected to attenuate any additional surface water generated as a result of modifying the existing site. Stormwater management systems that utilize LID technologies may have a centralized stormwater management system to assist in peak release rate control. The additional source control is provided by LID BMPs dispersed throughout the development area to control the amount of runoff volume. LID techniques aim to control the smaller and more frequent rainfall events, which are usually less than a 2-year return period, but generate most of the runoff in urban watersheds such as that found in the City of Doral.

The primary structural LID BMPs and practices that are most applicable to the City, include the following:

- Bioretention Basins or Rain Gardens
- Tree Box Filters or Infiltration Planters
- Vegetated Swales
- Filter Strips or Vegetated Buffers
- Infiltration Trench
- Exfiltration Trench or French Drains
- Green Roofs/Rain Barrels or Cisterns
- Permeable Pavement
- Detention Ponds
- Parking Chambers

When designing these LID systems, greater attention to runoff abstraction potentials has to be considered than when designing conventional systems. Abstraction potential is defined as the ability of the landscape to retain runoff with minor surface storage, such as puddles, evapotranspiration from vegetation, and groundwater recharge. Antecedent soil moisture conditions prior to a storm event also require greater attention when designing for smaller, more frequent storm events. As set forth in *The Stormwater Quality Applicant's Handbook, Section 3.1. Florida Department of Environmental Protection, March 2010 Draft,* a stormwater treatment system shall be designed to meet the minimum level of water quality treatment for nutrients and shall follow the design criteria for BMPs.

For future development and redevelopment projects within the City, it is recommended that adequate LID BMPs are also implemented to maintain the pre-development runoff volume at or below the post-development runoff. It is also recommended that the National Resources Conservation Services (NRCS) Urban Hydrology for Small Watersheds Technical Release 55 Methodologies (TR 55); SFWMD Environmental Resource Permit Applicant's Handbook Volume II (SFWMD Volume II); Standard Test Method for

Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer (ASTM D3385); Exfiltration Trench Reference Manual (ETRM) and ICPR Applications Manual (ICPR-AM) developed by the Florida Department of Transportation (FDOT) District 6; and procedures implemented by DRER are used to estimate the pre- and post-development runoff volumes. The recommended approach focuses on the following design parameters and hydrologic analysis:

- **Runoff Curve Number (CN)** is an empirical parameter established by NRCS and used in hydrology for predicting direct runoff or infiltration from excess rainfall. In Section 2-1 of TR 55, the approach to determine the CN is based on the surface-to-groundwater depth relationship. The CN is computed from sites soil storage using equation:

Equation 1 – Curve Number

$$CN = \frac{1000}{(S + 10)}$$

Where, CN = Curve Number and S = Soil Storage (inches)

Soil storage in the region of the City of Doral is determined by the depth of unsaturated soil above the seasonal high groundwater elevation. The relationship between the depth to groundwater and available soil storage is provided in **Table 5-1**, from Section 5.7.4.2 of SFWMD Volume II. The table also provides soil storage values that have been adjusted to account for a 25% loss of soil storage due to the typical compaction of soils during construction.

Table 5-1 – Soil Storage (S) Relative to Depth to Groundwater (SFWMD Volume II)

Depth to Groundwater (feet)	Available Soil Storage (inches)	Available Compacted Soil Storage (inches)
1	0.6	0.45
2	2.5	1.88
3	6.6	4.95
4 or greater	10.9	8.18

- **Time of Concentration (Tc)** is the time it takes runoff to travel from the hydraulically most distant point of the site to an outlet or other point of interest within the watershed. Chapter 3 of TR 55 provides the established approach to calculate Tc.

- **Rainfall and Surface Runoff**. Rainfall is the depth of water delivered during a selected storm event. Rainfall depth is determined by measured data, an established design storm event of a given return frequency and duration, or an established average annual rainfall event. The surface runoff from a development site is the fraction of rainfall remaining after hydrologic abstractions. The approach for establishing surface runoff in the City of Doral is described in **Section 8.0.** The approach assumes the use of the average annual rainfall event established using the rain gauge data from the Miami Field Station shown in **Figure 8-1** and **Attachment F.**

- **Infiltration** is the downward, vertical percolation of rainfall into soil. The site in-situ infiltration rate in inches per hour per foot of head is determined by performing a Double-ring test in accordance with ASTM D3385.

- **Exfiltration** is the lateral or horizontal withdraw of rainfall through a French drain or gravel trench. Exfiltration rates and capacity are established by methodologies described in the ETRM and ICPR-AM.

- **Evapotranspiration** is the sum of evaporation and plant transpiration from the site to the atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, vegetation, and waterbodies. Transpiration accounts for the movement of water within a plant and the loss of water as vapor through stomata of the plant leaves. Use **Equation 20** from **Section 7.11** to estimate the annual evapotranspiration volume. The equation was used by the University of Florida Cooperative Extension Service Institute of Food and Agricultural Sciences,

- **Irrigation** is the artificial application of water to the land or soil. The majority of irrigation water within Doral is used for agriculture, maintenance of landscapes, and revegetation of disturbed soils. Irrigation water demand is the highest in dry areas and during periods of inadequate rainfall. An equation, used by the University of Florida Cooperative Extension Service Institute of Food and Agricultural Sciences, for estimating annual irrigation volume is provided in **Section 7.11**.

5.3 Additional BMP Analysis Methodologies

LID BMP benefits and functions are not limited to their flow volume and flow peak reduction capabilities. LID BMPs can also provide benefits of heat island reduction, vegetated shade areas, habitat for wildlife, enhanced aesthetics in the community, and reduced impact on infrastructure. LID BMPs perform functions related to volume and peak flow reduction, but also may perform functions of water treatment and groundwater recharge.

Table 5-2 describes the functions and benefits of each of the BMPs described in the previous LID BMP sections. By considering these BMP functions and benefits in the analysis of LID BMP implementation, it will encourage implementation of a greater variety of BMPs that serve a greater variety purposes than simple volume and peak flow reductions.

Table 5-2 – BMP Functions and Benefits Matrix

Best Management Practice (BMP)	Functions[18]						Benefits[18]				
	Flow Control	Detention	Retention	Filtration	Infiltration	Treatment	Heat Island Mitigation	Shade	Habitat	Aesthetics	Reduced Impact on Infrastructure
Wet Detention Pond with Aquatic Vegetation	x	x	x	x	x	x	x	x	x	x	x
Wet Retention Pond with Aquatic Vegetation	x		x	x	x	x	x	x	x	x	x
Bioretention Basin / Rain Garden	x		x	x	x	x	x	x	x	x	x
Tree Box Filters / Infiltration Planter	x		x	x	x	x	x	x	x	x	x
Vegetated Swale	x	x		x	x	x	x	x	x	x	x
Green Roof	x	x		x	x	x	x	x	x	x	x
Detention Pond	x	x		x	x		x	x	x	x	x
Retention Pond	x		x	x	x		x	x	x	x	x
Filter Strip / Vegetated Buffer	x	x		x	x		x	x	x	x	x
Infiltration Trench	x	x	x	x	x						x
Exfiltration Trench / French Drain	x	x	x	x	x						x
Permeable Pavement - Permeable Pavers				x	x		x			x	x
Permeable Pavement - Stabilized Aggregate				x	x		x				x
Permeable Pavement - Porous Asphalt				x	x		x				x
Permeable Pavement - Porous Concrete				x	x		x				x
Permeable Pavement - Structural Grids				x	x		x				x
Stormwater Chamber	x	x	x								x
Rain Barrels / Cisterns	x	x	x								x

[18]Functions and benefits of BMPs based on City of Mesa, AZ LID Toolkit

6.0 LID DESIGN CRITERIA

6.1 Bioretention Basins or Rain Gardens

Bioretention facilities should be located close to the source of runoff. Bioretention areas can be incorporated into either new or retrofit sites based on the site-grading plan. They are not recommended in areas where slopes adjacent to the facility exceeds 20% due to the risk of erosion and should not be constructed in locations where removal of native trees is required. **Figure 6-1** shows a typical cross section of a Bioretention. Typical locations are near parking lots, in traffic islands and near building roof leaders as shown in **Figure 6-2.**

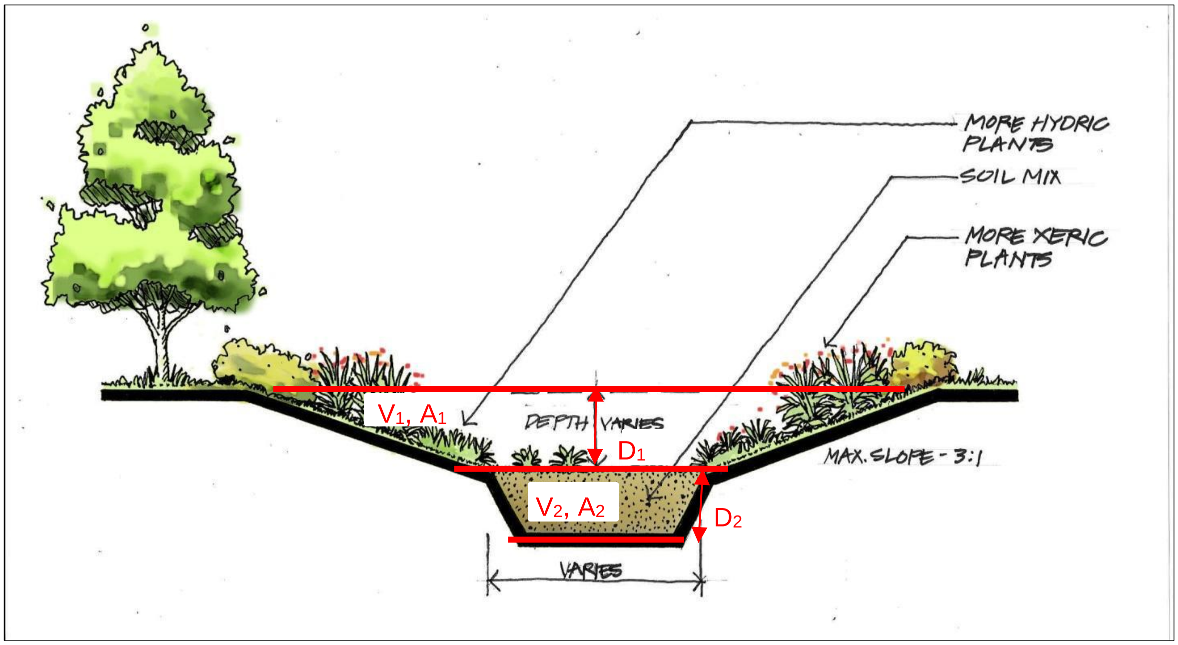


Figure 6-1 – Bioretention Basins Cross Section

Figure 6-2 – Rain Garden at Doral Starbucks

6.1.1 Design Criteria

a) Suitable for individual lots in subdivisions or common areas, other landscaped areas, and some retrofit projects.
b) Soil conditions: Where infiltration rates are below 0.1 inches per hour, bioretention must be designed with underdrains or soil augmentation to improve function.
c) Topography: Bioretention BMPs may be difficult in areas where slopes are 10% or greater. Detailed engineering and geotechnical analysis must be completed prior to site clearing and implementation.
d) Depth of Water Table: Bioretention is not suitable if there is less than one foot of separation between the seasonal high water table and the bottom of the bioretention area, unless an alternative design can be shown to be appropriate for the specific site.

6.1.2 Inspection, Operation and Maintenance Requirements

Bioretention areas must be inspected periodically to ensure they are functioning as intended and ensure that stormwater is infiltrating within 72 hours of a storm event. The inspection should include checking for any erosion and if erosion is observed, repair as necessary. Invasive plants must be removed. The health of desirable plants should be checked; and if not healthy, they must be replaced. Excess plant growth should be trimmed or thinned, and any decaying plant material removed. Mulch should be replaced annually, and accumulated trash and sediment must be cleaned out. Removing built up sediment and debris should be the priority, as neglect may impair the long term effectiveness of the bioretention area.

The soil's infiltration capacity should be inspected after a rain event to determine whether the treatment volume is being recovered as designed. Routine maintenance may seem like an unnecessary expense, but long term neglect tends to cause larger structural problems that are much more expensive to repair. The maintenance costs over the life-time of a retention pond is generally more significant than its initial construction cost; therefore, maintenance must be included in the planning. A legally binding provision to fund life-time maintenance, or adequate funds in a separate account to cover expected maintenance may be required as part of initial construction budget.

6.2 Tree Box Filters or Infiltration Planters

Tree box filters or infiltration planters are similar to bioretention systems as they use vegetation and amended soils to filter and retain stormwater. Runoff from surrounding impervious surfaces is directed into box planters to provide source control treatment, allow for a small amount of retention within the growing media, and depending on subsoil types, facilitate deep infiltration. If infiltration is not an option, a perforated under-drain placed near the bottom of the box planter will convey excess water to the storm drainage system or reservoir for reuse purposes. **Figure 6-3** shows a typical cross section of an infiltration planter. Tree box and infiltration planters are often designed for highly urbanized areas and can be retrofitted in existing developments. Examples of a typical infiltration planter and a tree box filter that were retrofitted are shown in **Figure 6-4.**

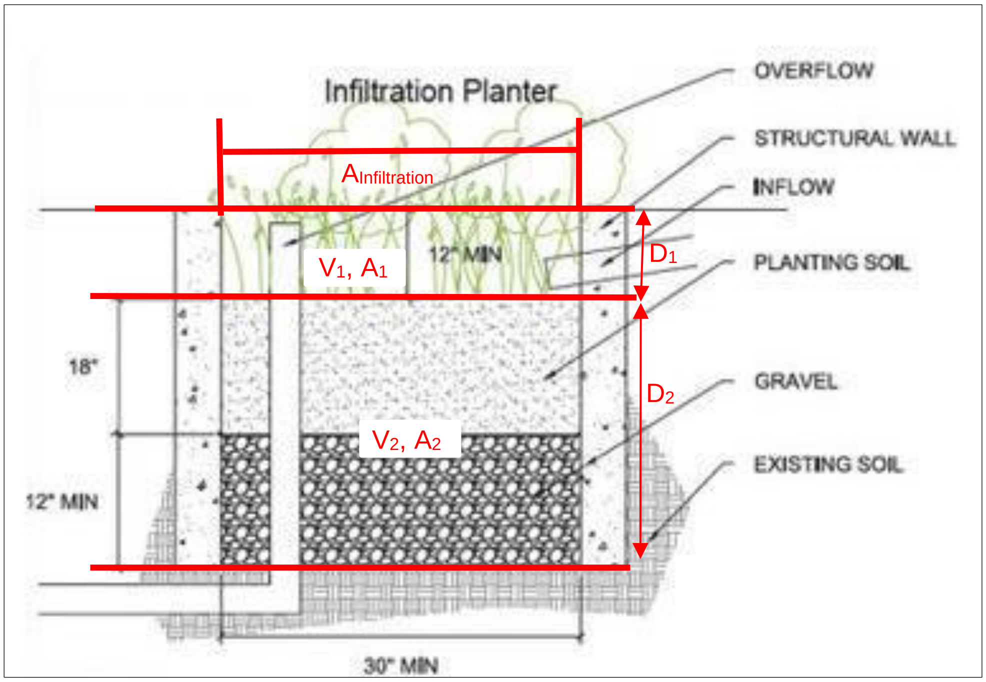


Figure 6-3 – Infiltration Planter Cross Section

Figure 6-4 – Infiltration Planter and Tree Box

6.2.1 Design Criteria

If trees are to be planted, the volume of soil provided must be considered carefully. It must be adequate for root development or the tree will not grow to a full size, and its health may be impacted. At maturity, tree roots often extend more than twice as far as the tree's canopy. In urban settings, that ideal volume is usually not available, but the reduction in volume of soil will directly impact the potential size of the tree. For example, a tree box containing 120 cubic ft of soil (typically a 4' x 10' x 3' tree box) can allow the tree canopy to spread to a 10 ft diameter before the tree growth begins to decline. The same tree planted in a box containing 500 cubic ft of soil could be expected to grow to a diameter of more than 20 ft.

Void spaces in the soil are necessary for the tree to obtain both water and air, so it is important that the surrounding soil is not compacted. A design reference for tree boxes can be found at: http://www.LID-stormwater.net/treeboxfilter_home.htm

Key design considerations include:

- Stormwater can enter tree boxes or infiltration planters through grating if the surrounding pavement is graded toward them.
- Curb cuts may be used as entry points for runoff to enter the tree box or infiltration planter.
- Infiltration beds should a minimum of 10 feet from building foundations, but each site must be considered individually. If they are located near buildings or roadways, waterproof liners may be needed to protect building foundations or street subgrade. Plastic sheeting, geo-membrane liners, or concrete walls are also possible options.
- The composition of soil both in and under the box/planter, must be evaluated, and usually amended with organic matter to improve moisture retention and microbial action. Other soil amendments may be required based on the soil type being used.
- Avoid soil compaction.
- Mulch or gravel must be placed on top of the soil, 4 inches of pine bark mulch or 2 inches of pea gravel.
- If trash, or sediment, is likely to be accumulated in the tree box or infiltration planter, a catch basin, grate, or other type of screening chamber is recommended to be installed for pretreatment before runoff enters the box.
- Provisions for overflow or diversion of high flows must be included in the design.

6.2.2 Inspection, Operation and Maintenance Requirements

If commercially manufactured boxes/planters are used, the first two years of maintenance are often included in the purchase price. After establishment, the trees or other plants should only need inspected for maintaining the health of the plants, removing any dead plant material, and pruning. The addition of mulch should be completed on a semi-annual basis. More frequent trash or debris removal may be required depending on the location.

6.3 Vegetated Swales

Swales have been used for conveyance of stormwater along roads for decades. However, swales can also be used for stormwater treatment, especially as part of a BMP treatment train, when properly designed and maintained to provide retention and infiltration of stormwater.

Swales are defined in Florida Statutes, Chapter 403.803(14) as “a manmade trench which:

1. Has a top width to depth ratio of the cross-section equal to or greater than 6:1, or side slopes equal to or flatter than 3 feet horizontal to 1 -foot vertical;

2. Contains contiguous areas of standing or flowing water only following a rainfall event;
3. Is planted with or has stabilized vegetation suitable for soil stabilization, stormwater treatment, and nutrient uptake (refer to **Attachment D** for Florida Friendly Landscapes); and
4. Is designed to take into account the soil erodibility, soil percolation, slope, slope length, and drainage area so as to prevent erosion and reduce pollutant concentration of any discharge."

Swales are inline retention systems and their treatment effectiveness is directly related to the amount of the annual stormwater volume that is infiltrated. Swales designed for stormwater treatment can be classified into two categories:

1. Swales with swale blocks or raised driveway culverts
2. Swales without swale blocks or raised driveway culverts

An example of vegetated swales in the City of Doral can be seen in **Figure 6-5**.

Figure 6-5 – Collection Suites Doral Vegetated Swale Example

6.3.1 Swales with Swale Blocks or Raised Driveway Culverts (Linear Retention Systems)

A swale with swale blocks or raised driveway culverts is essentially a linear retention system in which the treatment volume is retained and allowed to percolate. The treatment volume necessary to achieve the required treatment efficiency shall be routed to the swale and percolated into the ground before discharge. This type of swale system is recommended when multiple inflows occur to a swale.

6.3.2 Swales without Swale Blocks or Raised Driveway Culverts (Conveyance Swales)

Conveyance swales are designed and constructed to required dimensions to properly convey and infiltrate stormwater runoff as it travels through the swale. These swales are designed to infiltrate a defined quantity of runoff (the treatment volume) through the permeable soils of the swale floor and side slopes into the shallow ground water aquifer immediately following a storm event. **Figure 6-6** shows a typical cross-section of a Conveyance Swale without swale blocks.

Turf or other acceptable vegetation is established to prevent erosion, promote infiltration and stabilize the bottom and side slopes. Soil permeability and water table conditions must be such that the swale can percolate the required runoff volume. Conveyance swales may be part of a BMP treatment train providing pre-treatment of runoff before its release into another BMP depending upon the site conditions, the location of inflows, and the land use plan. **Figure 6-7** shows a typical vegetated swale that is used for a residential and parking lot area.

The swale holds water only during and immediately after a storm event, thus the system is normally “dry.” These types of swales are “open” conveyance systems. This means there are no physical barriers such as swale blocks or raised driveway culverts to impound the runoff in the swale prior to discharging = to the receiving water. In these types of swales, the inflow of stormwater occurs at the “top” of the swale system and the retention volume and associated stormwater treatment credit is based on the infiltration that occurs as the stormwater moves down the swale.

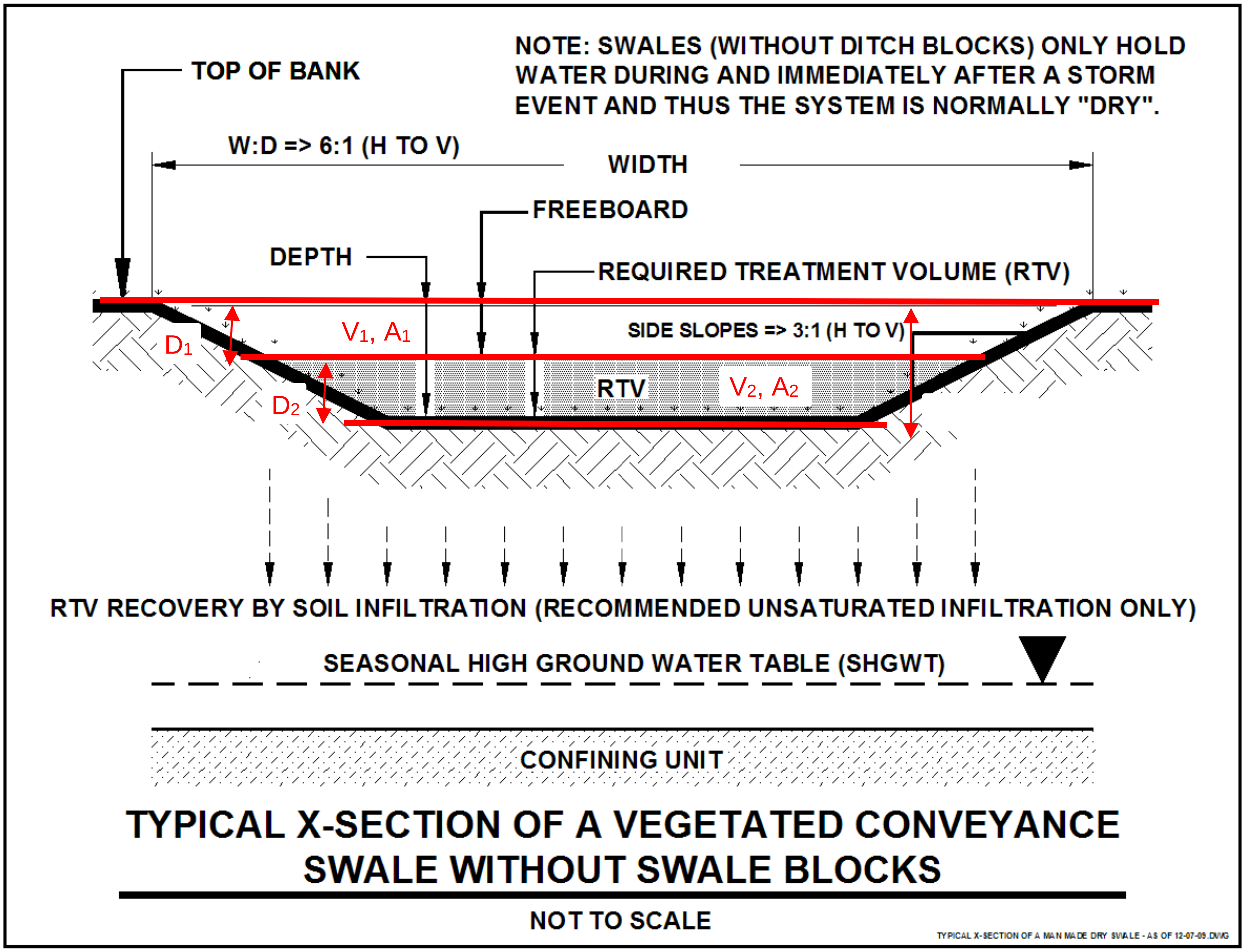


Figure 6-6 – Typical Cross-Section of a Vegetated Conveyance Swale

Figure 6-7 – Vegetated Swale in a Residential Area and a Parking Lot

6.3.3 Design Criteria

a) The seasonal high ground water table shall be at least one foot below the bottom of the swale unless the applicant demonstrates based on plans, test results, calculations or other information that an alternative design is appropriate for the specific site conditions.
b) The minimum infiltration rate through the vegetation and soil shall be at least one inch per hour.
c) The lateral slope across the bottom of the swale shall be flat to ensure even sheet flow and prevent channelized flow and erosion.
d) Longitudinal slopes shall not be so steep as to cause erosive flow velocities.
e) It is recommended that the bottom of the swale be at least two feet wide to facilitate mowing.
f) Off-street parking or other activities that can cause rutting or soil compaction is prohibited.
g) Swales shall not be constructed within 50 feet of a public or private potable water supply well.

6.3.4 Inspection, Operation and Maintenance Requirements

Typically, swales lose infiltration capacity due to clogging of the porous soils which slows recovery of the stormwater treatment volume and often results in standing water within the swale. Clogging can result from sedimentation and result in sealing of the bottom or side slope soils. It can also occur from excessive loading of oils and greases or from excessive algal or microorganism growth.

To determine if a swale is properly functioning or if maintenance is required, the swale shall be inspected shortly after a storm event. The inspection should determine if the swale is recovering its storage volume within its permitted time frames, generally 24 to 72 hours after a storm. If this is not occurring and resulting in standing water, then the cause of must be determined and appropriate actions undertaken beginning with those specified in the system's Operation and Maintenance Plan.

a) Inspection items:

   - Inspect swale for storage volume recovery within the permitted time, generally less than 72 hours. Failure to percolate the required treatment volumes indicates reduction of the infiltration rate and a need to restore system permeability
   - Inspect and monitor sediment accumulation on the bottom of the swale or at inflows to prevent clogging of the swale or the inflow pipes.
   - Inspect vegetation of bottom and side slopes to ensure it is healthy, maintaining coverage, and that no erosion is occurring within the swale.
   - Inspect the swale for potential mosquito breeding areas such as where standing water occurs after 72 hours or where cattails or other invasive vegetation becomes established.

- Inspect swale to determine if filling, excavation, construction of fences, or other objects are obstructing the surface water flow in the swales.
- Inspect the swale to determine if it has been damaged, whether by natural or human activities.

a) Maintenance activities to prolong service life:

- If needed, restore infiltration capability of the swale to ensure it meets permitted requirements.
- Remove accumulated sediment from swale and inflow or outflows and dispose of properly. Please note that stormwater sediment disposal may be regulated under Chapter 62-701, F.A.C. Sediment removal should be done when the swale is dry and when the sediments are cracking.
- Remove trash and debris, especially from inflow or outflow structures, to prevent clogging or impeding flow.
- Maintain healthy vegetative cover to prevent erosion of the swale bottom or side slopes. Mow grass as needed and remove grass clippings to reduce nutrient loadings.
- Eliminate mosquito breeding habitats.
- Remove fences or other obstructions that may have been built in the swale system.
- Repair any damages to the swale system so that it meets permitted requirements.

6.4 Filter Strips or Vegetated Buffers

Vegetated Buffer strips are sloping planted areas designed to allow stormwater to naturally infiltrate sheet flow from adjacent impervious areas. These are well-suited to addressing runoff from roads and highways, roof downspouts, and parking lots. Other advantages are they require minimal maintenance, establish habitat for birds and other pollinators, and are aesthetically pleasing. A schematic of a typical Vegetated Buffer and its contributing area is presented in **Figure 6-8.** Shown in **Figure 6-9** are typical vegetated buffers for a residential and roadside area.

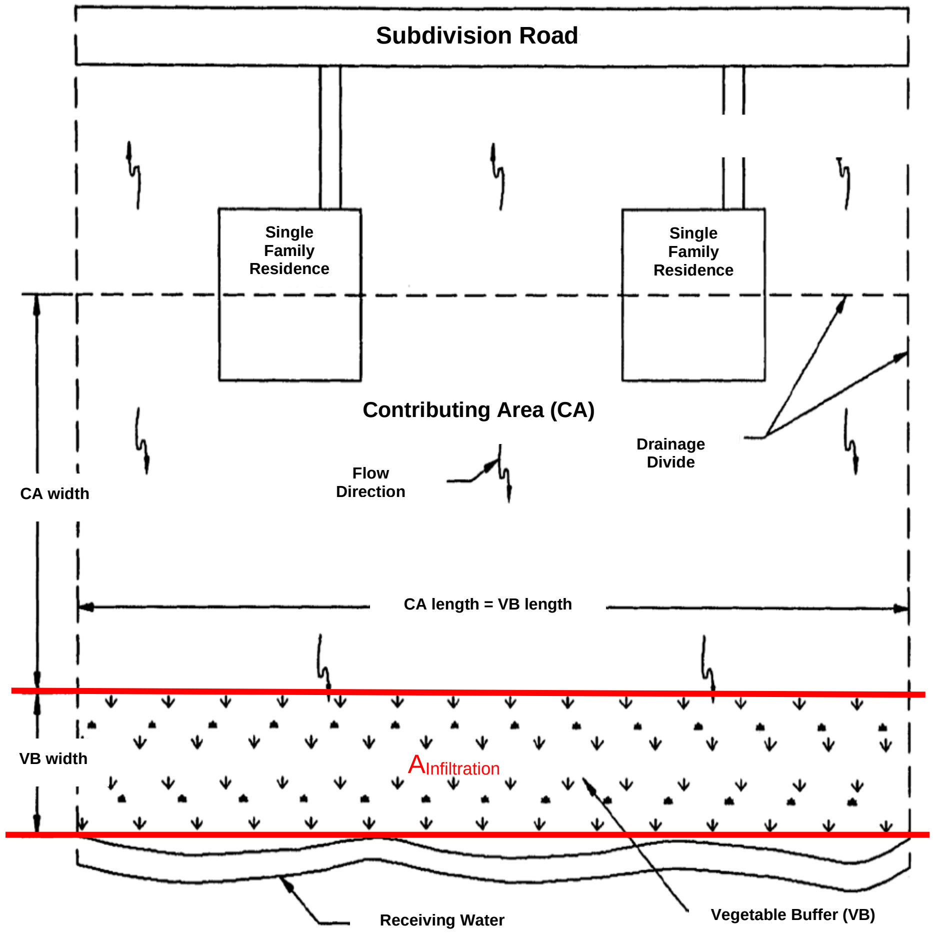


Figure 6-8 – Plan View Schematic of a Typical Vegetated Buffers

Figure 6-9 – Vegetated Buffer Strip

6.4.1 Design Criteria

a) The contributing area is defined as the area that drains to the vegetated buffer, such as roads and highways, roof downspouts, and parking lots
b) The seasonal high ground water table shall be at least one foot below the bottom of the vegetated buffer unless the applicant demonstrates based on plans, test results, calculations or other information that an alternative design is appropriate for the specific site conditions.
c) The minimum infiltration rate through the vegetation and soil shall be at least one inch per hour.
d) The minimum buffer width (dimension parallel to flow direction) shall be 25 feet to provide adequate area for infiltration and the maximum vegetated buffer width shall be 100 feet to ensure sheet flow conditions and the integrity of the treatment system. Factors affecting the minimum width (measured parallel to the direction of runoff flow) of vegetated buffer include infiltration rate, ground slope, rainfall, cover and soil characteristics, depth to water table and overland flow length. Infiltration is the primary means of treatment in vegetated buffers.
e) The maximum slope of vegetated buffer shall not be greater than 6:1.
f) The length of the buffer (measured perpendicular to the runoff flow direction) must be at least as long as the length of the contributing runoff area (see **Figure 6-8**).
g) Runoff from the adjacent contributing area must be evenly distributed across the buffer strip to promote overland sheet flow. If the flow regime changes from overland to shallow concentrated flow, the buffer is effectively “short-circuited” and will not perform as designed.
h) The Property Association Documents and Conditions Covenants and Restrictions (CC&R’s) will require that the contributing area must be stabilized with permanent vegetative cover that is consistent with the Florida Friendly Landscaping program (see Attachment B) and which is fertilized only with Florida-friendly fertilizers.
i) A legal reservation, in the form of an easement or other limitation of use, must be recorded which provides preservation of entire area of the vegetated buffer. The reservation must also include access for maintenance of the vegetated buffer unless the operation and maintenance entity wholly owns or retains ownership of the property.
j) The vegetated buffer area will be an existing undeveloped area which contains existing or planted vegetation suitable for infiltrating stormwater and soil stabilization. The existing vegetation must not be disturbed during or after the construction of the project. If the vegetated buffer will be planted, the proposed list of Florida-friendly plants must be submitted to the City for review. Maintenance shall ensure that the vegetated buffer contains less than 10 percent coverage by exotic or nuisance plant species.
k) Erosion control measures must be used during development of the contributing area so as to prevent erosion or sedimentation of the vegetated buffer.
l) Vegetated buffers shall not be constructed within 50 feet of a public or private potable water supply well.
m) The vegetated buffer and any required wetland buffer can be the same area provided that the functions and regulatory requirements for each are met.

6.4.2 Inspection, Operation and Maintenance

Maintenance of vegetated buffers are related to integrity of the vegetated buffer and damage to the natural or planted vegetation or the infiltration capabilities within the vegetated buffer. To determine if the vegetated buffer is properly functioning or whether it needs maintenance requires that an inspection be done during and soon after a storm. The inspection should determine if the vegetated buffer is providing sheet flow and infiltration of the required treatment volume within its permitted time frames, generally 24 to 72 hours after a storm. If this is not occurring, then the cause of must be determined and appropriate actions undertaken beginning with those specified in the system's Operation and Maintenance Plan.

Vegetated buffers must be inspected annually by the operation and maintenance entity to determine if there has been any encroachment or violation of the terms and condition of the vegetated buffer as described below. Reports documenting the results of annual inspections shall be filed with the City every year, or upon discovery of any encroachment or violation of design parameters, whichever occurs first.

a) Inspection items include:

- Inspect vegetated buffer for storage volume recovery within the permitted time, generally less than 72 hours. Failure to percolate the required treatment volumes indicates reduction of the infiltration rate and a need to restore system permeability.
- Inspect vegetated buffer to ensure that inflow is via sheet flow, for areas of channelized flow through or around the buffer, and for areas with erosion or sediment accumulation indicating channelized flow or that stabilization of the adjacent contributing area is needed.
- Inspect vegetated buffer for damage by foot or vehicular traffic or encroachment by adjacent property owners.
- Inspect vegetated buffer for the health and density of vegetation, and for the occurrence of exotic or nuisance plant species.

b) Maintenance activities to prolong service life:

- If needed, restore infiltration capability of the vegetated buffer to ensure it meets permitted requirements.
- Repair any areas where channelized flow is occurring and restore sheet flow.
- Repair any areas with erosion and carefully remove accumulated sediments if needed to ensure the health and functioning of the vegetated buffer
- Stabilize eroding parts of the adjacent contributing area as needed to prevent erosion and sedimentation.

- Repair any damage to the vegetated buffer by foot or vehicular traffic and remove any fences or other materials that have been placed in the vegetated buffer by adjacent property owners.
- Maintain the vegetated buffer vegetation and, if necessary, replant the vegetated buffer with approved Florida-friendly vegetation as needed to ensure sheet flow and prevent erosion and sedimentation. Maintenance of exotic or nuisance species within the vegetated buffer is not required but their removal is recommended.
- All repairs to the vegetated buffer must be made as soon as practical in order to prevent additional damage to the buffer. Repaired areas must be re-established with approved Florida-friendly or native vegetation.

6.5 Infiltration Trench

An infiltration trench is a rectangular excavation lined with a geotextile filter fabric and filled with coarse stone aggregate. These trenches serve as underground infiltration reservoirs. Storm water runoff directed to these trenches infiltrates into the surrounding soils from the bottom and sides of the trench.

Infiltration trenches can be used to intercept stormwater from landscape or open space before it crosses onto paved areas or can be used as part of a treatment train with other BMPs (such as Vegetated Buffer Strips or Vegetated Swales). **Figure 6-10** shows a typical cross-section of an Infiltration Trench. In order for infiltration trenches to be effective, they must be located in areas where the local soil is appropriate for infiltration and they must be designed accordingly. **Figure 6-11** shows a typical example of infiltration trench applications.

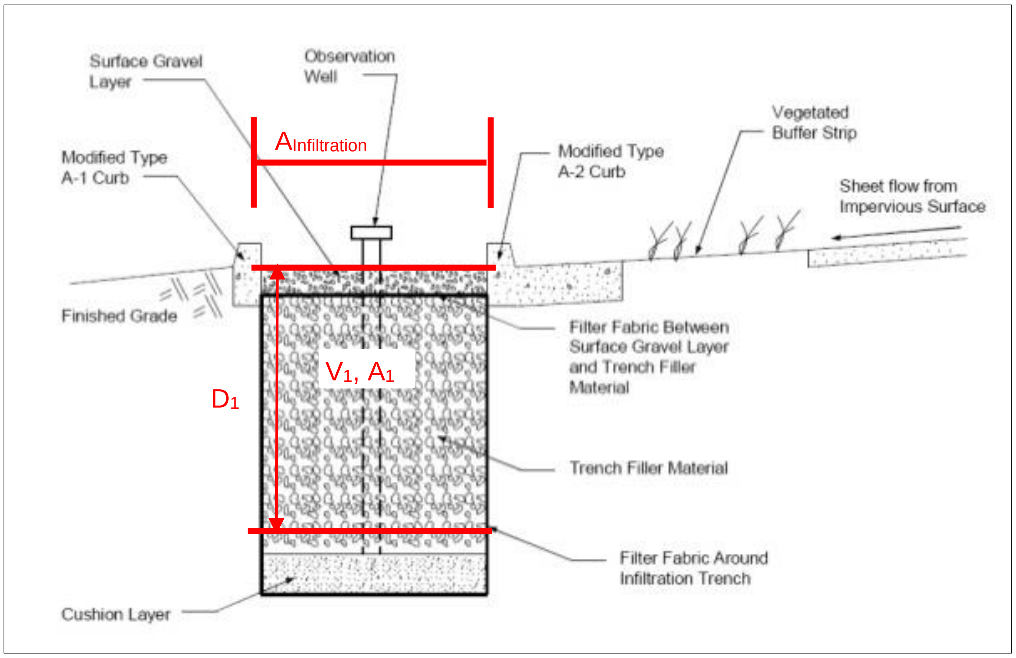


Figure 6-10 – Infiltration Trench Conceptual Drawing

Figure 6-11 – Infiltration Trench

6.5.1 Design Criteria

a) Soil must have sufficient permeability to accept water from exfiltration tanks.
b) The depth to the seasonal high ground water table must be at least one foot.
c) Modular systems wrapped in a geo-textile fabric are available, and adapt to a range of dimensions.
d) The cost of materials is greater than an equivalent surface infiltration BMP, but can be cost effective in areas with high costs for land. The cost of an equivalent reduction in size for other stormwater management facilities should be included in a comparison.
e) An underdrain (infiltration pipe) can be used as a back-up to withdraw water if the system becomes clogged.

6.5.2 Inspection, Operation and Maintenance

The most important maintenance requirement is to prevent sediment from washing onto and clogging the media and surrounding gravel or sand. The design should include some type of observation well to monitor the rate of exfiltration from the tank.

6.6 Exfiltration Trenches or French Drains

An exfiltration trench is a subsurface retention system consisting of a conduit such as perforated pipe surrounded by natural or artificial aggregate which temporarily stores and infiltrates stormwater runoff. Like other types of retention systems, exfiltration trenches provide reduction of stormwater volume which reduces pollutant loads. Additionally, substantial amounts of suspended solids, oxygen demanding materials, heavy metals, bacteria, some varieties of pesticides and nutrients such as phosphorus may be removed as runoff percolates through the soil profile. **Figure 6-12** shows a generic “wet” exfiltration trench. **Figure 6-13** shows an exfiltration trench system being installed on the roadway for a residential neighborhood.

Soil permeability and water table conditions must be such that the trench system can percolate the required stormwater runoff treatment volume within a specified time following a storm event. The trench system is returned to a normally "dry" condition when drawdown of the treatment volume is completed. Similar to retention basins, the treatment volume in exfiltration trench systems is not discharged to surface waters.

Because of the unique hydrogeological conditions found in Miami-Dade County, exfiltration trenches are not typically designed to be completely above the SHGWT as is the case in the rest of the state. These systems are termed "wet" exfiltration trenches as shown in **Figure 6-12.**

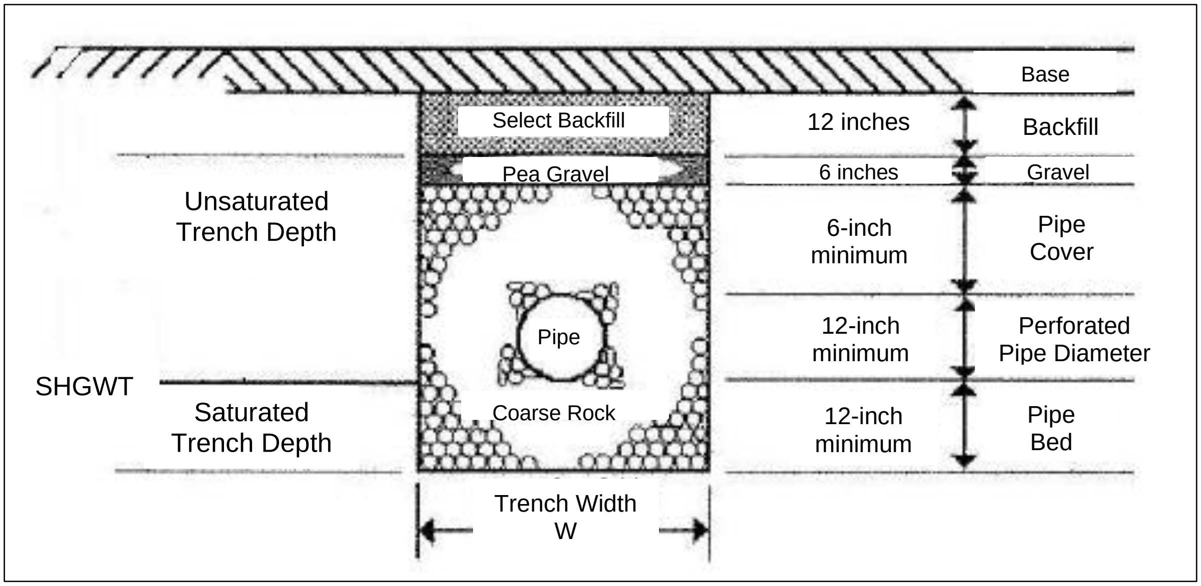


Figure 6-12 – Generic "WET" Exfiltration Trench

Figure 6-13 – Exfiltration Trench

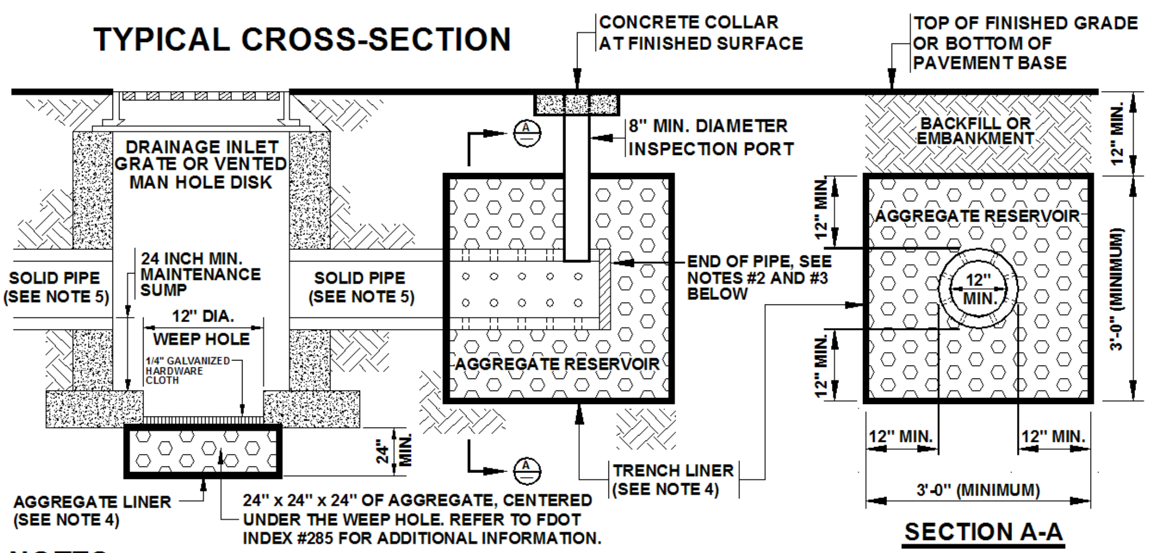
6.6.1 Design and Performance Criteria

a) Exfiltration trenches must have the capacity to retain the required treatment volume without a discharge and without considering soil storage.
b) The required treatment volume initially shall be retained in the perforated/slotted pipe and the surrounding aggregate reservoir.
c) Exfiltration trenches shall only be permitted for projects to be operated by entities with single owners or entities with full-time maintenance staffs.
d) The exfiltration trench must provide the capacity for the required treatment volume of stormwater within 72 hours, with a safety factor of two, following a storm event assuming average antecedent runoff condition (ARC 2). In exfiltration systems, the stormwater is drawn down by natural soil infiltration and dissipation into the ground water table as opposed to underdrain systems which rely on artificial methods such as drainage pipes.
e) Minimum perforated or slotted pipe diameter shall be twelve (12) inches.
f) Minimum aggregate reservoir trench width shall be three (3) feet.
g) To ensure recovery of the Required Treatment Volume (RTV), a dry exfiltration trench must be designed so that the invert elevation of the trench must be at least one foot above the seasonal high ground water table elevation unless the applicant demonstrates, based on plans, test results, calculations or other information, that an alternative design is appropriate for the specific site conditions.
h) Because of the unique aquifer characteristics, wet exfiltration trenches will only be allowed within Miami-Dade County.
i) To prevent surrounding soil migration into the aggregate reservoir, the reservoir must be enclosed on all sides by a permeable woven or non-woven filter fabric. The permeability of the filter fabric must be greater than the permeability of the surrounding soil.
j) To facilitate inspection of proper operation and maintenance of the exfiltration system, the system must be designed with sufficient access for inspection. Appropriate inspection access is dependent on the design of the specific system, but all must provide the ability to determine whether the system is maintaining the design infiltration rate and storage volume. Examples of acceptable inspection methods include designing the system so the terminal ends of any perforated/slotted pipe or storage areas meets one of the following criteria:
    - Terminates in an accessible drainage inlet or manhole; or
    - Has an inspection port installed with a minimum diameter of eight (8) inches
    - Has an observation well that allows checking of the recovery of the RTV
k) To provide a collection space for trash and other inflow debris, a minimum 24-inch deep maintenance sump will be required for all system inlets and manholes. A minimum twelve-inch (12”) diameter weep hole shall be placed in the bottom of the maintenance sump to facilitate the infiltration of stormwater into the underlying soils after a rainfall event.
l) To reduce the potential for trash, debris and oil/grease inflow into the exfiltration trench system; a baffle, trash tee or other equivalent device must be installed at the end of the perforated/slotted pipe(s) in all access inlets and manholes. **Figure 6-14** shows an example drawing of exfiltration trench sumps and dead-end details.

m) Sustainable void spaces must be used in computing the storage volume in the aggregate reservoir. These aggregate void space values shall be the greater of the following:
   - 35% of aggregate volume; or
   - 80% of the measured testing lab values for the selected aggregate(s), if obtained and certified by a Florida licensed geotechnical professional.

n) The material used in the aggregate reservoir shall be washed to ensure that no more than five percent (5%) of the materials passing a #200 sieve.

o) Exfiltration trenches shall not be constructed within 50 feet of a public or private potable water supply well.



NOTES:
1. SEE THE SEPARATE DETAIL SKETCHES FOR SEDIMENT / TRASH BAFFLES & TEES, OR OTHER EQUIVALENT DEVICES.
2. PERFORATED OR SLOTTED PIPES SHALL TERMINATE A MINIMUM OF TWO (2) FEET FROM THE END OF THE EXFILTRATION TRENCH, OR CONNECT TO ADDITIONAL INLETS OR MANHOLES.
3. PIPE "DEAD ENDS" (IF UTILIZED) SHALL TERMINATE INTO A SOLID PLUG OR END CAP.
4. SIDES, TOP, BOTTOM, AND ENDS OF TRENCH (AND AGGREGATE BELOW DRAIN HOLE) SHALL BE LINED WITH A PERVIOUS WOVEN OR NON-WOVEN ENGINEERING FILTER FABRIC. OVERLAP FABRIC LINING MATERIAL A MINIMUM OF TWELVE (12) INCHES AT THE TOP OF THE AGGREGATE.
5. REFER TO FDOT INDEX #285 FOR ADDITIONAL INFORMATION ON THE MINIMUM LENGTHS OF SOLID PIPE EXITING THE ACCESS MANHOLE OR DRAINAGE INLET, AND THE MINIMUM CROSS SECTIONAL DIMENSIONS OF THE AGGREGATE RESERVOIR.

"GENERIC" EXFILTRATION TRENCH SUMPS & DEAD END DETAILS

NOT TO SCALE

EXFTREN SUMPS & DEAD END DETAILS - AS OF 02-23-10.DWG

Figure 6-14 – Typical Exfiltration Trench Sumps and Dead End Details

6.6.2 Inspection, Operation and Maintenance

a) Inspection items:

   - Monitor facility for sediment accumulation in the pipe (when used) and storage volume recovery (i.e. drawdown capacity). Observation wells and inspection ports should be checked following 3 days' minimum dry weather. Failure to percolate stored runoff to the design treatment volume level within

72 hours indicates binding of soil in the trench walls and/or clogging of geotextile wrap with fine solids. Reductions in storage volume due to sediment in the distribution pipe, also reduces efficiency. Minor maintenance measures can restore infiltration rates to acceptable levels short term. Major maintenance (total rehabilitation) is required to remove accumulated sediment in most cases or to restore recovery rate when minor measures are no longer effective or cannot be performed due to design configuration.

- Inspect appurtenances such as sedimentation and oil and grit separation traps or catch basins as well as diversion devices and overflow weirs when used. Diversion facilities and overflow weirs should be free of debris and ready for service. Sedimentation and oil/grit separators should be scheduled for cleaning when sediment depth approaches cleanout level. Cleanout levels should be established not less than 1 foot below the invert elevation of the chamber.

a) Maintenance activities to prolong service life:
   - Remove sediment from sediment or oil/grease traps, catch basin inlets, manholes, and other appurtenant structures and dispose of properly.
   - Remove debris from the outfall or “Smart Box” (diversion device in the case of off-line facilities).
   - Removal of sediment and cleaning of trench system. This process normally involves facilities with large pipes. Cleanout may be performed by suction hose and tank truck and/or by high-pressure jet washing.

b) To maintain a 72-hour exfiltration rate:

   - Periodic clean-out or rehabilitation of the system to remove any accumulated trash, sediment and other inflow debris and remediate any clogging of perforated pipes.
   - Total replacement of the system. In some cases, the system may not be able to be rehabilitated sufficiently to restore the design storage and infiltration rate. In these cases, complete replacement of the system may be necessary. The applicant shall provide an estimate of the expected life expectancy of the exfiltration trench and an estimate of the cost to replace the trench.

6.7 Green Roof or Rain Barrels/Cisterns

Rainwater harvesting collects and conveys rainwater from a building roof to storage in a Rain Barrel or a Cistern for reuse in irrigation or approved non-potable uses. Components include the roof surface, gutters and downspouts, roof washer to remove contaminants, cisterns, and pumping and piping systems. A green roof/cistern system is a retention BMP and its effectiveness is directly related to the annual volume of roof runoff that is captured, retained, and reused.

Green roofs are suitable for a wide range of buildings, including industrial, educational and governmental facilities, offices, commercial properties, and residences. In general, buildings with large roof areas are targeted for stormwater management. They can be designed as part of a new construction or retrofit following a structural assessment. They also provide shade to underlying surfaces thus reducing heat transmission to the building and effectively lowering cooling costs by 25%.

There are two types of green roofs described in this report. An *Extensive Green Roof* is one where the root zone (pollution control layer and growth media layer) is less than 6 inches in depth. Whereas *Intensive Green Roofs* have root zones greater than or equal to 6 inches and are typically intended for public or private access. There are two distinct functions for green roofs, one is passive and the other is active. Passive green roofs are intended only for maintenance access and typically require less maintenance, while an active roof is used for public and private access. Green roofs can be built on any type of roof deck with a minimum slope of one inch per foot. **Figure 6-15** and **Figure 6-16** provide typical green roof details for the different types of roofs and various component details.

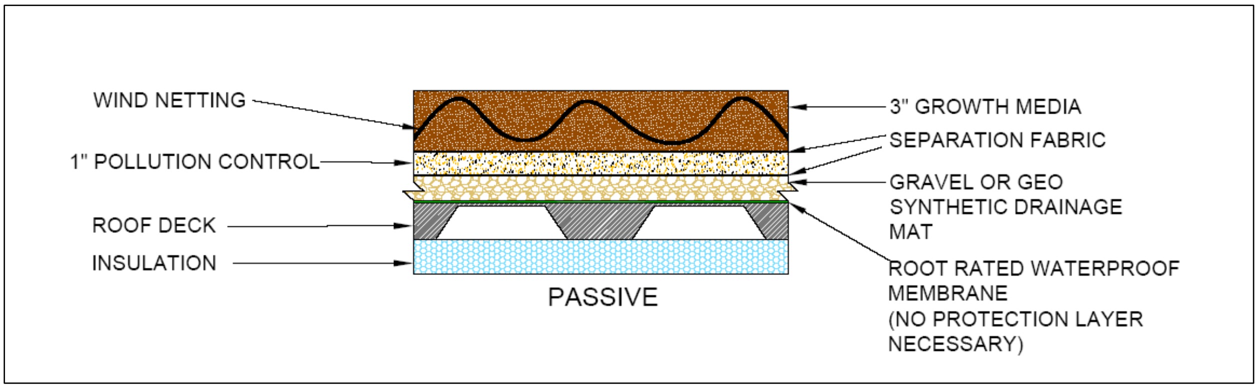


Figure 6-15 – Extensive Green Roof Section (Usually Passive Function)

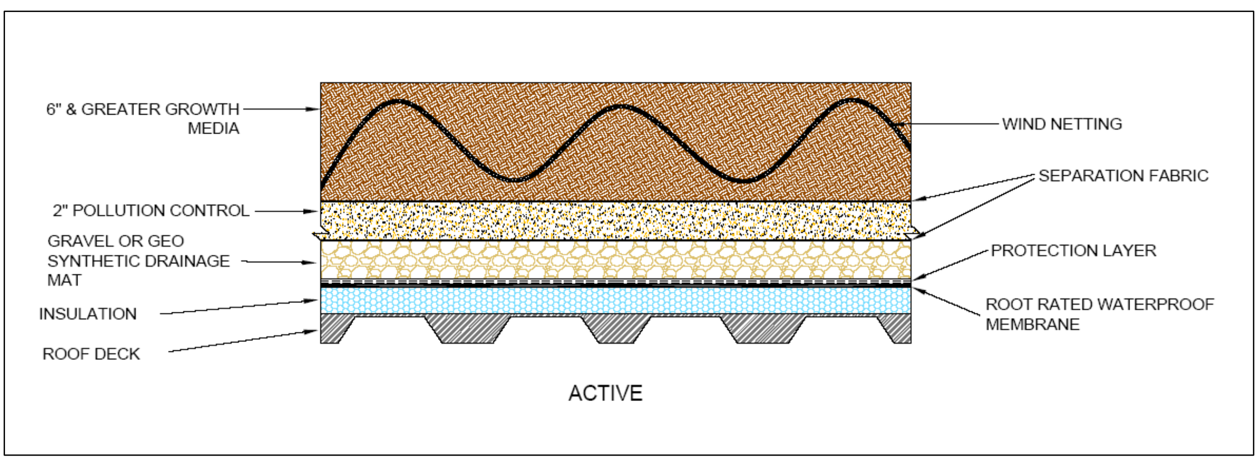


Figure 6-16 – Intensive Green Roof Section (Usually Active Function)

An example of a green roof and residential barrels/cisterns systems are provided in **Figure 6-17**.

Figure 6-17 – Green Roof and Rain Barrels/Cisterns System for Residential

6.7.1 Design Criteria

a) Waterproof Membrane - A waterproof membrane layer must be incorporated into the roof system to protect the structure from moisture damage. There are several options for this layer such as, polypropylene or polyethylene membrane, polyvinyl chloride, or spray applied elastomeric waterproofing membrane as well as others. The applicant must check with the membrane manufacturer to ensure that the membrane is rated as a root protection material. All permitted design specifications and manufacturer's installation directions shall be followed to ensure that the proposed product will function as intended with green roof overburden.

b) Drainage Layer - The major function of the drainage layer is to facilitate lateral movement of the filtrate to the point of drainage to ensure no standing water is present. The drainage layer can consist of several different materials such as gravel, recycled products, or geo-synthetic drainage mats. It is important to note that whatever material used shall not depress or elevate the pH of the filtrate more than 1.5 pH units from neutral. When using aggregate as drainage layer materials, it must contain no more than 7% "fines" (particles passing sieve number 200) by mass. The drainage material must be able to structurally support the intended green roof overburden, as well as maintenance activities, without deflection such that drainage is blocked or restricted. A non-woven geotextile separation fabric must be installed on top of the drainage layer to prevent clogging of the drainage layer. This fabric shall have a thickness to pass the drainage water and void spaces such that the pollution control media does not fill the surface void area of the drainage layer and cause clogging. The hydraulic conductivity of the fabric must exceed 1.5 inches per hour.

c) Growth Media - The growth media is intended to be the main support coarse for the vegetation. The growth media is installed on top of the separation fabric. Growth media shall meet all of the following specifications.

- Unit Weight is no more than 45 pounds per cubic foot when dry.
- No more than 10% of the particles passing the #200 sieve.
- Contains no shale.
- At least 3 inches in thickness.
- Water holding capacity is at least 30%, and as measured by porosity.
- Permeability is at least 1.5 inches per hour. Permeability is vertical hydraulic conductivity at the specified unit weight noted above.
- Organic content is no more than 10% by volume.
- pH is between 6.5 and 8.0.
- Soluble salts are less than 3.5 g (KCL)/L.

d) Preventing wind uplift – To assure that a green roof built in Florida remains operable, the green roof must be designed to prevent wind uplift. A three-dimensional netting made of polyamide (nylon) filaments connected together woven into the growth media layer or other equivalent method is acceptable. As an alternative, a parapet of sufficient height can be used. For buildings less than 100 feet tall, a parapet height of 36 inches can be used in place of wind netting.

e) Vegetation – Florida native vegetation is recommended on green roofs used for stormwater treatment. Low maintenance plants and drought tolerant plants are recommended but not mandatory because of the use of stored stormwater for irrigation. However, plants tolerant to high levels of direct sunlight and high temperatures are necessary for the success of a healthy green roof plants. Care should be made to ensure that the available root zone of the green roof is sufficient for the intended plants. When designing an intensive green roof, larger plants with more rigorous maintenance schedules are acceptable. Plants must achieve at least 80% cover of the green roof area within one year of planting. When the vegetation density is less than 80%, new plants shall be added. **Table 6-1** includes plants that have been successfully used on green roofs in the different parts of Florida. Other plants are acceptable and applicants are encouraged to consult landscape architects and native nursery personnel for appropriate plants.

Table 6-1 – Plants That Have Been Successfully Used on Green Roofs in Florida

Plant	North FL	Central FL	South FL
Muhly Grass	YES	YES	YES
Butterfly Weed		YES	YES
Blanket Flower	YES	YES	YES
Sunshine Mimosa		YES	YES
Perennial Peanut	YES	YES	YES
Snake Weed		YES	YES
Asiatic Jasmine	YES	YES	YES
Simpson Stopper		YES	
Black Eyed Susan	YES	YES	
Beach Sunflower	YES	YES	YES

For plants used on green roofs in coastal areas, salt tolerance is an important consideration. Some examples of plants used along the coast are Simpson stopper, Snake plant, Muhly grass, Inkberry, and Beach sunflower.

f) Irrigation - Irrigation is required on all green roofs in Florida to ensure plant survival. Drip irrigation applied at the growth media surface is required, usually with one foot on-center spacing. Irrigation pumps must be installed with an alarm system to signal any mechanical problems. Irrigation will vary by season and a rain shut-off sensor is required. Flow meters shall be installed as a means of documenting when irrigation occurs and the volume of water used for irrigation. The addition of make-up water will be required during parts of the year depending on local rainfall patterns and records must be kept to document how much make-up water is added. The recommended source of make-up water is stormwater or gray water, whenever available. An in-line filter is recommended to reduce the maintenance problems and cost of irrigation line replacement. Depending upon the green roof retention volume and design, irrigation shall occur three to four times per week with a maximum total application of one (1.0) inch per week if filtrate or stormwater are available.

g) Roof Drain - The green roof must drain into a storage device, typically a barrel/ cistern. The slope of the roof must be at least ¼ inch per foot. The primary drain can be an interior drain or gutter drain. A one-foot barrier must be maintained around the drain to prevent vegetation and debris from clogging drain as well as providing easy inspection. This barrier can be an aluminum break or a washed river stone section. An overflow shall also be provided to ensure drainage in the event that a clog occurs in the primary drain.

h) Barrel/Cistern or Other Water Storage Area - The barrel/cistern or other water storage area serves to store filtrate for use as irrigation. Filtrate volumes in excess of those required for irrigating the green roof can be used to either irrigate ground level landscaping or can be directed to other retention BMPs that allow for infiltration. Barrel/Cistern or other storage placement can be below ground or above ground. If an above ground barrel/cistern is used it must be UV stable, dark in color, and must be placed in areas of low to no direct sunlight. Direct sunlight may cause irrigation water temperature to get too hot for plants.

6.7.2 Inspection, Operation and Maintenance

Maintenance issues associated with green roof/cistern systems are related to the health of the plants, the drainage capabilities of the system, and proper functioning of the irrigation system. Green roof/cistern systems must be inspected annually by the operation and maintenance entity to determine if it is operating as designed and permitted. Reports documenting the results of annual inspections shall be filed with the City every year.

a) Inspection items:

- Inspect operation of the green roof/cistern system to ensure that rainfall is flowing properly through the green roof and into the cistern.
- Inspect the plants on the green roof to ensure they are healthy and growing. Ensure plants are covering at least 80% of the surface area of the green roof and that plant species not on the approved plant list are not becoming established.
- If an intensive green roof, inspect it for damage by foot traffic or other human uses of the green roof.
- Inspect the operation of the pumping system and the irrigation system to ensure they are working properly.

c) Maintenance activities to prolong service life:

- Repair any components of the green roof drainage system which are not functioning properly and restore proper flow of stormwater or filtrate.
- Maintain the plants on the green roof on an as needed basis to ensure healthy growth and meet the required 80% coverage of the green roof. Weeding to remove plants not on the approve design plant list will be needed on a regular basis. Whenever plant coverage is less than 80%, new plants shall be established as soon as possible.
- Repair any damage to the green roof by foot traffic or other human uses.
- Repair or replace any damaged components of the pumping and irrigation system as needed for proper operation.

b) Record keeping:

The owner/operator of a green roof/cistern system must keep a maintenance log of activities that is available at any time for inspection or recertification purposes. The log will include records related to the use of the filtrate water for irrigation. A flow meter to measure the quantity and day/time of irrigation is required. Visual observations of the success of plant growth and cover, including photo documentation is also required. The maintenance log shall include the following:

- Irrigation volume measured using a flow meter specifying the day and amount;
- Cistern overflow volumes and makeup water volumes;
- Observations of the irrigation system operation, maintenance, and a list of parts that were replaced;
- Pruning and weeding times and dates to maintain plant health and 80% coverage;
- A list of dead, dying, or damaged plants that are removed and replaced;
- Maintenance of roof mechanical equipment;

- Dates on which the green roof was inspected and maintenance activities conducted; and
- Dates on which fertilizer, pesticide, or compost was added and the amounts used.

6.8 Permeable Pavement

Pervious pavement systems include the subsoil, the sub-base, and the pervious pavement as shown in **Figure 6-18.** They can include several types of materials or designed systems such as pervious concrete, pervious aggregate/binder products, pervious paver systems, and modular paver systems. Pervious asphalt and pervious pavements using crushed and recycled glass will not be allowed until future improvements are made and verified with testing to address their structural capability, hydraulic performance and manufacturing process. Recent studies on the design, longevity, and infiltration characteristics of pervious pavement systems are available on the University of Central Florida's website http://stormwater.ucf.edu/.

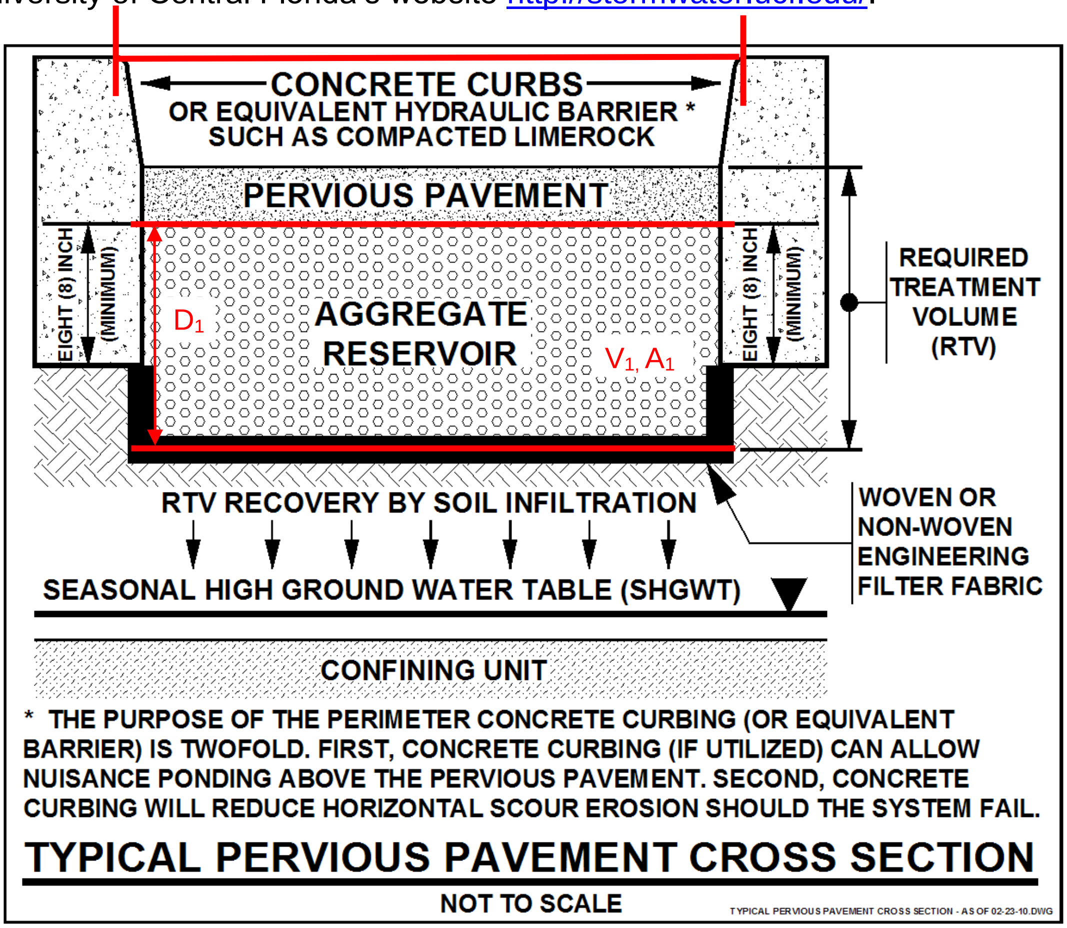


Figure 6-18 – Typical Pervious Pavement Cross-Section

Permeable pavements can be used for low traffic roads, parking lots, driveways, pedestrian plazas and walkaways as shown in **Figure 6-19**. They are ideal for sites with limited space for other stormwater LID BMPs.

Figure 6-19 – Permeable Pavement in Parking Lot and Park/Walkaway Area

6.8.1 Design Criteria

Pervious pavement system design has two major components: structural and hydraulic. The pervious pavement system must be able to support the traffic loading while also (and equally important) functioning properly hydraulically. This section does NOT discuss structural designs of pervious pavement systems. Engineering consultants should consult the product manufacture's pavement design standards to ensure that pervious pavements will be structurally stable, and not be subject to premature deterioration failure.

Below are the types of practices, specifications, recommendations, tools and potential conditions for applicants to consider for the approval of pervious pavement systems. This is not intended to cover all potential designs. Professional judgment must be used in the design and review of proposed pervious pavement systems.

a) The applicant must provide reasonable assurances that the pervious pavement construction will be performed by a contractor trained and certified by the product manufacturer to install the proposed pervious pavement system.
b) The seasonal high ground water table shall be at least one foot beneath the bottom of the pervious pavement system unless the applicant demonstrates, based on plans, test results, calculations or other information, that an alternative design is appropriate for the specific site conditions. The "system" is defined as the pervious pavement itself, the underlying storage reservoir, if used (i.e., pea rock, #57 stone, etc.), and the geo-fabric that wraps the underlying storage reservoir.
c) The pervious pavement system must provide the capacity for the recovery of the required treatment volume of stormwater within 72 hours, with a safety factor of two, assuming average Antecedent Runoff Condition (ARC 2). In a pervious pavement system, the stormwater is drawn down by natural soil infiltration and

dissipation into the ground water table, as opposed to underdrain systems which rely on artificial methods like perforated or slotted drainage pipes.

d) The minimum vertical hydraulic conductivity of the pervious pavement system shall not be less than 2.0 inches per hour.

e) Pervious pavement systems shall not be constructed within 50 feet of a public or private potable water supply well.

f) The in-situ (or imported) subgrade soil (below the pervious pavement system) shall be compacted to a maximum of 92% - 95% Modified Proctor density (ASTM D-1557) to a minimum depth of 24 inches. For proposed pervious pavements within redevelopment projects, the existing pavement section and its compacted base shall be removed. The underlying soils are to be scarified to a minimum 16-inch depth, re-graded, filled with hydraulically clean soils (if applicable) and proof rolled to a maximum compaction of 92% - 95% Modified Proctor density (ASTM D-1557).

g) Other than pedestrian walks, bicycle paths and driveway ingress or egress areas, the maximum slope for pervious pavements is 1/8 inch per foot (1.04%) although zero percent slope is preferred.

h) Except for pervious walks and bike paths, curbing, edge constraint or other equivalent hydraulic barrier will be required around the pervious pavement to a minimum depth of eight (8) inches beneath the bottom of the pavement and to the depth necessary to prevent scouring from the horizontal movement of water below the pavement surface depending on the adjacent slopes. The horizontal movement of water can cause scour failure at the edge of the pervious pavement system, or mask the hydraulic failure of the system due to plugging of the deeper voids in the pervious pavement or aggregate reservoir. The cross sectional construction drawings of the pervious pavement system and its relationship to the slopes of adjacent areas must include a demonstration that the depth of the curbing, edge constraint or other equivalent hydraulic barrier is sufficient to prevent erosion and scour.

i) To provide an indicator that the pervious pavement system has failed or needs maintenance, the system shall be designed to allow a minimum ponding depth of one (1) inch and a maximum ponding depth of two (2) inches prior to down-gradient discharge with the exception of pervious walks and bicycle paths. Additional details are provided in **Attachment G.** The permitted construction plans shall delineate the areas of pervious pavement that may be subject to nuisance ponding.

j) The pervious pavement system must be designed to have an overflow at the nuisance ponding elevation to the down-gradient stormwater treatment or attenuation system or outfall (see **Attachment G**).

k) Runoff from adjacent landscaped areas must NOT be directed onto pervious pavement system areas unless the Applicant demonstrates that the offsite areas that drain onto the pervious pavement will not increase sediment, silt, sand, or organic debris that increases the potential for clogging the pervious pavement. The design must reduce the likelihood of silts and sands from plugging the pavement void spaces.

l) With the exception of pervious walks and bicycle paths, the installation of Embedded Ring Infiltrometer Kit (ERIK) is required (see **Attachment G**). A minimum one (1) ERIK in-situ Infiltrometer will be required for each section of pervious pavement installed. For larger sections, a minimum of two (2) in-situ ERIK Infiltrometer per acre of pervious pavement will be required. ERIK Infiltrometer shall not be placed at locations where subsequent testing may produce non-representative conclusions regarding the hydraulic function of the pervious pavement system. The location of the ERIK Infiltrometer shall be shown on the construction plans or other supporting sketches or drawings for the project.

m) Documentation of ERIK Infiltrometer construction, and post-construction testing, shall be required with submittal of the construction completion certification. Test results shall be provided in report form, certified by the appropriate Florida Registered Professional. The construction completion certification shall not be accepted if the vertical hydraulic conductivity is less than 2.0 inches per hour or is less than the permitted design percolation rate in any of the required ERIK Infiltrometer.

n) For proper maintenance of most pervious pavement systems, periodic vacuum sweeping is recommended. If ERIK tests indicate a vertical hydraulic conductivity rate less than 2.0 inches per hour, or is less than the permitted design percolation rate, or when nuisance ponding occurs, vacuum sweeping will be required. Vacuum sweeping also will be required for areas that are subject to wind transported soils (near sand dunes or other coastal areas) or other conditions where excessive soil or other debris deposition is expected to occur (from adjacent landscaping mulch and leaf litter, from areas with high leaf fall, fugitive sands and limerock fines from adjacent construction sites). Vacuum sweeping will be required annually.

o) The entrances to pervious pavement areas shall be posted by signs to inform users they are entering a pervious pavement area and that any vehicles with heavy wheel loads or with muddy tires should not enter.

6.8.2 Inspection, Operation and Maintenance

Maintenance issues associated with pervious pavements are related to clogging of the porous surfaces which reduces or prevents infiltration thereby slowing recovery of the stormwater treatment volume and often resulting in standing water and the designed nuisance flooding.

To determine if the pervious pavement is properly functioning or whether it needs maintenance requires that either an inspection be within 72 hours of a storm and that the ERIK devices be used to test the infiltration rate as specified below.

a) Inspection items:

- Inspect pervious pavement for storage volume recovery within the permitted time, generally less than 72 hours. Determine if nuisance flooding is occurring in those areas of the parking lot that were designed to flood if the pervious pavement was failing. Nuisance flooding indicates that the required treatment volume is not infiltrating because of a reduction of the infiltration rate and a need to restore system permeability

- Use the ERIK Infiltrometer at least once every two (2) years to test if the vertical hydraulic conductivity is less than 2.0 inches per hour or is less than the permitted design percolation rate in any of the required ERIK Infiltrometer. If any of the ERIK Infiltrometer have rates less than the permitted rate, maintenance activities shall be undertaken to restore the permeability of the pervious pavement. The results of the ERIK Infiltrometer testing shall be submitted to the City.
- Inspect all edge constraints and overflow areas to determine if any erosion is occurring and repair as needed.

d) Maintenance activities to prolong service life:

- Vacuum sweeping will be conducted annually and whenever the vertical hydraulic conductivity is less than 2.0 inches per hour or is less than the permitted design percolation rate in any of the required ERIK Infiltrometer. Vacuum sweeping will be done on an as-needed basis on pervious pavements located in areas that are subject to wind transported soils (near sand dunes or other coastal areas) or other conditions where excessive soil or other debris deposition is expected to occur (from adjacent landscaping mulch and leaf litter, from areas with high leaf fall, fugitive sands and limerock fines from adjacent construction sites, etc.).
- A remediation plan shall be submitted to the City should vacuum sweeping fail to improve the vertical hydraulic conductivity to a rate greater than 2.0 inches per hour, or equal to or greater than the permitted design percolation rate, or resolve the nuisance ponding. The remediation plan shall be prepared and submitted to the City's compliance staff for review and approval.
- Repair erosion near edge constraints or overflows and ensure that the contributing drainage area is stabilized and not a source of sediments.

6.9 Retention Pond

Retention basins provide numerous benefits, including reducing stormwater volume, which reduces the average annual pollutant loading that may be discharged from the system. Additionally, many stormwater pollutants such as suspended solids, oxygen demanding materials, heavy metals, bacteria, some varieties of pesticides, and nutrients are removed as runoff percolates through the soil profile.

Soil permeability and water table conditions must be such that the retention basins can percolate the required treatment runoff volume within a specified time following a storm event. After drawdown has been completed, the basin does not hold any water, thus the system is normally “dry.” Unlike detention basins, the treatment volume for retention systems is not discharged to surface waters. **Figure 6-20** shows a typical cross-section of a “dry” retention pond. Retention basins shall be designed in accordance with the following design and performance criteria. Examples of Retention ponds are illustrated in **Figure 6-21** and **Figure 6-22**.

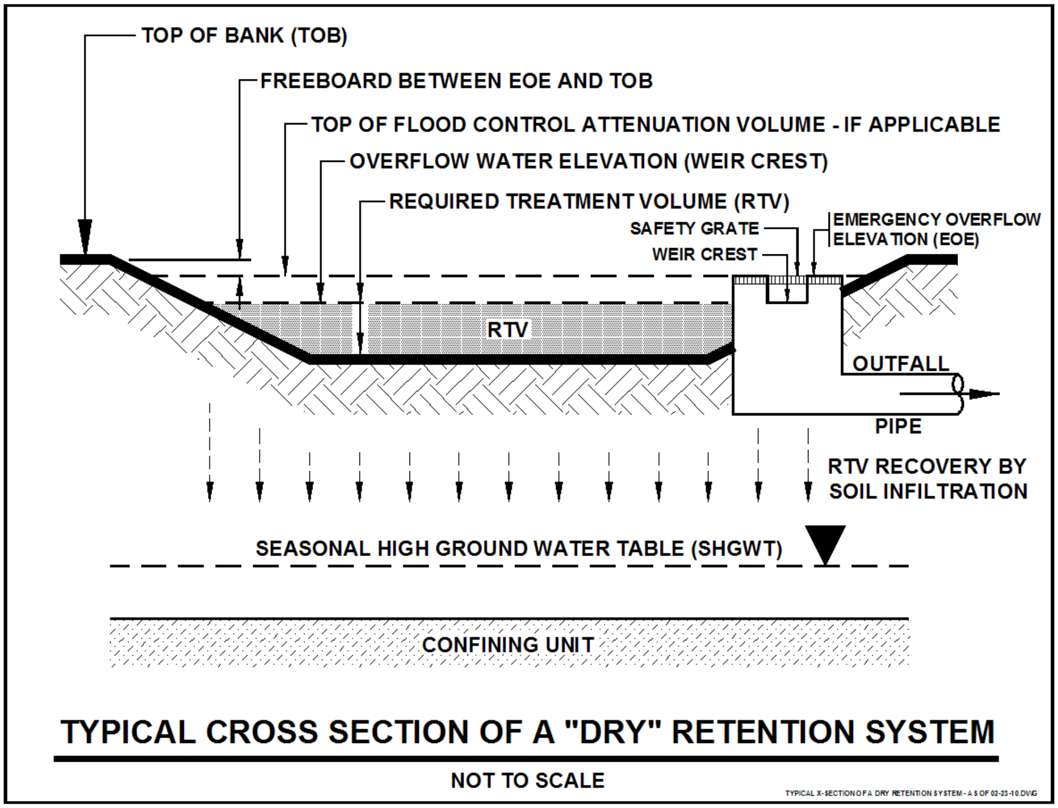


Figure 6-20 – Typical Cross-Section of a “DRY” Retention Pond

Figure 6-21 – Typical Dry Retention Pond

Figure 6-22 – Doral Glades Park Stomwater Wet Retention Pond

6.9.1 Design Criteria

a) The retention basin must recover the required treatment volume of stormwater within 72 hours, with a safety factor of two, assuming average Antecedent Runoff Condition (ARC 2).
b) The seasonal high ground water table shall be at least one foot beneath the of the retention basin unless the applicant demonstrates, based on plans, test results, calculations or other information, that an alternative design is appropriate for the specific site conditions.
c) The retention basin sides and bottom shall be stabilized with permanent vegetative cover, some other pervious material, or other methods acceptable to the City that will prevent erosion and sedimentation.
d) Retention basins shall not be constructed within 50 feet of a public or private potable water supply well.

6.9.2 Inspections, Operation and Maintenance

Maintenance issues associated with retention basins are related to clogging of the porous soils, which reduces or prevents infiltration thereby slowing recovery of the stormwater treatment volume and often resulting in standing water. Sedimentation can cause clogging and resulting sealing of the bottom or side slope soils. It can also occur from excessive loading of oils and greases or from excessive algal or microorganism growth. Standing water within a retention basin can also result from an elevated high water table or from ground water mounding, both of which can present long term operational issues that may require redesign of the system.

To determine if an infiltration system is properly functioning or whether it needs maintenance requires that an inspection be done within 72 hours after a storm. The inspection should determine if the retention basin is recovering its storage volume within its permitted time frames, generally 24 to 72 hours after a storm. If this is not occurring and there is standing water, then the cause must be determined and actions undertaken beginning with those specified in the system's Operation and Maintenance Plan.

e) Inspection items:

- Inspect basin for storage volume recovery within the permitted time, generally less than 72 hours. Failure to percolate the required treatment volumes indicates reduction of the infiltration rate and a need to restore system permeability.
- Inspect and monitor sediment accumulation on the basin bottom or inflow to prevent clogging of the retention basin or the inflow pipes.
- Inspect vegetation of bottom and side slopes to ensure it is healthy, maintaining coverage, and that no erosion is occurring within the retention basin.
- Inspect inflow and outflow structures, trash racks, and other system components for accumulation of debris and trash that would cause clogging and adversely impact operation of the retention basin.
- Inspect the retention basin for potential mosquito breeding areas such as where standing water occurs after 72 hours or where cattails or other invasive vegetation becomes established.

f) Maintenance activities to prolong service life:

- If needed, restore the infiltration capacity of the retention basin so that it meets the permitted recovery time for the required treatment volume.
- Remove accumulated sediment from retention basin bottom and inflow and outflow pipes and dispose of properly. Please note that stormwater sediment disposal may be regulated under Chapter 62-701, F.A.C). Sediment removal should be done when the system is dry and when the sediments are cracking.
- Remove trash and debris inflow and outflow structures, trash racks, and other system components to prevent clogging or impeding flow.
- Maintain healthy vegetative cover to prevent erosion in the basin bottom, side slopes or around inflow and outflow structures. Vegetation roots also help to maintain soil permeability. Grass needs to be mowed and grass clippings removed from the basin to reduce internal nutrient loadings.
- Eliminate mosquito breeding habitats.
- Ensure that the contributing drainage area is stabilized and not a source of sediments.

6.10 Parking Stormwater Chambers

Stormwater Chambers are used as underground infiltration or retention/detention systems in replacement of swales, ponds, concrete structures or pipe and stone installations. They are installed in trench or bed configurations according to site restrictions or client preference. For commercial applications, the placement of stormwater management systems beneath parking areas allows for further site development without sacrificing land area. Since retail development is often directly related to the number of parking spaces available, sub-surface installation of stormwater chambers maximizes land use and capability of additional parking spaces. **Figure 6-23** shows a typical cross-section of a parking stormwater chamber. Examples of these are illustrated in **Figure 6-24**.

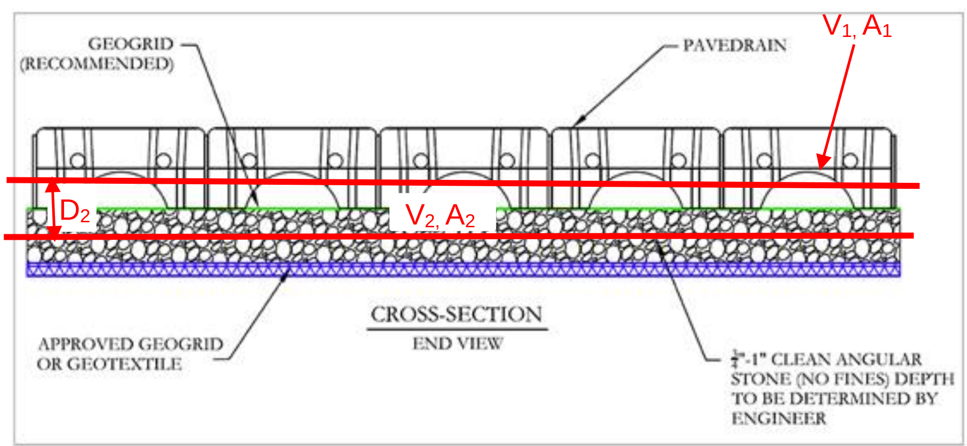


Figure 6-23 – Parking Stormwater Chambers Cross Section

Figure 6-24 – Stormwater Chambers

6.10.1 Design Criteria

Stormwater chamber systems consist of parallel rows of open-bottom, perforated plastic chambers (half pipes) surrounded by stone aggregate. The void ratio is maximized in the storage chambers and, when full, the void space in the gravel also provides stormwater storage. As proprietary technologies, stormwater chamber designs are developed and modified on a regular basis, and should be installed according to manufacturers' specifications. Stormwater chambers are intended to be used as infiltration practices where site conditions allow.

6.10.2 Inspections, Operation and Maintenance

Underground systems are primarily designed to function similar to surface basins at locations where usable space and real estate costs come at a premium. Thus, they're commonly built beneath parking lots and other solid-surfaces.

Generally, underground stormwater systems offer either retention or detention functions, and can help ensure the water quality of the runoff they release to sewers, waterways, or the ground. They are often made of high-density, polyethylene infiltration chambers, but there are many material variations in use. In fact, there are so many options for this type of stormwater system on the market that there's no one-size-fits-all maintenance procedure.

As with surface basins, the size and location of your underground system will dictate the frequency of the inspection and maintenance requirements. For instance, a system built under a large commercial parking lot will be exposed to more trash and debris than a smaller one meant for residential use, and will therefore require more frequent attention.

For underground retention systems with significant sediment accumulation, the use of a high-powered vacuum truck to extract accumulated sediment is the standard recourse. With underground detention systems, however, the low-flow orifice will be the key point in the system's maintenance, since it regulates stormwater outflows. In such a system, the low-flow orifice needs to be kept clear of any trash, sediment, or debris.

7.0 LID PERFORMANCE AND RETENTION CREDITS

The following subsections describe the performance credit available for each structural LID BMP implemented for development sites. To determine the LID BMP retention credits for the reduction of discharge runoff volume from the site, the sum of the total retention volume of storage provided by all the BMPs on the site and the total infiltration volume must be accounted for based on each BMP infiltration capacity.

Each structural LID BMP has a unique approach for determining the storage volume it provides. **Section 7.1 through 7.10** describes the approach for each structural LID BMP recommended for use within the City of Doral.

7.1 Bioretention Basins or Rain Gardens

Volume provided by Bioretention or Rain Garden BMPs is estimated by the following equations.

Equation 2 - Storage Volume of Bioretention Basin or Rain Gardens

$$V_{Bioretention} = V_1 + V_2 \text{ , } (ft^3)$$

Where,

$$V_1 = A_1 \, x \, D_1 \, x \, 0.75 \; (assumed\ 25\%\ vegetated\ cover), (ft^3)$$

$$V_2 = A_2 \, x \, D_2 \, x \, 0.50 \; (assumed\ void\ ratio), (ft^3)$$

Refer to **Figure 6-1** for a schematic of the equation parameters.

Infiltration provided by Bioretention or Rain Garden BMPs is estimated by the following equation.

Equation 3 - Infiltration Provided by Bioretention Basin or Rain Gardens

$$I_C = I_R \, x \, A_{Bioretention} \text{ , } \left(\frac{ft^3}{s/(ft\ of\ head)}\right)$$

Where,

$$A_{Bioretention} = \frac{V_{Bioretention}}{D_C}$$

Refer to **Figure 6-1** for a schematic of the equation parameters.

7.2 Tree Box Filters and Infiltration Planters

Volume provided by Tree Box Filter or Infiltration Planter BMPs is estimated by **Equation 4**.

Equation 4 - Storage Volume of Tree Box Filter or Infiltration Planter

$$V_{Tree\ Box} = V_1 + V_2\,, (ft^3)$$

Where,

$$V_1 = A_1\ x\ D_1\ x\ 0.75\ (assumed\ 25\%\ vegetated\ cover), (ft^3)$$

$$V_2 = A_2\ x\ D_2\ x\ 0.50\ (assumed\ void\ ratio), (ft^3)$$

Figure 6-3 for a schematic of the equation parameters.

Infiltration provided by Tree Box Filter or Infiltration Planter BMPs is estimated by the following equation.

Equation 5 - Infiltration Provided by Tree Box Filter or Infiltration Planter

$$I_C = I_R\ x\ A_I, \left(\frac{ft^3}{s/(ft\ of\ head)}\right)$$

Refer to **Figure 6-3** for a schematic of the equation parameters.

7.3 Vegetated Swales

Volume provided by Vegetated Swale BMPs is estimated by the following equations.

Equation 6 - Storage Volume of Vegetated Swales

$$V_{Swale} = V_1 + V_2\,, (ft^3)$$

Where,

$$V_1 = A_1\ x\ D_1\ x\ 0.75\ (assumed\ 25\%\ vegetated\ cover), (ft^3)$$

$$V_2 = A_2\ x\ D_2\,, (ft^3)$$

Infiltration provided by Vegetated Swale BMPs is estimated by the following equation. Refer to **Figure 6-6** for a schematic of the equation parameters.

Equation 7 - Infiltration Provided by Vegetated Swales

$$I_C = I_R\ x\ A_{Swale}, \left(\frac{ft^3}{s\ (ft\ of\ head)}\right)$$

Where,

$$A_{Swale} = \frac{V_{Swale}}{D_C}$$

7.4 Filter Strips or Vegetated Buffers

The volume associated with the Filter Strip or Vegetated Buffer BMPs is estimated by the following equation

Equation 8 - Storage Volume of Filter Strips or Vegetated Buffers

$$V_{Buffer} = A_I \; x \; D_I \; x \left(\frac{1ft}{12in}\right), (ft^3)$$

Where,

$$A_I = Area\ of\ Infiltration, (ft^2)$$

$$D_I = 1\ in, Filter\ Strips\ or\ Vegetated\ Buffers\ with\ slopes\ < 1{:}10$$

$$D_I = \frac{1}{2}\ in, Filter\ Strips\ or\ Vegetated\ Buffers\ with\ slopes\ \geq\ 1{:}10\ and\ \leq 1{:}6$$

No volume credit will be accounted for filter strips or vegetated buffers with less than 25 ft wide or with a slope greater than 1:6 because this extraction is already accounted for in the ½ inch to 1 inch in **Equation 8**. Refer to **Figure 6-8** for a schematic of the equation parameters.

7.5 Infiltration Trench

Volume provided by Infiltration Trench BMPs is estimated by the following equations.

Equation 9 - Storage Volume of Infiltration Trench

$$V_{Infiltration\ Trench} = V_1, (ft^3)$$

Where,

$$V_1 = A_1 \; x \; D_1 \; x \; 0.50\ (assumed\ void\ ratio), (ft^3)$$

Infiltration provided by Infiltration Trench BMPs is estimated by the following equation. Refer to **Figure 6-10** for a schematic of the equation parameters.

Equation 10 - Infiltration Provided by Infiltration Trench

$$I_C = I_R \; x \; A_I, \left(\frac{ft^3}{s\ (ft\ of\ head)}\right)$$

7.6 Exfiltration Trench or French Drains

Volume provided by Exfiltration Trench or French Drain BMPs is estimated by the following equation.

Equation 11 - Storage Volume Provided by Exfiltration Trench

$$V_{Exfiltration\,Trench} = A_1 \; x \; 3.28 \; in \; x \; \left(\frac{1ft}{12in}\right), (ft^3)$$

Where,

$$A_1 = Project\ Site\ Area\ Captured\ by\ the\ Exfiltration\ Trench\ , (ft^2)$$

Refer to **Figure 6-12** and **Figure 7-1** for a schematic of the equation parameters.

Drainage trenches in a given system have the ability to exfiltrate, or extract, up to 3.28 inches of the total rainfall depth produced by a design rainfall event over the area contributing runoff. This is an accepted practice by DRER and the SFWMD. The project area shown in **Figure 7-1**, the total project area is contributing to an exfiltration trench.

Figure 7-1 - Area Attributed to an Exfiltration Trench Length

The 3.28-inch parameter in **Equation 11** is the amount of rainfall produced from 5-year, 1-hour storm event and the maximum extraction amount allowed by SFWMD. No additional exfiltration credit is accounted for the drainage trench systems because the volume is accounted for by the 3.28 inch.

Infiltration provided by Exfiltration Trench BMPs is estimated by **Equation 12**.

Equation 12 - Infiltration Provided by Exfiltration Trench

$$I_C = I_R \; x \; A_{Exfiltration} \, , \left(\frac{ft^3}{s \; (ft \; of \; head)}\right)$$

Where,

$$A_{Exfiltration} = \frac{V_{Exfiltration \; Trench}}{D_C}$$

7.7 Green Roofs or Rain Barrels/Cisterns

Volume provided by the Rain Barrel/Cistern BMP is estimated by the following equation.

Equation 13 - Storage Volume Provided by Green Roofs and Cisterns

$$V_{Rain \; Barrels} \; (ft^3) = Total \; Volume \; of \; Rain \; Barrel \; or \; Cistern, \; (ft^3)$$

There is no infiltration extraction associated with this BMP. Refer to **Figure 6-12** and **Figure 7-1** for a schematic of the equation parameters.

7.8 Permeable Pavements

Volume provided by Permeable Paver BMPs is estimated by the following equations.

Equation 14 - Storage Volume of Permeable Pavement

$$V_{Permeable \; Pavement} = V_1 \, , (ft^3)$$

Where,

$$V_1 = D_1 \; x \; A_1 \; x \; 0.50 \; (assumed \; void \; ratio) \; , \; (ft^3)$$

Infiltration provided by Permeable Paver BMPs is estimated by the following equation.

Equation 15 - Infiltration Provided by Permeable Pavement

$$I_C = I_R \; x \; A_I \, , \left(\frac{ft^3}{s \; (ft \; of \; head)}\right)$$

Refer to **Figure 6-18** for a schematic of the equation parameters.

7.9 Retention Ponds

Volume provided by Retention Pond BMPs is estimated by the following equations.

Equation 16 - Storage Volume of Retention Ponds

$$V_{Retention\ Pond} = V_1\ , (ft^3)$$

Where,

$$V_1 = Physical\ Volume\ of\ Retention\ Pond, (ft^3)$$

Infiltration provided by Retention Pond BMPs is estimated by the following equation. Refer to **Figure 6-20** for a schematic of the equation parameters.

Equation 17 - Infiltration Provided by Retention Ponds

$$I_C = I_R\ x\ A_{Retention\ Pond}\ , \left(\frac{ft^3}{s\ (ft\ of\ head)}\right)$$

Where,

$$A_{Retention\ Pond} = \frac{V_{Retention\ Pond}}{D_C}$$

7.10 Parking Stormwater Chambers

Volume provided by parking stormwater chamber BMPs is estimated by the following equations. Refer to **Figure 6-23** for a schematic of the equation parameters.

Equation 18 - Storage Volume of Parking Stormwater Chambers

$$V_{Chamber} = V_1 + V_2\ , (ft^3)$$

Where,

$$V_1 = (Total\ Volume\ of\ Chamber\ ), (ft^3)$$

$$V_2 = A_2\ x\ D_2\ x\ 0.50\ (assumed\ void\ ratio), (ft^3)$$

Infiltration provided by Parking Stormwater Chamber BMPs is estimated by **Equation 19**.

Equation 19 - Infiltration Provided by Parking Stormwater Chambers

$$I_C = I_R\ x\ A_{Chamber}\ , \left(\frac{ft^3}{s\ (ft\ of\ head)}\right)$$

Where,

$$A_{Chamber} = \frac{V_{Chamber}}{D_C}$$

7.11 Site Credits

The following credits are established to account for evapotranspiration and irrigation:

1. Evapotranspiration (ET) represents the loss of water from the soil through the combined process of evaporation (from soil and plant surfaces) and plant transpiration. Daily evapotranspiration rates for South Florida are provided in **Table 7-1**.

Table 7-1 – Daily Evapotranspiration Rates for South Florida

Month	South Florida (in/day)
January	0.1
February	0.13
March	0.16
April	0.19
May	0.19
June	0.18
July	0.18
August	0.17
September	0.15
October	0.14
November	0.12
December	0.1

Source: Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, 1994.

Based on this information, the annual average ET volume credit is 0.15 inch per day. Therefore, the total annual ET volume (V_{ET}) credit would be computed as:

Equation 20 – Volume of evapotranspiration

$$V_{ET} = 0.15\frac{in}{day}\ x\ 365\ days\ x\ Site\ Vegetated\ area\ (ft^2)\ x\ \left(\frac{1ft}{12in}\right), (ft^3)$$

2. The frequency of irrigation varies based on each sties vegetation, rainfall amount, soil conditions, and drainage characteristics. The quantity of irrigation water demand will vary seasonally, and is greater on sites with more compacted soils and greater direct sunlight. As an example of irrigation water demand, the monthly irrigation water demand used for common varieties of turf-grass in Miami-Dade County are provided **Table 7-2**. The calculation of demand took into account monthly precipitation, average temperature, and other geological characteristics of the study area.

Table 7-2 – Monthly Irrigation Demand for Turf-grass

Month	Miami (in/month)
January	2.09
February	1.99
March	3.12
April	3.24
May	3.05
June	2.69
July	4.32
August	4.75
September	2.74
October	1.13
November	2.85
December	2.61

Source: Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, 2011

Based on this information, the annual irrigation volume credit is 2.88 inches per month. Therefore, the total annual irrigation volume (V_{IR}) credit is computed using **Equation 21**.

Equation 21 – Volume of irrigation water demand

$$V_{IR} = 2.88\frac{in}{month}\ x\ 12\frac{months}{year} x\ Site\ Irrigated\ Area\ (ft^2)\ x \left(\frac{1ft}{12in}\right), (ft^3)$$

Irrigation volume credits are accounted for in areas irrigated from runoff volume retained within storage LID BMPs. Irrigation credits will not be established for well or potable water irrigation sources.

8.0 APPROACH TO ESTABLISH EXCESS ANNUAL RUNOFF VOLUME

As part of the Stormwater Management Master Plan development for the SFWMD C-4 and C-6 Basins, DRER developed an average annual rainfall distribution (Miami FS) using the rainfall measure at the rainfall gauge from the Miami Field Station from January 1, 2012 through December 31, 2012. The total average rainfall for this period of record was 60.11 inches. The rainfall distribution is shown in **Figure 8-1**. The daily rainfall distribution matrix for this average annual rainfall event is included in **Attachment F**. This average rainfall event was also implemented as part of the City of Doral Stormwater Master Plan update in 2014 to estimate annual pollutant loading. The approach described herein assumes the adoption of this average annual rainfall event by the City of Doral for LID hydrologic and hydraulic analysis of development sites.

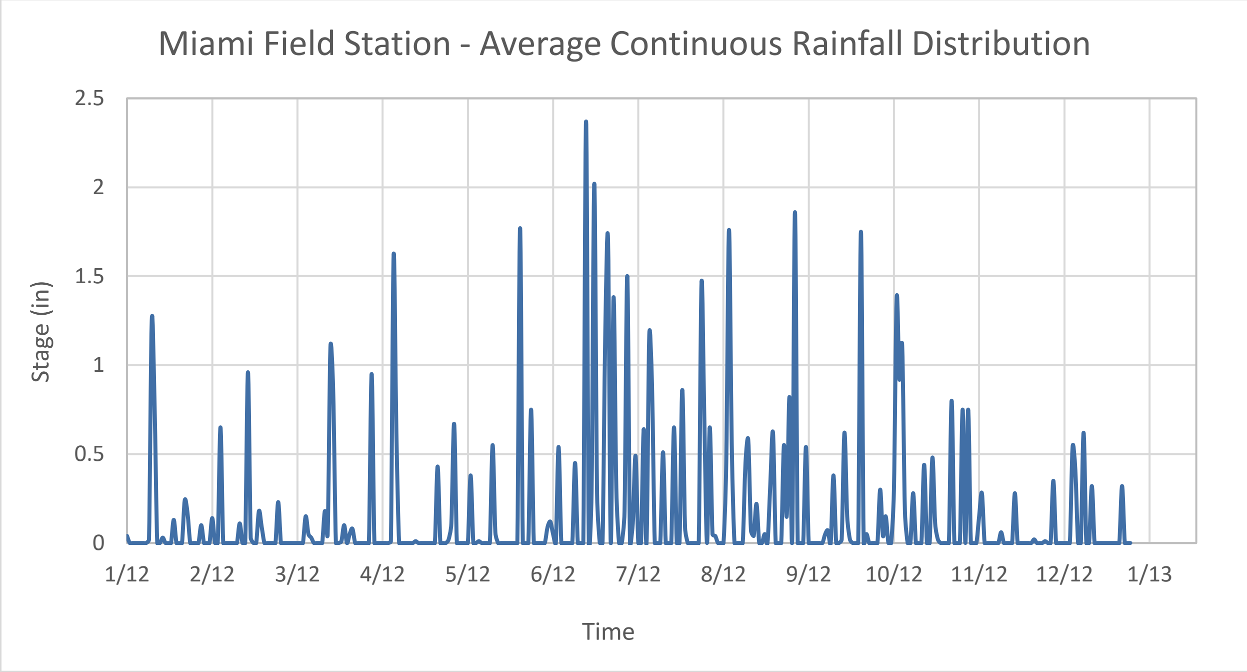


Figure 8-1 – Miami Field Station Average Continuous Rainfall Distribution

Quantification of the excess annual runoff from development sites will use hydrological/hydraulic computer modeling software to simulate routing the average annual rainfall distribution through the pre-development site and post-development site. The site parameters described in **Section 5.1** and **Section 5.2** are used to represent the site-specific conditions in the models for quantifying the excess runoff.

The models are constructed using basins, nodes, and links to represent the hydraulic and hydrologic data of the site. Nodes typically represent junctions in the model, runoff storage, and points of discharge leaving the site. Links represent the conveyance of water between nodes including overland flow, flow through traditional pipes, and infiltration.

An example of a node-link schematic for a typical model of a development site is shown in **Figure 8-2.** The site in the example is represented using a single B01 drainage basin with runoff discharging to the S01 onsite node. The parameters provided in the box callout for the drainage basin are the design parameters determined for the characteristics of the site. The OFFSITE node represents the offsite area receiving excess runoff from the site, typically the City right-of-way for sites in Doral. The groundwater table, receiving infiltration from the site is represented using the triangular Ground model node.

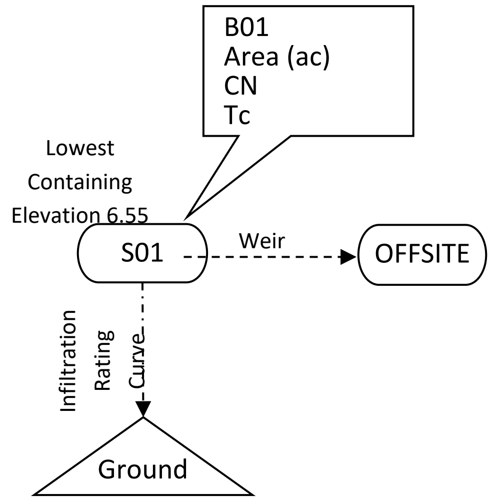


Figure 8-2 – Node-Link Schematic for a Model of a Development Site

It is recommended to use the stage-area relationship for the model nodes and to represent the treatment provided by structural LID BMPs. The representative area of the treatment provided by the structural LID BMP is determined by dividing the calculated LID BMP storage volume(s), using the equations provided in **Section 7.1 through 7.10**, and dividing by the containing depth, **Equation 22.**

Equation 22 - Representative BMP Area

$$A_{R.BMP} = \frac{\sum V_{BMP}}{D_C}$$

Where,

- $A_{R.BMP}$ = Representative BMP area (acres)
- $\sum V_{BMP}$ = Sum of the storage volume(s) calculated for each BMP with the approach outlined in **Section 7.1 through 7.10** (acre-feet)
- D_C = Containing Depth (feet)

For the stage-area relationship, the stages will range from the average October elevation at the site to the highest site containing elevation as illustrated in **Figure 8-3**.

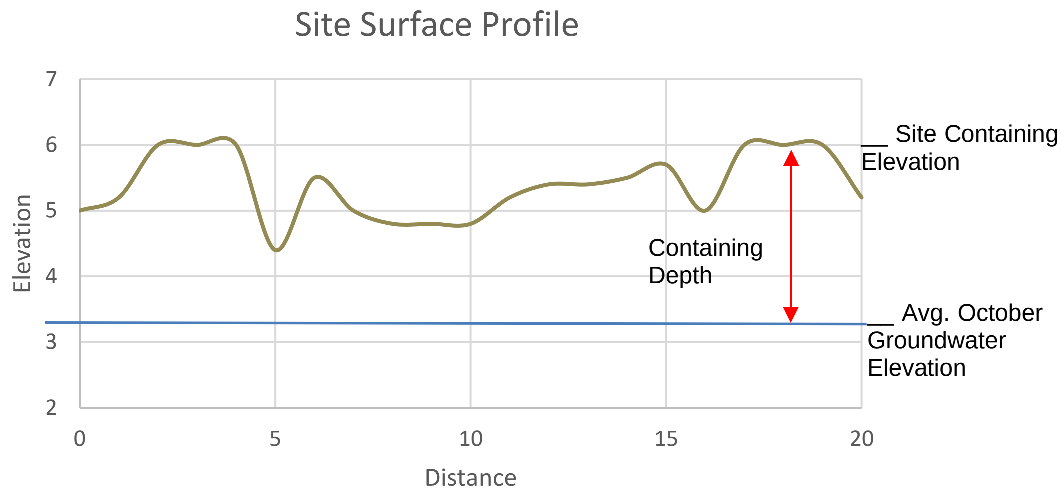


Figure 8-3 – Stage-Area Relationship

The amount of infiltration credit for LID BMPs discharging to the groundwater table will be simulated with a rating curve link in the model, using the sum of the infiltration capacity of all LID BMPs in cubic feet per second per foot of head. The infiltration capacity is calculated using **Equation 23**.

Equation 23 - Sum of Infiltration Capacity

$$\sum I_C = I_R \, x \, A_I$$

Where,

- $\sum I_C$ = Sum of Infiltration Capacity (cubic feet per second per foot of head)
- I_R = Infiltration Rate (feet per second per foot of head) *
- A_I = LID BMP Infiltration Area (square feet)

*I_R is estimated by performed Double-ring infiltration tests on site. It is recommended that that a minimum of one (1) Double-ring test per five (5) acres of existing or proposed open area.

The process used for development of the model representing the pre-development site and the model specific parameters needed depends on the pre-development site classification.

For the City of Doral, pre-development conditions will be classified as one of the following:

1. Natural, undeveloped site
2. Site with existing development

8.1 Natural, Undeveloped Pre-Development Site

A natural, undeveloped pre-development site is an area with no existing infrastructure including stormwater control infrastructure. Based on the sources cited in **Section 5.2**,the steps recommended for determining the pre-development excess annual runoff volume from a natural, undeveloped pre-development sites are as follows:

1. Develop the rainfall-runoff relationship for the catchment, or model node, using topographic and geologic data from the project site. Linear storage can be applied to most natural, undeveloped sites. It is recommended to use stage-area for the site storage representation in the model node.
2. The initial condition for each node should set as the lowest topographic elevation or the average October groundwater elevation as established by DRER for sites with open water or lakes. The average October groundwater elevation for the City of Doral ranges from 1.43 to 2.43 feet relative to the North American Vertical Datum of 1988 (ft-NAVD). The elevation conversion in the City of Doral is the National Geodetic Vertical Datum (NGVD) minus 1.57 to obtain NAVD.
3. Use the method described in Section 2-1 of TR 55 to establish the CN of the site based on the surface-to-groundwater depth relationship (see **Table 5-1**).
4. Determine the Tc for each catchment. The approach to estimate Tc is outlined in Chapter 3 of TR 55 (see **Section 5.2**).
5. Establish the available infiltration rate per foot of head based on information obtained from a Double-ring infiltration test performed at the site. The amount of infiltration will be simulated in the model by a rating curve link using the infiltration rate as a function of available hydraulic head.
6. Establish the available annual evapotranspiration volume. **Section 7.11** describes the approach for estimating the annual evapotranspiration volume.
7. Estimate the perimeter length of the lowest site elevation where runoff would be discharged offsite via overland flow (typically the City's right-of-way within the City of Doral). This will be simulated in the model by using a vertical weir link from the site model node to the Offsite model node.
8. Route Miami FS depicted in **Figure 8-1, Section 5.2**. The total average yearly rainfall for the period of record was 60.11 inches.

The total estimated pre-development annual runoff volume discharged offsite from the existing site to the City's right-of-way is determined by subtracting the total annual evapotranspiration volume from the total annual runoff volume discharged to the offsite model node.

8.2 Pre-Development Site with Existing Development

Sites that have infrastructure are classified as a pre-development site with existing development. This includes sites in which the existing infrastructure will be modified or replaced. The establishment of the excess annual runoff volume from the pre-development site needs to take into account the existing stormwater BMPs, and the existing irrigation use for vegetated areas. The steps to develop a pre-development site condition model of a site with existing development are as follows:

1. Develop a stage-storage node based on the topographic and geologic information for the project site. The storage node is most commonly represented in the model using a stage-area relationship.
2. If the site has existing LID BMPs, determine the retention volume available for each BMP by implementing the procedures described for each applicable LID BMP in **Section 7.0**. For existing LID BMPs using soil storage, reduce the retention volume by 50% to account for media clogging in the exfiltration systems and reduced system performance. The available BMP volume is then implemented as a stage-area relationship in the model.
    a. The area of the BMP is the total BMP retention volume divided by the total depth of the BMP.
    b. The stages for the structure will range from the average October elevation to the highest elevation of the site.

   This stage-area relationship is then added to the site model to develop and overall site stage-area relationship.
3. The initial condition for the stage-area node should be set as the lowest site elevation or the average October groundwater elevation as established by DRER for sites with open water, lakes or existing LID BMPs (whichever is the highest). The average October groundwater elevation for the City of Doral ranges from 1.43 to 2.43 ft NAVD.
4. Use the approach described in Section 2-1 of TR 55, to establish the CN of the site based on the surface-to-groundwater depth relationship (see **Table 5-1**).
5. Determine the Tc for each catchment. The approach to estimate Tc is outlined in Chapter 3 of TR 55 (see **Section 5.2**).
6. Establish the available infiltration rate per foot of head based on information obtained from a Double-ring infiltration test for all open areas and existing LID BMPs that promote infiltration. For existing infiltration systems reduce the infiltration capacity by 50% to account for reduced system performance. The amount of infiltration will be implemented in the model using a rating curve link and the infiltration rate as a function of available hydraulic head.
7. Establish the annual irrigation volume based on the vegetation areas of the site that are currently irrigated from runoff retained within the existing LID BMPs. Irrigation credits will not be established for well or potable water irrigation sources. **Section 7.11**. describes the approach for estimating annual irrigation volume credit for the site.
8. Establish available annual evapotranspiration volume credit for open vegetated areas. **Section 7.11**. describes the approach for estimating annual evapotranspiration volume credit for the site.
9. For a site with no outfall to a canal or receiving water body, estimate the perimeter length of the lowest site elevation where runoff would be discharged via overland flow to an offsite area (typically the City's right-of-way for sites in Doral). This will be simulated in the model by using a vertical weir link from the Site Node to the OFFSITE node, as shown in **Figure 8-2**. For sites with outfall(s) or control

structure(s), include the outfall(s) and control structure(s) as an additional link(s) discharging to the OFFSITE node.

10. Route Miami FS total average annual rainfall distribution depicted on **Figure 8-1** (see **Section 5.2**). The total average yearly rainfall for the period of record was 60.11 inches and this will be used to evaluate pre versus post conditions.

An example of a node-link schematic for a model representing a pre-development site with existing development is shown **Figure 8-4**.

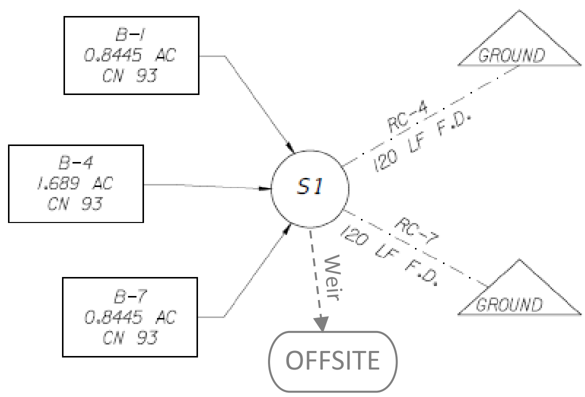


Figure 8-4 – Node-Link Schematic for Sites with Pre- Developments Condition Model for a site with Existing Infrastructure

In this example, the site has three French drains that are represented in the schematic by the three basin box callouts. The total length of French drain and total infiltration is implemented using rating curves represented in the schematic by RC-4 and RC-7. The total estimated pre-development annual runoff volume discharged offsite from the existing site is determined by subtracting the total annual evapotranspiration and irrigation volume from the total annual runoff volume discharged to the OFFSITE node.

8.3 Post-Development Conditions

For post-development sites the approach is very similar to pre-developed sites. The excess annual runoff is determined by routing the annual average rainfall distribution included in **Attachment E** through the available onsite storage, including the additional storage provided by the LID BMPs implemented, while accounting for available infiltration, evapotranspiration and irrigation. To develop post-development sites condition model:

1. Develop a stage-storage node based on the proposed site grading conditions. The storage should be represented in the model as a stage-area relationship.
2. For the proposed structural LID BMPs, determine the available BMP retention volume by implementing the procedures outlined in **Section 7.0**. The volume is then represented as a stage-area relationship in the model. The area is determined by dividing the total BMP retention volume by the total depth. The stages will then range from the average October elevation for the site to the highest site containing

elevation. This stage-area relationship is then added to the site storage defined above to develop and overall site stage-area relationship.

3. The initial condition for the stage-area node should set as average October groundwater elevation as established by DRER for sites with open water, lakes or existing LID BMPs. The average October groundwater elevation for the City of Doral ranges from 1.43 to 2.43 feet relative to the North American Vertical Datum of 1988 (ft-NAVD).
4. Use the SFWMD method to establish the CN of a site based on a surface-to-groundwater depth relationship (see **Section 5.2**).
5. The approach to estimate Tc is outlined in Chapter 3 of TR 55 (see **Section 5.2**).
6. Establish the available infiltration rate per foot of head based on information obtained from a Double-ring infiltration test and procedure outlined in **Section 5** for all open areas and proposed LID BMPs that promote infiltration. The amount of infiltration will be simulated in the model by developing rating curve link using the infiltration rate as a function of available hydraulic head.
7. Established annual irrigation volume based on site areas that will be irrigated from runoff volume retained within onsite LID BMPs. Irrigation credits will not be established for well or potable water irrigation sources. **Section 7** describes the approach for estimating annual irrigation volume credit for the site.
8. Establish available annual evapotranspiration volume credit for open vegetated areas. **Section 7** describes the approach for estimating annual evapotranspiration volume credit for the site.
9. For a site with no outfall to existing canal or receiving water body, estimate the perimeter length of the lowest proposed site elevation where runoff would be discharged via overland flow to an offsite area (typically the City's right-of-way). This will be simulated in the model by using a vertical weir link from the Site Node to the OFFSITE node. For sites with outfall(s) or control structure(s), include the outfall(s) and control structure(s) as an additional link(s) discharging to the OFFSITE node.
10. Example of a node-link schematic for sites with existing developments condition model is shown in **Figure 8-5.**Error! Reference source not found.
11. Route Miami FS total average annual rainfall distribution depicted on **Figure 8-1.** The total average yearly rainfall for the period of record was 60.11 inches and this will be used to evaluate pre- versus post conditions.

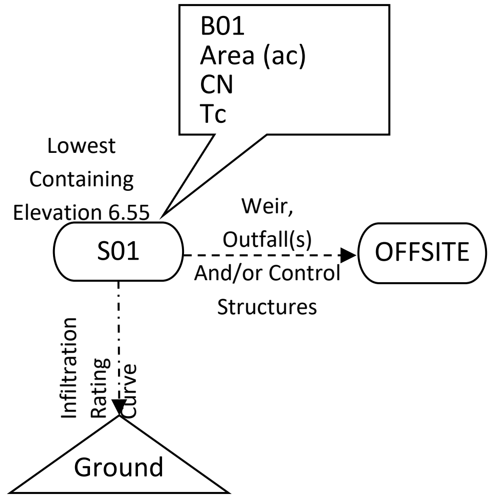


Figure 8-5 - Node-Link Schematic for Post Developments Condition Model

The total estimate post-development annual runoff volume discharged offsite from the existing site to the City's right-of-way is determined by subtracting the total annual evapotranspiration and irrigation volume from the total annual runoff volume discharged to the OFFSITE node.

9.0 SAMPLE APPLICATION

The intent of the sample application is to provide an example of applying the LID BMPs pre- versus post-development runoff volume approach outlined in this manual for the Doral area. For the following example, all the parameters were obtained using the processes outlined in the previous sections of this Master Plan. The average annual rainfall provided in **Attachment F** was the rainfall event used in this example.

9.1 Existing Conditions

The selected project site is the Proposed Doral Commons based on the plans prepared on January 20, 2014 and provided by the City of Doral. The site in existing conditions is an undeveloped natural site consisting primarily of vegetation and grass areas. The containing elevation varies greatly along the perimeter of the site with the lowest elevations along the back side of the property. A hydrologic/hydraulic model was developed using ICPR4 to quantify the pre-development annual offsite runoff volume of the natural site condition.

- Total Site Area = 22.06 Ac.
- Pervious Area = 22.06 Ac.
- Impervious Area = 0.00 Ac.
- Containing Elevation = 3.81 ft-NGVD

The following approach was implemented in setting up the pre-development ICPR model (see **Attachment H** for the Node-Link Schematic):

1. Develop a linear storage or stage-storage node for the site area:
    a. Node S1: stage-area node (22.06 acres)
    b. CN 94
    c. TC 60 minutes
    d. Initial condition set to 3.8-ft (Average October Groundwater Elevation)
2. DHW elevation is set to 3.8-ft NGVD
3. Infiltration rate per foot of head obtained from a double-ring test for all open areas (61.02 ft^3/s per ft-head).
    a. Develop a rating curve link using the infiltration rate as a function of available hydraulic head for all site area where infiltration is possible.
4. Vertical Weir was set up and the containment elevation to allow runoff to be discharged to the OFFSITE node:
    a. Weir back at elevation 3.81 ft

The total estimated pre-development annual runoff volume discharged offsite from the existing site to the City's right-of-way is determined by subtracting the total annual evapotranspiration volume from the total annual runoff volume discharged to the OFFSITE node. Refer to **Attachment H** for calculations and supporting information.

1. Total annual runoff received by OFFSITE Node: 108.8 ac-ft.

2. Annual evapotranspiration volume for open vegetated areas (22.06 Ac) is 100.6 ac-ft.
3. Total Runoff to City's right-of-way for Pre-Development Conditions: 8.2 ac-ft.

9.2 Proposed Condition

Under the post-development conditions, the Proposed Doral Commons site consists of multiple commercial buildings, large open parking lots with vegetated islands, a dry retention pond, and Exfiltration Trenches. The post-development site has approximately 20% of open areas remaining.

- Total Site Area = 22.06 Ac.
- Pervious Area = 4.41 Ac.
- Impervious Area = 17.65 Ac.
- Containing Elevation = 7.0 ft-NGVD

The following approach was implemented in setting up the pre-development ICPR model (see **Attachment H** for Node-Link Schematic):

1. Developed a stage-storage node based on the proposed site grading conditions.
    a. Node SITE: stage-area node
    b. CN 97
    c. TC 10 minutes
    d. Initial condition set to 3.8 ft-NGVD (Average October Groundwater Elevation)
2. For the proposed structural LID BMPs, determined the available BMP retention volume by implementing the procedures outlined in **Section 7.0**. The volume was then represented as a stage-area relationship in the model.
    a. Area (total BMP retention volume/total depth).
        i. Dry Retention Pond:1.30 Ac
        ii. Exfiltration Trenches: 0.35 Ac.
    b. Stages range (3.8 ft-NGVD to 7.0 ft-NGVD)
    c. This stage-area relationship for each BMP was combined and added to the overall site stage-area relationship.
3. DHW elevation is set to 3.8-ft NGVD
4. Infiltration rate per foot of head (procedure outlined in **Section 7.0**) for all open areas and proposed LID BMPs that promote infiltration (3.60 ft^3/s per ft-head).
5. Develop a rating curve link using the infiltration rate as a function of available hydraulic head. Vertical Weir was set up at the containing elevation.

The total estimated post-development annual runoff volume discharged offsite from the proposed site to the City's right-of-way is determined by subtracting the total annual evapotranspiration volume from the total annual runoff volume discharged to the OFFSITE node. Refer to **Attachment H** for calculations and supporting information.

1. Total annual runoff received by OFFSITE Node: 0.00 ac-ft

   a. No offsite runoff is shown as the Dry Retention Pond and Exfiltration Trenches captured the annual volume of runoff.
2. Annual evapotranspiration volume for open vegetated areas (4.41 Ac) is 20.1 ac-ft
3. Total Runoff to City's right-of-way for Post-Development Conditions: 0.0 ac-ft

The total reduction in runoff from the pre-development to post-development condition is 8.2 ac-ft. The LID BMPs (dry retention pond, open areas and exfiltration trenches implemented in this example are more than adequate to ensure the post-development site does not contribute more runoff volume than the pre-development site to the City's right-of-way on an annual basis.

In addition to the hydrologic volume and discharge benefits, the Doral Commons retention pond BMP contains vegetation that provides benefits of habitat for wildlife, shade, improved aesthetics, and heat island mitigation.

10.0THE CITY OF DORAL SOIL EROSION AND SEDIMENT CONTROL PRACTICES

The City of Doral participates as a co-permittee with Miami-Dade County in the National Pollution Discharge Elimination System (NPDES) program. The program is aimed at improving stormwater runoff water quality and control erosion from construction activities. The City of Doral must address specified activities and program compliance stated within the Annual Reports and NPDES permit conditions.

The permit conditions require the Building Department, Planning & Zoning Department, Public Works Department, and Code Compliance Department to enforce the following activities as part of the Construction Site Erosion and Sedimentation Control (construction activity means the act of developing or improving land that involves the disturbance of soils and includes clearing, grading, and excavation). The Florida Department of Environmental Protection (FDEP), which administers the NPDES permits in Florida for the US Environmental Protection Agency (EPA), has determined that demolition activities must also meet the definition of construction activity:

1. **Submission of Erosion & Sedimentation Control plan**: Applicants for new construction projects or substantial improvements (i.e., additions, pools, etc.) shall submit as part of the mandatory permit submittal documents of an erosion and sedimentation control plan for the development of the site.

2. **Best Management Practices (BMPs) for Erosion and Sedimentation Control:** Three (3) mandatory erosion and sedimentation control best management practices shall always be implemented at each development site. These are:
   a) Temporary Gravel Construction Entrance & Exit **(Figure 10-1)**
   b) Storm Drain Inlet Protection **(Figure 10-2)**
   c) Staked Turbidity Barrier or Silt Fence **(Figure 10-3)**

   NOTE: The Preceding three elements of the plan must be implemented at the development site, inspected and approved by the Chief Building Official or designated inspector prior to the acceptance of the first mandatory Florida Building Code inspection request.

3. **Compliance with Erosion and Sedimentation Control Plan:** Mandatory Florida Building Code inspections and inspection for erosion and sedimentation control shall be performed simultaneously with construction inspections. Failure to maintain Erosion and sedimentation control measures during the entire construction phase will result in a rejected inspection request and/or Code Compliance Department action to be treated as a violation of the City's Code or Ordinance by the Code Compliance Office.

Figure 10-1 – Temporary Gravel Construction Entrance & Exit (a)

Figure 10-2 – Storm Drain Inlet Protection (b)

Figure 10-3 – Stacked Turbidity Barrier or Silt Fence (c)

10.1 Sustainable soil erosion and sediment control LID Practices

Uncontrolled erosion and sediment from land development activities can result in costly damage to aquatic areas and to both private and public lands. Excessive sediment blocks stormwater conveyance systems, plugs culverts, fills navigable channels, impairs fish spawning, clogs the gills of fish and invertebrates, and suppresses aquatic life.

The application of LID concepts and the associated emphasis on minimizing the areas disturbed, as well as breaking up drainage areas into small manageable sub-catchment areas, is in total agreement with the basic principles of erosion and sediment control. The application of LID technology can easily result in improved erosion and sediment control without significant additional effort.

An effective sediment and erosion control plan is essential for controlling stormwater pollution during construction. An erosion and sediment control plan is a site-specific plan that specifies the location, installation, and maintenance of best management practices to prevent and control erosion and sediment loss at a construction site. There are five basic stages for the development and implementation of a sound erosion and sediment control plan for any land development activity:

1. Planning
2. Scheduling of Operations
3. Soil Erosion Control
4. Sediment Control
5. Maintenance

10.2 Planning

Factors that influence erosion potential include topography, soils characteristics, timing of construction, drainage ways, natural vegetation and the areal extent of land clearing activities. These are described below:

- Topography: because of the effect of runoff, the longer and steeper the slope, the greater the erosion potential. Plan the development to fit topography.
- Soil Characteristics: include erodibility, permeability, depth to water table, and soils with special hazards including shrink/swell potential or slippage tendencies.
- Timing of Construction: schedule activities during the dry season or during dry periods whenever possible to reduce the erosion potential.
- Drainage Ways: apply perimeter controls to protect disturbed areas from off-site runoff and to trap eroded material on-site to prevent sedimentation in downstream areas. Keep runoff velocities low (less than 4 to 6 feet per second) and retain runoff on-site. Stabilize disturbed areas immediately after final grade has been attained or during interim periods of inactivity resulting from construction delays;
- Natural Vegetation: any existing vegetation that can be saved will help prevent erosion. Grass buffer strips can be used to remove sediment from surface runoff. Vegetation also slows the velocity of runoff and helps maintain the infiltration capacity of a soil.

- Areal Extent of Land Clearing Activities: minimize both the extent of area exposed at one time and the duration of exposure.

10.3 Scheduling of Operations

The scheduling stage should aim to expose the smallest practical area of land for the shortest possible time. In other words, 1 acre of exposed land will yield less sediment than 2 acres of exposed land, and an area exposed for 3 months will yield less sediment than an area exposed for 6 months.

The clearing, grubbing and scalping of excessively large areas of vegetated land at one time is an unnecessary invitation to sediment problems. These initial earth disturbing activities should be kept to a bare minimum or phased appropriately. The techniques that can be used to reduce erosion include, staging of construction, temporary seeding, and /or temporary mulching.

Staging of construction involves stabilizing one part of the site before disturbing another. In this way the entire site is not disturbed at once, and the time without ground cover 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.

10.4 Soil Erosion Control Practices

Soil erosion control practices does not begin with the perimeter sediment trap or basin. It begins at the source of the sediment, the disturbed land area, and extends down to the control structure. It is important to apply soil erosion control practices on disturbed areas to prevent off-site damage. The process of erosion occurs for the most part by the impact of falling raindrops and the energy exerted by moving water and wind. A reduction in the rate of soil erosion is achieved by controlling the vulnerability of the soil to erosion processes or the capability of moving water to detach soil particles. This can be accomplished by the use of techniques such as soil stabilization and runoff control practices.

Soil Stabilization includes vegetative, chemical, and structural measures to shield the soil from the impact of raindrops or to bind the soil in place preventing it from being detached by surface runoff or wind erosion. These include:

- Vegetative stabilization/seeding (temporary and permanent)
- Topsoiling
- Erosion control mattings
- Mulching
- Geotextiles
- Tree protection
- Preservation of mature vegetation

Runoff Control Practices are designed to reduce the amount of runoff generated on a construction site, prevent off-site runoff from entering the disturbed area, or slow the runoff moving through and exiting the disturbed area. The principal cause of soil erosion is stormwater runoff. Its control can be achieved through the proper use of vegetative and structural practices, and construction measures that control the location, volume and velocity of runoff. The following practices alone or in combination can accomplish proper stormwater handling for erosion control:

1. Reduction and Detention of the Runoff
    - Staging Operations
    - Grading and Shaping of Soil Surfaces
    - Manipulation of Slope Length and Gradient
2. Interception and Diversion of Runoff
    - Diversion Berm or Dike
    - Reverse Benches
    - Drainage Swales
    - Vegetation Buffers
3. Proper Handling and Disposal of Concentrated Flow
    - Vegetative Swales
    - Down-drain Structures
    - Outlet Stabilization

10.5 Sediment Control Practices

Whereas erosion control practices are designed to prevent soil particles from being detached, sediment control involves using practices that prevent the detached particles from leaving the disturbed area and reaching the receiving waterways. This is accomplished by reducing the capacity of surface runoff to transport sediments and by containing the sediments on site.

Sediment control practices are designed to slow the flow of water by spreading, ponding, or filtering. These will reduce the capacity of the water to transport sediment, and sediment settles out of suspension. Commonly used control practices include:

1. The preservation or installation of vegetated buffer areas downslope of the disturbed area to slow and filter the runoff
2. The construction of small depressions or dikes to catch sediment (particularly coarse-textured material) as close to its point of origin as possible
3. The construction of sediment traps or basins at the perimeter of the disturbed area to capture additional sediment from the runoff.

The amount of sediment removed from the runoff is mostly dependent upon, the speed at which the water flows through the filter, trap, or basin; the length of time the water is detained; and the size, shape, and weight of the sediment particles.

One of the underlying concepts of LID technology involves breaking up the drainage areas of a given site into very small catchment areas to disconnect hydraulically connected areas and to provide opportunities to increase the time of concentration and thus reduce peak discharges. Accordingly, this approach will benefit sediment control efforts by diffusing surface flow into many directions and providing more flexibility in the use of a variety of sediment control practices. Currently the most frequent approach is the use of Structural Practices or Sediment Basins.

Structural practices divert flows from exposed soils, store flows, retain sediment on-site, or otherwise limit runoff and the discharge of pollutants from exposed areas of the site. Such practices may include the following:

- Silt Fences
- Stone Outlet Trap and The Riprap Outlet Trap
- Earth Dikes
- Diversions
- Swales
- Sediment Traps
- Check Dams
- Subsurface Drains
- Pipe Slope Drains
- Level Spreaders
- Storm Drain Inlet Protection
- Reinforced Soil Retaining Systems
- Gabions
- Coagulating Agents

Examples of structural practices are shown in **Figure 10-4** through **Figure 10-6**.

Figure 10-4 – Sediment Trap & Spillway

Figure 10-5 – Level Spreader

Figure 10-6 – Stone Check Dams in Swale and Stone Outlet Trap

Sediment Basins (temporary or permanent) collect and detain runoff to allow suspended solids to settle out prior to leaving the site. The following guidelines are provided:

a) For drainage basins with 10 or more disturbed acres at one time, a temporary (or permanent) sediment basin providing 3,600 cubic feet of storage per acre drained, or equivalent control measures, should be provided, where attainable, until final stabilization of the site. The 3,600 cubic feet of storage area per acre drained does not apply to flows from offsite areas and flows from onsite areas that are either undisturbed or have undergone final stabilization where such flows are diverted around both the disturbed area and the sediment basin. For drainage basins with 10 or more disturbed acres at one time and where a temporary sediment basin providing 3,600 cubic feet of storage per acre drained, or equivalent controls is not attainable, a combination of smaller sediment basins and/or sediment traps and other BMPs shall be used. At a minimum, silt fences, or equivalent sediment controls are required for all sideslope and downslope boundaries of the construction area.
b) For drainage basins of less than 10 acres, sediment basins and/or sediment traps are recommended but not required. At a minimum, silt fences or equivalent sediment controls are required for all side slope and down slope boundaries of the construction area.
c) Areas that will be used for permanent stormwater infiltration treatment (e.g., stormwater retention ponds) shall not be used for temporary sediment basins unless effective measures are taken to assure timely removal of accumulated fine sediments, which may cause premature clogging and loss of infiltration capacity, and to avoid excessive compaction of soils by construction machinery or equipment.
d) Sizing of sediment sumps or basins – Key components in sizing sediment sumps for a BMP or in sizing a sediment basin include the soil particle size(s) to be settled, the flow velocity, and the length to depth ratio.

10.6 Inspection and Maintenance

It is important to implement a thorough inspection and maintenance program. This stage is vital to the success of an erosion and sediment control program. A site cannot be controlled effectively without thorough, periodic checks of all erosion and sediment control practices. When inspections reveal problems; modifications, repairs, cleaning, or other maintenance operations must be performed immediately. Particular attention must be paid to water handling structures such as diversions, sediment traps, grade control structures, sediment basins, and areas being revegetated. Breaches in the structures or areas being revegetated must be repaired quickly, preferably before the next rainfall.

Maintenance differs from the other activities in that it must begin as soon as the first practice is installed and must continue through all the succeeding activities until the permanent erosion control measures are established and functioning. All structural measures should be checked at the close of each workday and particularly at the end of the workweek. Also, they must be checked before and after each rainstorm of ¼ inch or more.

Diversion berms should be checked to see that they have not been breached by equipment. The condition of level spreader areas, waterways, and other outlets should also be checked. Traffic should be moving within the established access routes. Channels should be checked for sediment deposits or other impeding material. Repairs should be made promptly when damage is discovered. When repairing swales or other channels, the new lining material should be at least as erosion resistant as the original material. Vegetative measures and vegetative cover on structural BMPs require maintenance fertilizer and perhaps mowing. All sediment traps should be checked and cleaned out after each storm. Sediment basins should be cleaned out when the deposited material reaches the level designated in the plan or standards and specifications.

For further information on erosion and sediment control refer to the *State of Florida Erosion and Sediment Control Designer and Reviewer Manual (June 2007) and the Florida Stormwater, Erosion, and Sediment Control Inspector's Manual (FDEP 2005).* These manuals provide guidance for the planning, design, construction, and maintenance of erosion and sediment control practices.

11.0 CITY OF DORAL ORDINANCES

Current site development or redevelopment projects must meet, at a minimum, the stormwater quality and flood protection requirements outlined by the SFWMD, DRER, and the City of Doral. Normally, the water quality requirement is to provide retention of one inch of runoff over the entire site or 2.5 inches over the impervious areas, whichever is greater. For flood protection, at a minimum, roads and parking areas must be built at or above the 5-year, 24-hour design peak stage, the post-development runoff rate cannot exceed the pre-development rate, and the building finish floor elevations must be set at or above the 100-year, 3-day design storm event or the FEMA flood elevation, whichever is greater.

Developments incorporating LID techniques are required to adhere to the same ordinances, zoning regulations, water quality and quantity requirements, and land use designations as developments designed utilizing traditional stormwater management techniques. However, conventional zoning and land use regulations often limit the use or extent of LID alternatives available to the developer.

Typical zoning ordinances layout the requirements for the lot size and shape, the minimum width required for setbacks, right-of-way areas, and property frontages, and the width required for roadways, turnabouts, sidewalks, and driveways, and the extent of clearing and grading the site.

LID zoning alternatives provide more environmentally sensitive alternatives for development designs and encourage the use of green infrastructure. Alternative zoning options include the use of overlay districts, performance zoning, incentive zoning, impervious overlay zoning, and watershed-based zoning. These zoning alternatives provide greater flexibility for LID site development and set zoning regulations based on protecting the environmental resources of the site and often provide added incentives to the developer.

The City of Doral has amended their Land Development Code with Ordinance #2013-37, which provides general guidance for implementing green design concepts and LID practices in the Land Development Code. Article XIV, XV, and XVI, of the Doral Land Development Code, permits the use of rainwater harvesting, requires energy efficient lighting, and mandates LID practices be implemented in the development design and site plans. The City Ordinance Articles related to green design concepts and LID practices are provided in **Attachment I**.

Developers are required to implement LID practices for new developments and redevelopment sites. If it is not practical to implement LID practices on a site, the developer must demonstrate that these practices cannot be implemented because of site constraints and not because of financial impacts. Non-structural LID practices are required to be incorporated into site plans. In addition, structural LID practices must be implemented to ensure the post-development annual runoff volume does not exceed the pre-development annual runoff volume. The pre-development site is assumed to be in a natural vegetated state.

The following are the LID practices and site development criteria recommended for the City of Doral to implement for future development sites:

- Minimum vegetated/stormwater management space:
    - Commercial/Industrial – 15%
    - Residential – 25%
- Implement the following non-structural LID practices to the maximum extent practical. If not practical, developers must demonstrate that these practices cannot be implemented because of site constraints and not financial impacts.
    - Restoration and preservation of pre-development topography and soil profile
    - Preservation of native and local vegetation
    - Open space design and conservation
    - Minimization of total impervious areas
    - Reduction of DCIA
- The post-development annual runoff volume cannot exceed pre-development annual runoff volume for a defined average annual runoff event. The pre-development site condition must be assumed as natural and undeveloped when performing the pre-development hydrologic analysis.
- Implement a minimum of three (3) Structural LID practices from the following list**. At least one (1) of the chosen Structural LID practice must provide the function/benefit of treatment, aesthetics, and/or habitat as described in **Table 5-2**:
    - Bioretention Basins or Rain Gardens
    - Tree Box Filters or Infiltration Planters
    - Vegetated Swales
    - Filter Strips or Vegetated Buffers
    - Infiltration Trench
    - Exfiltration Trench or French Drains
    - Green Roofs/Rain Barrels or Cisterns
    - Permeable Pavement
    - Detention Ponds
    - Parking Stormwater Chambers

    ** Developers may introduce or propose other LID practices not included in this list for review and consideration by the City.

- Implement recommended onsite soil erosion and sediment control practices.
- Implement a five (5) year permit recertification process or add language in the permit conditions that the City has the authority to request maintenance records of LID practice every five (5) years.

12.0 CONCLUSION & RECOMMENDATIONS

The rapid land development and urbanization taking place in the City of Doral will have an impact on the natural urban hydrologic processes of surface water runoff patterns, infiltration, percolation to ground water, and evapotranspiration. Low Impact Development takes an innovative approach to mitigating these impacts and seeks to retain runoff and treat stormwater pollution at the source. The purpose of the LID Master Plan is to provide the City of Doral with guidelines and recommendations to adopt integrated LID BMPs and green infrastructure practices in future development sites.

The City of Doral has two ordinances (Ord. No. 2013-37, § 2, 12-3-2014) for the incorporation of LID practices into building plans, project designs, and site plans. The ordinances mandate that LID practices be included as part of site development plan, and provide provisions for rainfall harvesting facilities. It is recommended that the current Site Planning Regulations be amended with the addition of a requirement for a hydrological assessment of the pre- versus post-development conditions, implementation of a Site LID Design Strategies Checklist document into the current permit application, and the addition of more substantial details for the implementation of LID requirements, as well as provisions for sites where LID techniques are technically infeasible.

In addition, it is recommended that provisions for long-term maintenance, monitoring, and enforcement be developed. Long-term maintenance and inspection plans are required for LID systems and the entity responsible for the maintenance and monitoring should be clearly defined. Site Planning Regulations should be evaluated to minimize the requirements for property setbacks, traffic distribution network widths, sidewalk widths, and right-of-way areas.

Based on the data previously collected and evaluated, non-structural and structural LID planning practices were identified that will naturally treat and retain stormwater for new developments and redevelopment sites. The site planning process should incorporate LID strategies in each step of the process. The recommended priority for managing and capturing stormwater runoff is infiltration, evapotranspiration, capture and use, and treatment through biofiltration/bioretention systems.

Based on a review of the current City of Doral LID ordinance and LID management practices, the City's current site development approach does not require any LID BMP implementation or provide any guidelines. In the City of Doral, there is no requirements for minimum vegetated/stormwater management space for commercial or residential land use development, the water quality retention requirement is the first 1 inch of runoff, and the stormwater management system is required to meet pre- versus post-development peak discharge flow only.

12.1 Soil Erosion and Sediment Control

The measures outlined effectively isolate the development site from surrounding properties and, in particular, control sediment where it is produced, thus preventing its transport from the site. Diversions, berms, sediment traps, vegetative filters, and sediment basins are examples of practices to control sediment. Vegetative and structural sediment control measures are either temporary or permanent, depending on whether they will remain in use after development is complete. Generally, sediment is retained by (a) filtering runoff as it flows through an area and (b) impounding the sediment-laden runoff for a period so that the soil particles settle out. The best way to control sediment, however, is to prevent erosion.

The City of Doral implements standard on-site practices for sediment control which include inlet protection systems, silt fence, turbidity barriers, and temporary gravel construction entrances and exits. However, it is recommended that the City should include other erosion control practices as described, such as soil stabilization and runoff control. The erosion control practices would ensure the control of sediment at the source and again at the control structure, not only at the control structure as it is currently established.

13.0 SELECTED REFERENCES

1. Design Handbook for Low Impact Development Best Management Practices. Riverside County Flood Control and Water Conservation District. Riverside, California. September 2011.
2. Development Best Management Practices Handbook. Low Impact Development Manual. Part B – Planning Activities. City of Los Angeles. 4th Edition. June 2011.
3. Exfiltration Trench Reference Manual (ETRM) and ICPR Applications Manual (ICPR-AM) developed by the Florida Department of Transportation (FDOT) District 6.
4. Federal Interagency Stream Restoration Work Group (FISRWG). 1998. Stream Corridor Restoration: Principles, Processes, and Practices.
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6. Low Impact Development Design Manual. Alachua County, Florida. Draft September 2011.
7. Low-Impact Development Hydrologic Analysis. Prince George's County, Maryland. July 1999.
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10. Prince George's County Soil Conservation District. 1994. Soil Erosion & Sediment Control/Pond Safety Reference Manual.
11. SFWMD Environmental Resource Permit Applicant's Handbook Volume II, Section 3. (SFWMD Volume II).
12. State of Florida Erosion and Sediment Control Designer and Reviewer Manual. June 2007.
13. Stormwater Manual. Pinellas County, Florida. Draft January 16, 2016.
14. The Stormwater Quality Applicant's Handbook. Florida Department of Environmental Protection (FDEP), Draft March 2010.
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16. USDA Soil Conservation Service (USDASCS). 1967. Soil Survey, Prince George's County, Maryland. Prepared by USDA Soil Conservation Service in cooperation with the Maryland Agricultural Experiment Station.
17. San Francisco Stormwater Design Guidelines. June 2010 Version.
18. ASTM D3385-09, Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer, ASTM International, West Conshohocken, PA, 2009, www.astm.org

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ATTACHMENT A

City of Doral Low Impact Development Master Plan
Resident Workshop
June 1, 2016

On the evening of Wednesday, June 1, 2016 the City of Doral (The City) and ADA Engineering hosted a special workshop for the residents of The City regarding the development of Low Impact Development (LID) Master Plan and the establishment of protocols to minimize impacts from anticipated new development and redevelopment projects. The workshop was held at City of Doral Government Center Training Room as an informal open-house where residents were invited to attend and speak directly with engineers carrying out the development of the LID Master Plan, while also providing input to City officials.

Upon arriving, residents were asked to sign in and were given a packet containing general information about the LID Master Plan, as well as a list of Frequently Asked Questions. They were then referred to several boards that listed examples of non-structural LID Best Management Practices, depicted examples of structural LID Best Management Practices and LID erosion control practices, and conceptual diagrams illustrating impervious and pervious surfaces.

Roughly twenty residents attended the meeting, and each was able to speak directly with City officials who were present, which included Mayor Luigi Boria. Each resident was also able to speak directly with the engineers that are working on the LID Master Plan who were able to listen to resident's questions, complaints, and comments. All residents were encouraged to fill out a comment card with their thoughts, concerns, or suggestions.

The Workshop was a productive event that informed the City residents of the LID Master Plan and the benefits it will bring to The City in a very simple and accessible terms. Those residents in attendance who already had a working knowledge of the LID practices also profited from the experience, as they were encouraged to use their familiarity with the process and the plan to make suggestions.

City of Doral Low Impact Development Master Plan
Developer Workshop
June 29, 2016

As part of the public outreach efforts for the City of Doral LID Master Plan, the City of Doral (The City), in conjunction with ADA Engineering and EV Services, Inc. held a special workshop on the evening of Wednesday, June 29, 2016. The Workshop was held in the City of Doral Government Center Training Room. The City invited ADA Engineering to host a special meeting in which they would explain the LID Master Plan process and goals and solicit feedback on the recommended LID protocols.

The main purpose of the meeting was to build consensus on the final recommendations for the LID Master plan. A secondary goal of the meeting was to address any concerns about the impact the LID protocols being established would have on new developments and redevelopments. The Workshop also gave developers the opportunity to speak directly with engineers carrying out the development of the LID Master Plan and City officials including Mayor Mayor Luigi Boria.

Upon arriving, developers were asked to sign in and were given a packet containing general information about the LID Master Plan, as well as a list of Frequently Asked Questions. Alex Vazquez of ADA Engineering gave a brief presentation on the purpose and benefit of the LID Master Plan, went through a number of structural and non-structural LID site planning practices, and the LID integrated management practices, soil erosion controls, and sediment controls recommended for The City to implement.

Roughly twenty developers attended the meeting. All developers were encouraged to fill out a comment card with their thoughts, concerns, or suggestions. The Workshop was a productive event that informed the developers of the LID Master Plan and the recommended LID practices being established within The City. Those developers in attendance were also able to make recommendations to the engineers and City officials.

ATTACHMENT B

DATA REQUESTED - MATRIX

	Today's Date:	**9/9/2015**		**Low Impact Development Master Plan The City of Doral**	
	Entity	**CONTACT**	**PHONE/FAX**	**ACTION/RESPONSE**	**ACTION/RESPONSE**
1	**Miami Dade County** 701 NW 1st Court Miami, FL 33136	Planning Department Kimberly Brown brownk@miamidade.gov	P F P F	Provided information regarding their Comprehensive Development Master Plan - 8/31/2015	Waiting reply on policies related to specific aspects of LID - 9/8/2015
2	**City of Miami Gardens** 18605 NW 27th Ave Miami Gardens, FL 33056	Associate Planner Irma Matos imatos@miamigardens-fl.gov	P 305-622-8000 F x.2675 P F	Waiting on reply - 9/8/2015 Sent reminder. Request forwarded to Public Works Department	
3	**City of Miami Beach** 1700 Convention Center Dr Miami Beach, FL 33139	Environmental & Sustainability Division - Building Dept. Margarita Wells mwells@miamibeachfl.gov	P 305-673-7010 F P F	Waiting on reply - 9/8/2015 Sent reminder	
4	**SFWMD** 3301 Gun Club Road West Palm Beach, FL 33406	Kenneth Konyha kkonyha@sfwmd.gov		Provided information regarding SFWMD LID workshop focused on SLR - 8/31/2015	
5	**City of Orlando**	Ben Gray Stormwater Assistant Division Manager 407-246-2754	F	Directed to Municode website. Some city codes call for LID practices but the City does not have an LID Manual	Searching Municode website for LID practices in place.
6	**City of Sanford**	Michael Cash 407-688-5148	F	Contacted by phone and awaiting a return call. Many city ordinaces call for developers to follow LID guidelines.	
7	**City of Tampa**	Alex Awad 813-274-7865	F	Tampa does not have a formal LID due to lack of maintenace ability.	

DATA REQUESTED - MATRIX

	Today's Date:	9/9/2015		Low Impact Development Master Plan The City of Doral	
	Entity	**CONTACT**	**PHONE/FAX**	**ACTION/RESPONSE**	**ACTION/RESPONSE**
8	**Alachua County**	Stephen Hofstetter shofstetter@alachuacounty.us	F	LID Manual requested by email.	
9	**Hillsborough County**	Pete Owen 813-627-2600	F	Spoke to Marsha at Environmental Protection Commission of Hillsborough County (EPCHC). Was advised to speak to Pete Owen who is currently out of town	
10	**Orange County**	Online Research	F	Manual for LID Pilot program as well as project specific LID Report.	
11	**Pinellas County**	Manual Found Online	F	LID Plan & Incentives	
12	**Sarasota County**	Manual Found Online	F	LID Manual provided	

ATTACHMENT C

ASCE – EWRI Permeable Pavement Technical Committee Introduction of Committee Goals and Chapter 1of Guidelines "Design Considerations Common to all Permeable Pavements"

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ABSTRACT

The growing trend towards low impact development (LID), with distinct goals to increase infiltration, protect water quality and reduce costs for stormwater management, has resulted in a rapid increase in the use of permeable pavements across the country. In addition to the more commonly specified porous asphalt and pervious concrete materials, new products continue to emerge in the marketplace. These new products are made with materials ranging from recycled tires to ceramics.

Engineers, designers, regulators and/or planners are interested in using permeable products in place of standard impervious surfaces, but there are gaps in the technical data and historical performance data to support an open endorsement of the newer products. Standardized specifications are not available for many of these products and up-to-date technical information in a format useful for promoting, designing and implementing LID is needed.

The ASCE Permeable Pavement Technical Committee is comprised of individuals from the academic and scientific communities, engineering and planning professions, the regulatory community and industry technical representatives with expertise in permeable pavements. This paper will discuss the status of the Committee's goal to provide a guidance document for the use of permeable pavements. This paper has been prepared with material for the opening presentation to a mini-symposium on permeable pavement and also discusses the outline for Chapter 1 of the Committee Report to date. Chapter 1 discusses design considerations common to all types of permeable pavements including the need to identify site conditions; pollutant concerns; and installation, inspection and maintenance requirements.

INTRODUCTION

Many industry leaders and academic institutions have completed in-depth studies and prepared papers, design details and guidance documents related to the design and implementation of permeable pavements. However, there is currently no central clearinghouse for this evolving technical information. The lack of access to technical guidelines for design, installation and maintenance for permeable pavements has resulted in some failures in past installations [1]. While well designed, installed and maintained pavements are proven to have significant benefits without failure, past failures have reduced confidence in the widespread use of permeable pavements.

The goal of the Committee is to gather the most current information and prepare a technical guidance document to further the implementation of these technologies. While developing the outline for the document, which includes separate chapters for each of the current industry-accepted permeable pavement products, it became evident that certain design considerations were common to all practices. The specific practices currently included in the document are as follows: porous asphalt (PA), pervious concrete (PC), permeable interlocking concrete pavements (PICP), concrete grid pavers (CGP), plastic grid pavers (PGP) and pavements identified as “other” due to the variability in the manufacturer materials such as recycled rubber. Chapter 1 of the document describes some of the universal design considerations for permeable pavements. The workgroup is planning to prepare a decision tree to assist in the design process.

The design considerations identified to date for inclusion in the pending document are provided in the following sections and are generally categorized as 1. Regulatory Requirements, 2. Soil Conditions, 3. Site Conditions, and 4. Installation and Maintenance Concerns.

DESIGN CONSIDERATIONS COMMON TO ALL PERMEABLE PAVEMENT PRACTICES

1. Regulatory Requirements

Before considering permeable pavements for any site, it is critical to check for state or local requirements that may promote, prohibit or regulate the use of permeable pavements. Questions to ask regarding federal, state or local requirements include the following:

- Does your local regulatory agency allow permeable pavements?
- Are permeable pavements prohibited in certain areas, such as groundwater recharge zones?
- Are there credits in terms of stormwater utility fees, permitting fees, or site development benefits given for using permeable pavements?
- Are there regulatory hydrologic control requirements associated with the use of permeable pavements?
- Are there water quality control requirements specific with the use of permeable pavements?
- Are there specific design guidelines or specifications mandated under applicable federal, state or local regulations?

2. Soil Conditions

The driving factor for most design decisions is related to the existing soil conditions.

Preliminary Geotechnical/Soils and Subsurface Information

It is critical to obtain geotechnical/soils and subsurface information prior to the design of a permeable pavement system. It is necessary to determine if the existing soils have high, low or relatively no permeability. Permeable pavements can be implemented successfully with poor or limited permeability soils using subsurface reservoirs and/or under drains. Permeable pavements can also be used with minimal storage and infiltration when the goal is to focus on water quality benefits or delaying smaller more frequent storm flows (first flush) while larger flows are managed with other on-site stormwater system features. Subsurface condition information can aid in determining the goals of the permeable pavement system and the suitability of the specific site to meet those goals… which then determines the design.

While detailed geotechnical information, such as specific permeability rates, is required for the final design of the permeable pavement system, preliminary information is typically enough to determine design features and goals. This preliminary information can be obtained from site observations, soils maps, subsurface geology maps and test pit data.

Preliminary subsurface information includes the following:

- Soil classification from test pit data and/or soils maps
- Estimated permeability rate (range) based on soil classification
- Depth to groundwater
- Depth to bedrock, if present
- Identification/estimated elevation of aquatard or low permeability soils, if present
- Identification of known buried utilities or easements for past/future utilities
- Identification of known hazardous materials in subsurface soils and/or groundwater (on-site or in close proximity)
- Existing septic systems
- Existing wells

3. <u>Site Conditions</u>

Review of preliminary soils/subsurface information will help characterize site conditions, which is integral to evaluating permeable pavement design options. The following questions related to overall site conditions coupled with the identification of the preliminary soils conditions can help further refine design choices and goals:

- ***Regional Considerations*** – Is my site located in a region where the weather or availability of materials could effect my selection for permeable pavements and/or design specifications?

  While engineering details and specifications exist for certain permeable pavements, not all practices and specifications are transferable from one region of the country to another. The availability of materials or weather conditions may require modifications to specifications or the decision to not choose specific types of pavements.

- ***Infiltration*** - What level of, if any, infiltration is feasible with estimated permeability rates?

- ***Permeability Rates*** - If permeability rates are low:
    - Will site conditions support the design of a reservoir storage area with under drains?
    - If site conditions do not support the design of a reservoir system, is permeable pavement with under drains and no reservoir storage desired?

- ***Liners*** - Is a liner required to prohibit increased infiltration
    - Into a potentially contaminated area?
    - Into utility conduits, manholes, etc.?
    - From a high pollutant loading area into groundwater without additional treatment?

- ***Groundwater*** - Does depth to groundwater
    - Result in unacceptable groundwater mounding conditions?
    - Satisfy local/state infiltration system/groundwater separation requirements if applicable?
    - Allow for proper draining of the infiltration systems to ensure that storage is available for frequent design storms and that subsurface gravel base (where used) will function properly, (especially in cold weather climates)?

- ***Utilities*** - If buried utilities or easements are present, can the system be designed around them/away from them, or can they be appropriately protected or moved?

- ***Fine Particles*** - Is there a high level of fines in the existing soils?

  As noted in various studies completed by researchers from North Carolina State University and others[2, 3, 5], the percentage of fine particles (silts and clays) in existing soils is an important factor. While existing soils may be removed and replaced with higher permeability soils beneath the permeable pavements (to provide storage and potentially increase the infiltration potential), the threat of run-on of fine particles from adjacent soils onto the permeable pavement may still exist. This run-on of fine particles could result in clogging at the surface.

- ***Slope/Contours*** - What are the existing site contours? Would the subsurface infiltration be near any open sloped areas that would cause a concern for potential breakout/slope erosion?

- ***Land Use*** - What are the existing land uses, proposed land uses and neighboring land uses? Would increased infiltration effect:
    - Basements?
    - Septic systems?
    - Wells?

- ***Traffic Load* –** What is the anticipated traffic load/type? This will help define the best pavement options available.
    - What pavement is best suited for the traffic load/type?
    - What base course depth is appropriate for the traffic load expected?
    - Will all areas of the pavement receive the same type of traffic load and usage?

- ***Surface Clogging Threats*** – Is there potential for transport of clogging materials to the pavement surface? Such threats may include:
    - Fine materials from adjacent/disturbed soils
    - Particles from deicing practices that may enter the site via tires/vehicles
    - Leaf litter/plant debris from site

- ***Critical Resources*** –Are there critical resources, (e.g. drinking water supply) on or near the site? What measures can be taken to protect those resources if necessary?

4. Installation and Maintenance Concerns

All permeable pavements require protection from sources of clogging as well as maintenance to rejuvenate and maintain the intended permeability of the pavement. Reduced permeability is often a result of the following:

- Improper installation
- Pavements such as pervious concrete or permeable asphalt not mixed as specified and not field tested and approved prior to installation
- Lack of protection of the surface during construction activities
- Installation in the vicinity of disturbed soils under post-construction conditions
- Lack of regular maintenance

  Studies[1, 2] show that properly installed permeable pavements that have become clogged at the surface can be rejuvenated with cleaning practices and full replacement of the surface or sub-surface media can be avoided. Prior to recommending a permeable pavement installation, the designer should determine whether the location can be protected during construction and post construction from clogging sources, and that the recommended cleaning method(s) and schedule can be reasonably adhered to.

CONCLUSION

In summary, the permeable pavement designer must first complete an assessment of the applicability of permeable pavement for the project site and then focus on the specific type of pavement material, details for design and installation, as well as the long term maintenance and protection requirements for the pavement selected.

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Considerations in Selecting a (Bio)filtration Media to Optimize Lifespan and Pollutant Removal

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ABSTRACT

Many research studies have been published regarding the treatment efficiency of bioretention for a wide variety of pollutants found in urban stormwater runoff. However, limited information is available on predicting the treatability of these pollutants between media and between sites. Predicting the treatment ability of bioretention/infiltration/filtration media is a function of both soil and water chemistry. This paper begins that meta-analysis of pollutant removal as a function of chemistry. The results presented here are from a single project evaluating candidate bioretention media to meet numeric effluent limits and are based on a limited number of samples. As additional data becomes available in the spring, the analysis will be expanded. The preliminary results indicate that the media that appear to have the best removal ability for a wide range of metallic pollutants are those that have both cation exchange ability and comparatively high organic matter content. For metals, this also may require a lower media pH because of the generally increased solubility of metals at lower pHs. Lower pHs and higher organic matter contents, however, must be evaluated further if phosphorus removal is also desired since phosphorus is removed better at higher pHs and lower organic matter contents. These results also highlight the trade-offs in pollutant capture versus export when using ion-exchange media.

INTRODUCTION

Many guidance documents list percent removal rates for different stormwater controls. In filtration, infiltration, and biofiltration/bioretention treatment devices, these efficiencies (often extracted from the literature) may range from <30% to almost 100%. With the introduction of Total Maximum Daily Load (TMDL) and other water-quality permits/load allocations to some stream reaches and lakes around the U.S., it is imperative that reasonably accurate and defensible predictions of pollutant removals and effluent quality be made. These TMDLs may result in load allocations to nonpoint sources described as numeric effluent limits. While these load allocations may be presented as total recoverable (total) metal concentrations in the effluent water, achieving those concentrations may require removal of both particulate-associated and filtered ("dissolved") pollutants.

"Dissolved" pollutants are defined traditionally as the fraction of the total pollutant concentration that is measured after the water has passed through a 0.45-µm membrane filter. These are the pollutants that are considered to be the most bioavailable to the aquatic biota and therefore the greatest concern when they are discharged to receiving waters. For some pollutants, such as the nutrients and many of the major cations and anions in water, the majority of the pollutant is considered to be "dissolved." For example, nitrates and chlorides are mostly, if not all, found in the filtered fraction. However, for metals, the fraction of a certain metal that passes through the 0.45-µm filter is dependent on the metal and other constituents in the source water, so a consistent ratio of filtered to total metals cannot be applied (Figure 1). For metals such as copper and cadmium in the data set below, much of the total metals concentration can be particulate-associated (not filtered through a 0.45-µm membrane filter), while for others, such as thallium and antimony, most of the total concentration was associated with the filtered fraction, although the range of the filtered fraction can be highly variable, even for the same sampling location.

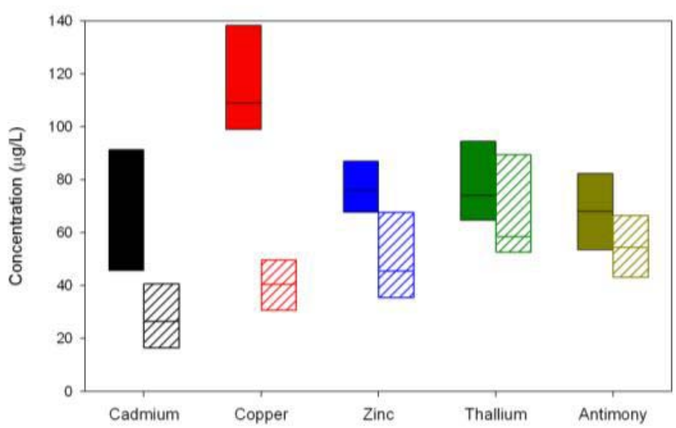


Figure 1. Total (solid fill) versus filtered (striped fill) metals concentration in example stormwater runoff (used to test biofiltration media).

Comparatively, particulate-associated pollutant removal is easy in (bio)(in)filtration systems. As the water passes through the pores, the larger particulates are strained out and trapped in the pore spaces of the media. This removal does not depend on the chemistry of the water and media, but on the pore size and the particle diameters. The removal of filtered pollutants, though, is dependent on the chemistry of the influent water and of the media. Laboratory testing and ranking of media has often been based on synthetic stormwater where the pollutants, particularly the metals, are in ionic form and performance rankings have been developed based on these tests. However, researchers such as Morquecho et al. (2005) have shown that metals that pass through these filters are not just ionic, but also can be associated with colloidal particles (both organic and inorganic) (Table 1). These complexes have different charge states than the original metal ions and therefore will react differently than the metal ion by itself. A media's ability to remove "dissolved" pollutants thus should be expressed not in generic terms but instead as a function of both the soil and water chemistry.

Table 1. Fraction Ionic vs. Bound Metals in Filtered Fraction from Source Area Stormwater (Morquecho 2005).

	% Ionic	% Bound
Zinc	15	85
Copper	70	30
Cadmium	10	90
Lead	12	88

This paper describes the preliminary investigation of the impact of both water and soil chemistry on pollutant removal. The paper is based on a long-term investigation of biofiltration media to remove pollutants to levels required for a southwestern United States NPDES permit. Detailed methods and results of this project can be found in Pitt et al. (2010). This paper focuses on generic measures of pollutant removal as a function of the water and soil chemistry. The preliminary conclusions in this paper will be further refined as data from ongoing research projects.

EFFECTS OF INFLUENT WATER CHEMISTRY

This effect of influent chemistry can be seen when comparing the removals of various filtered metals for a single media, for example, a peat-moss sand mixture (50/50 v/v) compared to a natural zeolite (50/50 v/v with sand) (Fig. 2). The three metals shown in the graph all have a preferred charge of +2 and should be equally removed by a medium if the primary removal mechanism is only ion exchange. However, the removals of these metals are different both within a single filter medium and when comparing removals between two or more media. Each of these metals can complex with both organic and inorganic material in water and their charge state after complexation may affect the preferential binding ability of the media for a particular metal. Removal of copper was slightly greater with peat moss than with zeolite, while antimony removals were better and occurred at higher volumetric loadings in the peat moss. This is likely due to peat moss's complex chemical nature which offers a variety of potential sorption/ion exchange sites. Another interesting note is the release of zinc from the media. Zinc may be participating in an ion exchange reaction on these media and therefore, zinc is released as copper or antimony is removed.

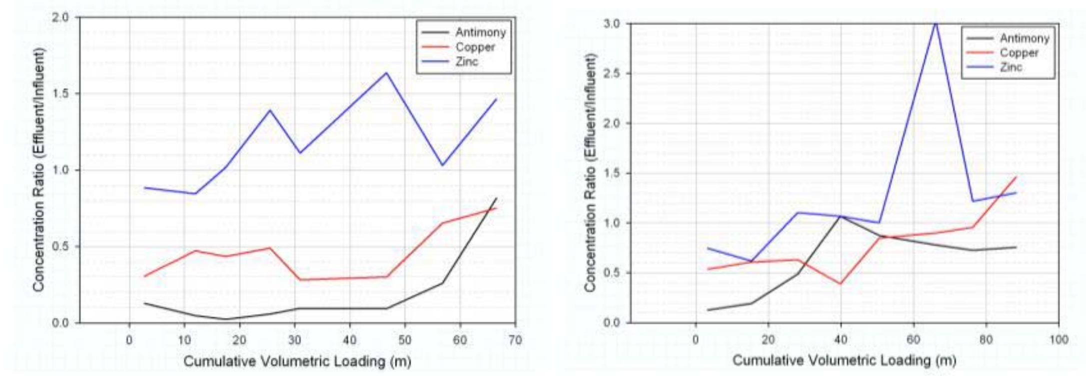


Figure 2. Removal of dissolved antimony, copper and zinc by a peat moss-sand mixture (left) and by a clinoptilolite zeolite-sand mixture (right).

Zeolite's primary removal mechanism is ion exchange of a loosely-bound cation (such as calcium, magnesium, and potentially aluminum or other polyvalent ion) with the metal of interest that is in solution. Zeolite retains these metals until a metal/cation that is more strongly attached to the charged lattice structure attempts to bind to the zeolite. At that point, previously captured metals may be released. Peat moss is a complex mixture of organic matter with a variety of organic acids available to participate in ion exchange. However, peat generally is low in divalent major cations such as calcium and magnesium and tries to scavenge calcium as a preferential exchange. The similarities in removals between the zeolite and the peat moss indicate that ion exchange is likely occurring in the media as a dominant mechanism. The lower effluent concentrations of antimony and copper with peat moss indicate that peat moss has the potential to participate in other binding reactions, such as those with the organic part of the complex. These are not reaction sites that are available on a zeolite.

In contrast to the zeolite, activated carbon's removal mechanisms tend to bind organic molecules. The removals of metals by peat moss and a virgin coconut hull-based granular activated carbon (GAC) are shown on Figure 3. The peat has approximately 40% of the carbon content of the GAC, and the data shows that the GAC has much poorer removals of antimony compared to the peat, but better removal of copper. Copper is more likely to complex with organic matter than antimony, the reduction of removal efficiency for antimony is not surprising in a media that is not known for substantial ion exchange of ionic free metals in solution.

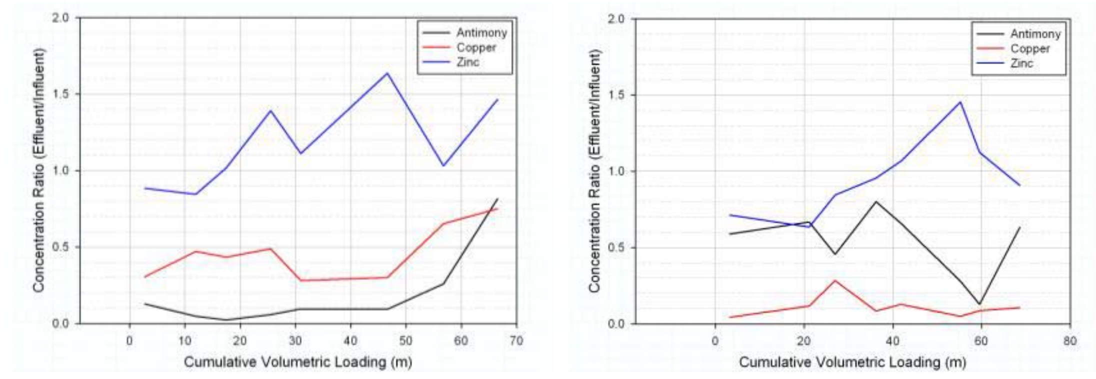


Figure 3. Removal of dissolved antimony, copper and zinc by a peat moss-sand mixture (left) and a GAC-sand mixture (right).

EFFECTS OF SOIL CHEMISTRY

Soil chemistry can be described using several parameters, including cation exchange capacity (CEC), anion exchange (AEC), soil pH, soil organic matter content, and the concentrations of phosphorus, nitrogen, iron, aluminum, and manganese. Parameters such as CEC and AEC do not measure specific chemicals in the soil but instead measure the ability of the soil to attract certain pollutants based on their valence charge. These parameters/constituents are easily measured and often are reported from a soils' analysis performed at the state agricultural laboratory. The concentrations/values of these parameters have been linked by many researchers to improved or degraded pollutant removal performance. Many researchers are working to optimize bioretention media for the removal of specific pollutants and are reporting the values for their specific media. Based on these studies, states have tried to improve bioretention media performance by suggesting ranges of values for various chemical properties. Table 2 shows a comparison of media composition guidance with a focus towards those documents that specify media chemical properties. A scan of the chemical properties column shows similar recommendations for media chemical composition. In some cases, the guidance has been copied from one region to another based on success in areas with a longer history of stormwater quality management. Another interesting point to note is that the media requirements are different between infiltration and bioretention systems. However, in many cases, these devices are used for the same purpose – water quality treatment, and use the same unit removal processes for the same pollutants.

Table 2. Bioretention Media Comparison for Different Areas of the US.

EPA Rain Zone	City, State	Infiltration Rate	Soil Type	Chemical Properties
BIORETENTION SYSTEM MEDIA				
1	PA		75% Loam, 25% Compost, <10% clay	pH: 5.5-6.5 Organic Matter (OM): 5-10%
2	VA		50% Sand, 20% Compost, 30% top soil	
3	Atlanta, GA		Loam w/ 10-25% clay	pH: 5.5-6.5 OM: 1.5-3% Soluble salts: <500 ppm
4	Columbia, MO		10-25% clay; 30-55% silt; 35-60% Sand	pH: 5.2-7.0 OM: 1.5-4% Mg: 35 lb/acre P_2O_5: 75 lb/acre K_2O: 85 lb/acre Soluble salts: <500 ppm
5	Austin, TX		S: 70-90%; clay: 2-10%	n = 0.45 OM: 1-4% CEC: 10 meq/100g
6	CA		L (10-25% clay)	pH: 5.5-6.5 OM: 1.5-3% Soluble salts: <500 ppm
7	WA		65% Loamy Sand; 35% Compost	pH: 5.5-7.0
8	WA		Loamy Sand	CEC: ≥ 5 meq/100g
9	Colorado Springs, CO		Sandy Loam and sand-peat mix	
		INFILTRATION SYSTEM MEDIA		
1	PA		loamy	
2	VA	0.52-8.27 in/hr	loamy mix (<30% clay)	
3	Atlanta, GA	3-5 in/hr		
4	Columbia, MO		HSG A and B	
5	Austin, TX	3.5 ft/day		
6	CA	0.2-0.38 in/hr w/ ponding	HSG A-D type soils w/ low clay	
7	WA	0.13 - 10 in/hr	loamy sands	CEC: ≥ 5 meq/100g
8	WA	0.5-2 in/hr	loamy sands	CEC: ≥ 5 meq/100g
9	Colorado Springs, CO	> 0.5 in/hr		

To date, no meta-analysis has been published of pollutant removal from stormwater runoff based on soil chemical properties. The research groups at Penn State Harrisburg and the University of Alabama have the data to draw preliminary conclusions about optimal mixtures for pollutant removal in infiltration/biofiltration/bioretention/ filtration systems for stormwater treatment, as noted in the above discussion. In addition, relationships between the soil parameters will be evaluated so that relationships can be developed between pollutant removal and a minimum number of soil chemistry measurements to minimize cost of analysis.

The three parameters most frequently listed above (in the guidance documents) and in the studies of bioretention media are OM content, CEC, and soil pH. Figure 4 shows the effects of each of these parameters on pollutant removal, with a focus on five pollutants (four filtered metals and phosphorus), each of which have different water chemistry and different levels of complexation in water. In addition, because much of the guidance historically has been focused on removal efficiencies and because the data shown here are from a single project with similar influent concentrations, the data is presented as median fraction removed ($1 - (C_e/C_0)$). Median fraction removed was selected as the exploratory parameter for effluent quality because it provides an "average" condition of the media. The median was used so that the influences of early washout from the media and later breakthrough, where it occurred, would be minimized.

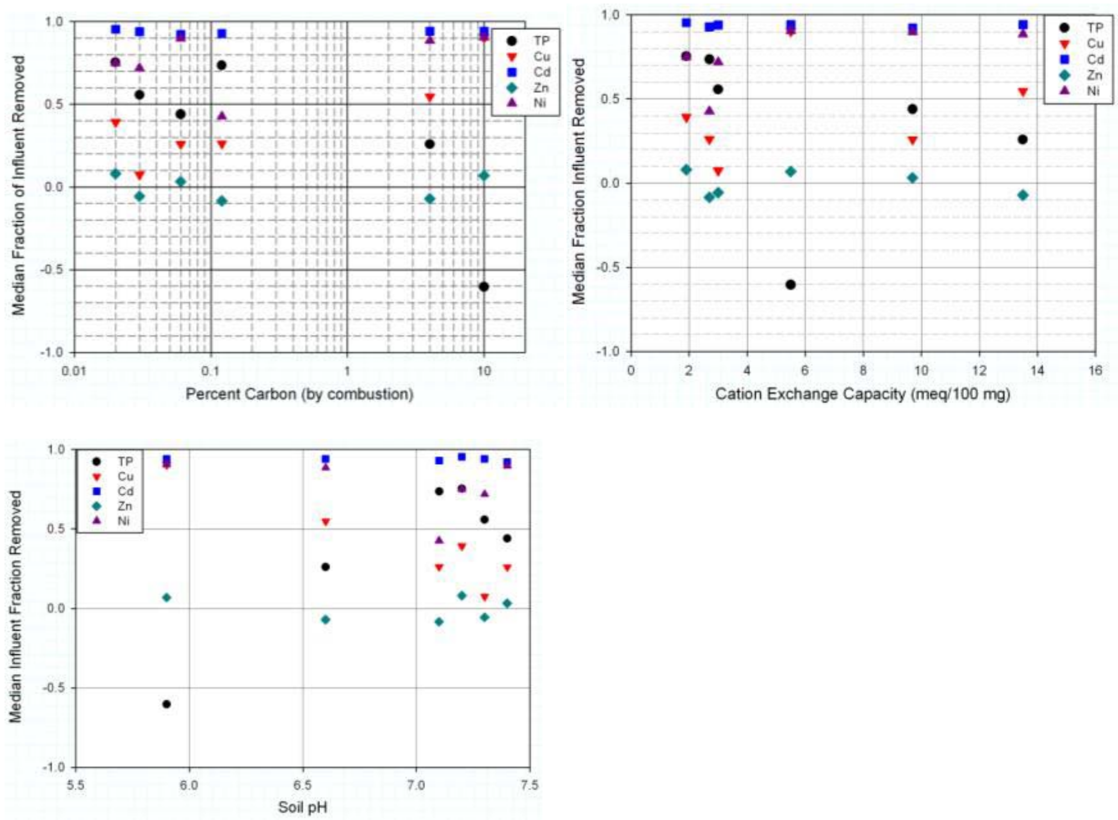


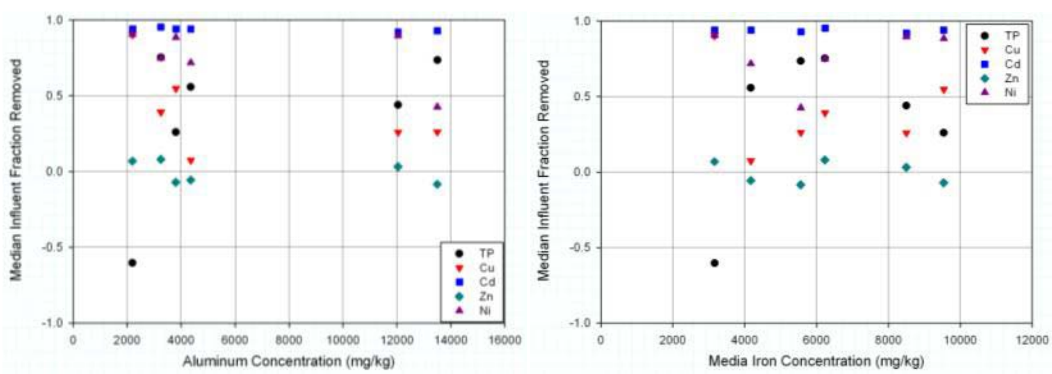
Figure 4. Effects of Percent Carbon (as a measure of OM), CEC, and soil pH on the removals of total phosphorus (TP), copper (Cu), cadmium (Cd), zinc (Zn), and nickel (Ni).

For the suite of metals analyzed, it was expected that removals would increase as the OM and CEC increased. However, this only held true for the dissolved copper. The CEC reported by the soils lab was effective CEC (CECe). It is the sum of the calcium, magnesium, and potassium concentrations released from the media during testing. It is a measure of the readily-exchangeable cations. CEC may be measured by several different methods. Other methods would likely have reported different values of CEC; however, it is anticipated that the data trends would remain consistent.

Although an increase in removal of filtered copper was observed as the CEC and OM increased, copper removal was found to decrease as the pH increased. As shown in Figures 2 and 3, copper removal was similar between the zeolite and peat moss media, with excellent removals seen with the coconut-hull GAC. This carbon had the lowest soil pH, while having the highest CEC and percent carbon. The CEC and OM of the soil decreased as the soil pH increased. This was not expected since the GAC effluent typically had the highest pH. For the other metals, however, median removal of these filtered metals was not dependent on soil pH, OM, or CEC. Zinc removal was poor, nickel was generally good, and cadmium removal was generally complete at the range of values seen in this study. These results indicate that, over the range of values and media used to date, removals may not be impacted by the media chemistry for Ni, Cd, and Zn. Zinc removal may be limited by prior zinc saturation of the media. Samples have been sent out for a comprehensive metallic analysis of the media.

Like filtered copper, phosphorus removal also showed trends based on soil chemistry. Phosphorus removal decreased as the organic matter content of the media increased and as soil pH decreased. Based on this limited set of data, carbon content in the media greater than 5 – 7% resulted in phosphorus export from the media, rather than its removal. This is particularly important in watersheds where phosphorus is a limiting nutrient. These preliminary results indicate that minimizing phosphorus content to the amount required for plant growth will improve phosphorus removal and retention in the media, although these results are limited because most of the media has a low organic content. Testing is ongoing with a local leaf-litter compost to add data points to that region of the graph to better isolate where phosphorus removal ends and export begins.

Studies also have related pollutant capture and retention to the concentrations of nitrogen, phosphorus, aluminum, iron and manganese in the media. The median fraction removed based on these parameters is shown in Figure 5.



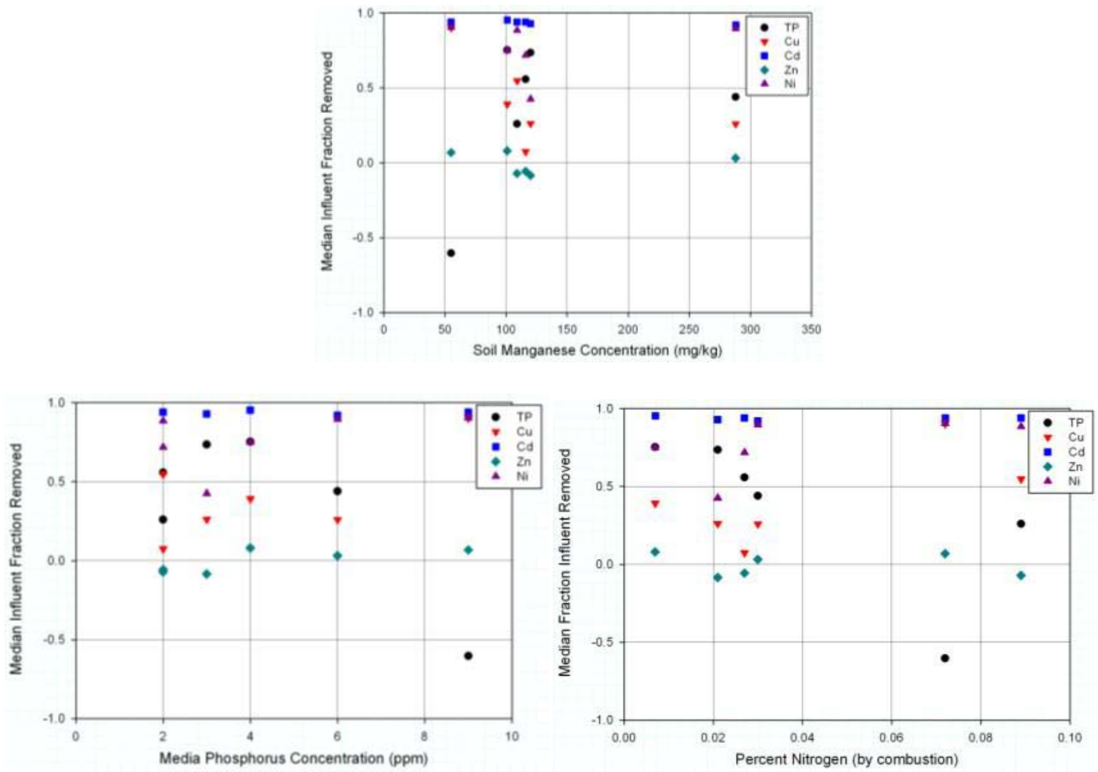


Figure 5. Effects of the concentrations of aluminum, iron, manganese, phosphorus and nitrogen on the removals of total phosphorus (TP), copper (Cu), cadmium (Cd), zinc (Zn), and nickel (Ni).

Since Cd, Ni, and Zn removals were consistent in the data used in these studies across the range of soil chemistry conditions (CEC, OM, and pH), it was expected that no effect of the concentrations of Al, Fe, Mn, P and N would be seen. The two pollutants for which effects were seen in Figure 4 were copper and phosphorus. For phosphorus, it can be seen that increasing aluminum concentration in the media will increase removals, while for phosphorus media content, concentrations above 6 ppm appear to result in reduced removals and potential transport. Additional samples from other media (such as compost and biosolids) will be analyzed to better isolate where the breakpoint is between removal and export of phosphorus. Copper removals were not affected by the concentrations of either nitrogen or phosphorus in the media, however, it appears that increasing the iron concentration in the media may lead to increases in copper removal. In general, the manganese data is extremely limited in its utility because most of the media had similar manganese contents.

These are preliminary analyses. The results indicate that interactions of media parameters/chemistry likely affect pollutant removals, as would be expected. Future work will be investigating these interactions as new data is available.

TRADE-OFFS

Pollutant removals in the bioretention media generally occur through ion-exchange reactions. For the design of bioretention facilities, it is important to know what ions are being exchanged during pollutant removal and to determine whether these exchanged ions are problematic in the effluent water and discharge location. An example of the trade-offs in pollutant capture versus ion export is shown in Figure 5 for a GAC-sand column of varying depths. In this case, the capture of cadmium was excellent and was not a function of column depth. However, deeper columns results in greater export of potassium from the media, likely as a result of ion-exchange reactions occurring in the media. These ion exchange reactions likely involve the capture of the metals as well as the capture of the hydrogen (hydronium) ion, since the pH of the effluent water was at least 1 pH unit higher than the influent water for these columns.

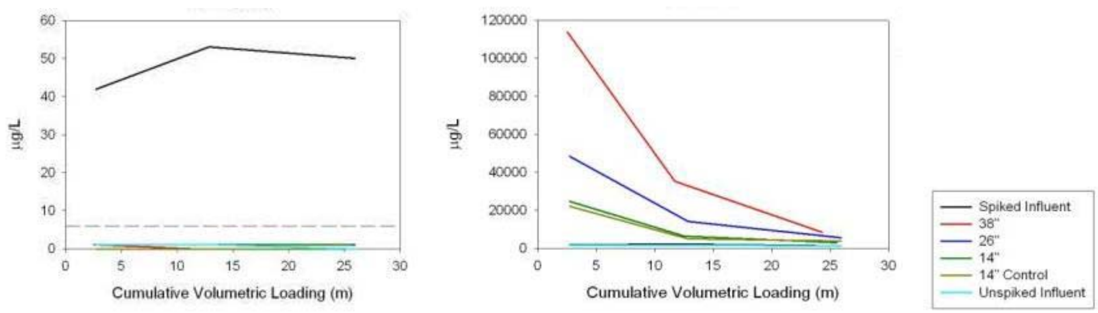


Figure 6. Ion exchanges for a coconut-hull GAC-sand mixture as a function of column depth for cadmium (left) and potassium (right).

Based on the results in Figure 6, it appears that a depth of 14 inches would be ideal since cadmium capture is not a function of depth in the ranges investigated during the supporting study, and it would minimize export of potassium from the media. However, as seen in Figure 7, this is not true for all pollutants. This GAC provided excellent capture of nitrate until its removal capacity was saturated. Increasing the depth increased the nitrate capture substantially. This is because the capacity for nitrate capture is small on a unit weight basis. Therefore, increasing the mass of GAC in the media improved the nitrate capture and resulted in a later breakthrough on a cumulative loading basis.

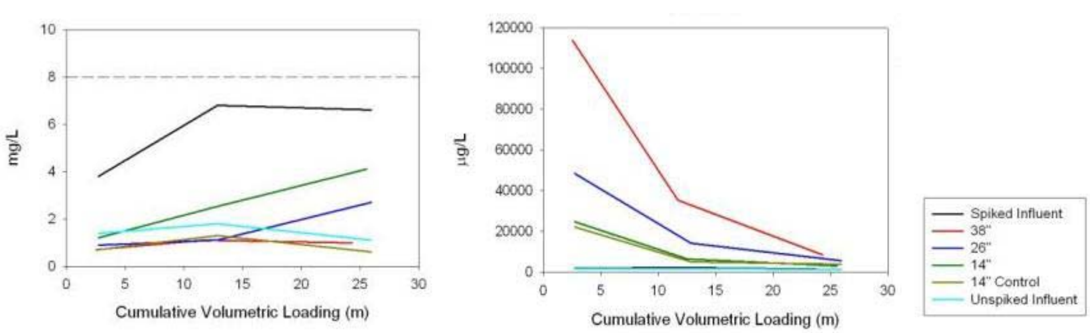


Figure 7. Ion exchanges for a coconut-hull GAC-sand mixture as a function of column depth for nitrate (left) and potassium (right).

CONCLUSIONS

What these simple data evaluations indicate is that predicting the treatment ability of bioretention/infiltration/filtration media is a function of both soil and water chemistry. It also indicates that the assumptions that all dissolved metals are ionic and are removed rapidly by media that provide ion exchange benefits are not true. Media that appear to have the best removal ability for a wide range of metallic pollutants are those that have both cation exchange ability and comparatively high organic matter content. For metals, this also may require a lower media pH because of the generally increased solubility of metals at lower pHs. Lower pHs and higher organic matter contents, however, must be evaluated further if phosphorus removal is also desired since phosphorus is removed better at higher pHs and lower organic matter contents. These results also highlight the trade-offs in pollutant capture versus export when using ion-exchange media. Additional data analysis is ongoing and will be completed by early spring 2010 to evaluate the correlations between various soil chemistry parameters/descriptors (cation exchange capacity, organic matter content, phosphorus content, iron content, aluminum content, soil pH) and the effluent water quality for more media types (and soil chemical parameters). Predictions of the water chemistry and complexation will be based on modeling, but using the measured water pH and measured metals concentrations. The percent complexed will be included as a factor in the analysis of pollutant removal efficiency.

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Pervious Asphalt Roads and Parking Lots: Stormwater Design Considerations

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ABSTRACT

Use of pervious asphalt requires creative stormwater design using available and adapted hydrologic and hydraulic modeling tools, highly integrated site design, and a coordinated design process. This is demonstrated by two very different Puget Sound area installations: Brickyard Park and Ride Lot Expansion, and Snoqualmie Point Community Park. Brickyard Park and Ride is an overcrowded park-and-ride lot on a constrained site requiring 200 additional spaces within a limited, suitable footprint. Snoqualmie Point Community Park is a new city park with an access road, turn-around, and parking for 23 vehicles on a sloped, wooded site.

Conventional stormwater facilities (traditional pavement with underground vault) were considered for Brickyard Park and Ride Lot and found to be more expensive than pervious pavement with detention storage in the pavement section. At Snoqualmie Point Park, utilization of an integrated low-impact stormwater approach was a primary design goal, in keeping with the natural character of the surrounding area and park design. This paper presents the stormwater design considerations for both projects.

BRICKYARD PARK AND RIDE LOT EXPANSION

Background.

King County's Metro Transit Division operates an overcrowded park-and-ride lot on a site located in unincorporated King County. The old lot had 257 parking spaces. The expansion site is at the north end of a vacant, 18-acre lot immediately south of the existing park-and-ride. Project goals were to expand the available parking by at least 200 spaces and to provide a comfort station (restroom) for bus drivers. Additional improvements to the site include: modifications to an existing bus-only access road and installation of a new traffic signal to provide passenger vehicle access to the new parking lot, and restriping of the old lot to gain additional spaces and provide for additional ADA requirements of the expanded lot.

Site constraints limited the available area for the parking expansion, with the new lot bordered on the west and south by wetlands, on the east by Interstate 405, and on the north by the existing lot. King County Department of Development and Environmental Services (DDES) has permitting jurisdiction for this development and required that the site meet stringent flow control and water quality treatment requirements, while maintaining existing hydrology of adjacent wetlands. Utilization of an integrated stormwater detention and asphalt pavement design allowed for overall cost savings and enhanced hydrologic benefit to the surrounding area. An experimental adjustment was required for permitting of the detention system due to the novel approach utilized at this constrained site.

Drainage System Description.

The stormwater management system at Brickyard Park and Ride starts with a pervious asphalt surface that allows rain falling on the paved surface to pass through the pavement to the rocked reservoir course below. The surface slope is 5%. The subgrade is also sloped to match the surface grade, allowing flow of stormwater to travel subsurface through the pavement base course to the low side of the parking lot to the west. At the low side of the parking lot, water is collected subsurface in an open chamber system that consists of several rows of arch-pipe sections with open bottoms set on a level surface. Drain rock is placed above, below, and adjacent to the arch-pipe sections to provide stability and additional storage volume. This underground chamber area provides the detention volume required to mitigate flow rates from the new parking lot. The bottom of the detention system is set approximately 2.5 feet above the seasonal high groundwater elevation. On the downslope side of the subsurface detention chambers, a compacted earthen berm prevents seepage of detained water westerly to the protected wetland. Instead, stormwater is released slowly through a two-orifice control structure that discharges to a minimally sloped biofiltration swale that provides basic water quality treatment and conveyance to downstream roadside swale. See Figure 1 below for an elevation view of the pavement and detention system configuration.

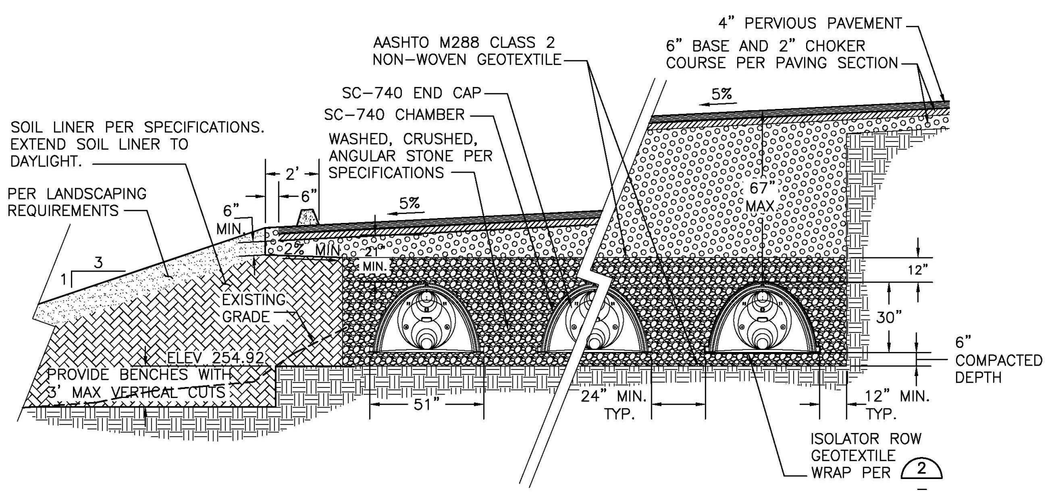

Figure 1. Integrated pervious asphalt and detention system

Other stormwater management components include interception of offsite runoff to prevent entry into the pavement subgrade. Intercepted offsite flows bypass the pervious asphalt detention system, and are discharged to vegetated areas upstream of wetlands A and B respectively. Other improvements to the site included a 2,180-square-foot expansion of the bus layover area, which is considered high-use and subject to higher loadings of oil and grease from the repeated parking of transit buses. For this reason, the expanded layover area was constructed of traditional (impervious) pavement, and a catch basin insert was provided for treatment of oils and grease from this small section of pavement. Runoff from this area post treatment is tightlined directly to the sub-pavement detention chamber system. See Figure 2 below for general layout of the new parking lot with existing and proposed drainage features.

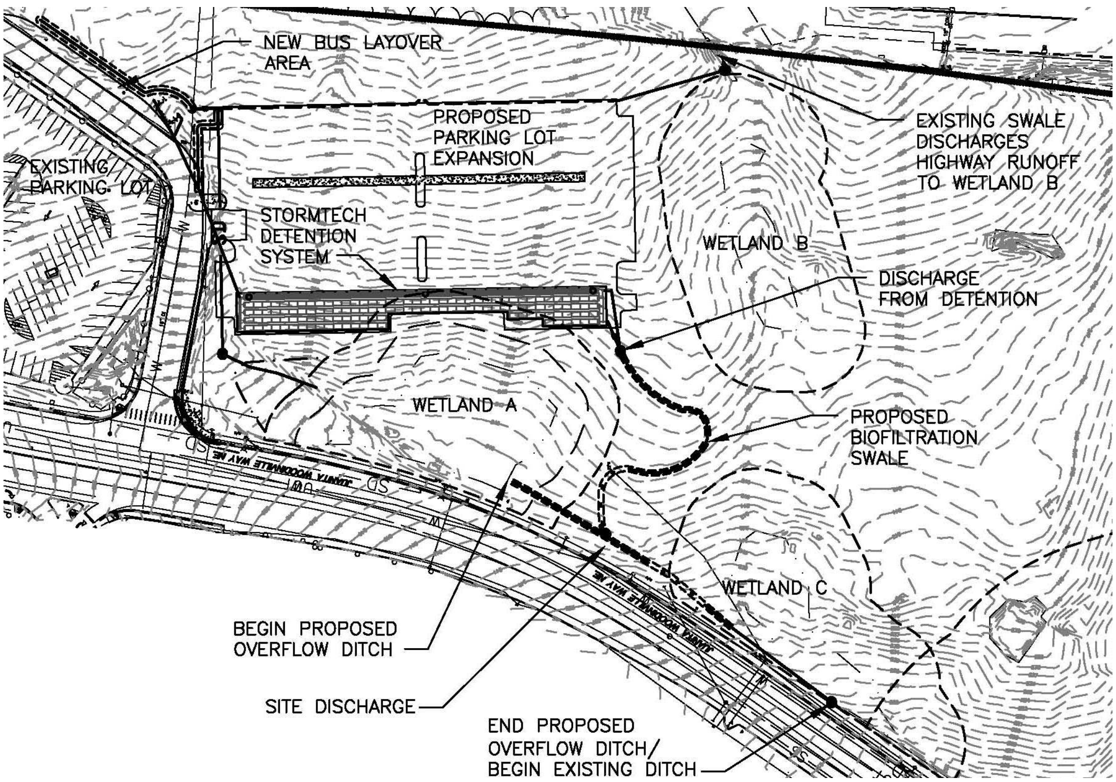

Figure 2. Site plan and conceptual drainage at Brickyard Park and Ride

SNOQUALMIE POINT COMMUNITY PARK

Background.

The Snoqualmie Point Community Park was made possible through the partnership of multiple stakeholders, including, Mountain to Sound Greenway Trust, the City of Snoqualmie, the USDA Forest Service and the Trust for Public Land. This project is located on a somewhat remote site owned by the City of Snoqualmie's Parks and Recreation Department, with incredible panoramic views of the Cascade Mountains and Snoqualmie Valley. A major component of the vision for its development is recognition of the regional view asset. The development is intended to highlight the natural environment. As such, site surface water management mimics the natural environment and uses low impact development techniques.

Local regulations required stormwater quality treatment and detention for the paved access road and parking, but did not specify green infrastructure techniques. However, the City readily agreed to an LID approach, including converting the existing gravel access road to a pervious asphalt road, turn-around and 23 parking spaces totaling almost one–half acre of pavement. Unique challenges included a 6% longitudinal slope on the road, and that the road was situated at the toe of hillside slopes on both sides, which resulted in considerable runoff being directed toward the roadway.

Drainage System Description.

Stormwater runoff at Snoqualmie Point Community Park is split between two sub-basins, with all of the pervious asphalt located in the western drainage sub-basin. The western sub-basin consists of a localized valley that receives onsite runoff from a vegetated spoils pile to the north, and offsite runoff from the hillside slope to the south. A gravel access road sloped at approximately 6% to the west is centered in the bottom of the valley. Runoff sheet flows to the gravel access road, then travels as sheet flow along the road or collects in a roadside ditch on the south side of the road. All runoff travels westerly towards the existing King County right-of-way.

The new drainage system in the western basin closely mimics the existing site conditions by maintaining the existing flow paths and providing mitigation for the improved access road and parking areas under the pavement section. The existing gravel access road was replaced with an expanded pervious asphalt access road with emergency vehicle turn-around. Parking spaces are provided along the access road for 23 cars. See Figure 3 below for a typical cross section of pervious pavement.

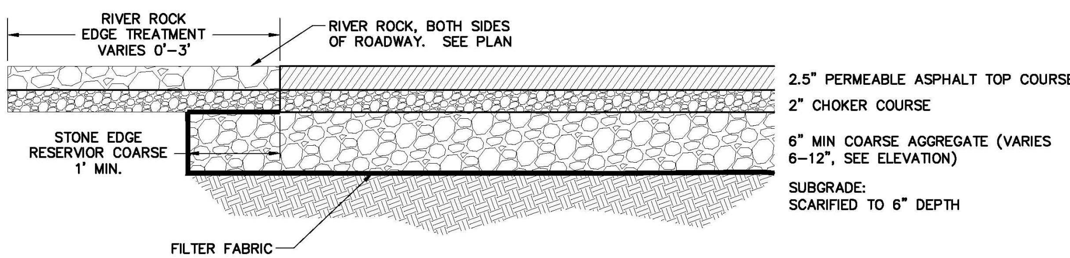

Figure 3. Pervious asphalt section

In order to maximize infiltration under the sloped access road and parking spaces, the subgrade was stair-stepped to provide flat-bottomed chambers under the pavement. Low-permeability filter fabric was placed on the downstream side of each underground chamber to provide a dam or barrier to keep water from free-flowing downstream within the pavement section. This effectively slows the migration of water, allowing it to infiltrate close to where it enters the pervious pavement system (see Figure 4 below). The reservoir course under the pavement was designed to provide storage and infiltration of all runoff from the access road and related parking, as well as offsite runoff from adjacent slopes.

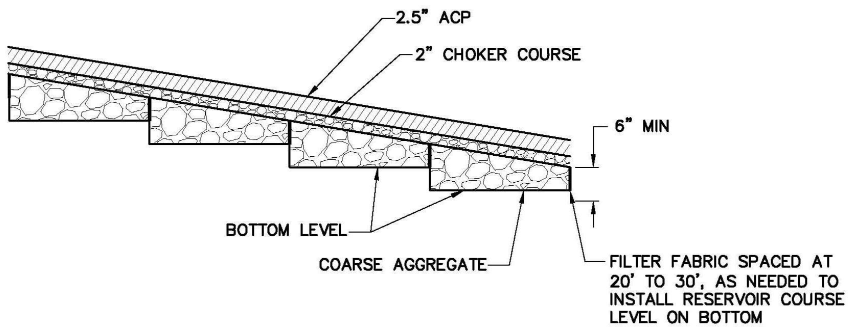

Figure 4. Pervious asphalt roadway elevation

Water quality treatment is provided within the native soils underlying the pavement section. This is allowed in the permitting jurisdiction when site infiltration rates are less than 9 inches per hour and there is 100% infiltration of runoff. These conditions are met, so no additional water quality treatment was required. However, a small raingarden is located within the turnaround island at the eastern end of the access road. The area is graded such that a low point will collect runoff from a portion of the localized hillside within the turnaround. This area has an overflow drain that conveys flows to the proposed roadside swale on the south side of the access road. This drainage component is a landscape feature, and is not sized to detain or treat surface water flows. However, due to amended soils, biological treatment capacity of vegetation, and the additional storage area provided, the raingarden provides beneficial mitigation, including storage and treatment within the west drainage sub-basin. See Figure 5 below for the site plan with existing and proposed drainage features.

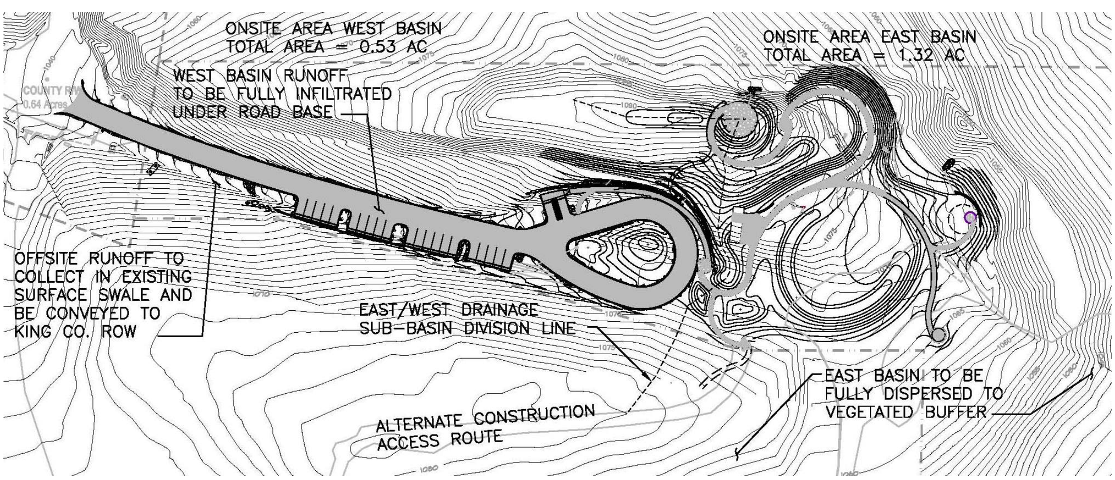

Figure 5. Site plan and conceptual drainage at Snoqualmie Point Community Park

STORMWATER DESIGN CONSIDERATIONS

The following stormwater design considerations must be taken into account for any integrated stormwater management plan utilizing pervious asphalt. Two design projects (Brickyard Park and Ride Lot Expansion and Snoqualmie Point Community Park) with very different design constraints are utilized to illustrate these design considerations. These projects demonstrate how stormwater modeling and overall civil site design can be creatively adapted through a highly integrated design process to suit specific site constraints.

Design Infiltration Rate.

Much importance in traditional infiltration facility design has been placed on having a design infiltration rate that will provide for quick drawdown of water within a facility. However, having a fast infiltration rate is not as much of a concern when designing a facility that distributes stormwater over a large area. This is because water can be stacked under the entire pavement section for distributed storage and slow release to the ground or slow release to a downstream conveyance system via an under-pavement flow control structure.

Infiltration rates at both Brickyard and Snoqualmie Point were relatively slow, with a design rate ranging from 0.04 to 0.2 inches per hour at Brickyard, and a design rate of 1 inch per hour at Snoqualmie Point. Due to the very slow design infiltration rate at Brickyard and other considerations to be discussed later in this paper, flow control modeling was designed as a detention-only system and did not account for infiltration in the design volume of the system. At Snoqualmie Point, the slightly faster design infiltration rate allowed for 100% infiltration of stormwater under the pervious pavement system. Stormwater sizing for both designs is discussed in detail under the Stormwater Modeling section of this paper.

Soil Type.

Western Washington soils are generally characterized as till, outwash, or wetland soils for the purposes of modeling stormwater runoff. Outwash soils tend to have faster infiltration rates and lower runoff potential than till or wetland soils. They are generally composed of highly permeable sands and gravels. Till soils are characterized by a relatively impermeable layer of glacial till at shallow depths, which tends to create interflow between the surface and impermeable layer. Runoff varies based on land use, with forested areas having very little potential for runoff and grassed areas having substantially higher runoff potential. Wetland soils typically have the highest runoff potential, as they are poorly drained and remain seasonally saturated.

The Brickyard Park and Ride site is underlain by Alderwood Material, which is generally categorized for stormwater modeling purposes as a till soil. Till soils are also consistent with the soil description given in the site geotechnical report, which identified soils as consisting of approximately 6 inches of surficial topsoil underlain by fill, native recessional outwash, and till.

Onsite soils at Snoqualmie Point Park in the vicinity of the proposed pervious asphalt access road are identified as Klaus Sandy Loam per the 1992 King County Soils survey. Supporting this finding, the site geotechnical engineer confirmed the soils as recessional outwash deposits. Also, Klaus soils are identified in the 2005 King County Stormwater Design Manual as outwash soils. However, for modeling purposes, the design team chose to model the soils as till. This decision was based on the fact that the existing gravel access road was compacted after years of use, reducing infiltrative capacity of the native soils below. Also, modeling soils as till results in a greater runoff potential for the developed condition hydrologic analysis, providing for a more conservative (larger) facility size when sizing storage volume for 100% infiltration.

To summarize, soil types for both projects were modeled as till soils. Generally till soils have a higher runoff potential and are less permeable than outwash soils, resulting in greater storage volumes required for stormwater management.

Topography.

Generally, pervious pavement applications work best in flat conditions. The LID Technical Guidance Manual for Puget Sound advises that slopes be less than 5%, with optimal design between 0% and 2% slope. Both sites were constrained by design slopes at the maximum end of the recommendation for effective stormwater management.

At Brickyard, we chose to grade the entire site to the maximum 5% slope in order to reduce cut and fill volumes to the extent feasible while remaining within a tolerable slope. This approach was in line with King County park-and-ride design guidelines, which also favor gentler slopes for driver and pedestrian safety and convenience. Existing slopes at the lot expansion site range from about 8% to 12%, so this design decision was a matter of balancing earthwork costs against effectiveness of the integrated stormwater management within the pervious asphalt section. A flatter slope across the lot would have resulted in a greater disturbance area needed to match back to existing grades, or construction of costly retaining walls on the upslope and/or downslope edges of the new parking lot.

At Snoqualmie Point the existing gravel access road was sloped at approximately 6%. In order to maximize infiltration under the sloped access road and parking spaces, the subgrade was stair-stepped to provide flat-bottomed chambers under the pavement. Low-permeability filter fabric was placed on the downstream side of each underground chamber to provide a dam or barrier to keep water from free-flowing downstream within the pavement section. This effectively slows the migration of water, allowing it to infiltrate close to where it enters the pervious pavement system. See Figure 4 of this paper for a graphic of the described system.

At both project sites, slope was a critical design factor that was carefully designed for in the stormwater management system. Two very different approaches to addressing slope were utilized based on site constraints, including permeability of the underlying soils. The slope greatly affected the final design and required extra coordination with the entire design team to ensure that an optimal balance between cost and stormwater management was achieved.

Depth to Groundwater.

Depth to groundwater is an important design consideration for facilities that will be storing stormwater below ground. Jurisdictions vary in the allowed spacing between seasonal high groundwater elevation and the bottom of the facility, and also have different requirements for detention than for infiltration facilities.

Potential high groundwater was a major consideration with the design of Brickyard. Early in the design process, the site geotechnical engineer gave measured groundwater elevations that were used for the preliminary design. Due to concerns about seasonal high groundwater elevations potentially impacting the under-pavement storage system, PACE requested that the geotechnical engineer install a piezometer in the vicinity of the proposed detention area. Readings were taken during saturated conditions in 2008, establishing the seasonal high groundwater elevation at approximately 252.5 feet. The bottom elevation of the detention system was set at 254.9, approximately 2.4 feet above the measured seasonal high groundwater elevation.

The seasonal high groundwater elevation was discussed with DDES staff at the pre-application meeting, where it was confirmed that the high groundwater elevation need only be below the bottom of detention storage, since this system is not designed for infiltration. In King County, infiltration facilities require 3 feet of separation from the bottom of the facility to the high groundwater elevation.

Confirming impacts of the seasonal high groundwater level was critical to stormwater design at Snoqualmie Point Park. Due to the 6% longitudinal slope of the road grade, the road subgrade required a significant amount of cut to produce areas of level subgrade. The geotechnical investigation provided borings from 10 to 12 feet deep and no groundwater or groundwater seepage was encountered. Site soils were very favorable for this application, given the significant depth to groundwater.

Adjacent Land Use.

The land use and cover of areas adjacent to a permeable pavement installation may require special considerations or adaptations to the design. Slopes that could potentially contribute offsite runoff to the pervious asphalt surface need to be especially considered with an edge treatment design that protects pavement from clogging with fines. Offsite runoff may need to be routed away from pavement if it cannot be effectively incorporated into the design. Finally, the presence of sensitive areas such as wetlands can influence how subsurface storage and release of stormwater is handled.

At Brickyard Park and Ride, the design was impacted both by offsite runoff from the upslope (east) side of the lot, and by a wetland located on the western edge of the expanded lot. In order to accommodate offsite runoff, an interceptor drain with perforated pipe was installed along the upslope edge of the lot. Runoff collected in this interceptor drain was then tightlined either south to an existing conveyance channel that discharges to Wetland B, or north to a bypass drain line that discharges west of the new lot to a vegetated area that drains to Wetland A. The interception and bypass of offsite flows around the parking lot support the continued hydration of the adjacent wetlands with runoff that potentially would have been collected and bypassed downstream of the wetlands had it been collected in the under-pavement detention system.

The presence of a wetland with a 50 foot buffer on the downslope side of the new pervious parking lot also presented a design challenge. Since water is detained subsurface adjacent to the wetland, a compacted earthen berm with high clay content was chosen to act as a barrier to subsurface flows. Hydraulic relief is provided subsurface via a flow control structure that releases stored water slowly to a controlled discharge at a bioretention swale. A separate emergency overflow structure also provides hydraulic relief to the underground storage chamber should the control structure become clogged, or storage within the chamber overtop the 100-year design storage elevation. The overflow elevation is set below the top of the compacted berm to ensure that stored water does not flow to the wetland. Wetland hydrology is maintained by water infiltrated throughout the pavement section, as well as by upstream offsite flows that are bypassed around the pavement section to the wetlands.

At Snoqualmie Point Park, areas adjacent to the pervious asphalt surface remain vegetated with a Western Washington foothills mixed forest of conifer and deciduous trees, as well as thick native understory plants. This results in significant forest duff, which limits runoff of eroded soil from the adjacent slopes migrating to the pavement section. However, some minor migration of soils can be expected, especially in the initial years following construction while disturbed plantings immediately adjacent to the access road are being reestablished. For that reason, an edge treatment was designed to ensure additional protection of the pervious pavement from runoff contributed from adjacent slopes.

A beautiful, natural-looking edge treatment was desired, in order to augment the natural landscaping design of the improved sections of the park. In keeping with the character of the park landscape design, a customized meandering "river-rock" edge was designed to line the edges of the asphalt. The reservoir course under the pavement section was extended 1 foot beyond the pavement edge and wrapped with filter fabric. The stone edge sets over this extended reservoir course to provide hydraulic connectivity while providing protection of the reservoir course with filter fabric. See the left-hand side of Figure 3 for a detail of the described edge treatment.

Offsite flows from the northern slope are allowed to migrate to the pavement section via this edge treatment, and the pavement was designed to allow infiltration of this minor amount of runoff. Offsite flows from the southern slope are collected in an existing drainage swale that runs adjacent to the access road. The existing swale was modified to accommodate the parking area, allowing post-development flows to maintain the same flow path as in the previously existing conditions.

Edge treatments, including whether to allow runoff to enter the pavement from upslope areas, or bypass the pavement, are a critical component of pervious asphalt design. There are many ways to handle this design component, but care must be taken to prevent migration of fines into the designed system, as well as account for additional volume of runoff within the storage under the pavement. Intensive coordination between the landscape designer and drainage engineer is critical.

Permitting.

Based on a relative lack of reviewer experience with pervious pavements and the uniqueness of local storm drainage codes, there is immense benefit in early and ongoing conversations with reviewers during design and permitting, and potentially during construction as changed conditions arise. Inexperience with pervious pavements and integrated stormwater management techniques can result in onerous permit approval requirements, as described below. Unique code requirements that do not anticipate new and adapted applications of products can require additional permitting hurdles. For example, use of arch-chamber technology was newly accepted in King County for stormwater infiltration systems and required no special approval. However, the Brickyard system was adapted for detention only, which was not specifically approved by King County's permitting authority, the Department of Development and Environmental Services, (DDES). As a result, an experimental adjustment was required, with additional review and oversight by DDES.

One condition of permit approval at Brickyard was the requirement to replace any pervious asphalt damaged by future utility installation or other repair with the same pervious product. In the future, we would seek to modify this requirement and condition it upon the percentage of surface impacted compared to the total impervious area, for example. Due to the very permeable nature of the pervious asphalt, a small area replaced with impervious surfacing would likely have a negligible impact on overall stormwater facility function. Temperature requirements for successful placement of the material are especially stringent for polymer-based mixes, such as that used at Brickyard. This requirement could potentially require placing a temporary fix of a standard asphalt mix until temperatures increase sufficiently to place the permanent, pervious mix. Due to the difficulties that many asphalt plants have in supplying a polymer-enhanced mix in small quantities, the requirement to replace with pervious becomes an even greater obstacle. For small areas, this can be cost prohibitive for the stormwater results achieved.

Cost.

Pervious asphalt installation per square foot, including the subgrade preparation and pavement base, is more expensive than traditional asphalt. However, considerable savings can be realized when considering the elimination of traditional stormwater management components such as conveyance piping, catch basins, and underground storage vaults and tanks.

At Brickyard Park and Ride, engineer's estimates of probable construction costs were prepared at 60% design for both a traditional pavement and pervious asphalt design. The first estimate was based on traditional impervious asphalt pavement with a stormwater conveyance infrastructure and additional below-grade detention storage. The second estimate was for the project with pervious asphalt and reduced stormwater infrastructure, as bid. Quantities for six items vary between the two alternatives, as follows:

- Catch basins and pipe are added for the traditional approach (8 catch basins and 630 lineal feet of 12-inch conveyance pipe).

- Underground storage volume in the arch-chamber system is increased for traditional approach.
- Earthwork cut and haul varies in two ways. Greater excavation is required to install underground storage for traditional pavement. However, this is offset roughly by the greater excavation required with pervious asphalt to account for the reservoir course.

The cost comparison results at 60% design are presented in Table 1 below.

Table 1. 60% Design cost comparison.

Pavement Type	Probable Construction Cost
Traditional (Impervious) Asphalt Pavement	$ 2,307,000
Pervious Asphalt Pavement	$ 2,219,000
Total Cost Difference	**$ 88,000**

A cost comparison was not performed for the design at Snoqualmie Point Community Park. However, similar if not greater savings would be anticipated due to elimination of the need for an underground storage vault or tank.

Contractor Experience.

In Washington State, the general contractor for public projects is selected through a competitive bidding process. On private projects, a general contractor may be brought on board at the developer's or owner's discretion and can also be selected through a competitive bid process. Due to the limited number of pervious asphalt projects that have been constructed, a designer can generally assume that the contractor will have limited experience preparing a site for pervious asphalt installation. Typical subgrade compaction practices cannot be utilized with pervious asphalt, so education of the prime contractor and all subcontractors that will be onsite prior to paving needs to be a primary focus during construction. Installation of pervious asphalt can typically be subcontracted to a paving contractor with experience installing pervious asphalt. At both representative projects, Lakeside Industries provided the pavement and installation. Lakeside had the most local experience with pervious asphalt and was a valued partner in the design and construction of both projects.

At Brickyard Park and Ride, avoidance of subgrade compaction was a real issue during construction. Due to the existing slopes of 8% to 12% and final desired maximum cross slope of 5%, significant earthwork was required, and included both cut and fill sections. Specifications were explicit about subgrade preparation to maintain the maximum infiltration capacity of the subgrade. Heavy construction equipment was to avoid compacting the subgrade with unnecessary travel as grading operations approached subgrade. Unfortunately, as the parking lot grading was occurring, a related operation was driving many full dump trucks across the under-construction parking lot, causing concern by the design team related to overcompaction of the subgrade. The contractor was directed to drive the hauling operation trucks through the cut sections of the parking lot; as cutting progressed, a minimum of six inches of cover was required to be maintained over the subgrade at all times. When hauling was completed, the parking lot grading was finalized and the last two feet of soil were removed.

At Snoqualmie Point Community Park, the general contractor also had no experience with pervious asphalt. The contractor was fortunate to have available a forest road to access the other work areas of the project. This allowed the new access road grading to be completed and the fabric-wrapped road segments to be installed and then not traveled over until paving was completed. Conveying the importance of not driving equipment over the graded access subgrade was critical, as well as working with landscape subcontractors in keeping their materials from washing into the rocked segments as they completed the landscaping.

STORMWATER MODELING

Flow control and water quality treatment can both be achieved in conjunction with pervious asphalt pavement design in a multitude of ways. This requires a highly adaptive and sometimes creative approach to stormwater modeling. Adaptive modeling is demonstrated by the diverse approach taken for the two representative case studies in this paper. Modeling at Brickyard Park and Ride includes detention storage sizing with water quality treatment provided in a downstream biofiltration swale, while modeling at Snoqualmie Point Community Park utilizes distributed infiltration storage under the pavement section, with water quality treatment provided in the native soil below the pavement section.

Both projects were designed to the requirements of the 2005 King County Surface Water Design Manual (KCSWDM). This manual encourages the use of low impact development stormwater management techniques, and prioritizes infiltration where appropriate for stormwater management. Flow control modeling for both sites was performed using the King County Runoff Time Series (KCRTS) software, a simplified continuous simulation modeling tool developed for projects permitted by DDES. The following describes modeling of each system.

Brickyard Park and Ride Lot Expansion Stormwater Modeling.

The KCSWDM requires "conservation" flow control and "basic" water quality treatment at the Brickyard site location. Conservation flow control requires matching historic flow durations for 50% of the 2-year through 50-year peak flows and also matching of released peak flow rates to the historic 2- and 10-year peak flow rates. Full infiltration and full dispersion of flows would meet this requirement, but unfortunately were not feasible for the Brickyard site due respectively to the low design infiltration rate of the underlying soils and the proximity of adjacent wetlands. For this reason, detention was chosen for flow control. A biofiltration swale was chosen to provide water quality treatment due to optimal spacing and gradient immediately downstream of the detention system.

The KCSWDM allows a sizing credit to be applied on storage volume when utilizing low impact development stormwater management techniques. The credit provided for use of pervious asphalt allows the designer to model the paved surface as half grass, half impervious, resulting in a significant reduction in the required storage volume. Note that all pre-development areas, regardless of existing land cover, are modeled as forested per jurisdictional requirements. The following table summarizes pre- and post-developed surfaces utilized to calculate runoff rates in KCRTS.

Table 2. Detained target surfaces.

Land Cover	Pre-developed (Ac.)	Post-developed (Ac.)
Till Forest	1.47	
Till Pasture		
Till Grass		*0.74
Impervious		*0.73
Total Area	**1.47**	**1.47**

*Note: The asphalt parking lot is actually 1.4 acres, and these numbers include a credit of half grass, half impervious for the post-developed areas.

Flow control sizing utilizing the KCRTS software indicates that 16,584 cubic feet of storage is required to meet jurisdictional requirements. The storage provided in the arch-chamber system is approximately 17,028 cubic feet. For comparison, storage for a traditional impervious pavement parking lot without the LID credit was also sized. Required storage for a traditional lot was sized at 51,130 cubic feet, approximately three times as large as the facility sized with a credit taken for the use of permeable asphalt.

Snoqualmie Point Community Park Stormwater Modeling.
The City of Snoqualmie as the permitting jurisdiction required conservation flow control and basic water quality treatment at Snoqualmie Point Community Park. Also, the City agreed to utilize the 2005 King County Surface Water Design Manual (KCSWDM) as a substitute for their adopted manual because of its greater design flexibility around low impact development stormwater management techniques. Full infiltration of runoff from the paved surface and tributary areas was calculated to be feasible within the pavement section, and so no further flow control was required beyond the reservoir course within the pavement section. Basic water quality treatment is also provided by infiltration in the native soils below the pavement. The following table summarizes pre- and post-developed surfaces utilized for sizing the volume of retention storage required under the new pavement section.

Table 3. Detained target surfaces.

	Land Cover	Pre-developed (Ac.)	Post-developed (Ac.)
Onsite	Till Forest	0.53	
	Till Grass		0.09
	Pervious Asphalt		0.44
Offsite	Till Forest	1.78	1.65
	Till Grass		0.11
	Impervious		0.02
	Total Area	**2.31**	**2.31**

Infiltration facility sizing utilizing the KCRTS software indicates that 16,240 square feet of pavement with 6 inches of reservoir course is required to provide infiltration capacity for runoff from the paved and tributary areas. The actual paved area is 19,327 square feet, providing more than enough storage for infiltration of the 100-year storm under the pavement section.

CONCLUSION

Pervious asphalt allows a variety of options for the integration of stormwater management with the permeable pavement section. Attenuation and treatment of stormwater runoff that has been infiltrated through or directed under the pavement section can be accomplished in multiple ways utilizing a combination of approaches. Each project has unique design considerations for stormwater management, which, when considered as a whole, may require unique or creative engineering to meet both jurisdictional requirements and provide for a site-appropriate design. The highly coordinated and customized designs utilized for stormwater management at Brickyard Park and Ride Lot Expansion and Snoqualmie Point Community Park illustrate two successful approaches for the use of pervious asphalt with integrated stormwater management.

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Pervious Pavement Systems in Florida – Research Results

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ABSTRACT

Pervious pavement systems are being studied for stormwater quality and quantity control and as a major component of low impact development (LID). To assess the potential of several types of pervious pavement systems, the Stormwater Management Academy at the University of Central Florida is studying the behavior of these systems at its field laboratory. These pervious pavements are also considered as part of the new Stormwater Rule in the state of Florida.

Research is being conducted on five types of pervious pavements, namely pervious concrete, Flexipave^{TM}, porous asphalt, and two types of brick pavers. One more pavement system called Filterpave^{TM} has recently been installed and is currently undergoing testing. This paper will present the results of the infiltration testing on these systems. Keeping in mind the long-term performance and maintenance requirements, these pavements are intentionally being loaded with sediment (sand and fine grained crushed limerock) to simulate clogging as indicated by significant reduction in their infiltration capacity. The pavements are then subjected to a rejuvenation technique using a vacuum sweeper truck. This paper will also present the results of these rejuvenation techniques on the performance of the pavements. This paper aims to update the water resources community on the new developments with these types of pavements.

INTRODUCTION

Pervious pavement systems offer designers and planners an effective tool for managing stormwater and minimizing its adverse impacts on the environment. The demand for these low impact design tools in today's society are rapidly increasing along with their importance in protecting one of our most vital natural resource, water. Impervious surfaces are responsible for a significant portion of the nation's leading threat to surface water quality, namely nonpoint source pollution by producing and transporting unnatural quantities, dynamics, and quality of stormwater runoff into receiving waters. In the past, the principal concern about runoff from pavements has been drainage and safety, focusing primarily on draining the water off the pavement surface as quickly and efficiently as possible (Chester, 1996). Historically many have considered that once the stormwater was off the pavement surface and into the drainage structure, no further consideration was necessary. The pavement is designed with sufficient cross slope and longitudinal slopes to increase the velocity of the runoff water away from the pavement before ponding can occur. As a result of increased velocity, the stormwater's ability to cause erosion, sedimentation, and spreading of pollutants is enhanced. Furthermore, impervious pavements are designed with costly measures taken to keep water from accumulating under the pavements and subsequently damaging the structure. Pavements in the US incur economic losses of an estimated $15 billion/yr due to poor drainage practices, which can reduce the service life down to 1/3 of a typical well drained pavement (Reddi, 2003). The larger volumes of runoff produced by impervious surfaces and the increased efficiency of water conveyance through pipes, gutters, and other artificially straightened channels, results in increased severity of flooding in areas adjacent and downstream of pavements. It was reported by Chester (1996) that this shift away from infiltration reduces groundwater recharge and impacts the natural ground water table levels that could threaten water supplies and reduce the groundwater contribution to stream flow resulting in intermittent or dry stream beds during low flow periods. When runoff bypasses the natural filtering process provided by soils, access to critical ecosystem service is lost.

The pervious pavement systems can also function as parking areas along with on-site stormwater control (Dreelin et al., 2006). Research conducted on permeable pavement systems by Scholz and Grabowiecki (2007) shows that the structure itself can be used as an "effective in-situ aerobic bioreactor," and function as "pollution sinks" because of their inherent particle retention capacity during filtration due to its high porosity. The enhanced porosity allows for good infiltration, air exchange rates, and geothermal properties that help in attenuation of pollutants. Most of the factors that allow for better attenuation of the pollutants are found in natural soils and in pervious pavement systems and the opposite are found in traditional impervious pavements. Infiltration is encouraged to replace natural infiltration capacity lost through urbanization and to use the natural filtering and sorption capacity of soils to remove pollutants. The porosity of pervious concrete pavements has been studied by Haselbach and Freeman (2006) and Montes and Haselbach (2006). Pervious concrete parking lot applications is already recognized as a best management practice (BMP) by the Environmental Protection Agency (USEPA, 1999), and has the potential to become a popular alternative for dealing with stormwater runoff. All of the pervious pavement systems share similar applications and all have several advantages over traditional impervious pavement systems. To mention a few, pervious pavement systems reduce overall runoff, level of pollution contained in runoff, ponding/hydroplaning, tire spray, glare at night, tire noise, skidding from loss of traction, velocity and temperature of runoff, erosion, and sedimentation (Tennis, 2004). The pervious pavement systems allow water to evaporate naturally from the systems similar to natural soils also providing a cooling effect which can even prevent tire blowouts caused by high temperatures.

Even though pervious pavement systems have been around for many years there is still a lack of needed experimental data associated with the in-situ performance over time. Previous studies have been conducted mostly on a laboratory and pilot scale basis but lack the technical data from field testing on full scale operational systems. The results of the present study will provide designers, regulators, and contractors with an understanding of how well do the pervious systems perform as intended, and the effectiveness of maintenance through use of a vacuum sweeping truck in the restoration of the clogged pavement system back to a fully operational system.

The main objective of this paper is to present results of long term infiltration testing on different types of pervious pavement systems that are subjected to discrete sediment loading events. In order to effectively measure the in-situ infiltration rate over time, an in-situ monitoring device called the embedded ring infiltrometer kit was developed (Chopra et al. 2009). It is similar to the existing (ASTM D3385, 2003) test for infiltration measurement of soil/vegetated surfaces using a double ring infiltrometer test. The limitation of using the double ring test on pervious systems is that the rings cannot be driven into the pavement surfaces unlike a soil or vegetative surface. Therefore, due to excessive lateral flow of water in the more permeable layers, the test overestimates the infiltration rate of the entire pervious system that is made up of several layers with varying permeability rates. The outer ring is incorporated to mimic an actual rain event in which there would be the same curtain of water surrounding any one spot on the pavement. In some of the past experiments, there were reported instances of running a surface infiltration test similar to the double ring. The water would flow quickly down through the surface layer and once it reached the next less permeable layer, it was found to back up and flow upwards out of the surface near the outside of the outer ring. According to Bean et al. (2007), many of the permeable pavement sites had surface infiltration rates that were greater than the filling rate for the double ring and thus modified versions using only the single (inner) ring called single ring infiltration test and surface inundation test were performed. It was mentioned that there was difficulty in not only transporting the required amount of water to remote sites to run these, but some difficulty was also encountered when filling the inner ring with enough water at a fast enough rate to maintain a constant head above the surface. The double ring or single ring test do provide a method for quantifying the surface infiltration rates of pervious pavements, and may serve as a surrogate for the pavement's surface hydraulic conductivity (Bean et al., 2007). The embedded ring infiltrometer was designed to overcome these difficulties in obtaining infiltration measurements of the pervious system using an efficient, non-destructive, repeatable, and economical approach.

Keeping in mind the long-term performance and maintenance requirements, these pavements are intentionally loaded with sediment (sand and fine grained crushed limerock) to simulate clogging as indicated by significant reduction in their infiltration capacity. The pavements were then vacuum swept. Preliminary testing on cores obtained from existing pervious concrete installations was presented in Chopra et al. (2009). This present paper will also present the results of these rejuvenation techniques on the performance of all pavements installed at the research site.

PAVEMENT SECTIONS

The Stormwater Management Academy research site with three different types of pervious pavement systems is shown in Figure 1. The first pervious pavement system installed was 1500 ft^2 of Portland cement pervious concrete (PC) divided up into three sections. One section designated for the heavy sediment loading and rejuvenation portion of the study, and the other two for sub-base material comparison with natural sediment loading conditions. The PC rejuvenation section has a cross section consisting of 6 inches of PC pavement with 10 inches of Bold & Gold™ pollution control media underneath as the sub-base. The other two sections of PC are for the natural sediment clogging over time while comparing the infiltration rates of different sub-base materials (Bold & Gold™ with mason sand vs. local A-3 type fill) underneath the PC layer. Two well points were installed near the pavement sections to monitor the groundwater table levels on each day of testing infiltration rates. The FlexiPave (FP) systems were installed second with the same surface area dimensions and arrangement as the (PC) layout. This pavement system consists of recycled rubber tires and stone aggregate with a binder. The cross section of the 700 ft^2 FP rejuvenation area included a 2 inches pavement layer resting on top of 4 inches of #57 crushed concrete followed by 10 inches of clean fill.

Figure 1 Pervious Pavement Sections at the UCF Research Facility

The next pavement system installed was the first set of Permeable Paver (PP-1) sections with a total surface area of 660 ft^2. One section was dedicated to the rejuvenation study while the other two were for the natural erosion clogging and water quality comparison testing. The cross section of the rejuvenation area involved using a 3 1/8 inch brick resting on a 2-inch thick bedding course of #89 stone for level placement of the brick surface. The bedding course was underlain by a 4 inch thick layer of #57 lime rock and then 7 inches of #4 stone extending down to the parent earth. The section named “fill” was identical to the rejuvenation cross section as the stone was required for fill for stability of the brick paver section. The B&G

test section was identical to the rejuvenation and fill, except in the bottom layer where the 2 inches of Bold & Gold^{TM} was placed under only 5 inches of the #4 stone.

The porous asphalt (PA) systems are comprised of a rejuvenation section with 4 inches of porous asphalt over 4 inches of #57 crushed concrete and 8 inches of fill dirt. We then installed another permeable paver system (PP-2) made by a different brick pavers manufacturer. The cross sections were the same as the above mentioned for the permeable pavers with the exception of a fourth section dedicated to testing a pollution control geotextile. Impermeable ribbon/flush curbing was installed around the perimeter of the test pads prior to placement of the pervious systems. The curbing extends the depths of the systems (16 inches) to prevent washout of the sub-base media due to lateral migration of the infiltrated water and flush with the surface of the pavement to prevent a tripping hazard.

PAVEMENT TESTING METHODOLOGY

Long-term Infiltration Testing

The field-scale testing site was selected to simulate a typical parking lot that acted as a construction access path and staging area and was thus subjected to sediment loading. This allowed for simulation of heavy vehicle turning loads and worst case scenario of sediment loading conditions in a short period of time. The different system types had 3 to 4 designated and partitioned sections of pavements each of which were constructed flat, level, and flush with the others. One section of each pavement was designated to represent the clogging and rejuvenation portion of the study in which sediments were intentionally loaded on to the surfaces. The other 2 to 3 sections of each type were dedicated to “natural” or day-to-day sediment loading conditions from unintentional erosion, ambient dust conditions, and tire tracking. These natural loading sections of pavement differ only in their sub-base materials comparing different types of pollution control media.

Each of the pavement systems had at least one embedded ring infiltrometer installed at time of construction for the measurement of infiltration rates. The pervious pavement system consists of a compacted porous sub-base and the pavement layer at the surface level. This test has been developed as an in-situ, non-destructive test that can be repeated throughout the service life of the pavement. Results of the infiltration testing using the embedded infiltrometer are presented in the next section.

Pavement Rejuvenation Testing

To gage the impact of clogging and investigate the effectiveness of vacuum sweeping as a rejuvenation methodology, large amounts of sediments were intentionally spread over the surface of the pervious concrete rejuvenation pad with a skid steer loader. The sediments were dumped on and then spread evenly about the surface of the pavements using a skid steer loader bucket. To simulate field clogging conditions where precipitation would have washed the sediments into the pore structure and then vehicle loads lead to the compacting of the sediments into the pore throats, the sediments were repeatedly washed into the surface pores using a hose, and then driven on back and forth with the loader to create agitation and compaction of the lubricated soil particles into the pavement system. The above steps were repeated until the surface pores were clogged and would not accept the passage of any more sediment.

The initial sediments used to clog the systems were local A-3 soils (Figure 2a). This was followed by a second loading event using crushed limestone powder (Figure 2b) that was created by spreading 2 to 3 inches of #57 limestone rock over the surface and subsequent driving over the rocks. The rocks were crushed from the vehicle loading and produced a significant amount of fine limestone powder over the surface of the pavements. Once the larger pieces were scraped off, the remaining limestone powder was then washed into the surface pores with a garden hose and driven on repeatedly with the loader and other vehicles.

It was not necessary to try to quantify how much sediment penetrated the surface because of the difficulty estimating how much naturally eroded sediments entered or left the system in the months prior to the clogging event. In addition, during the time of intentional clogging the there was at least an inch of sediment left on top of the surface during the wash in, compaction, and subsequent infiltration testing of the clogged pavements. Due to the nature of the field testing, it is not possible to measure how much sediment entered or left the surface of the pavement by natural erosion and tire tracking events over that course of time.

Once the surfaces were determined to be clogged, and would not allow for more sediments to penetrate, the systems were testing using embedded ring infiltrometer device. Four embedded infiltrometers were installed into the pervious concrete rejuvenation pad, two that were embedded 14 inches into the system in the north and south location reaching the base soils, and the other two were only embedded 4 inches at the east and west locations. The reason for the shallow infiltrometers was to get a better idea of the infiltration rate of the surface region of the pervious concrete only, without interference from the less permeable sub-base material. These results could serve as an indicator of a 'major change' in the surface rate due to clogging.

Figure 2 (a) Sandy sediment loaded surfaces (b) Fine limestone dust loaded surfaces

Figure 3 (a) Vacuum sweeping of sandy sediment loaded surfaces (b) vacuum sweeping of fine limestone dust loaded surfaces

The pavement sections were then subjected to vacuum sweeping using a standard pavement maintenance sweeper (Elgin Whirlwind MV truck). The rate of sweeping was 2-4 mph for heavy sweeping followed by 5-7 mph for light sweeps. Three to four passes were made over each section with some overlap as seen in Figure 3. Infiltration rates were measured pre- and post-cleaning.

DISCUSSION OF RESULTS

Pervious Concrete

Results from the infiltrometer in the north section of the pervious concrete pavement are shown in Figure 4. The infiltrometer initially measured average rates of 26.2 in/hr and 26.1 in/hr for the first two tests before any intentional loading took place. After the first sand loading, the rate decreased to 13.0 in/hr. Subsequently, after the first vacuuming event, the rejuvenated pervious concrete system rate rose back up to 29.8 in/hr. After a month or so, due to several reasons, the rate dropped to 2.7 in/hr. Three more tests were conducted within a month and the rates fluctuated from 4.7 in/hr to 23.4 in/hr when the ground water table (GWT) was deeper than 6 ft from the bottom of the system. The second loading of the powdered limestone seemed to cause more clogging that decreased the rate significantly down to 1.5 in/hr. However, the next vacuum sweep restored the performance of the system back to 9.9 in/hr even when the GWT depth had risen above the bottom of the pervious concrete system due to a tropical storm during that period.

The south infiltrometer in the rejuvenation pad experienced more extreme rates of infiltration during testing compared to the north infiltrometer. Figure 5 presents the results of the infiltration testing in the south section. The initial results of the first two tests were 32.2 and 42.5 in/hr. The sand clogging event depreciated the rate to 17.8 in/hr. The first vacuum attempt did not show an increase in the rate after vacuuming resulting in a 6.4 in/hr rate, but after a second attempt , the rate was increased back up to 19.9, 23.9, and 23.2 in/hr for three consecutive post vacuum tests. When the pervious concrete was clogged with the limestone powder the infiltrometer measured a decrease in rate to 1.0 and 0.7 in/hr during a time of high GWT (0-3 ft below the bottom of the system). However, with the use of vacuum sweeping, the system rate was improved back to 6.3 in/hr.

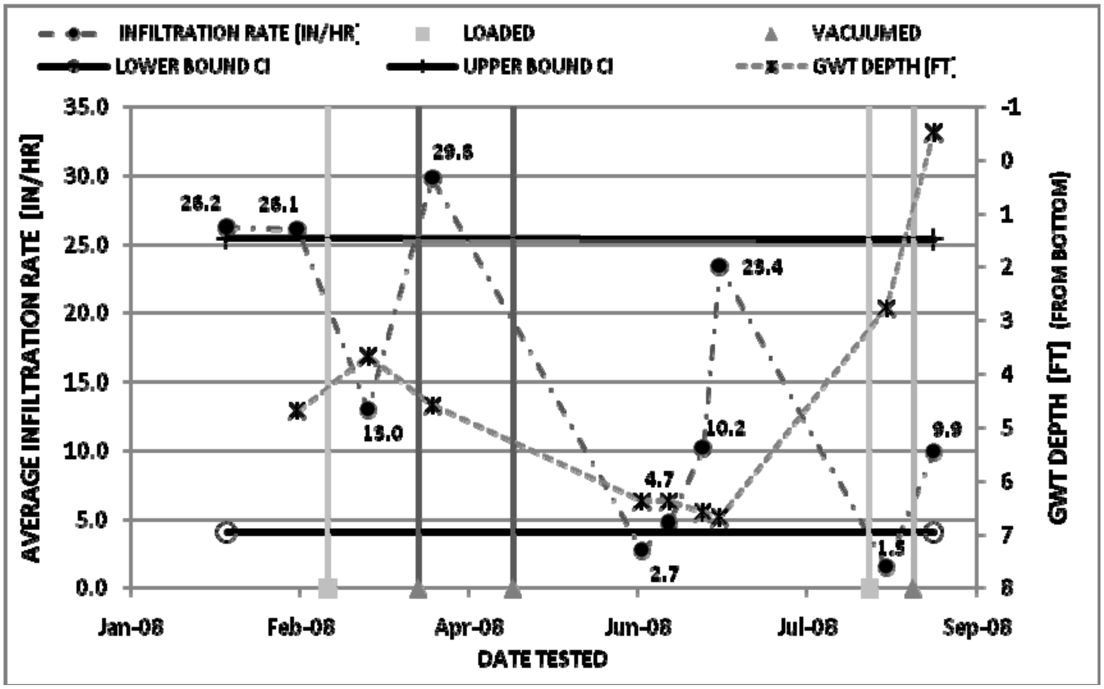

Figure 4 Infiltration Rate with Time for Pervious Concrete Pavement North Section

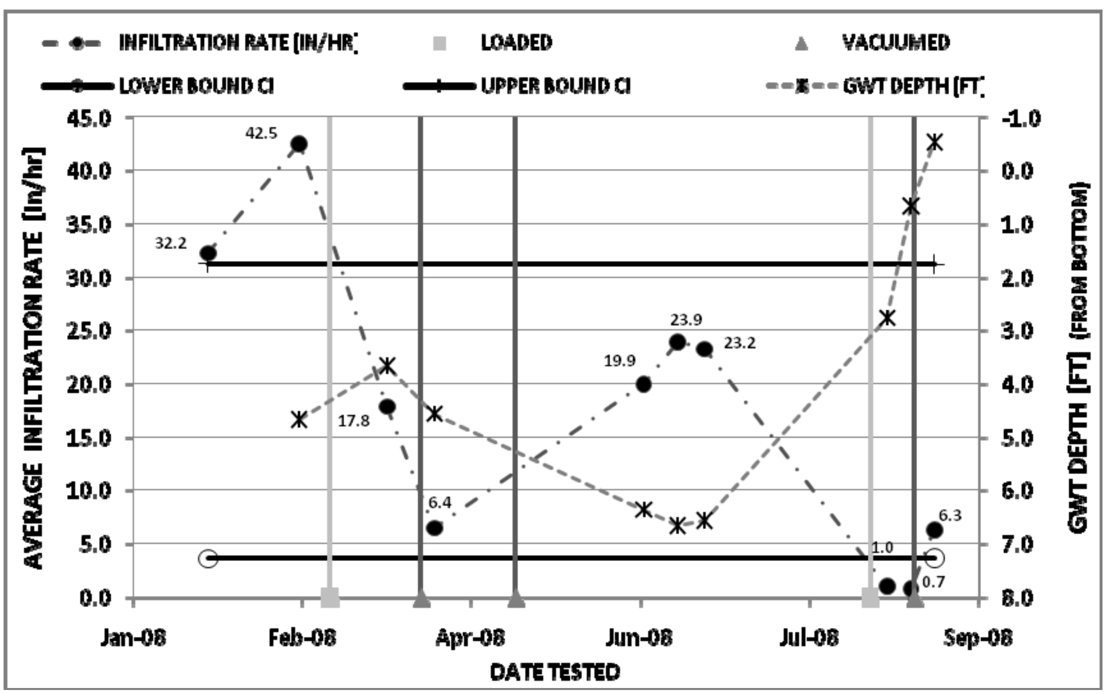

Figure 5 Infiltration Rate with Time for Pervious Concrete Pavement South Section

Flexipave^{TM} System

The initial infiltration rate measured at the north infiltrometer located in the rejuvenation pad of the Flexipave^{TM} system was 3.8 in/hr as shown in Figure 6. After the first sand loading event the measured rate showed no decrease and recorded about 5.0 in/hr. Then the pad was vacuumed and the measured rate dropped to about 3.1 in/hr. One might conclude that due to the variable nature of infiltration rates through these systems that these small differences can be expected and conclude that the first loading and vacuuming attempt did not affect the infiltration rate significantly. Similarly after a second vacuum attempt the next two tests confirmed that the rates remained close to the initial values and were 3.5, and 2.1 in/hr.

However, loading using powdered limestone did affect the pavement's ability to infiltrate by causing the rate to plummet to 1.0 and 0.6 in/hr. It is noted that during the limestone clogged tests, the GWT was only at a depth of less than three feet below the bottom of the system. Once vacuuming occurred on the limestone clogged pavement the subsequent test resulted in an increase back to 1.9 in/hr. Four months of natural sediment loading caused by erosion was allowed before the pavement was intentionally reloaded with sufficient quantity of sandy soils to ensure clogging of the system. The post-loaded result from the test showed that the rate of infiltration was 0.8 in/hr with minimal success of the next two vacuuming attempts. The first two tests measured after the vacuuming the sand indicated infiltration rates of 0.5 and 0.2 in/hr. The surface was vacuumed again but the rate remained around 0.4 in/hr. It was not possible to improve the performance of this pavement section any more.

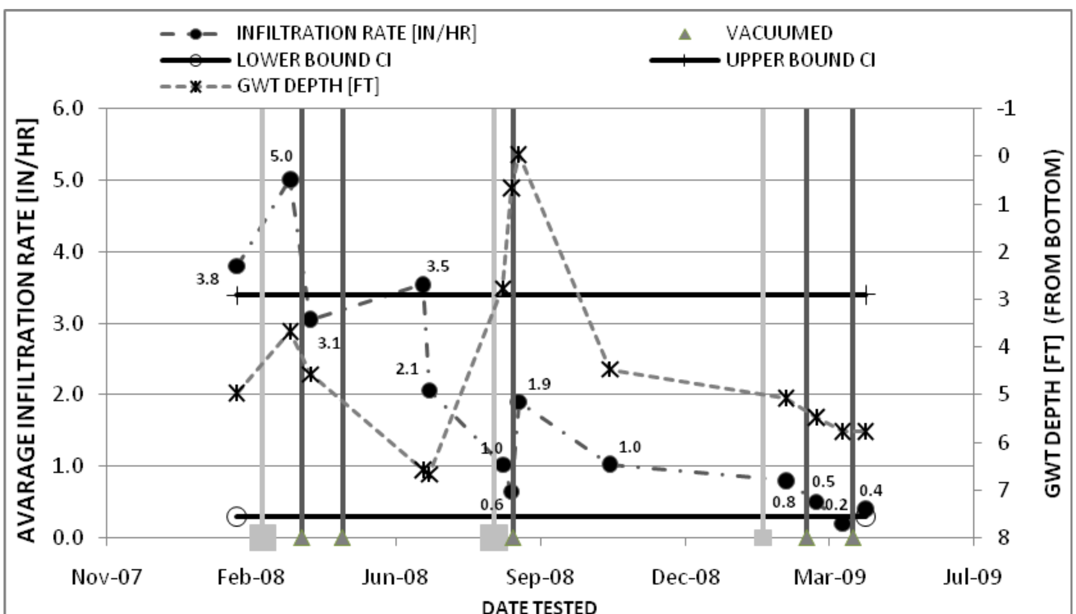

Figure 6 Infiltration Rate with Time for Flexipave^{TM} Pavement North Section

Pervious Pavers Type PP-1

The PP-1 permeable paver rejuvenation pad was equipped with two identical infiltrometers that were 14 inches long and were located in the north and south positions of the pad. It is important to note that this infiltrometer went down to the stone reservoir layer and resulted in higher infiltration rates compared to the ones that terminated in the base soil layer. Results from the north infiltrometer are shown in Figure 7. It measured an initial rate of 1850 in/hr at the beginning of the study period. After sand was used to clog the system the rate dropped to 9.7 in/hr. The first vacuum attempt only restored the rate to 10.2 in/hr but when re-vacuumed, the rate was rejuvenated back up to 1169 and 1278 in/hr. The limestone powder was washed and compacted into the surface pores next which caused the rate to fall to 627.8 and 40.8 in/hr. The vacuum sweep then increased the infiltration of the pavers to 1992 in/hr followed by three tests measuring 1383, 1305, and 1324 in/hr. After about a month the rate had dropped to measured rates of 802.9 and 878.3 in/hr. Towards the end of the study period, the pavement was loaded again with the sandy soils and resulted in decreased infiltration rates measured at 3.2 and 1.3 in/hr. The restoration of the infiltrating capacity of the system was effective and the final rate stabilized around 77 in/hr.

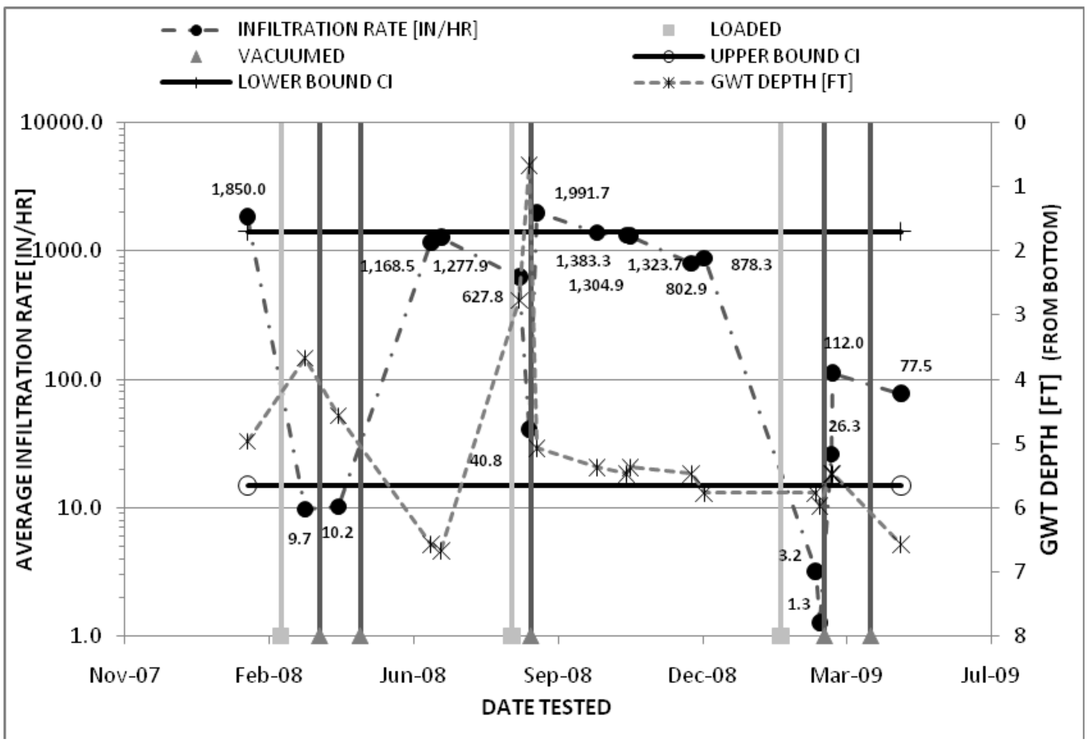

Figure 7 Infiltration Rate with Time for Pervious Paver PP-1 North Section

Pervious Pavers Type PP-2

The PP-2 type permeable paver rejuvenation pad had a tighter surface paver packing with narrower gaps. Two identical infiltrometers were utilized to measure the rates. The final embedment depth was again 14 inches implying that this infiltrometer went down to the stone reservoir layer and resulted in higher infiltration rates compared to the ones that terminated in the base soil layer. Results from the east infiltrometer are shown in Figure 8. It measured an initial average rate of 1800 in/hr which were almost the same as that of Paver Type-1 indicating that both sections had about the same surface voids. After sand was used to clog the system the rate dropped to 2.8

in/hr. The first vacuum attempt restored the rate to 2321 in/hr. The limestone powder was washed and compacted into the surface pores next which caused the rate to fall to 14.6 in/hr. Several attempts with the vacuum sweeper were not able to recover the original value of infiltration and the rate is around 9.8 in/hr at the end of the study period.

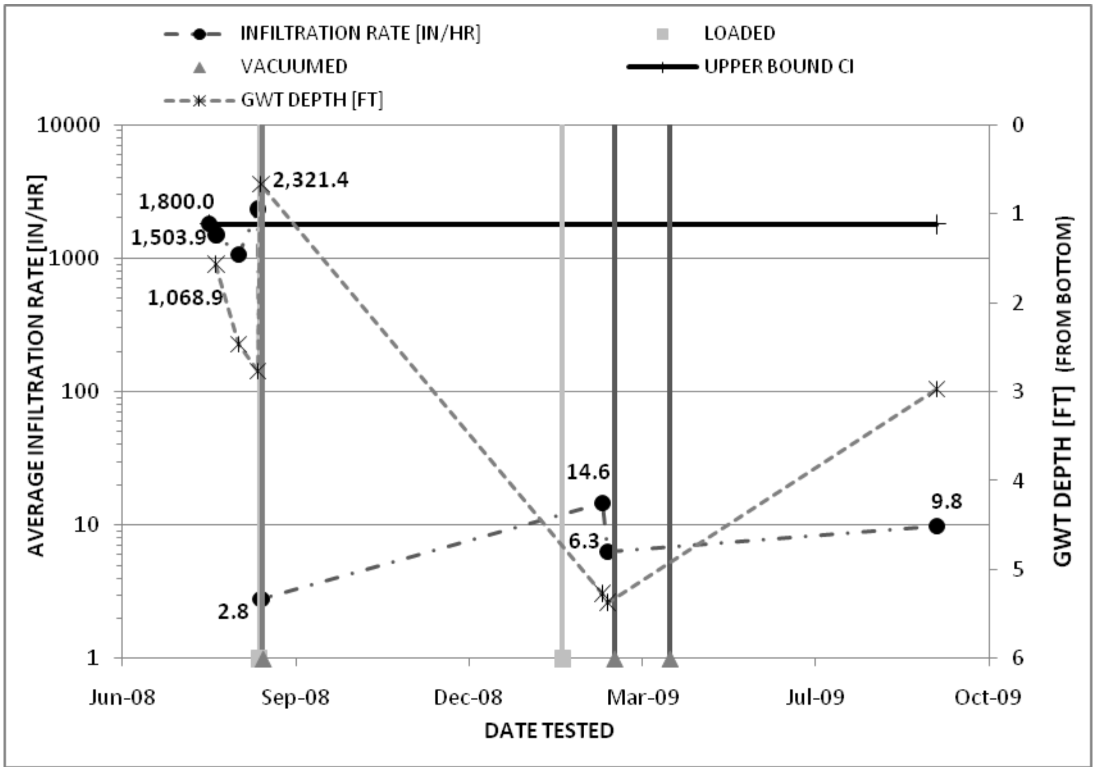

Figure 8 Infiltration Rate with Time for Pervious Pavement PP-2 Section

<u>Porous Asphalt Pavement</u>

The porous asphalt sections were each equipped with two 14 inch long system infiltrometers in the east and west locations, and one 4 inch long surface infiltrometer located in the middle of the pad. The rejuvenation section used local A-3 soils for the sub-base layer beneath the porous asphalt and #57 stone layers. Results from the east section infiltrometer are shown in Figure 8. An infiltration rate of 63.4 in/hr was measured initially and then the system was vacuumed. The rate decreased to 23.5 in/hr after sandy sediments were applied, washed, and compacted into the pavement. The first vacuum attempt only increased the rate to 26.5 in/hr and the successive vacuuming led to a decrease in the measured rates to 14.3, 11.3, and 8.5 in/hr.

The system was then loaded with the fine limestone powder in which the measured rate only decreased to 8.4 in/hr. After vacuuming the limestone powder, the rate did increase to 33.6 in/hr but the next four tests measured values of 3.1, 4.8, 3.7, and 2.7 in/hr during the next four months of testing. The porous asphalt was finally loaded again with the sandy soils and resulted in a decrease in the measured rates of 4.8, 3.2, 3.1, and 3.5 in/hr. The porous asphalt sections displayed visual evidence of structural failure due to excessive settlement under traffic loads.

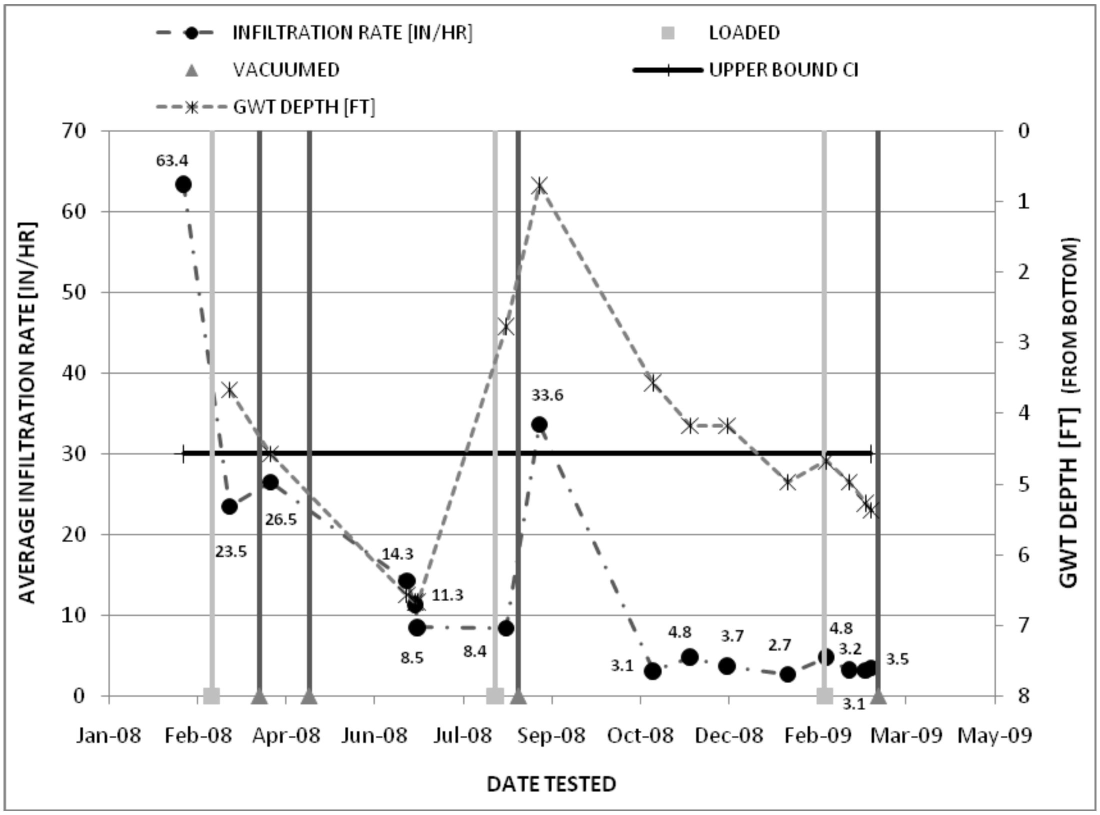

Figure 9 Infiltration Rate with Time for Porous Asphalt Pavement East Section

CONCLUSIONS

Five types of pervious pavement systems have been investigated for long-term infiltration rates and recovery of these rates after vacuum sweeping of the pavement surfaces. It was found that different pavement types clog at different rates and the ability to rejuvenate the pavement depends on the fabric of the pavement surface. For instance, Flexipave™ systems were much harder to clog but once the sediment penetrated deep into the fabric, it was more difficult to rejuvenate this type of pavement. On the other hand, brick paver Type 1 was easier to rejuvenate since it has larger inter-paver openings but will require replacement of the gravel that is used in this gap during maintenance since the vacuum sweeping process sucks up all these stones. Paver PP-2 had a much tighter inter-paver gap and was not able to recover to the same extent post-sweeping. Pervious concrete pavement sections were successfully rejuvenated by vacuum sweeping though not to their initial levels. Lastly, porous asphalt had some difficulties with surface melting which attracted and bonded the sediments on its surface permanently.

The intense level of sediment loading, particularly due to the fine-grained limestone powder resulted in significant drop in the infiltration rates of all pavement systems which was difficult to rejuvenate. It is important to note that the depth of the ground water table during each testing event was an important factor in the response due to available storage in the system as a whole. This will be analyzed further and presented in the future. In summary, vacuum sweeping appears to be an effective method to recover the infiltration capacity of pervious pavement systems.

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The Urban Green BioFilter, An Innovative Tree Box Application

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ABSTRACT

The UrbanGreen BioFilter™ is a new Proprietary and Enterprise Technology which serves as a tree box filter combined with the well known Stormwater Management StormFilter® (StormFilter) technology. The unit is constructed in a curb inlet or area drain configuration and designed to treat runoff from roadways, parking lots, roof tops, and other runoff generating surfaces.

The system utilizes a variety of complex treatment processes including physical, chemical, and biological activities which occur as stormwater infiltrates through a 91 cm (36 in) bed of engineered soil mixture and interfaces with the root system of a tree or other vegetation within a bioretention bay with a flow control orifice located at the outlet. The specific components of the engineered soil mixture were selected to provide high pollutant removal and permeability while maintaining sufficient moisture content for plant growth. After infiltrating through the engineered soil mixture stormwater exits the bioretention bay via the bioretention bay under drain which directs the treated stormwater to the outlet chamber.

The UrbanGreen BioFilter employs two distinct treatment components. The first is the bioretention component as described above. The second is a media filtration component. When the bioretention bay reaches its treatment capacity, runoff begins to flow over a weir into a secondary chamber containing a set of Stormwater Management StormFilter® (StormFilter) media cartridges which then treat additional flow prior to discharging into the outlet. StormFilter media cartridges are among the most highly tested and proven stormwater treatment devices and can be designed with a variety of media types including CSF leaf compost, Perlite, and ZPG (a blend of Zeolite, Perlite, and Granular Activated Carbon) to target the specific pollutants of concern.

The entire unit is also designed with a high flow bypass separated from the treatment areas to prevent bed scour and maintain conveyance for extremal events.

This combination adds a robust feature to allow for the treatment and storage of smaller storms via bioinfiltration while allow more robust treatment by the StormFilters for higher flows.

Data from flow testing, laboratory performance testing are presented.

INTRODUCTION

The UrbanGreen BioFilter™ is an enhanced biofiltration system that combines a tree box bio-filter with the proven performance capabilities of Stormwater Management StormFilter ® (StormFilter), a cartridge based media filtration system. This combination of biological and engineered media filtration create a robust approach for the removal of common pollutants found in stormwater runoff.

The UrbanGreen BioFilter will complement any site design, however it has been specifically developed as a component to low impact development (LID) sites. LID is a new approach to stormwater management which emphasizes the use of small, decentralized management practices to treat rainfall close to its source and facilitate infiltration back into the ground. The goal of LID is to maintain the predevelopment hydrology and to lower the overall environmental impact footprint of the site. Common LID practices include biofiltration, bioretention, and media filtration. The UrbanGreen BioFilter incorporates all three of these processes into one system to maximize the pollutant removal capabilities. Furthermore, the UrbanGreen BioFilter is specifically designed to treat small catchment areas and can easily be combined with underground infiltration such that the runoff can be treated and infiltrated close to where the rain falls. This decentralized approach to managing stormwater is a core principle of LID.

BASIC OPERATION

The UrbanGreen BioFilter is constructed in a curb inlet or area drain configuration and designed to treat runoff from roadways, parking lots, roof tops, and other runoff generating surfaces. The basic components of the UrbanGreen BioFilter are illustrated in Figure 1. As illustrated, initial runoff enters the system and is directed by the inlet weir into the bioretention bay. A variety of complex treatment processes including physical, chemical, and biological activities occur as stormwater infiltrates through the engineered soil mixture and interfaces with the root system of the tree or other plant. The specific components of the engineered soil mixture were selected to provide high pollutant removal and permeability while maintaining sufficient moisture content for plant growth. Flow rate through the engineered soil mixture is controlled by an orifice placed at the outlet such that the maximum design flow rate is reached when the water surface elevation in the bioretention bay reaches the invert of the overflow weir to the StormFilters. After infiltrating through the engineered soil mixture stormwater exits the bioretention bay via the bioretention bay under drain which directs the treated stormwater to the outlet chamber.

The UrbanGreen BioFilter employs two distinct treatment components. The first is the bioretention component as described above. The second is a media filtration component. When the Bioretention Bay reaches its treatment capacity, runoff begins to flow through the cartridge bay inlet located at a set elevation above the surface of the engineered soil mixture. This runoff is then treated by Stormwater Management StormFilter® (StormFilter) media cartridges prior to discharging into the outlet chamber. StormFilter media cartridges are highly tested and proven stormwater treatment devices and can be designed with a variety of media types including CSF leaf compost, Perlite, and ZPG (a blend of Zeolite, Perlite, and Granular Activated Carbon) to target the specific pollutants of concern.

The two stage treatment process of the UrbanGreen BioFilter ensures that the initial runoff, which for small urban catchments commonly carries the highest pollutant concentrations, is treated via bioretention while higher flows are treated by StormFilter media cartridges.

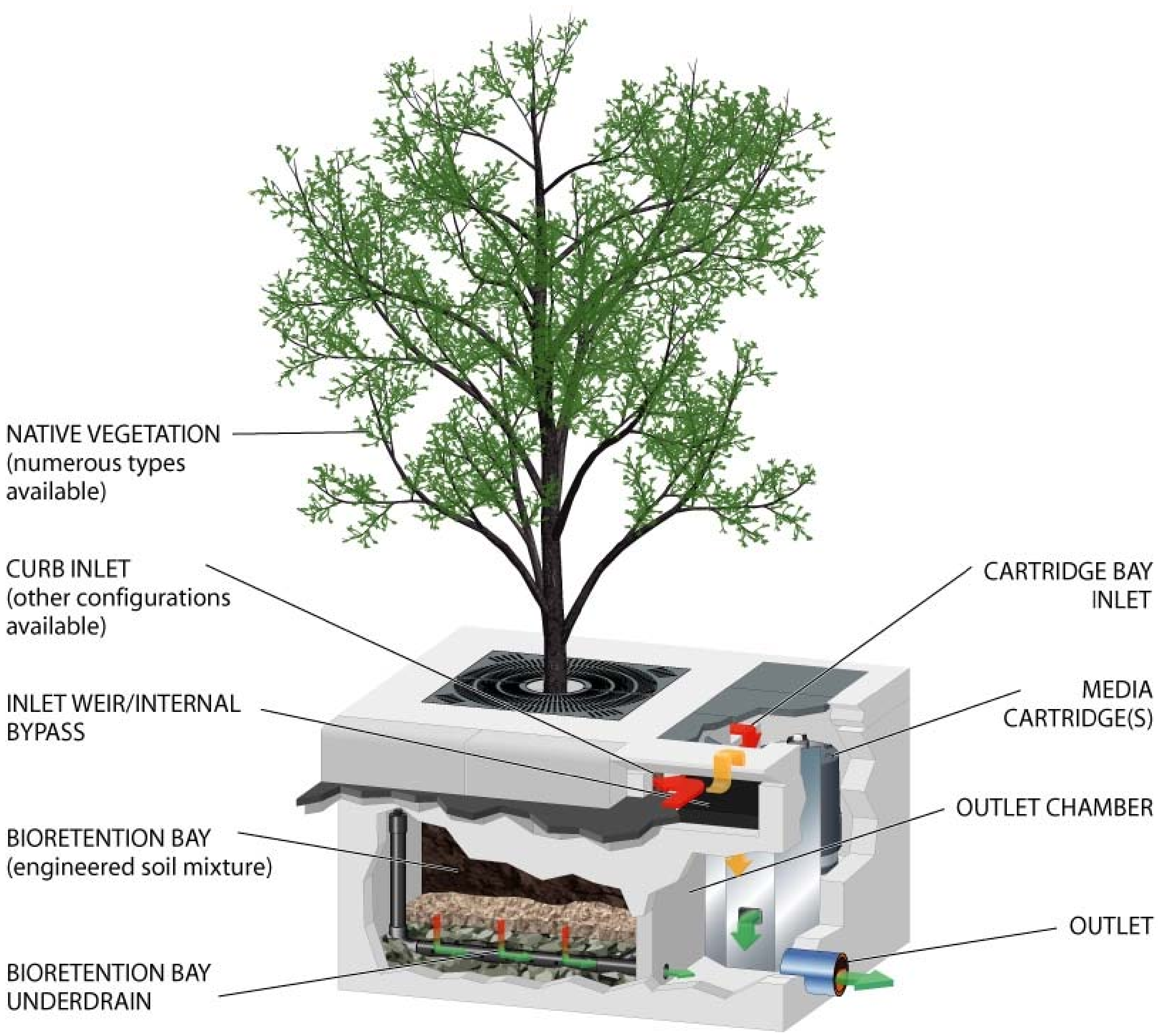

Figure 1 – UrbanGreen™ BioFilter, Basic Operation & Components

The UrbanGreen BioFilter is designed with an internal offline bypass which allows runoff exceeding the capacity of both the bioretention bay and the media cartridges to discharge directly into the outlet chamber. This feature protects against high flow washout of previously captured pollutants as well reduction of overall project costs by eliminating the need for external structures to manage these high flows. Treated and bypassed flows are joined in the outlet bay of the system where they can then be directed to infiltration, detention or retention, or direct discharge, as required by site conditions and regulations.

UNIT SIZING AND DESIGN

Sizing of the UrbanGreen BioFilter is based on testing of the individual treatment and flow components coupled with specific regulatory requirements. As shown in Table 1 below, the UrbanGreen BioFilter is currently available in one standard size and has a total treatment capacity of 3.85 liters/second (61.0 gpm). The total treatment capacity is the aggregate of the treatment capacities of the bioretention bay and media cartridges. The design infiltration rate of the Bioretention Bay is controlled by the initial media permeability and a flow control orifice. Though the infiltration rate may vary in different jurisdictions, 127 cm/hour (50 in/hr) or approximately 0.34 cm/sec/m^2 (0.5 gpm/ft^2) of surface area is the typical design infiltration rate. The surface of the engineered soil mixture is approximately 3 m^2 (32 ft^2) which equates to a treatment capacity of 1 /sec (16 gpm). It should be noted that although testing has shown that the engineered soil mixture in the bioretention bay can infiltrate at a rate of 914 cm/hour (360 inches per hour) at the design driving head of 30.5 cm (12 in), an outlet flow control orifice limits the rate such that significant pollutant loads can be accumulated before the media infiltration rate drops below the design infiltration rate thus requiring maintenance. This is a key feature which provides uniform flow control vs. unregulated flow which is solely a function of head loss across a media which has a highly variable permeability.

The treatment capacity of the media cartridge portion of the UrbanGreen BioFilter is based on treating runoff at a rate of 81 liters/m^2/min (2 gpm/ft^2) of cartridge surface area and utilizing two 68.6 cm (27 in) media cartridges. The treatment capacity of each cartridge is calculated to be 1.5 l/sec (22.5 gpm) for a total capacity of 3 l/sec (45 gpm) for both cartridges. Like the soil mixture, the media cartridges are designed with a flow control which restricts the flow through each cartridge to the design rate. This feature improves both the performance and longevity of the cartridges.

Local regulations will typically determine how much flow needs to be treated. Many regulatory agencies specify a water quality “design storm” such as a 6-month or 1-year return period storm event as the required amount of flow to treat. Local guidelines should be consulted for calculation of the design storm. Once the amount of flow to treat has been determined, simply divide that amount by the total treatment capacity of the UrbanGreen BioFilter (4 l/sec or 61.0 gpm) to determine the number of units needed. The system can also be design to meet volume based requirements. This is accomplished with the placement of slotted drain pipe to intercept sheet flow from roadways, parking lots, or rooftop downspouts.

The water quality volume stored is accounted for by the pipe volume plus the volume of water stored within the UrbanGreen BioFilter. Other design options include the addition of subsurface infiltration chambers which accept treated flow from the treated portions of the flows. If the infiltration capacity is exceeded, excess flows are routed to the outlet pipe.

Placement of the UrbanGreen BioFilter is a key element. Once a location for the UrbanGreen BioFilter has been determined, the calculated peak conveyance flow should be compared to the bypass capacity to ensure that the system has sufficient capacity to handle these higher flows. The unique internal bypass of the UrbanGreen BioFilter is designed to handle a peak flow of 75 l/sec (2.5 cfs). This substantial integrated external bypass capacity is a key feature of the UrbanGreen BioFilter as it eliminates the need for additional external structures. If required however, additional bypass capacity can be added with a separate external bypass.

Table 1: Basic Urban Green BioFilter Design Criteria

Treatment Capacity[1]	*Peak Conveyance Flow*	*Footprint*[2]	*Depth*[3]
4 l/sec	75 l/s	1.8 x 2.4 meters	1.55 meters
61 gpm	2.5 cfs	6 x 8 Ft	5.08 feet

Notes:
1. Combined capacity of bioretention and media cartridges
2. Inside dimensions
3 Distance from tree grate to invert of outlet pipe (or vault floor)

One of the most critical elements of the design is which kind of tree or shrub to use for a given site. Considerations such a climatic zones, tree size, overall landscape planning and design, local regulations for plant selection, plant sizes within travel ways need to be considered. Selection can be done in collaboration with the site civil engineer and the individual(s) responsible for the landscape design.

Other factors such as plant tolerance to soil moisture, fertilization and pruning requirements all need to be considered in the selection. Plants with diffuse or fibrous root systems are preferred over those with tap rooted systems.

HYDRAULICS AND SCOUR TESTING

A full scale UrbanGreen BioFilter prototype was subjected to hydraulic testing to confirm bypass function and capacity and observe scour characteristics of the Biofiltration Bay. A large reservoir was used to send gravity flow to a manifold simulating a curb and gutter installation. Flow was controlled using a gate valve and measured using a paddlewheel flow sensor.

The concrete prototype was located on a level footing at ground level. The unit was filled with engineered soil media and planted with a small balled tree placed in the soil bed. To simulate bi-directional gutter flow to the inlet bay, a manifold was constructed and attached to the vault so as to resemble the curb inlet section.

Hydraulics

The critical question concerning the hydraulics of the prototype was to verify the bypass flows. During the "instant on" hydraulic test (Trial 5), a flow rate of 59 l/sec (2.1 cfs) was observed 27 seconds after flow was initiated and while the Biofiltration and StormFilter Bays were still filling (Figure 2). At this flow rate and vault condition, very little bypass flow was observed. After approximately 50 seconds, all bays were observed to be full and the system appeared to be in full bypass (bypassing of flow in excess of that being treated by the treatment bays). The highest flow recorded after this system condition was reached was 57 l/s (2.0 cfs) (Figure 3). At this point, water levels in the treatment bays remained static and just shy of overtopping, and the narrow space between the steel divider wall and the bypass weir comfortably contained the bypass flow.

Figure 1. View of Inlet/Outlet Bay and a portion of the StormFilter Bay at 59 l/sec (2.1 cfs), 27 seconds into "instant-on" hydraulic test. Note that StormFilter Bay is still empty which indicates that the system is still in the process of filling.

Figure 2. View of Inlet/Outlet Bay and a portion of the StormFilter Bay at 57 l/sec (2.0 cfs), 56 seconds into "instant-on" test. This image shows hydraulics once system has filled.

Scour Testing

Several scouring tests were conducted. The first test, Trial 1, involved the use of no energy dissipation or flow spreading strategies to minimize or eliminate disruption to the soil bed from flows entering from the Biofiltration Bay from the Inlet Bay. The purpose of Trial 1 was to confirm the need for a scour prevention strategy and also to assess how much of a problem it might be so as to refine mitigation strategies and further testing procedures. Three trials followed, each involving a different scour mitigation strategy. Trial 5 was performed in conjunction with the bypass hydraulics confirmation test and involved a catastrophic flow scenario involving near instantaneous peak flow and no scour protection. Results for Trials 1 through 5 are shown in Figures 4 through 8, respectively.

Based upon the outcome of Trials 1 through 5, additional effort was expended to find a better scour mitigation strategy. Trial 6 examined the use of 5cm to 15 cm cobbles placed 8 cm to 15 cm deep in an approximately 0.37 m^2 area of the Biofiltration Bay directly in front of the port leading from the Inlet Tray. Trial 7 involved subjecting this scour mitigation strategy to catastrophic flows in the same fashion as Trial 5. Results for Trials 6 and 7 are shown in Figures 9 and 10, respectively.

A critical observation regarding scouring was that scouring potential was greatest during the beginning of an operating cycle, when the Biofiltration Bay was devoid of standing water. Once the Biofiltration Bay filled with water such that the port connecting the Inlet Tray and the Biofiltration Bay began to submerge, scouring appeared to rapidly decrease to the point of disappearing entirely. However, rapid increases in influent flow that caused the water level in the Biofiltration Bay to increase in response caused some degree of scour until a new equilibrium was reached. Overall the soil bed in the Biofiltration Bay appeared to be most vulnerable to scour during the fill period and decreased significantly once the port between the Inlet Tray and Biofiltration Bay started to submerge.

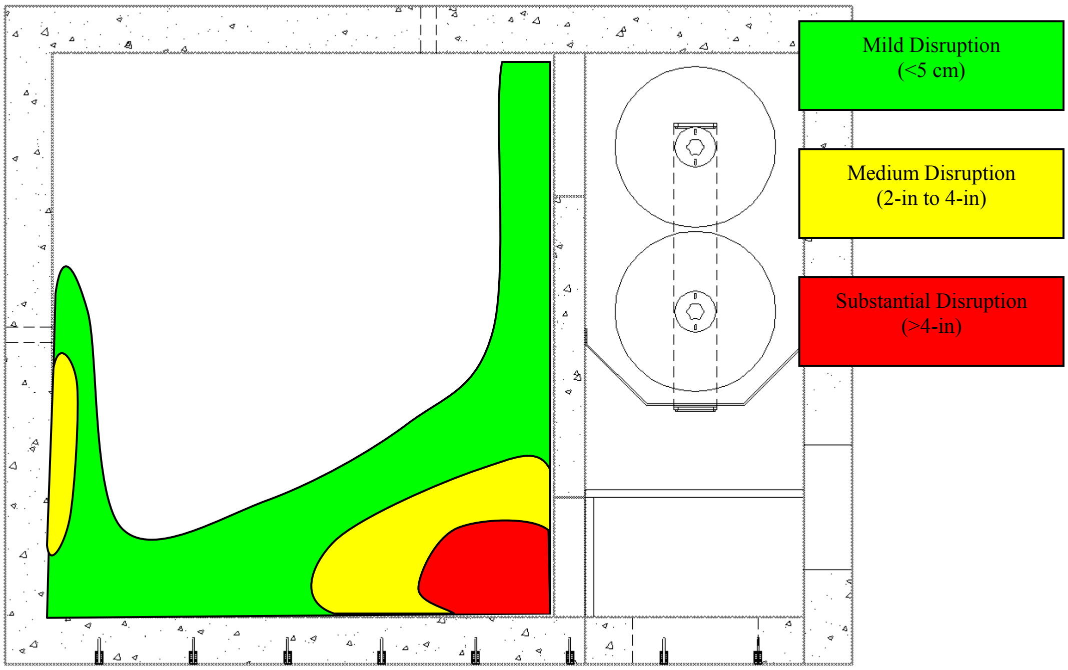

Figure 3. Surface disruption pattern for Trial 1, which involved no armoring.

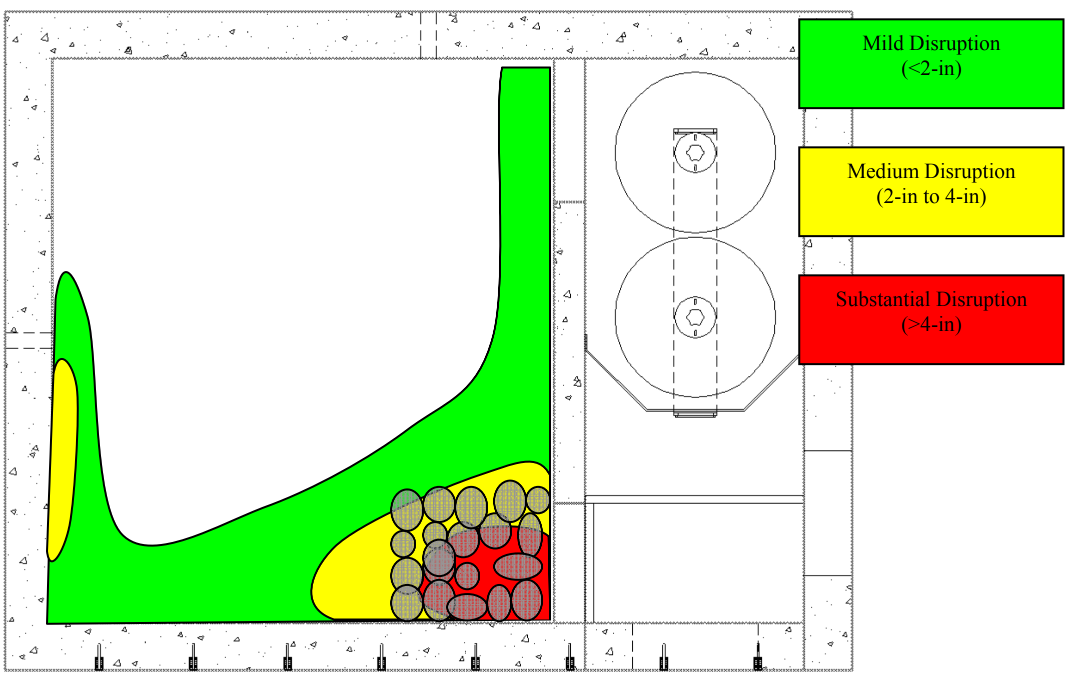

Figure 4. Surface disruption pattern for Trial 2, which involved an 50 cm x 50 cm layer of 15 cm cobbles placed one layer deep (this was observed to be almost identical to Trial 1).

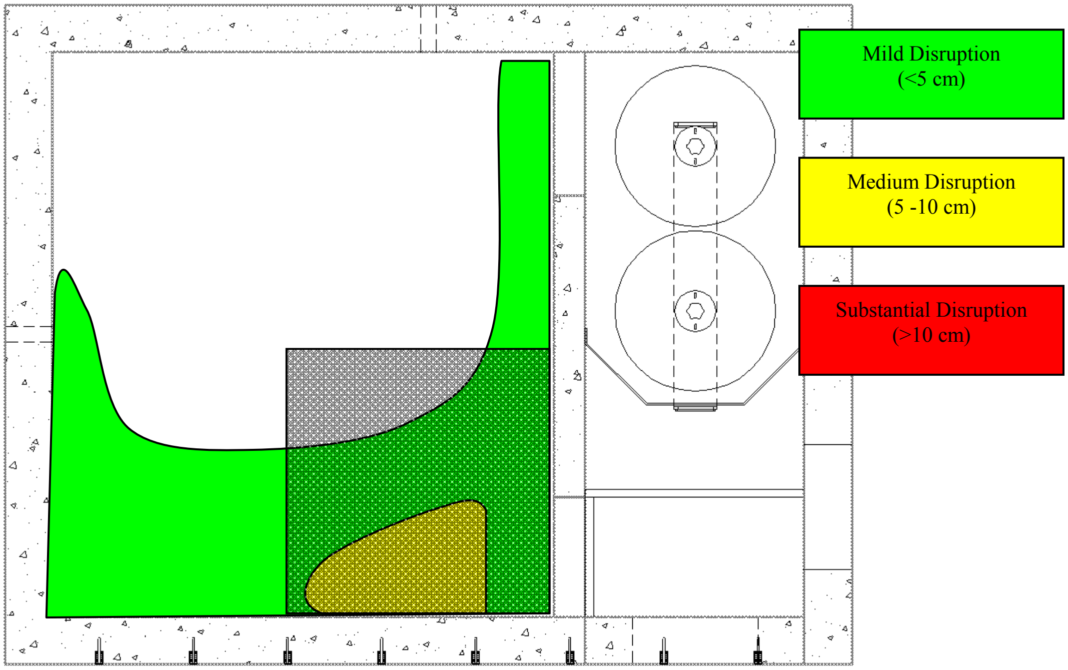

Figure 5. Surface disruption pattern for Trial 3, which involved a 1 meter x 1 meter rubber mat with 1.6 cm perforations.

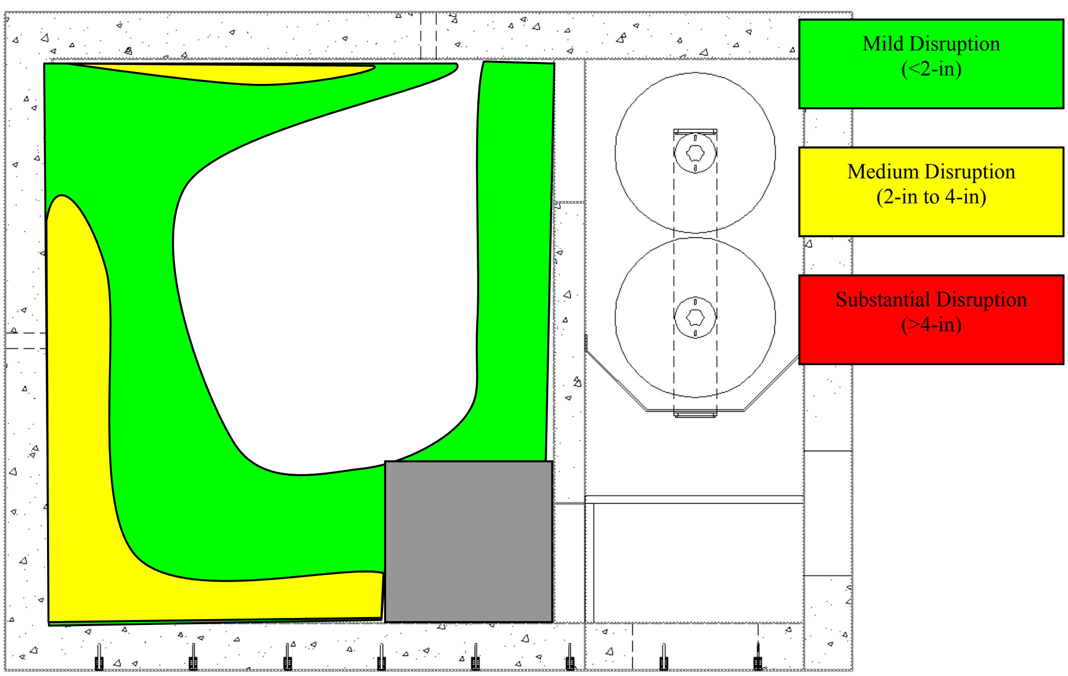

Figure 6. Surface disruption pattern for Trial 4, which involved a 50 cm x 50 cm impervious layer.

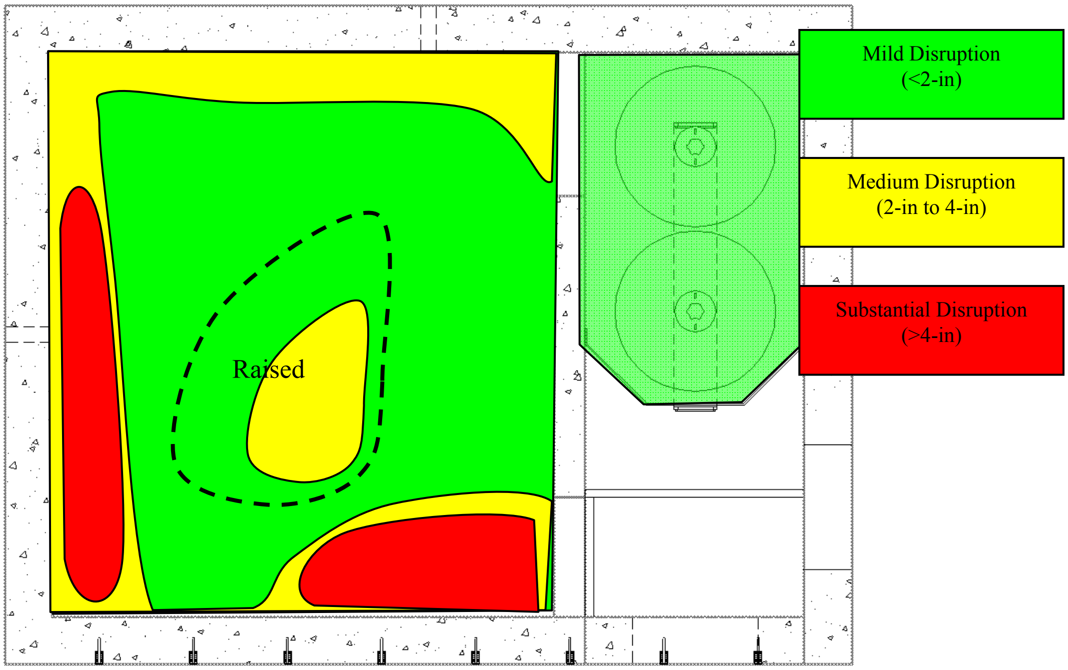

Figure 7. Surface disruption pattern for Trial 5, which involved instantaneous peak flows and no armor.

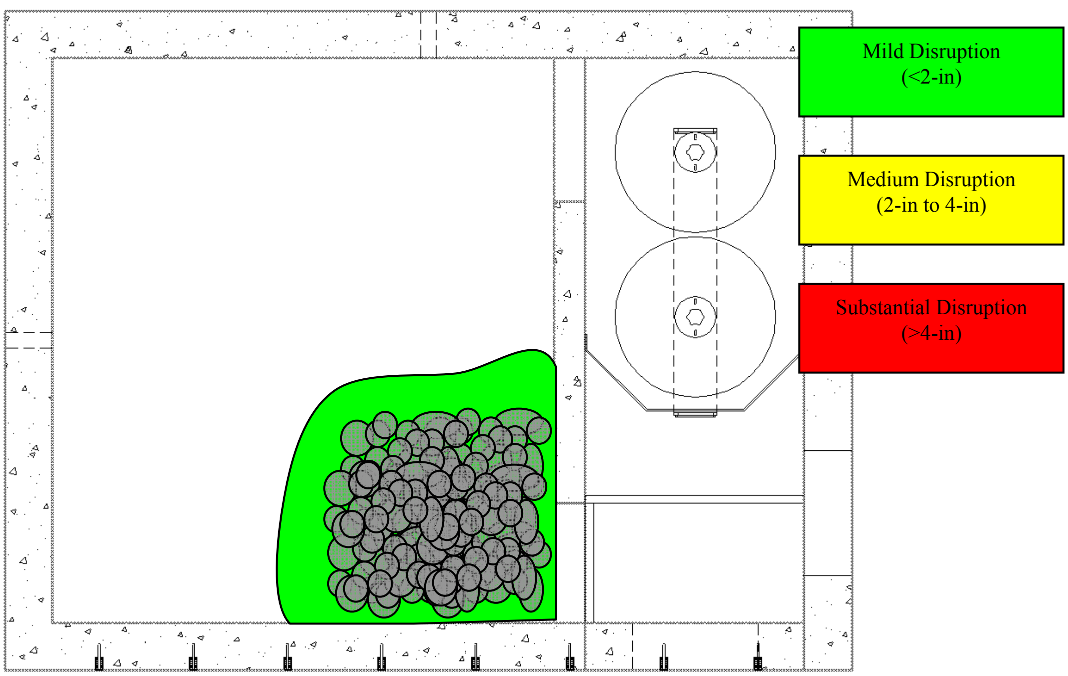

Figure 8. Surface disruption pattern for Trial 6, which involved 5 cm - 15 cm cobble armor 16 cm deep in an approx. 0.37 m^2 area.

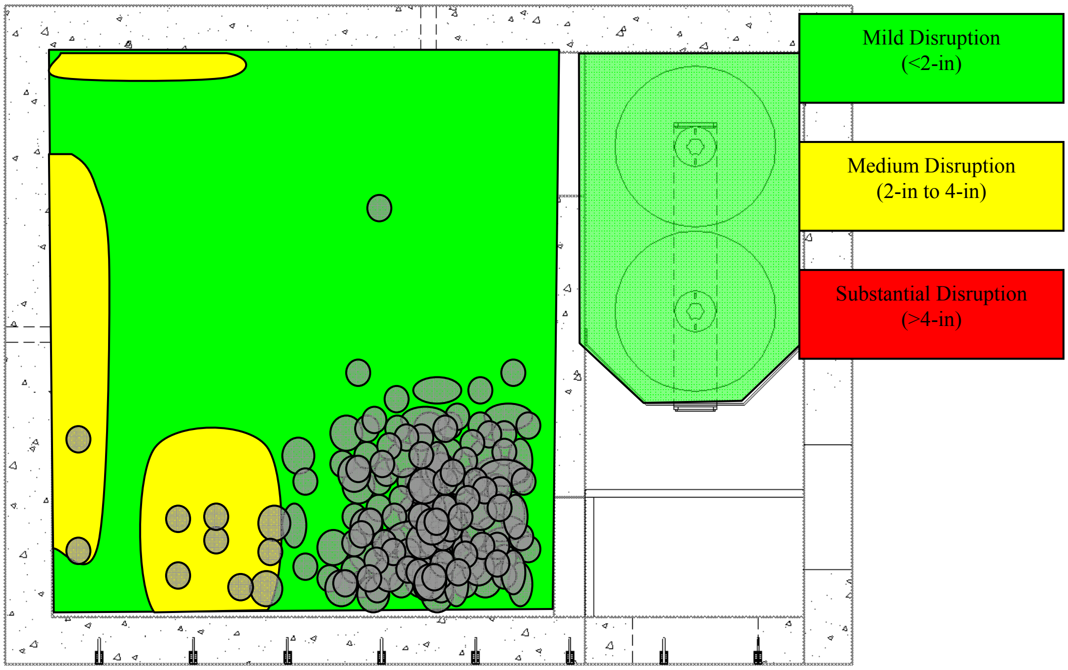

Figure 9. Surface disruption pattern for Trial 7, which involved instantaneous peak flows and 5 cm - 15 cm cobble armor 16 cm deep in an approx. 0.37 m^2 area.

Discussion and Conclusion

This experiment confirmed that the hydraulic bypass of the UrbanGreen BioFilter was capable of handling flows in excess of 57 l/sec (2 cfs) with a design value set at 75 l/sec (2.5 CFS) given available freeboard. Scour test results confirm that incoming flows are capable of disrupting the surface of the soil bed. None of the scour mitigation strategies tested were able to completely eliminate this disruption, though it appeared that the strategy involving 5 to 15 cm cobble armor 8 cm - 16 cm deep in an approx. 0.37m^2 area performed the best and allowed a stable bed form.

PERFORMANCE TESTING

Key to the performance of the BioFilter is the composition of the engineered soil bed. An "engineered" media is one that is specifically made to meet desirable characteristics including, high infiltration rates, adequate pollutant removal performance, adequate soil moisture retention capacity, provision of a structural and biological environment for plant growth, and low cost.

As part of the development of the UrbanGreen BioFilter several soil mixtures were subjected to large-scale column tests in order to identify a combination of soil components that offered the best combination of porosity, conductivity, treatment capacity, water retention capacity, and performance. Testing was conducted using an apparatus constructed 50 cm (1.5 foot) diameter column to represent a full-scale UrbanGreen BioFilter soil bed. Experiments included: 1) Attrition—observation of residuals lost during initial use; 2) Retention—water retention characteristics; 3) Head Loss—stage-discharge relationships; and 4) Sediment Removal Potential—assessment of sediment removal capabilities. The best mixture identified for use with the UrbanGreen BioFilter consisted of a specific mixture of sand, processed leaf compost (Lenhart, 2007), porous aggregate, and absorbent starches to increase soil moisture retention capacity during the developmental stages of plant growth

Attrition results for this mixture indicated an initial loss of residual dust from media shipping and handling followed by an exponential decrease to non-detect (5 mg/L SSC) levels within 8 bed volumes. The expected loss of orthophosphate (SRP) from organic soil components was also observed and similarly dropped to 0.6 mg/L within 8 bed volumes. These results were similar to all other combinations of organic and inorganic soil component mixtures.

With respect to water retention, the chosen soil mixture demonstrated a 1-hr specific yield (ratio of volume of water that drains due to gravity in 1-hr to the total volume of soil) of 0.39 and a 1-hr specific retention (ratio of volume of water retained against gravity in 1-hr to the total volume of soil) of 0.12. These values were similar to those observed for soil mixtures with particle size distributions that were much finer than the chosen soil mixture.

The biofiltration component of the UrbanGreen BioFilter is designed to treat stormwater at a rate of 130 cm/hr (50 in/hr) with 30 cm (12-in) of driving head. As shown in Figure 11, the high conductivity of the chosen soil mixture provides the desired hydraulic loading rate at a much lower driving head. This suggests that the chosen soil mix will allow the UrbanGreen BioFilter to operate at design hydraulic loading rates for an extended period of time despite continuous interstitial sediment accumulation.

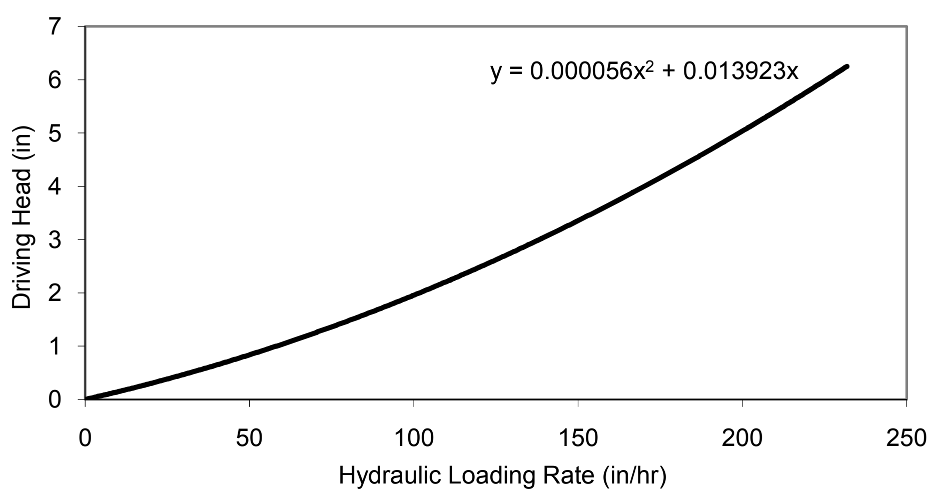

Figure 11 - Hydraulic Loading Characteristics of the Filter Media

Sediment removal characteristics of the chosen soil mix were very high. Greater than 95% removal was observed at the design operating rate of 50 in/hr using the Sil-Co-Sil 106 sediment removal testing standard (SG = 2.65, d50 = 25-um) at concentrations of 100 mg/l or greater.

INSTALLATION AND PLANTING

The UrbanGreen Biofilter (Figure 12) is provided as a precast system and arrives on site with the engineered soil mixture and construction debris bypass barriers preinstalled. Once deliver to the site the unit is placed in a prepared bedding, connected to the specified pipes, irrigation lines, etc. and backfilled according to specifications and project plans. The unit is equipped with a construction bypass to keep sediment laden run from the soils media.

Activation of the UrbanGreen BioFilter is a simple two step process. Activation should be should be performed once the site is completely stabilized and coincide with the timing of the installation of other landscape features such as street trees or other vegetated amenities if applicable.

Activation consists of removal of the construction debris barriers which protect the system from becoming inundated with sediment and debris during construction. There are two barriers that need to be removed for activation. The first is a fabric blanket that is located just below the tree grate. This barrier is designed to prevent construction runoff from entering the system through the tree grate during the construction period. To remove this barrier simply remove the grate and pull the fabric blanket completely out of the system. The second barrier to remove is a metal plate that is located at the inlet of the Bioretention Bay. This barrier is designed to prevent construction runoff from entering the Bioretention Bay inlet during the construction period.

Figure 12 - Newly Installed Urban Green BioFilter

The internal bypass is designed with a small inlet drain hole at the base to eliminate any standing water in the system during the construction. Once the barrier is removed from the Bioretention Bay inlet as described above, the inlet drain hole is sealed.

Planting and caring for the specified tree is critical for a successful installation and needs to be carefully completed. Due to the specialized media type in the UrbanGreen BioFilter, the planting hole does not need to be deeper or much larger in diameter than the root ball. As general rule, trees should be transplanted no deeper than the soil in which they were originally grown however, a small amount of differential settling may occur such that the plant can be placed where the new soil surface is from 0-1” above the original soil surface.

Plants from the nursery can be in balled, container or bare root form, depending on the tree and the time of the year. Balled and burlapped (B & B) trees, should always be lifted by the ball, never by the trunk. The burlap or other wrapper surrounding the ball of earth and roots are cut away completely insuring any string or twine should also be removed.

The procedure for planting container trees is similar to that for B & B trees. In the case of metal or plastic containers, remove the container completely. In the case of fiber containers, tear the sides away. Once carefully removed from the container, check the roots. If they are tightly compressed or ‘potbound’, tease the fine roots away from the tight mass and then spread the roots prior to planting. In the case of extremely woody compacted roots, it may be necessary to use a spade to open up the bottom half of the root system. The root system is then pulled apart or ‘butterflied’ prior to planting. Loosening the root structure in this way is extremely important in the case of container plants. Failure to do so may result in the roots ‘girdling’ and killing the tree. At the very least, the roots will have difficulty expanding beyond the dimensions of the original container. To further assist this, lightly break up even the soil outside the planting zone. This allows roots that quickly move out of the planting zone to be more resilient as they anchor into existing surrounding soil conditions.

Planting bare-rooted trees is a little different as there is no soil surrounding the roots. Most importantly, the time between purchase and planting is a more critical issue. Plant as soon as possible. When purchasing bare-rooted trees, inspect the roots to ensure that they are moist and have numerous lengths of fine root hairs (healthy). Care should be taken to ensure that the roots are kept moist in the period between purchase and planting. Prune broken or damaged roots but save as much of the root structure as you can.

To plant, first build a cone of earth in the centre of the hole around which to splay the roots.

Make sure that when properly seated on this cone the tree is planted so that the ‘trunk flare’ is clearly visible and the ‘crown’, where the roots and top meet, is about two inches above the soil level.

Watering should be done at the time of planting. In addition, during the first growing season, as a rule of thumb, they should be watered at weekly in the absence of rain, more often during the height of the summer. However, care should be taken not to overwater as this may result in dry weather runoff, in fact due to the high permeability of the engineered soil frequent water ing with a slowly applied water spray is best.

If water runs out of the system through the outlet pipes, cease watering.

Young trees should be able to support themselves, but when they are transplanted, they often need time to reestablish. Once a tree is planted, it will concentrate its energy on standing upright. If it is unable to do so, try thinning out the upper branches to reduce wind resistance. If that is not enough and you find you have to stake a tree.

The truck and the crown of the tree should also be wrapped to prevent sun scalding and mechanical damage. Use wraps that allow good air circulation to help prevent disease reduce the harboring of insects

Use restraint when pruning your newly-planted trees. Remove any damaged branches. Look to maintain the branch framework while maximizing the number of branches to increase juvenile growth

The UrbanGreen BioFilter contains a specially designed engineered soil mixture that does not require mulching. Also note that since the UrbanGreen BioFilter discharges to waterways, it is critical not to over fertilize. If fertilizers are needed then organic source fertilizers with low N-P-K slow release should be used. Concentrated water soluble fertilizers are not recommended. Fertilizers should be applied to the tree at the drip line or just outside the active root zone and cultivated into the first few inches of soil. Another solution for long term care are fertilizer and pesticide inserts found at www.treerx.com

OPERATIONS AND MAINTENANCE

Final O&M Guidelines need to be established as part of observations and monitoring of field installations. However, the UrbanGreen BioFilter should be inspected at regular intervals and maintained when necessary to ensure optimum performance. The rate at which the system collects pollutants will depend heavily on site activities than the size of the unit, e.g., unstable soils or winter sanding will cause the system to fill more quickly but regular sweeping will slow accumulation. In cold weather climates, be aware of salting operations for pavement deicing. Maintenance of the UrbanGreen BioFilter should be performed by a qualified professional who is familiar and has experience with maintenance of stormwater management systems.

Inspection is the key to effective maintenance and is easily performed. During the first year of growth and plant establishment the system should be observed for tree health. Look for proper growth paying special attention to soil moisture and irrigation needs. Routine maintenance starts with trash & debris removal and should be performed during each inspection if needed. Inspection the media cartridge bay well. If greater than three inches of sediment is found on the chamber floor or on the tops of the cartridges then cartridge replacement should be performed.

Periodic full maintenance will be required to maintain the function of the tree bed and the media cartridge bay and replacement of cartridges. The first step in the clean-out of the Media Cartridge Bay is to remove the sediment and debris that has collected in this chamber. A vacuum truck or manual operations can be used for this procedure. Once the sediment and debris has been removed, the existing cartridges should be removed from the system. Cartridges are connected to the under drain manifold by a simple quarter-turn connection and are easily disconnected. Once the cartridges are removed from the vault, any remaining sediment and/or debris should be cleaned out. The final step in the cartridge replacement process is to install the replacement cartridges. Replacement cartridges should be installed securely to the quarter-turn connection system and the cover placed securely back over the media cartridge bay.

Replacement of the BioFilter media needs to be assessed and determined if replacement of all or a portion of the media requirement removal and replacement.

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A Non-dimensional Modeling Approach for Evaluation of Low Impact Development from Water Quality to Flood Control

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ABSTRACT

Regulations in the United States establish water quality protection requirements that typically are targeted at relatively small, frequent events, comprising the bulk of non-point source pollutant loading to receiving waters. Although water quality requirements vary from municipality to municipality, typical requirements include promoting infiltration to reduce runoff volume and peak flows, storage and release of runoff or some combination of infiltration and storage/release. Examples of such requirements include ordinances requiring development to maintain runoff rates and, in some cases, volumes at pre-development levels for up to a specified design event and/or requirements to capture, store and release runoff from frequent events.

Complying with these types of water quality requirements can be expensive, so it is understandable to question what benefit these requirements have for flood control. Flood control benefits of water quality facilities typically can be quantified using hydrologic and hydraulic calculations; however, there are important considerations that belie the simplicity of calculations, including ownership, operation and maintenance of facilities. These issues are especially important for on-site water quality facilities and "distributed" controls, which generally are not publicly owned and maintained.

This paper presents hydrologic and hydraulic modeling to explore water quality and flood control benefits of water quality facilities, especially infiltration-based Low Impact Development (LID) practices. The paper presents a method for calculating an Imperviousness Reduction Factor (IRF) that can be used to calculate effective imperviousness based on total site imperviousness. This paper demonstrates that while water quality facilities are important for smaller, more frequently occurring events and play a role in water quality and stream channel protection when it comes to larger flooding events, hydrologic benefits diminish and must be complemented with sound detention, conveyance and floodplain management policies and practices. Failure to recognize and plan for this fact will inevitably subject properties to higher than appropriate flood risk.

INTRODUCTION

Reducing the volume of runoff generated from development and redevelopment projects is fundamental to effective stormwater management. The ability to easily quantify volume reduction associated with minimizing directly connected impervious area (MDCIA), Low Impact Development (LID) practices and other Best Management Practices (BMPs) is important for evaluating the feasibility of these types of practices. One of the primary barriers to wider use of LID in the United States is the need for a relatively simple method for quantifying volume reduction benefits of LID practices (Earles et al. 2008).

The concepts discussed in this paper are dependent on the concept of Effective Imperviousness. The term “Effective Imperviousness” refers to impervious areas that contribute surface runoff to the drainage system. In engineering literature, this term is sometimes used interchangeably with “Directly Connected Impervious Area.” For the purposes of this paper, “Effective Imperviousness” is more broadly defined, including portions of the Unconnected Impervious Area that contribute to runoff from a site. For small, frequently occurring events, the “Effective Imperviousness” is equivalent to Directly Connected Impervious Area since runoff from Unconnected Impervious Areas infiltrates into Receiving Pervious Areas; however, for larger events, the “Effective Imperviousness” is increased to account for runoff from Unconnected Impervious Areas that exceeds the infiltration capacity of the Receiving Pervious Area.

To evaluate the effects of MDCIA and other LID practices, the Urban Drainage and Flood Control District (UDFCD) has performed modeling using the United States Environmental Protection Agency (USEPA) Stormwater Management Model (SWMM) to develop tools for planners and designers, both at the watershed/master planning level, when site-specific details have not been well defined, and at the site level, when plans are at more advanced stages. This paper focuses on site-level analysis. Watershed/master planning level tools have been included in the UDFCD *Urban Storm Drainage Criteria Manual, Volume 3* (USDCM Volume 3), since the mid-2000’s (UDFCD 1999, latest revision 2008) and are currently being revised as a part of an overall update to Volume 3 of the USDCM in 2010.

Conceptual Model for Volume Reduction BMPs

The hydrologic response of a watershed during a storm event is characterized by factors including shape, slope, area, imperviousness (connected and disconnected) and other factors (Guo 2006). Total imperviousness of a watershed can be determined by delineating roofs, drives, walks and other impervious areas within a watershed and dividing the sum of these impervious areas by the total watershed area. In the past, total imperviousness was often used for calculation of peak flow rates for design events and storage requirements for water quality and flood control purposes. This is a reasonable approach when much of the impervious area in a watershed is directly connected to the drainage system; however, when there are significant amounts of unconnected impervious area in a catchment, using total imperviousness will result in an overestimation of peak flow rates and storage requirements.

Unlike many conventional stormwater models, SWMM allows for more complex evaluation of flow paths through the on-site stormwater BMP layout. Conceptually, an urban watershed can generally be divided into four land use areas that drain to the common outfall point as shown in Figure 1. These four areas are: Directly Connected Impervious Area (DCIA), Unconnected Impervious Area (UIA), Receiving Pervious Area (RPA), and Separate Pervious Area (SPA) (UDFCD 1999a).

A fundamental concept of LID is to route runoff generated from the UIA onto the RPA to increase infiltration losses. To model the stormwater flows through a LID site, it is necessary to link flows through their physical flow paths to take into consideration additional depression storage and infiltration losses over the pervious landscape. One of the more recent developments in SWMM allows users to model overland flow draining from the upper impervious areas onto a downstream pervious area. As illustrated in Figure 1, the effective imperviousness is only associated with the cascading plane from UIA to RPA, while the other two areas, DCIA and SPA, are drained independently.

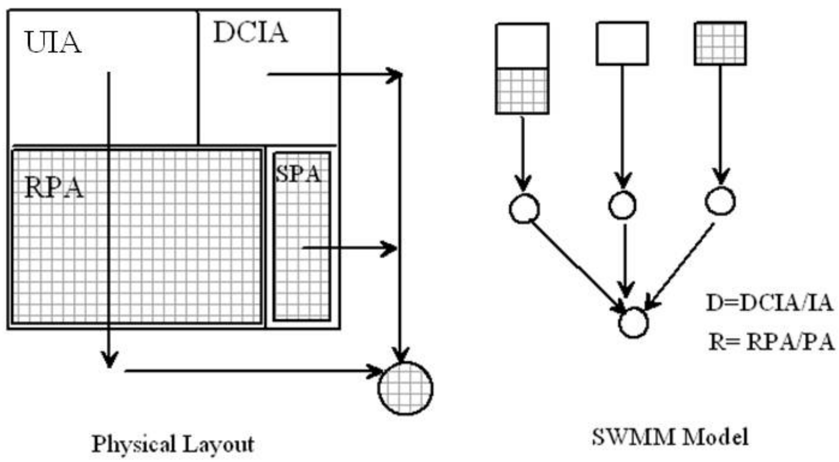


Figure 1. Four Component Land Use

For a LID site, the effective imperviousness is less than the total imperviousness. Aided by SWMM, effective imperviousness can be determined by a runoff-volume weighting method that accounts for losses along the selected flow paths. When designing a drainage system, design criteria that account for effective imperviousness can potentially reduce stormwater costs by reducing the size requirement of hard infrastructure to convey and/or store the design stormwater flows and volumes. To be practical, it is necessary to relate the effective imperviousness of a LID site to its area-weighted total imperviousness, because the surface-area map for a project site is typically available and total area-weighted imperviousness is a commonly calculated parameter.

QUANTIFICATION OF VOLUME REDUCTION

For site-level planning, whether at a conceptual level or a more advanced stage of design, volume reduction can be determined from SWMM modeling conducted by an experienced user. While it is possible to quantify volume reduction by varying inputs in SWMM including the fraction of impervious area directed to pervious areas, pervious area depression storage and other factors, design charts based on multiple SWMM runs can provide a useful tool for designers who do not wish to go to the effort or expense of detailed site-level modeling using SWMM.

This paper describes two options for quantification of volume reduction at the site level when these fractions have been identified:

- SWMM modeling using the cascading plane approach

- UDFCD Imperviousness Reduction Factor charts and spreadsheet

The Imperviousness Reduction Factor (IRF) charts presented in this paper were developed using a dimensionless SWMM modeling approach developed by Guo et al. (2010) that determines the effective imperviousness of a site based on the total, area-weighted, imperviousness and the ratio of the infiltration rate (saturated hydraulic conductivity), *f*, to the rainfall intensity, *i*. Because the Imperviousness Reduction Factor is based on cascading plane SWMM modeling, it will yield results that are generally consistent with creation of a site-specific SWMM model.

To apply either of the above methods, a project site must first be broken up into sub-watersheds based on topography and drainage patterns. For each sub-watershed, the areas of DCIA, UIA, RPA and SPA should be calculated. Sub-watersheds (and associated BMPs) will fall into one of two categories based on the types of BMPs used:

1. Conveyance-based—Conveyance-based BMPs include, but are not limited to, grass swales, vegetated buffers, pervious pavement systems without significant sub-surface storage and disconnection of roof drains and other impervious areas to drain to pervious areas (UDFCD 1999a). Conveyance based BMPs may have some incidental, short-term storage in the form of channel storage or shallow ponding but do not provide the Water Quality Capture Volume (WQCV) and/or flood-control detention volume.
2. Storage-based—Storage-based BMPs include bioretention/rain gardens, pervious pavement systems that provide the WQCV as sub-surface storage, extended dry detention basins and other BMPs that provide the WQCV and/or flood-control detention volume.

SWMM Modeling Using Cascading Planes

Because of complexities of modeling LID and other BMPs using SWMM, this alternative for site-level volume reduction analysis is recommended only for experienced users. The following list provides guidance for conveyance- and storage-based modeling:

- Each sub-watershed should be conceptualized as shown in Figure 1. Two approaches can be used in SWMM to achieve this:
  - Create two SWMM sub-catchments for each sub-watershed, one with UIA 100-percent routed to RPA and the other with DCIA and SPA independently routed to the outlet.
  - Use a single SWMM sub-catchment to represent the sub-watershed and use the SWMM internal routing option to differentiate between DCIA and UIA. This option should only be used when a large portion of the pervious area on a site is RPA and there is very little SPA since the internal routing does not have the ability to differentiate between SPA and RPA (i.e. the UIA is routed to the entire pervious area, potentially overestimating infiltration losses).
- Parameters for infiltration and depression storage are key input parameters for modeling LID. It is important to be realistic about infiltration parameters. When facilities are new, infiltration rates may be quite high; however, as facilities age and fine sediments penetrate into infiltration layers, the rate will decline. Therefore, the saturated hydraulic conductivity should not be overly-optimistic. For well drained sub-soils, a maximum value of 1 inch per hour is recommended to account for decaying infiltration over time and to be realistic about maintenance.
- For storage-based BMPs, there are two options for representing the WQCV:

- The pervious area depression storage value for the RPA can be increased to represent the WQCV. This approach is generally applicable to storage-based BMPs that promote infiltration such as rain gardens, pervious pavement systems with storage or sand filter basins. It should not be used when a storage-based BMP has a well defined outlet and a stage-storage-discharge relationship that can be entered into SWMM.
- The WQCV can be modeled as a storage unit with an outlet in SWMM. This option is preferred for storage-based BMPs with well defined stage-storage-discharge relationships such as extended detention basins.

These guidelines are applicable for EPA SWMM Version 5.0.018 and earlier versions going back to EPA SWMM 5.0. EPA is currently developing a version of EPA SWMM with enhanced LID modeling capabilities; however, currently, this new version is still undergoing testing and refinement.

Imperviousness Reduction Factor (IRF)

When UIA, DCIA, RPA, SPA and WQCV, if any, for a site have been defined, the IRF provides a relatively simple method for calculating effective imperviousness and volume reduction. Fundamentally, the IRF charts (and spreadsheet) are based on the following relationships.

For a conveyance-based approach:

$$K = Fct\left(\frac{F_d}{P}, A_r\right) = Fct\left(\frac{f}{I}, A_r\right) \quad \text{Equation 1}$$

For a storage-based approach:

$$K = Fct\left(\frac{F_d}{P}, A_r, A_d\frac{WQCV}{P}\right) \quad \text{Equation 2}$$

Where:

K = Imperviousness Reduction Factor = Effective Imperviousness/Total Imperviousness
F_d = Pervious area infiltration loss (in)
f = Pervious area infiltration rate (in/hr) corresponding to saturated hydraulic conductivity
P = Design rainfall depth (in)
I = Rainfall intensity (in/hr)
A_r = RPA/UIA
A_d = RPA
$WQCV$ = Water quality capture volume (watershed inches), and
Fct designates a functional relationship.

A full derivation of these expressions can be found in Guo et al. (2010). The results of cascading plane modeling based on these expressions are shown in Figure 2 for the conveyance-based approach and Figure 3 for the storage-based approach.

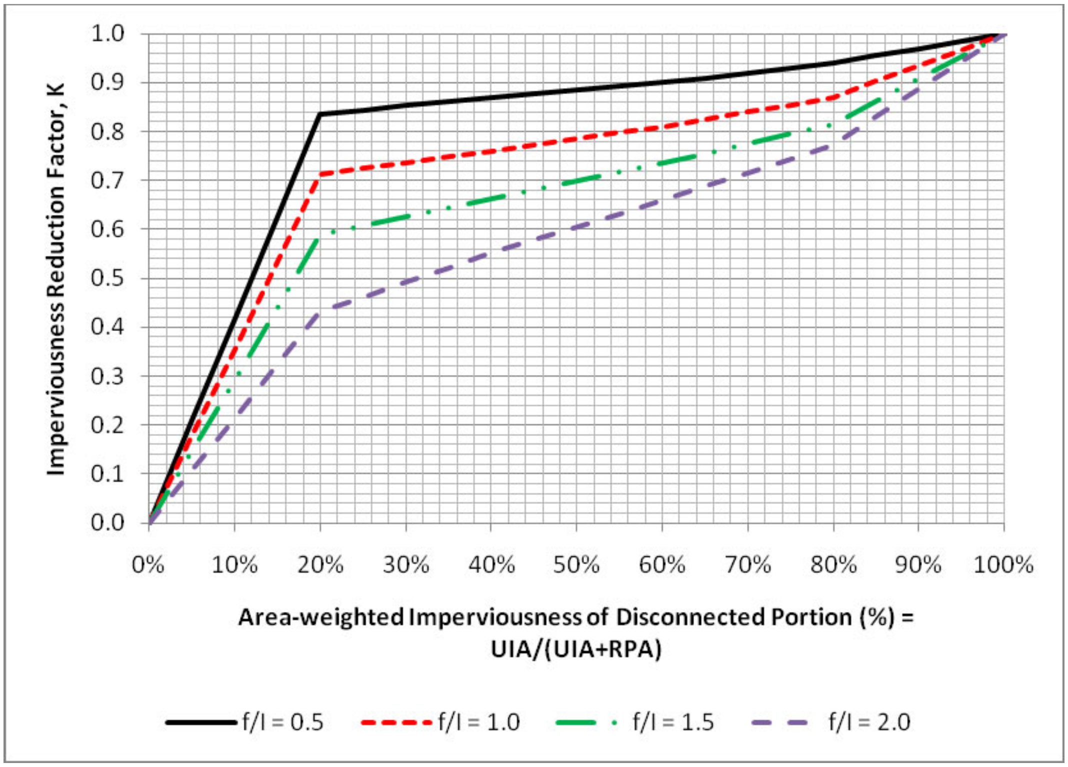


Figure 2. Conveyance-based Imperviousness Reduction Factor

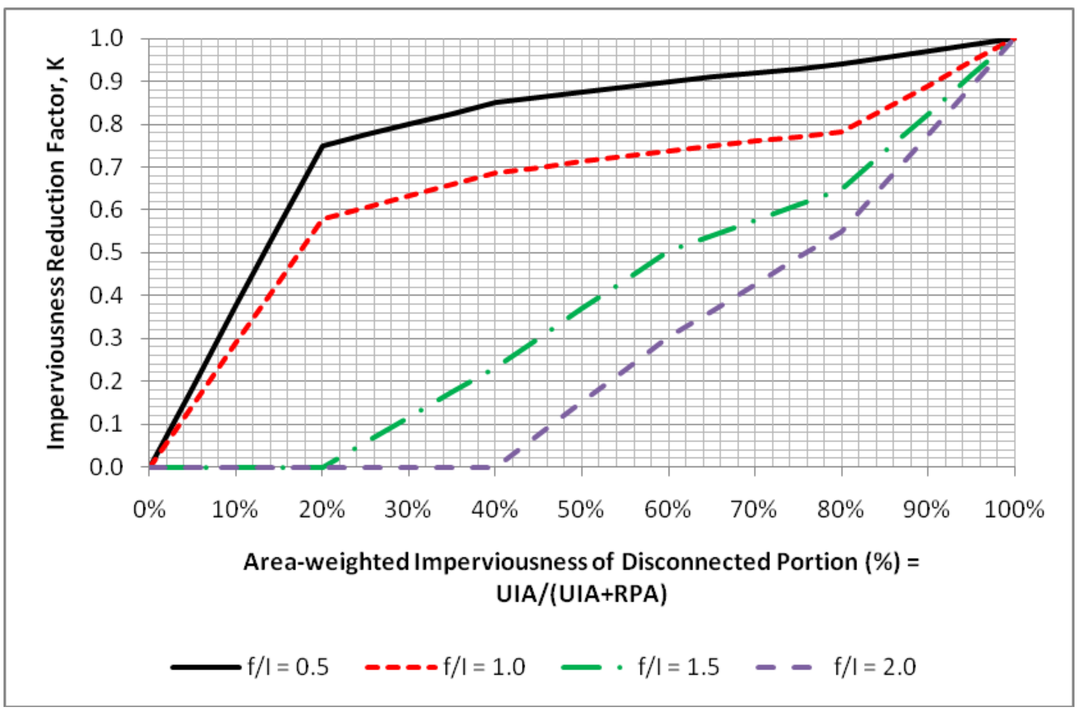
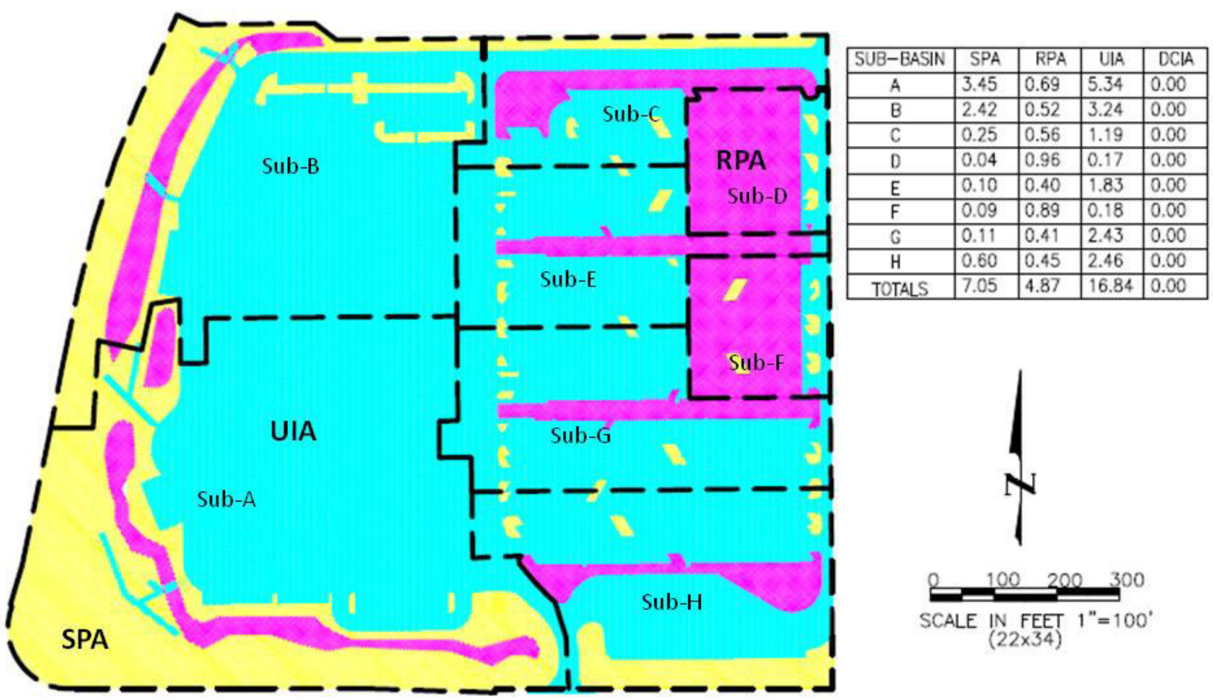


Figure 3. Storage-based Imperviousness Reduction Factor

Example Application

To implement the design charts shown in Figures 2 and 3, a spreadsheet was developed to calculate the IRF for a site plan. Spreadsheet inputs include fractions of UIA, DCIA, RPA and SPA; design rainfall; infiltration capacity of RPA and whether the sub-basin uses conveyance-based or storage-based BMPs. Calculations include the IRF for each input sub-basin as well as volume reductions for the water quality, major and minor events based on effective imperviousness.

The site chosen to demonstrate the spreadsheet IRF method is a commercial site in Aurora, Colorado that is one of the first sites in the metropolitan Denver area with widespread implementation of LID across the site. LID practices include pervious pavements, infiltration beds, and bioswales as well as more conventional BMPs such as extended dry detention basins on portions of the site. Figure 4 shows the site layout, conceptualized as the four area fractions. The total site area is approximately 29 acres with virtually no DCIA (areas are provided for each sub-basin in Figure 4).



SUB-BASIN	SPA	RPA	UIA	DCIA
A	3.45	0.69	5.34	0.00
B	2.42	0.52	3.24	0.00
C	0.25	0.56	1.19	0.00
D	0.04	0.96	0.17	0.00
E	0.10	0.40	1.83	0.00
F	0.09	0.89	0.18	0.00
G	0.11	0.41	2.43	0.00
H	0.60	0.45	2.46	0.00
TOTALS	7.05	4.87	16.84	0.00

Figure 4. Commercial Store Site Plan UIA, DCIA, RPA and SPA.

One-hour point rainfall totals for the Denver metropolitan area of 0.50 inches for the 3-month event, 1.55 inches for the 10-year event and 2.60 inches for the 100-year event were entered into the spreadsheet to evaluate the effects of the LID practices over a range of events. With the exception of only two sub-basins (A&B), storage-based BMPs were implemented on the site. The maximum infiltration rate specified for pervious areas in the spreadsheet was 1.0 inch per hour, representing the saturated hydraulic conductivity of the relatively sandy soils on site.

Table 1 presents the results of applying the IRF to calculate effective imperviousness. It is very important to note that the IRF is applied only to adjust the UIA. Effective imperviousness is calculated as follows:

$$Effective\ Imperviousness = \frac{UIA \times K + DCIA}{UIA + DCIA + SPA + RPA} \qquad \text{Equation 3}$$

with variables defined above.

Sub-basin ID	I_{total}	$I_{3\text{-month Effective}}$	$I_{10\text{-year Effective}}$	$I_{100\text{-year Effective}}$
A	56%	50%	54%	55%
B	52%	45%	50%	51%
C	60%	19%	54%	56%
D	15%	0%	11%	12%
E	79%	35%	74%	76%
F	16%	0%	12%	13%
G	82%	39%	79%	80%
H	70%	33%	67%	68%
Overall	59%	38%	56%	57%

Table 1. Effective Imperviousness for 3-month, 10-year and 100-year Events

The results in Table 1show that the effective imperviousness of the site is more than 20 percent lower than the total impervious area for the 3-month event. As would be expected, however, this effect diminishes for larger events and is only a 2% difference for the 100-year event when the rainfall intensity overwhelms the soil infiltration capacity.

The spreadsheet also uses effective imperviousness to project volume "credits" associated with LID practices. The spreadsheet calculates the water quality capture volume (WQCV) and 10- and 100-year detention storage volumes using empirical equations from the UDFCD *Urban Storm Drainage Criteria Manual* for total and effective imperviousness. The "credit" is the difference between the storage volumes calculated using total and effective imperviousness. Table 2 shows the results of WQCV and detention credit calculations.

Sub-basin ID	WQCV (ft^3) for I_{tot}	WQCV (ft^3) for I_{eff}	WQCV Credit (ft^3)	10-year Detention (ft^3) for I_{tot}	10-year Detention (ft^3) for $I_{10\text{-}yr\,eff}$	10-year Detention Volume Credit (ft^3)	100-year Detention (ft^3) for I_{tot}	100-year Detention (ft^3) for $I_{100\text{-}yr\,eff}$	100-year Detention Volume Credit (ft^3)
A	7723	7093	630	21313	20531	782	48303	47198	1106
B	4778	4349	429	12896	12325	572	29374	28550	824
C	1702	800	902	4759	4282	476	10738	10063	675
D	386	0	386	607	440	167	1301	1010	292
E	2702	1403	1299	7380	6960	420	16142	15605	537
F	403	0	403	649	476	173	1409	1107	302
G	3680	1906	1775	9812	9360	451	21311	20747	564
H	3509	2036	1473	9889	9401	488	21950	21300	650
Total	24884	17586	7298	67305	63776	3530	150528	145580	4949

Table 2. WQCV and Detention "Credit" Results

As a fraction of the total volume required, the greatest benefits are associated with the WQCV, with diminishing reductions in storage volume requirements for the 10- and 100-year events. It is notable that there are indeed reductions in detention volume requirements for these larger events; however, in terms of the overall detention volume required for the site, the credits amount to less than 6% of the total volume for the 10-year event and less than 4% of the volume for the 100-year event.

CONCLUSIONS

The method presented in this paper provides a methodology for calculating effective imperviousness based on factors including the fractions of UIA, DCIA, RPA and SPA on a project site; the design rainfall intensity; the infiltration rate of pervious areas, and water quality storage with extended release (WQCV). The procedures presented in this paper are based on modeling using USEPA SWMM, and a user familiar with SWMM can conduct site-level or watershed-level modeling to quantify benefits of LID practices and other BMPs.

The example provided illustrates application of the imperviousness reduction factor method and also quantifies volume "credits" associated with LID. While the impact of LID measures on effectiveness is quite prominent for frequently occurring events that are typically targeted for water quality purposes, these benefits diminish for larger events typically associated with storm sewer design and flood control.

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Comparison of BMP Infiltration Simulation Methods

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ABSTRACT

Prince George's County has developed a Best Management Practices Decision Support System (BMPDSS) to assist in assessing the effectiveness of Low Impact Development (LID) technologies. This module uses process-based algorithms to simulate BMP function and removal efficiency. The processes include weir and orifice outflow, flow and pollutant routing, evapotranspiration, infiltration, and a general loss/decay representation for a pollutant. Among these processes, infiltration is a key mechanism that controls the effectiveness of LID types of BMPs on both flow reduction and water quality improvement. Therefore, an accurate representation of the infiltration process is the basis of a successful BMP simulation module. The current version of BMPDSS employs the empirical Holtan-Lopez model. With the U. S. Environmental Protection Agency's support, the model is currently being enhanced to include a layered infiltration scheme using the process-based Green-Ampt method. This paper compares the performance of these two different approaches for simulating the infiltration process occurring in LID types of BMPs like bioretention, vegetated buffer strip, and bio-swales. The pros and cons of each method are discussed in this paper.

KEYWORDS

Infiltration Simulation Methods, Low Impact Development, Best Management Practices, Green-Ampt Model, Holtan-Lopez Model.

INTRODUCTION

Low impact development (LID) is a recognized approach that aims to solve stormwater problems by essentially mimicking a natural system: infiltrate, filter, store, evaporate, and detain runoff as close to its source as possible. Promoting infiltration through engineered means, for instance, bioretention cells, vegetated buffer strips, and bio-swales, is perhaps the most important mechanism in the LID practices.

As a LID pioneer, Prince George's County has developed a Best Management Practices Decision Support System (BMPDSS) to assist in assessing the effectiveness of LID technologies. This module uses process-based algorithms to simulate BMP function and removal efficiency. The currently available version of BMPDSS employs the empirical Holtan-Lopez model to simulate the infiltration process. Recognizing that an accurate representation of the infiltration process is the premise of a successful BMP simulation module, the model is currently being enhanced to include a layered infiltration scheme using the process-based Green-Ampt method. This paper compares the performance of these two different approaches for simulating the infiltration process occurring in engineered media layer, and discusses the potential impact on the BMP performance evaluation.

COMPARISON OF HOLTAN-LOPEZ AND GREEN-AMPT METHODS

Holtan-Lopez Method

The Holtan-Lopez empirical model is built on the concept that infiltration is proportional to the capacity of the soil to store water. This equation was developed on the principle that soil moisture storage, surface-connected porosity, and the effect of root paths are the dominant factors influencing infiltration capacity (Maidment, 1993).

$$f = GI\,A\,S_a^{1.4} + f_c$$

In the above equation, f is the infiltration rate (in/hr), GI is the growth index of vegetation in percent maturity, varying from 0.1 to 1.0, A is the vegetative parameter that characterizes surface-connected porosity and the density of plant roots which affect infiltration (a value of 0.8 is a typical number for sod or vegetation that would be found in a BMP), S_a is the available storage in the surface layer (inches), and f_c is the final constant infiltration rate, which is a function of the hydrologic soil group. The value of f_c ranges from 0.3 in/hr in group A to almost 0 in/hr in group D in-situ soils. For the engineered media, a value greater than 0.3 in/hr should be used to reflect the high permeability and influence of vegetation root system on infiltration.

Typical values Holtan's vegetative parameter A, and final infiltration rates are provided in Tables 1 and 2, respectively. Additional values may be found in other literature or site-specific studies.

Table 1.

Estimates of Vegitative Parameter **A** in Holtan Infiltration Model

Land Cover	Basal area rating	
	Poor condition	Good condition
Fallow	0.10	0.30
Row crops	0.10	0.20
Small grains	0.20	0.30
Hay (legumes)	0.20	0.40
Hay (sod)	0.40	0.60
Pasture (bunch grass)	0.20	0.40
Temporary pasture (sod)	0.20	0.60
Permanent pasture (sod)	0.80	1.00
Woods and forests	0.80	1.00

(Source: Table 5.5.3 -- Maidment, 1993. p. 5.31))

Table 2.

Final Infiltration Rates by Hydrologic Soil Groups

Hydrologic	Final rate, f_c (in/hr)	
Soil Group	min	max
A	0.30	0.30
B	0.15	0.30
C	0.05	0.15
D	0.00	0.05

(Source: Table 5.5.4 -- Maidment, 1993. p. 5.31)

Green-Ampt Method

The Green-Ampt model is based on the assumption that a wetting front that advances as plug flow through the soil column as infiltration of runoff occurs. The model assumes homogenous soil layers and a sharp wetting front. Figure 1 shows the conceptual formulation of the Green-Ampt model (Viessman and Lewis, 1998). Parameters used in the Green-Ampt infiltration calculations include:

F= Cumulative infiltration volume of runoff (in.)
S = Suction head (in)
Ho = Ponding depth (in)
i = Runoff loading intensity or rainfall intensity (in/hr)
f = Actual infiltration rate (in/hr)
Ks = Hydraulic conductivity of soil (in/hr)
Fs = Cumulative infiltration volume required to cause surface saturation (in)
IMD = Initial moisture deficit for the event (in/in)

The model implements the Green-Ampt method using the following equations:

For $F < Fs$:

$$Fs = \frac{S * IMD}{i / Ks - 1}$$

If $i > Ks$, then $f = i$

If $i <= Ks$, Fs is not calculated.

For $F >= Fs$:

$$f = Ks(1 + \frac{S * IMD}{F})$$

In order to reduce the accumulated error for a continuous simulation, the integrated equation is used in the model:

$$Ks(t2-t1)=F2-C*\ln(F2+C)-F1+C*\ln(F1+C) \quad \text{where } C = (S+Ho)*IMD$$

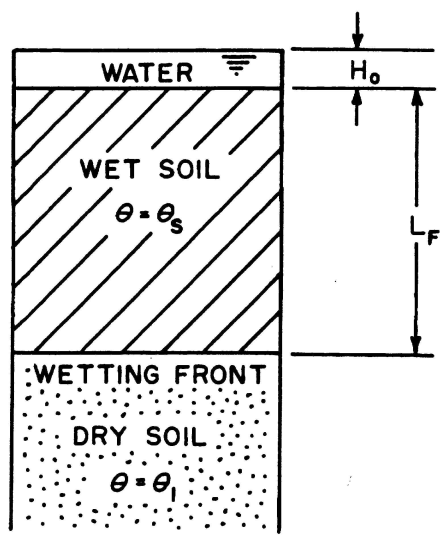

Figure 1. Conceptual Green-Ampt Model.
(Source: Viessman and Lewis, 1998)

The Green-Ampt model can be applied in multi-layered scheme. Infiltration is modeled for up to three layers in the Prince George's County BMP model: (1) root zone/mulch layer (2) media layer and (3) gravel (underdrain) layer. During simulation, the infiltrated water first saturates the root zone, then the soil layer and then the sand layer in that order. The dominant hydraulic conductivity is therefore the minimum saturated hydraulic conductivity of the layers above the wet front. For example, if the wet front is in the soil layer, the dominant *Ks* is the minimum value of hydraulic conductivity of the root zone and the soil layer.

TEST CASE

A hypothetical test case was constructed to compare the simulated infiltration process using the two methods. The soil media depth is 3.5 feet, and porosity is 0.4. The initial soil moisture content is set as 0.2. The simulation is driven by a 6 hour continuous inflow with a rate of 1.6 in/hr. The infiltration model parameters applied are summarized below:

<u>Holtan-Lopez Model Parameters:</u>
GI (growth index of vegetation): 1
A (vegetative parameter): 0.6
f_c (final constant infiltration rate): 0.6 (in/hr)

<u>Green-Ampt Model Parameters:</u>
S (Suction head): 8 (in)
Ks (Hydraulic conductivity): 1 (in/hr)

SIMULATION RESULTS AND DISCUSSION

Figure 2 shows the simulated surface infiltration rates and the ponding depth during the event. It clearly illustrates that the two models shows distinctly different infiltration behavior during the course of a storm. The simulated infiltration rate is largely controlled by the soil available storage in the Holtan-Lopez model, but not so much in the Green-Ampt model. Although it starts higher, the Holtan-Lopez simulated infiltration rate decreases more dramatically as water enter the soil column and soil available storage decreases. On the other hand, Green-Ampt simulated infiltration rate remains relatively constantly and only shows a slight drop as soil water storage decreases. Another difference between the two models is how the infiltration rate responding to the ponding depth. As Holtan-Lopez model was developed to simulate infiltration on a field, where ponding depth is negligible; therefore, ponding depth has no impact on the infiltration rate. For the Green-Ampt method, the water head added by ponding depth is counted as part of the driving force for infiltration; therefore, as ponding depth decreases, so does the infiltration rate.

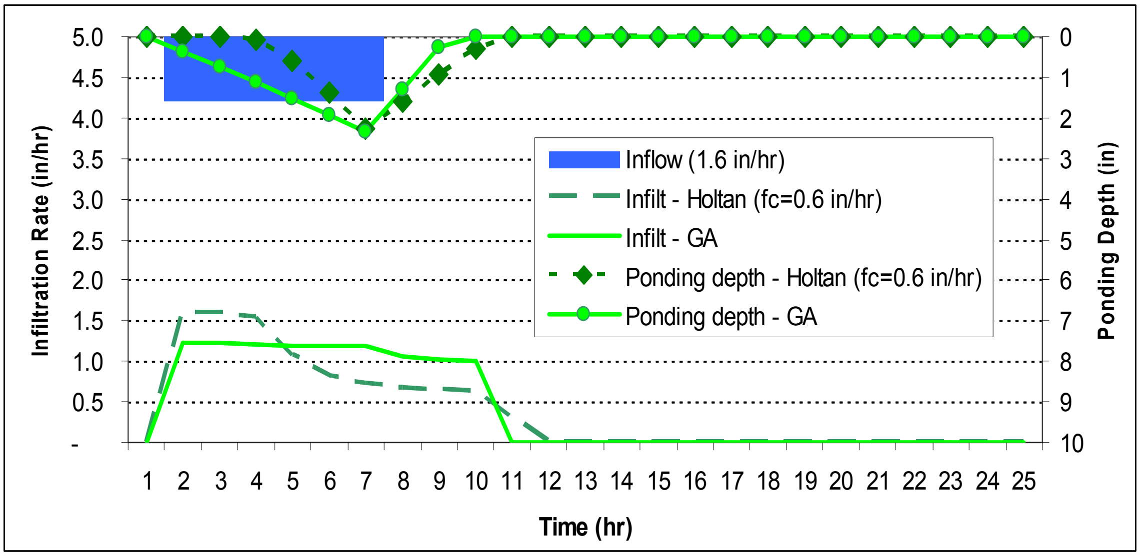

Figure 2. Comparison of the infiltration simulation results using Holtan-Lopez and G-A methods.

Despite the difference discussed above, by tuning the parameters, the two models can give comparable overall infiltration volume, especially for small storms during which no bypass occurs. For example, considering that the areas under the infiltration rate curves in Figure 2 are similar, if a small storm is completely contained with no bypass, then the net infiltration effect of both methods is the same. Considering the dominate pollutant removal mechanism is infiltration and filtration through media in most of the LID practices, it is expected that the two models would yield comparable overall load reduction estimates.

It is also important to note that solving the process-based Green-Ampt model requires iterations for convergence on a solution. The Holtan-Lopez is a semi-empirical model that solves the rate directly. For this reason, the Green-Ampt model is more computationally expensive than Holtan-Lopez model.

NEXT STEPS

The results presented herein are preliminary. Future investigation will be conducted to:

- Examine the impact of the recovery process on infiltration simulation. Recovery occurs from both evapotranspiration and gravitational draining of water from the soil column. The recovery process directly influences both the available soil water storage during the infiltration process, and the initial soil water storage for subsequent events.
- Validate the infiltration model using monitoring data. Laboratory and/or field test data need to be used to validate the infiltration models.

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Planning-Level Cost Estimates for Green Stormwater Infrastructure in Urban Watersheds

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ABSTRACT

The use of green stormwater infrastructure as an effective stormwater management technique has great potential in urban watersheds, and the development of accurate construction cost estimates is critical for achieving the desired results. This study evaluates a variety of factors that influence the development of construction cost estimates for implementing green stormwater infrastructure technologies, and provides the basis for unit-area planning level costs for use in large-scale urban watershed planning.

Green stormwater infrastructure costs depend on land cover, development density, the specific technology, size of the controlled area, and the level of stormwater management planning. The authors of this study developed cost estimates for implementing various green stormwater infrastructure techniques within several land use types. For the purposes of this study, a minimum level of control (infiltration or slow release of the first 1.0 inch of runoff) was used and normalized to the directly connected impervious tributary area at each site. For each stormwater management plan, construction costs were estimated for two cases: (1) a redevelopment construction cost, and (2) a full retrofit construction cost.

Green stormwater infrastructure construction costs depend on a variety of factors, but for planning level costs for large-scale urban watershed planning, these factors can be normalized to the directly connected impervious tributary area.

INTRODUCTION

Urban watershed management planning balances ecology, economics, and equity. Understanding the cost of implementing any type of infrastructure on a watershed scale is central to the development of any large-scale planning effort. This study presents the process and results of developing urban stormwater management planning-level construction costs using green stormwater infrastructure techniques. Green stormwater infrastructure techniques are also referred to as low-impact development or land-based stormwater management techniques; this paper will not differentiate these terms. Developing planning-level construction costs for these techniques requires an understanding of the factors that can influence cost, such as existing or proposed land use, type of development, and type of technique. In addition to indentifying factors that affect cost, this study created a cost basis for watershed scale planning that incorporates accurate cost estimates of detailed stormwater management plans and normalizes these estimates based on impervious drainage area.

A number of stormwater management plans and proposed standard details for projects in Philadelphia, Pennsylvania, were selected, representing a range of different green stormwater infrastructure techniques. Five of these were plans submitted by private developers and approved as complying with Philadelphia's stormwater ordinance and regulations. These types of plans included typical private development green stormwater management techniques, such as porous pavement, green roofs, and bioinfiltration. Ten plans were considered publicly funded projects based on the typical location of the stormwater management feature in or along public streets and sidewalks. Engineering cost estimates were developed based on materials, labor, overhead, and profit (see example in Table 1). Costs were adjusted to represent construction taking place within Philadelphia with union labor rates in 2008 dollars.

Direct construction costs were estimated using materials and labor quantities for the following two cases:

1. The marginal construction cost (beyond the cost of traditional measures) to implement each green stormwater infrastructure approach, assuming that redevelopment is already taking place. This case assumes that development is occurring and stormwater management is a part of the project scope. An example is a case where a developer is already planning to construct an office building and the cost of site preparations is included, so the cost to implement green stormwater infrastructure is separate from these set costs. Another example of this is a case where a public street is being reconstructed and the cost of the demolition and site preparations is included, and the addition of green stormwater management is separate from these costs.

2. The full construction cost required to implement each green stormwater infrastructure approach by retrofitting traditional development on an existing site. This case assumes that an existing site or building is being retrofitted to manage stormwater and the cost to implement a green stormwater management technique will include the demolition and site preparation not included in the marginal construction cost estimate. An example of this case is the construction of a planter or "bumpout" on an existing street. A bumpout is an extension of the sidewalk several feet into the street, often at a crosswalk, that traditionally serves to improve pedestrian safety by reducing the width of street to be crossed. By adding a vegetated area to the standard bumpout design, bumpouts can also be designed to intercept and manage stormwater.

STORMWATER CONTROL OBJECTIVES

Typical stormwater management regulations define a minimum level of performance for stormwater controls on developing and redeveloping land in a given municipality. For the purposes of this study, the Philadelphia stormwater management regulations were used as guidance for the minimum level of control. This level of performance is also used as a guideline for controls on public land. There are three major elements to the stormwater regulations: a water quality requirement, a channel protection requirement, and a flood control requirement (Philadelphia Water Department, 2007). This paper will discuss only the water quality requirement in detail.

The water quality requirement is equivalent to management of 1.0 inch of precipitation over the directly connected impervious area (DCIA) on a site. This requirement is established to: (1) recharge the groundwater table and increase stream baseflow; and (2) reduce stormwater runoff and combined sewer overflow. The requirement is similar to water quality requirements in surrounding states and in other major cities.

The management technique required is infiltration, unless infiltration is determined to be physically impossible (due to contamination, high groundwater table, shallow bedrock, impermeable soil) or where it can be shown that doing so would cause property or environmental damage. Infiltration efficiently reduces combined sewer overflow volume, frequency, and duration by preventing water from reaching the combined sewer system. Where infiltration is not feasible for the entire volume, any remaining portion that cannot be infiltrated must be detained and released at a specified rate. This slow release rate reduces overflow volume and frequency by diverting more flow to wastewater treatment plants. In addition to efficiency in preventing overflow, infiltration is desirable for a number of reasons:

- Infiltration restores a more natural water balance, reducing both the quantity and duration of runoff and overflow.
- The easiest way to manage the 1.0-inch water quality volume is to infiltrate it. Designing a control structure to store and release runoff at a slow rate is more difficult technically and requires more maintenance.
- Design alternatives exist to address many common objections to infiltration, such as wet basements and groundwater contamination, due to small amounts of pollutants in parking lot runoff.

GREEN STORMWATER INFRASTRUCTURE TECHNIQUES

This study focused on five green stormwater infrastructure and low-impact development techniques for use in urban stormwater management. These techniques included green roofs, bioretention/bioinfiltration, porous pavement, subsurface infiltration/retention, and street trees.

GREEN ROOFS

Green roofs, also referred to as eco roofs, vegetated roofs, and roof gardens, are composed of a multi-layer system that is top covered with vegetation. Green roofs are implemented on both flat and pitched roofs. The system of layers consists of waterproofing, drainage layer (such as pea gravel), soil media for plantings, and vegetation suited for the variable climate of the roof. Green roofs are ideally suited for large flat roofs, but can also be implemented on buildings with moderate pitches. Green roofs can be utilized as part of new construction or as retrofit on an existing building. The stormwater management effectiveness provided by green roofs is ideal as the roof can retain, slowly release, and evapotranspirate precipitation.

BIORETENTION / BIOINFILTRATION

Bioretention and bioinfiltration systems utilize a series of components to control stormwater. These components include surface ponding storage, vegetation, soil suitable for the vegetation selected, and inlet and outlet flow controls. The difference between bioretention and bioinfiltration systems is that the bioretention systems are utilized in areas where infiltration is not possible or feasible. These systems are designed with a slow release orifice that allows the system to drain down over an extended period of time, while allowing evapotranspiration through the soil and vegetation. Bioinfiltration and bioretention elements are ideally suited for urban stormwater management. The elements are flexible in size and configuration and can be utilized for street, sidewalk, parking lot, and roof runoff applications. Figure 1 is an example of a bioinfiltration system in an urban application.

Figure 1. Herron Playground Bioinfiltration Basin

POROUS PAVEMENT

Porous pavement allows the passage of stormwater runoff through voids in the surface. Porous pavement can be applied in many of the same applications as traditional pavement because the structural strength is very similar. Varieties of porous pavement include porous and permeable asphalt and concrete, and interlocking pavers. The porous surface of the pavement allows stormwater to pass through and into below ground void space filled with gravel. Similar to other green stormwater infrastructure systems, porous pavement can be designed to allow infiltration or slow release of runoff.

SUBSURACE INFILTRATION / RETENTION

Subsurface infiltration and retention systems are also components of porous pavement and bioretention/bioinfiltration systems, but can be considered their own technique because of their application in areas where surface treatments, such as bioretention/bioinfiltration or porous pavement, are not feasible or desirable. Similar to the other systems, subsurface infiltration and retention systems provide underground storage and infiltration or slow release of stormwater. These systems can use the void space in gravel, modified soils, pipes, and hollow crates for storage to meet minimum control requirements. Subsurface infiltration and retention systems are suited for applications below parking lots, sidewalks, streets, and lawns.

STREET TREES

Street trees are meant to describe any tree utilized in application where the tree canopy will be covering impervious surfaces. For example, trees planted in parking lots would also be considered in this category, because the tree is providing canopy coverage over impervious surface. Street trees provide interception of precipitation and then store and release this water through evapotranspiration. While street trees by themselves do not provide the same stormwater management control benefits of larger-sized green stormwater infrastructure, they are a key component of a watershed-scale application of green stormwater infrastructure. Trees along with other vegetation utilized in green stormwater infrastructure provide benefits in the form of improved aesthetics, improved quality of life, and reduction of heat and energy use.

COSTING APPROACH

The selected stormwater management plans were evaluated in detail and all necessary information to prepare construction costs was utilized. Lengths, areas, volumes, and quantities were obtained from plans and converted into appropriate units. Each component of the stormwater management plan was then matched with the appropriate unit cost. The majority of unit cost data was provided by R.S. Means Costworks (R.S. Means, 2009). Where specific unit cost data were not available through R.S. Means, engineering assumptions were made to provide conservative estimates of unit costs.

KEY MATERIALS & ACTIVITIES

Many of the materials and activities for green stormwater infrastructure are similar for multiple techniques. Key materials include appropriately graded gravel, select growing media and soil, trees, native plants and vegetation, and other conventional stormwater management components, such as inlets, manholes, and pipes. Activities that are utilized throughout green stormwater management infrastructure include excavation, hauling, and finishing off surfaces and landscapes.

Costs for many of these key components can vary by location and it should be noted that application of any costs to other areas should be verified by appropriate evaluation of location factors and preferred techniques.

UNIT AREA NORMALIZATION

In addition to accurate take offs and measurements of plans for unit cost considerations, the accurate measurement of impervious drainage area to the planned green stormwater management control is essential. Appropriately normalizing planning-level costs for green stormwater infrastructure requires two key measurements: level of control and directly connected impervious area. For this study, the level of control is infiltration or slow release of 1.0 inch of runoff and the impervious area is measured from the selected stormwater management plans.

RESULTS

The results from the takeoffs of LID stormwater management plans are provided in Tables 3, 4, and 5. Descriptions of the projects that are selected for the analysis are listed below in Table 3. The estimates are summarized into three categories: bioretention/subsurface infiltration/ porous pavement, green roof, and street trees in Tables 4 and 5. Each category was further broken down into a redevelopment and retrofit cost. These costs are direct construction costs with overhead and profit included. R.S. Means unit cost estimates include these as part of the unit cost. For the data set studied, construction costs for bioretention, subsurface infiltration, and porous pavement do not appear to be significantly different; costs for each technology exhibit a range and those ranges overlap. For the purpose of the study, results for these three technologies were pooled and treated as a single category. Similarly, possibly due to the small sample size, the results of construction costs across different land uses did not show significant differences. For the purposes of this study, no distinction is made in construction cost between different land uses for a single technology.

Table 3. Project Descriptions and Characteristics

Project Name	BMP Type	Land Use	Post Construction Impervious Cover (sq ft)
Private (1)	Subsurface Infiltration	High Density Residential	23,760
Public (1)	Bioretention	Street	19,318
Private (2)	Green Roof	High Density Mixed Use	23,012
Public (2)	Pervious Pavement and Detention	School	52,254
Private (3)	Subsurface Infiltration	School and Parking	121,384
Public (4)	Subsurface Infiltration	Street	17,346
Private (4)	Green Roof and Pervious Pavement	High Density Residential	52,230
Private (5)	Subsurface Infiltration	Commercial	105,415
Public (5)	Bioretention	Parking	424,870
Public (6)	Subsurface Infiltration	School	29,053
Curb Extension	Bioretention	Street	3,358
Swale without Parking	Bioretention	Street	2,550
Swale with Parking	Bioretention	Street	2,263
Planter with parking	Bioretention	Street	862
Planter without parking	Bioretention	Street	1,067
Street Trees	Street trees	Street	43,000*

*Typical urban street applications can provide enough area for 30 trees per acre placed in 16 sq. ft. tree boxes.

Table 4. Range in Direct Construction Cost Estimates (2008 Dollars)

Control	**Type**	**Minimum Cost ($ / impervious acre)**	**Max Cost ($ / impervious acre)**
Bioretention / Porous Pavement / Subsurface Infiltration	Retrofit	$65,000	$410,000
	Redevelopment	$44,000	$200,000
Green Roof	Retrofit	$430,000	$570,000
	Redevelopment	$200,000	$290,000
Street Trees	Retrofit	$18,000	$18,000
	Redevelopment	$15,000	$15,000

Table 5. Mean and Median Direct Construction Cost Estimates (2008 Dollars)

Control	**Type**	**Median Cost ($ / impervious acre)**	**Mean Cost ($ / impervious acre)**
Bioretention / Porous Pavement / Subsurface Infiltration	Retrofit	$120,000	$160,000
	Redevelopment	$90,000	$110,000
Green Roof	Retrofit	$500,000	$500,000
	Redevelopment	$250,000	$250,000
Street Trees	Retrofit	$18,000	$18,000
	Redevelopment	$15,000	$15,000

ADDITIONAL CONSIDERATIONS

OPERATIONS AND MAINTENANCE COSTS

Operations and maintenance (O&M) costs were evaluated for categories including orous pavement, subsurface infiltration, green roofs, bioretention, and street trees. For each category, O&M costs were broken down into required O&M activities, as described in the Philadelphia Stormwater Management Guidance Manual. O&M activities, hours of work required, and frequency were also estimated. O&M labor costs associated with each LID design were considered and marked up to cover the costs associated with overhead and profit. Additionally, equipment costs and materials costs were considered as part of the study. The activities to maintain a bioretention facility are provided in Table 6, as an example of detail involved in this analysis. A summary of operations and maintenance costs for green stormwater management techniques is provided in Table 7.

Table 6. Bioretention O&M Activities

Activity	**Schedule**	**Visits Per Year Per Impervious Acre**	**Hours Per Visit Per Impervious Acre**	**Total Hours Per Year per Impervious Acre**
Remulch void areas	As needed	1	0.5	0.5
Treat diseased trees and shrubs	As needed	1	0.5	0.5
Keep overflow free and clear of leaves	As needed	3	0.5	1.5
Inspect soil and repair eroded areas	Monthly	12	0.5	6
Remove litter and debris	Monthly	12	0.5	6
Clear leaves and debris from overflow	Monthly	12	0.5	6
Inspect trees and shrubs to evaluate health, replace if necessary	Twice per Year	2	1	2
Inspect underdrain cleanout	Twice per Year	2	2	4
Verify drained out time of system	Twice per Year	2	1	2
Add additional mulch	Annually	1	1	1
Inspect for sediment buildup, erosion, vegetative conditions, etc.	Annually	1	1	1
Maintain records of all inspections and maintenance activity	Ongoing	1	1	1

Table 7. Green Stormwater Infrastructure Operations and Maintenance Cost Estimates

Control	Annual O&M Costs ($/imp. Acre/yr)
Porous Pavement	$2,400
Subsurface Infiltration	$2,900
Green Roof	$4,000
Bioretention	$3,100
Street Tree	$1,800

LEARNING CURVE ASSUMPTIONS

Over the long term, the cost impact of green stormwater infrastructure techniques is expected to decline for a number of reasons. The expected future construction costs are shown in Tables 8 and 9. The reductions shown in this table are credited to improvements in site layouts, a reduction in the cost for materials, reduction in design costs, and reductions in perceived risk as green stormwater infrastructure techniques become the standard way of managing stormwater.

BETTER SITE DESIGN

Site designers are required to comply with stormwater regulations today. However, design features needed to comply are often added as an afterthought, after the site layout has been determined. Designs are very dense and do not leave open space for stormwater management (or resident enjoyment). This forces stormwater management features into underground, infrastructure-intensive facilities. Over time, local engineers will adopt better site design techniques. In the cost reduction estimates, it is assumed that impervious area on each site is reduced by 20% percent, compared to the actual designs submitted in recent years. A 20-percent reduction is reasonable; the Philadelphia stormwater regulations provide an incentive for a 20-percent reduction, and there is a precedent for this level of reduction in surrounding states.

REDUCTIONS IN MATERIAL COST

As green stormwater infrastructure techniques, such as porous pavement and green roofs become the standard way of managing stormwater, materials needed to build them will no longer be considered specialty materials. For example, the cost reduction estimates assume that in the future, porous pavement will have the same unit cost as traditional pavement today.

REDUCTIONS IN DESIGN COST

Because green stormwater infrastructure techniques are unfamiliar to many local engineers, design costs are currently high relative to total construction cost. This assumption does not affect the direct construction costs shown below.

Table 8. Range of Direct Construction Cost Estimates with Improved Development Practices and Economies of Scale (2008 Dollars)

Control	Type	Minimum Cost ($ / impervious acre)	Max Cost ($ / impervious acre)
Bioretention / Porous Pavement / Subsurface Infiltration	Retrofit	$52,000	$290,000
	Redevelopment	$35,000	$160,000
Green Roof	Retrofit	$340,000	$460,000
	Redevelopment	$160,000	$230,000
Street Trees	Retrofit	$15,000	$15,000
	Redevelopment	$12,000	$12,000

Table 9. Median and Mean Direct Construction Cost Estimates with Improved Development Practices and Economies of Scale (2008 Dollars)

Control	Type	Median Cost ($ / impervious acre)	Mean Cost ($ / impervious acre)
Bioretention / Porous Pavement / Subsurface Infiltration	Retrofit	$100,000	$130,000
	Redevelopment	$80,000	$80,000
Green Roof	Retrofit	$400,000	$400,000
	Redevelopment	$200,000	$200,000
Street Trees	Retrofit	$15,000	$15,000
	Redevelopment	$12,000	$12,000

COST CONSIDERATIONS

Appropriate cost estimates for green stormwater infrastructure should be verified as demonstration and development projects that implement these stormwater management features. A watershed scale implementation of these techniques should incorporate the necessary data management and tracking to verify assumed planning-level cost estimates were sufficient and to assist with adapting designs for enhanced cost efficiency. Local market forces and availability of materials can influence cost and will have an effect on total cost of large scale green stormwater infrastructure implementation. These uncertainties should be understood and considered when applying planning level cost estimates.

SIZING CONSIDERATIONS

As previously described, this study evaluated green stormwater infrastructure techniques sized to control the first 1.0 inch of runoff. Depending on local climatology and stormwater conveyance system performance, additional storage can provide cost savings when implemented on a watershed scale. Adding additional storage to an existing site should cost less than constructing that storage on a new construction site because some costs are fixed. However, there also is a diminishing return as more storage is added because the larger storms required to fill the additional storage are less frequent. This topic is not evaluated in this study but is worthy of noting as an additional consideration when applying planning level cost estimates of green stormwater infrastructure.

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LID, LEED and Alternative Rating Systems – Integrating Low Impact Development Techniques with Green Building Design

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ABSTRACT

The demand for developments that achieve green rating criteria continues to be strong despite the weakened economy. Many municipalities throughout the U.S. are adopting green development ordinances or policies with various environmental goals, often with an emphasis on addressing global climate change. At the same time, environmental advocates and state and federal stormwater regulators are increasingly emphasizing low impact development (LID) design techniques to reduce long-term water quality impacts from new development and significant redevelopment projects, replenish groundwater resources, and provide for rainwater capture and reuse. This paper explores opportunities for harnessing some of the momentum of the green building movement to further the implementation of LID strategies in new development and redevelopment projects. We examine the extent to which LID designs can earn green building credits under Leadership in Energy and Environmental Design (LEED) rating systems for new construction (LEED-NC) and neighborhood development (LEED-ND), as well as alternative rating systems such as the Sustainable Sites Initiative (led by the American Society of Landscape Architects, Ladybird Johnson Wildflower Center, and U.S. Botanic Society), and GreenPoint Rated (a program of Build It Green, a California non-profit organization). The paper features the results of a comparison of green building criteria in LEED and alternative rating systems with LID techniques that may earn green development credits. Gaps in credit availability for specific LID techniques are identified, along with opportunities to further integrate the LID approach and green building initiatives.

GREEN BUILDING DEMAND

Market forecasts indicate continuing growth in the green building sector, with growth in green building materials in the U.S. projected to outpace building construction expenditures through 2013 (Freedonia Group, Inc. 2009). In a survey of over 750 real estate executives, 75% of the executives indicated that 2008 developments in the credit markets would not make their companies less likely to construct green buildings (Turner Construction Company 2008).

Los Angeles, San Francisco, San Jose and more than 30 other cities in California have adopted green development ordinances that require green rating certification for various classes of public and private development projects (Brown 2009). Similar requirements are being adopted by growing numbers of municipalities throughout the U.S., including New York City, Washington DC, Chicago, Dallas, Atlanta, Portland (Oregon), and Boston, (Hupp 2009, City of Boston 2007, City of Portland 2009).

LEVERAGING GREEN BUILDING DEMAND TO IMPLEMENT LID

While the green building movement has placed a high priority on energy efficiency, in view of the large percentage of greenhouse gas emissions in the U.S. that is generated by buildings (Build It Green 2009a), green building rating systems also address issues related to water, which could potentially create opportunities to further the implementation of LID.

In California and other locations in the U.S., there is an increasing emphasis in municipal stormwater permits on LID techniques to reduce long-term water quality impacts from new development and significant redevelopment projects, replenish groundwater resources, and provide for rainwater capture and reuse (Low Impact Development Center 2007). Non-governmental organizations are concurrently promoting LID (Garrison *et al.* 2009, San Francisco BayKeeper 2009).

This paper explores opportunities for harnessing some of the momentum of the green building movement to further implement LID strategies in new development and redevelopment projects.[1]

SELECTING GREEN RATING SYSTEMS FOR ANALYSIS

Green development rating systems were selected for this study based on prevalence of use by municipalities in the Santa Clara Valley of California (also known as Silicon Valley), and/or recommendations by municipal staff members. The following rating systems were included in this analysis: Leadership in Energy and Environmental Design (LEED) for New Construction and Major Renovation (LEED-NC), LEED for Neighborhood Development (LEED-ND), the Sustainable Sites Initiative, and GreenPoint Rated-Single Family.

LEED-New Construction. The U.S. Green Building Council's LEED rating system has been described as the dominant green rating system in the US (U.S. Department of Energy 2006). The LEED-New Construction and Major Renovations (LEED-NC) rating system was developed to guide the design and construction of "green" commercial and institutional projects, including office buildings, high-rise residential buildings, government buildings, recreational facilities, manufacturing plants and laboratories (USGBC 2009a). Because it has wide application to many development

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[1] Initial findings on this topic were presented at the Santa Clara Valley Urban Runoff Pollution Prevention Program's 2008 C.3 New Development Workshop (Prickett 2008), and subsequently presented to a statewide audience at the 2008 California Stormwater Quality Association conference (Bicknell 2008). Since 2008 the green rating systems that were previously analyzed have all been revised, and this paper presents updated findings.

projects, this rating system is cited in green building ordinances of various municipalities in Santa Clara Valley, including San Jose (City of San Jose 2008) and Palo Alto (City of Palo Alto 2008). The U.S. Green Building Council recently published a new version, LEED-NC 2009, which was reviewed for this analysis.

The LEED-Neighborhood Development rating system has a more limited application, guiding the development of dense, compact neighborhoods, portions or neighborhoods, or multiple neighborhoods, with particular emphasis on neighborhood connectivity and facilitating alternative modes of transportation (USGBC 2009b). It was included in this analysis due to the watershed-scale water quality benefits achieved by dense, compact neighborhood development (USEPA 2006), and local emphasis in Santa Clara Valley on "smart growth" development that concentrates growth in areas that have already been developed (Santa Clara Basin Watershed Management Initiative 2003). A previous version of LEED-ND was available for pilot projects only, but in 2009 a new version of LEED-ND was published for general use and was reviewed for this analysis.

GreenPoint Rated-Single Family. A program of Build It Green, a California non-profit organization, the GreenPoint Rated system specifically addresses development in California. It offers rating systems for green development of single family and multifamily residences, as well as a rating system for existing homes (Build It Green 2009b). A number of municipalities in Santa Clara Valley cite the GreenPoint Rated green building rating system in local green building ordinances, including Santa Clara County (County of Santa Clara 2008) and Sunnyvale (City of Sunnyvale 2009). Because of California's arid, Mediterranean climate, the GreenPoint Rated system gives special attention to water conservation and drought tolerant landscaping. Version 4.0 of GreenPoint Rated-Single Family is scheduled for implementation in January 2010 and was reviewed for this analysis.

Sustainable Sites Initiative. The American Society of Landscape Architects, Ladybird Johnson Wildflower Center, and U.S. Botanic Society are leading this initiative to develop a green development rating system specific to land development and long-term management (Sustainable Sites Initiative 2009a). The USGBC is participating in the initiative and anticipates incorporating the Sustainable Sites Initiative Guidelines and Performance Benchmarks into future iterations of LEED (Sustainable Sites Initiative 2009b). The Sustainable Sites Initiative is currently soliciting pilot projects to apply the Guidelines and Performance Benchmarks it published in 2009, which were reviewed for this analysis.

HOW THE RATING SYSTEMS WORK

Each of the four green building rating systems includes a list or "menu" of a wide range of environmentally sustainable features that could potentially be included in a development project. A specific number of points or credits is assigned to each sustainable feature included in the rating system. Project developers then choose which sustainable features to include in their project, which will be certified as a green project if it receives a sufficient number of points. In order to receive credit for any of the sustainable features, the project must demonstrate it has met criteria specified in the applicable rating system. Table 1 demonstrates how green development rating criteria may vary among rating systems, with a comparison of stormwater facility sizing criteria for projects constructed on previously undeveloped sites.

Table 1. Comparison of Sizing Criteria for Awarding Credits for Stormwater Control on Previously Undeveloped Sites

Variables	LEED-NC 2009 (Quantity Control)[1]	LEED-ND 2009	GreenPoint Rated-Single Family (v. 4.0)	Sustainable Sites 2009 (Quantity Control) [1]
Sizing criteria	Peak post-development discharge rate and quantity must match pre-development peak rate and quantity for 1- and 2-year 24-hour design storms.	Retain onsite stormwater volumes based on percentile rainfall event (total rainfall on given day in the record that is greater than or equal to X% of all rainfall events over a 20-40+ year period).	Path 1: 25% of site paving is pervious; install bioretention, disconnected downspouts, non-leaching roofing, and/or smart street/driveway design; OR Path 2: Capture/treat 85% of total annual runoff.	TR-55 curve number for post-development storage capacity must equal predevelopment TR-55 curve number.
Number of credits earned	1 credit	80%: 1 credit 85%: 2 credits 90%: 3 credits 95%: 4 credits	Path1: 1-3 credits Path2: 3 credits	10 credits

[1] LEED-NC and Sustainable Sites Initiative also offer credit for stormwater quality control (Credits SS-6.2 and 3.6, respectively). Quantity control is included in this table based on its comparability to the LEED-ND stormwater control criteria and Path 1 of the GreenPoint Rated stormwater control criteria.

Sources: USGBC 2009a, USGBC 2009b, Build It Green 2009a, Sustainable Sites Initiative 2009

METHODOLOGY FOR REVIEWING THE RATING SYSTEMS

The full list of sustainable features in each of the four rating systems was reviewed to identify LID techniques for which a project may earn credits. These credits were then added to obtain a total number of credits, for each rating system, that could potentially be earned by incorporating LID features. An explanation of the approach for identifying LID techniques and addressing optional credits and ranges of credits is provided below.

Identifying LID Techniques. While definitions may vary, LID is typically considered an approach to site development that mimics the natural hydrologic functions of storage, infiltration, and ground water recharge, which may also include design strategies such as preserving environmentally sensitive site features (Low Impact Development Center 2000). This definition guided the identification of LID techniques in the reviewed rating systems, which are presented in Table 2. While the majority of LID features listed in the table fit this definition without ambiguity, further explanation is provided below regarding the identification of specific sustainable landscaping practices as LID techniques.

Table 2. Identified Credits for LID Techniques in Selected Rating Systems

LID Techniques	LEED-NC (2009)	LEED-ND (2009)	GreenPoint Rated-Single Family (4.0)	Sustainable Sites (2009)
Conserve/Restore sensitive areas	SS-1	SLL-7 SLL-8	--	3.3 3.4 4.8
Reduce surface parking footprint	SS-4.4	NPD-5	A.4	--
Reduce disturbance/ Preserve vegetated areas	SS-5.2	GIB-7	A.1	4.6
Restore native plant communities	--	--	--	4.9
Plant shade trees	--	NPD-14	C.5	--
Stormwater control: quantity	SS-6.1	GIB-8	P.A.	3.5
Stormwater control: quality	SS-6.2	--	--	3.6
Design stormwater feature as landscape amenity	--	--	--	3.7

Table 2. Identified Credits for LID Techniques in Selected Rating Systems

LID Techniques	LEED-NC (2009)	LEED-ND (2009)	GreenPoint Rated-Single Family (4.0)	Sustainable Sites (2009)
Green roof/open grid paving (heat island effect)	SS-7.1 SS-7.2	GIB-9	--	4.11 4.12
Percent reduction in potable water for irrigation[1]	WE-1	GIB-4	C.11	3.2
Specify native/adapted plants[1]	--	--	C.3.c	4.7
Avoid invasive species[1]	--	--	C.3.a	Pre-requisite
High efficiency irrigation[1]	--	--	C.6	--
Minimize turf[1]	--	--	C.4	--
Rainwater harvesting/use	WE-2	--	C.8	--
Submetering for irrigation and/or hydrozoning[1]	--	--	C.1 C.10	--
Mulch and/or compost[1]	--	--	C.2 C.7	--

[1] Indicates sustainable landscaping technique.

Sources: USGBC 2009a, USGBC 2009b, Build It Green 2009a, Sustainable Sites Initiative 2009

Sustainable Landscaping. Various water efficient landscaping strategies were identified as LID techniques because they reduce long-term water quality impacts from development projects by reducing impacts associated with overspray and runoff. These techniques include: reduce potable water for irrigation, specify native/climate-adapted plants, high efficiency irrigation, minimize turf, submetering for irrigation, hydrozoning, and application of mulch. Design techniques to reduce indoor water consumption were not identified as LID features because they are not directly linked to a reduction in stormwater impacts, and typically are not activities that are directly linked to meeting municipal stormwater requirements for development projects.

Additional sustainable landscaping techniques were identified as LID techniques because they help reduce the use of pesticides and synthetic fertilizers: restore native plant communities, avoid invasive species, and apply compost. While this may go beyond some traditional understandings of LID, it is consistent with the approach used by the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB) in its Municipal Regional Stormwater Permit, adopted on October 14, 2009, which regulates municipal stormwater systems in more than 70 municipalities and includes within its LID requirements pollutant source control techniques, including "landscaping that minimizes irrigation and runoff, promotes surface infiltration, minimizes the use of pesticides and fertilizers, and incorporates other appropriate sustainable landscaping practices… ." (SFBRWQCB 2009).

Optional Means of Earning Credits. The various rating systems frequently allow a specified green building credit to be achieved by various options. For example, in Table 1, the GreenPoint Rated-Single Family rating system offers two options, or paths, for obtaining credit for stormwater control. In this example, both options are LID techniques. In other cases, some but not all of the available options were identified as LID features. We have included in Table 2 all credits that may be earned with at least one option that was identified as an LID technique. For example, in LEED-NC Credit WE-2, two points may be earned by harvesting and using stormwater for flushing toilets, which is considered an LID technique. However, Credit WE-2 (Innovative Wastewater Technologies) may also be achieved by non-LID techniques, such as water conserving interior plumbing fixtures, and the use of recycled water for flushing toilets.

Ranges of Credits. The rating systems often allow projects to earn a range of points, based on the level of sustainability achieved. This is illustrated in Table 1, where the LEED-ND rating system offers from one to four points for stormwater control, depending on the percentage of stormwater volume retained onsite. To simplify the findings reported below, when identifying the number of points that may be earned with an LID technique, we report only the highest number of points that may potentially be achieved for each identified LID technique.

FINDINGS

The results of the analysis are shown in Table 3, which lists the identified LID techniques in each of the four selected green development rating systems. The table displays the maximum number of points that may be earned for each LID technique in each rating system. Summary totals of all points that may potentially be earned by implementing LID techniques are provided. The table also shows the minimum number of points needed for green development certification in each rating system, and the percentage of the minimum points required for certification that can theoretically be achieved with LID techniques.

Table 3. Comparison of Credits for LID Techniques in Selected Rating Systems

LID Techniques	LEED-NC (2009)		LEED-ND (2009)		GreenPoint Rated: Single Family (4.0)		Sustainable Sites (2009)	
	Credit No.	Points	Credit No.	Points	Credit No.	Points	Credit No.	Points
Conserve/Restore sensitive areas	SS-1	1	SLL-7 SLL-8	1 1	--	0	3.3 3.4 4.8	8 5 6
Reduce surface parking footprint	SS-4.4	2	NPD-5	1	A.4	1	--	0
Reduce disturbance/ Preserve vegetated areas	SS-5.2	1	GIB-7	1	A.1	3	4.6	8
Restore native plant communities	--	0	--	0	--	0	4.9	5
Plant shade trees	--	0	NPD-14	2	C.5	3	--	0
Stormwater control: quantity	SS-6.1	1	GIB-8	4	P.A.	3	3.5	10
Stormwater control: quality	SS-6.2	1	--	0	--	0	3.6	9
Design stormwater feature as landscape amenity	--	0	--	0	--	0	3.7	3
Green roof/open grid paving (heat island effect)	SS-7.1 SS-7.2	1 1	GIB-9	1	--	0	4.11 4.12	5 5
Percent reduction in potable water for irrigation[1]	WE-1	4	GIB-4	1	C.11	2	3.2	5
Specify native/adapted plants[1]	--	0	--	0	C.3.c	3	4.7	4

Table 3. Comparison of Credits for LID Techniques in Selected Rating Systems

LID Techniques	LEED-NC (2009) Credit No.	LEED-NC (2009) Points	LEED-ND (2009) Credit No.	LEED-ND (2009) Points	GreenPoint Rated: Single Family (4.0) Credit No.	GreenPoint Rated: Single Family (4.0) Points	Sustainable Sites (2009) Credit No.	Sustainable Sites (2009) Points
Avoid invasive species[1]	--	0	--	0	C.3.a	1	Pre-requisite	0
High efficiency irrigation[1]	--	0	--	0	C.6	5	--	0
Minimize turf[1]	--	0	--	0	C.4	6	--	0
Rainwater harvesting/use	WE-2	2	--	0	C.8	2	--	0
Submetering for irrigation and/or hydrozoning[1]	--	0	--	0	C.1 C.10	2 1	--	0
Mulch and/or compost[1]	--	0	--	0	C.2 C.7	2 3	--	0
Maximum Points for LID		14		12		37		73
Points needed for certification		40		40		50[2]		100
Percentage of points needed for certification theoretically achievable with LID techniques		35%		30%		74%[2]		73%

[1] Indicates sustainable landscaping technique.

[2] GreenPoint Rated specifies a minimum number of points in each of four categories: energy (30 points), water (9 points), resources (6 points) and indoor air quality/health (5 points). The required water points accounting for only 18 percent of the required total for GreenPoint Rated certification.

Sources: USGBC 2009a, USGBC 2009b, Build It Green 2009a, Sustainable Sites Initiative 2009

For each of the reviewed rating systems, we found that at least 30 percent of the required credits could theoretically be earned with LID techniques. The LEED-ND system offered the lowest percentage (30 percent), and the GreenPoint Rated system theoretically offered the highest percentage (74 percent). It should be noted, however, that the GreenPoint Rated system specifies a required number of credits in each of four categories (energy, water, resources, and indoor air quality/health), with the required water points accounting for only 18 percent of the required total for GreenPoint Rated certification. A closer analysis of the LID techniques included among the GreenPoint Rated credits indicated that only one of the LID techniques earns credit in a required category other than water (GreenPoint Rated Credit A.4 earns one point for energy and can be achieved by a reduction in surface parking). If this credit is included, a project could achieve 20 percent of the minimum required points by implementing LID techniques.

LEED-NC and LEED-ND also offer regional priority credits, which are awarded in the form of up to four bonus points. A specified number of bonus points is awarded to a project that earns a LEED credit that has been identified as a regional priority based on the project's zip code (USGBC 2009c). Within some zip codes in the City of San Jose, for example, a regional priority bonus point is earned for projects that achieve a 40 percent reduction in potable water use for irrigation, in accordance with the criteria for LEED-NC credit WE-3 (USGBC 2009d). Depending on availability of bonus points in the project location, projects may be able to earn from one to four LEED points for LID techniques, in addition to the totals shown in Table 3.

CONCLUSIONS AND RECOMMENDATIONS

The review of four rating systems identified a wide range of opportunities to obtain green building credits for including LID techniques in development projects in each of the rating systems, which can create additional incentives for project designers and builders to incorporate LID in their projects. To the extent that project proponents are unaware of the synergies between LID and green building rating systems, it may be useful for municipalities, regulatory agencies, and/or LID practitioners and advocates to develop educational materials that highlight this information.

The review of the rating systems also identified some gaps in the availability of green building credits for LID techniques, specifically in the categories of sustainable landscaping and preservation of environmentally sensitive areas.

Sustainable Landscaping Practices. LEED-NC, LEED-ND and the Sustainable Sites Initiative offer fewer points for sustainable landscaping practices (four, one, and nine points, respectively, or 10 percent, 2.5 percent and 9 percent of the respective total points needed for certification) than are offered by the GreenPoint Rated system (25 points, or a theoretical 50 percent of points needed for certification). As noted above, due to requirements for minimum numbers of points within specific categories, LID techniques can only contribute a maximum of 20 percent of the minimum points needed for GreenPoint Rated certification. Nevertheless, the

GreenPoint Rated system offers a wide range of sustainable landscaping options for earning points toward certification, and projects in California that emphasize sustainable landscaping may benefit from using this California-specific rating system.

Protecting Environmentally Sensitive Areas. The results in Table 3 show that the Sustainable Sites Initiative offers more credits (32, or 32 percent of the total needed for green certification) than the other three systems for preserving environmentally sensitive areas. LEED-NC, LEED-ND and GreenPoint Rated offer, respectively, 2, 3 and 3 points for the protection of environmentally sensitive areas, or a respective 5 percent, 7.5 percent and 6 percent of points needed for certification. Projects that emphasize the protection of environmentally sensitive areas may benefit from using the Sustainable Sites Initiative, either currently as pilot projects, or in the future public version of this rating system, assuming that the number of points for protecting environmentally sensitive areas remains consistent.

Qualifications and Opportunities for Further Study. Despite the variations in relative emphasis on specific types of LID, each of the rating systems reviewed offer incentives, in the form of points toward green building certification, for incorporating LID techniques. However, when using any rating system, the project applicant should carefully review the specific criteria for earning each credit for LID techniques. As noted above in the example of managing stormwater for a project on a previously undeveloped site (Table 1), criteria can vary among rating systems. In addition, the criteria in a particular rating system may differ from the criteria required for compliance with a municipal stormwater permit that applies to the project location. It was beyond the scope of the current project to review specific criteria for LID techniques, such as stormwater management; however, the wide variation in stormwater facility sizing approaches could be a topic of interest for future studies.

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Evaluation of Roadside Filter Strips, Dry Swales, Wet Swales, and Porous Friction Course for Stormwater Treatment

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Abstract. *Due to NPDES regulations, the North Carolina Department of Transportation (NC DOT) is required to treat stormwater from NC DOT facilities throughout North Carolina. There are hundreds of miles of existing right-of-way swales and filter strips across North Carolina. Relatively few roadside swales and filter strips have been tested for water quantity and quality control. Also, no studies exist on swales with wetland characteristics. This paper presents an assessment of dry swale, wetland swale, and filter strip performance along an interstate highway in North Carolina.*

Four existing right-of-way linear swales along I-40 were monitored to determine their hydrologic and water quality effectiveness. Two different treatments were examined: one dry swale and one which was allowed to establish wetland vegetation and hydrology. This experimental design was replicated once. Also addressed was the impact of the vegetated filter strip between the shoulder and the edge of the swale. Samples have been collected from 17-21 events (depending on the site) and analyzed for TKN, $NO_{2\text{-}3}$-N, TN, NH_4-N, Organic-N, TP, and TSS. It should be noted that this section of highway had a porous friction course (PFC) applied, which had an impact on swale and filter strip performance.

Mean effluent TN concentrations were lower for the swales with wetland characteristics than the non-wetland swales. No such difference was observed for TP effluent concentrations. TP concentrations measured at the edge-of-highway were low (mean <0.11 mg/L) at all four sites, resulting in poor reduction of TP EMCs by the swales and roadside filter strips. Due to the presence of a porous friction course on the highway, mean TSS concentrations from the roadway were below 32 mg/L at all four sites. Effluent concentrations of TSS from both the swales and filter strips were higher than edge-of-pavement concentrations. The swales and filter strips did not perform well using traditional concentration reduction metrics for TP and TSS; this was mainly due to the lower sediment-bound pollutant concentrations derived from the porous friction course overlay.

Keywords. Stormwater, BMPs, swales, filter strips, wetlands, porous friction course, permeable pavement

Introduction

The North Carolina Department of Transportation (NC DOT) is required through NPDES permits to treat stormwater runoff from its facilities across North Carolina. NC DOT has installed many retrofit stormwater practices across North Carolina and has researched the hydrologic and water quality function of several. Around the world, roadside swales typically drain stormwater runoff from highways. In Eastern North Carolina, where topography is almost nonexistent, many of these swales have hydrophytic vegetation, wetland hydrology, and hydric soils. An assessment of swales with and without wetland characteristics is presented herein. Also discussed are the effects of a porous friction course on highway stormwater runoff and the effects of roadside vegetative filter strips.

A research team in Northern Sweden studied several different grassed swales (Backstrom 2002; Backstrom 2003). They found that the swales retained significant amounts of particulate matter during high pollutant loading events. However, when the swales received TSS concentrations below 40 mg/L, pollutant concentrations increased as the water moved through a dry swale. Particles smaller than 25 μm were not trapped efficiently. TSS concentrations were reduced by 79-98% in two laboratory swales and seven field swales (Backstrom, 2003). Dissolved pollutants did not receive any perceptible treatment. The swales studied were regarded as facilities that even out pollutant peak loads, but were not able to consistently reduce pollutant loads.

Export of nitrogen and phosphorus was observed at two field tested swales in Florida (Yousef et al. 1985; Yousef et al. 1987). While concentrations of dissolved heavy metals decreased with increasing swale length, similar conclusions could not be made for N and P species.

Two swales were studied along highway medians in Virginia (Kaighn and Yu 1996). TSS concentrations were reduced by 30% and 49%, while mixed results were observed for COD, TP, and Zn. The authors note that significant variability exists in the swale literature, but that swale design should generally be based upon length, cross-sectional shape, slope, design flow rate, type of vegetation, and infiltration rate of the soil. In another field test of dry swales, Yu et al. (2001) showed that check dams along the swale substantially improve performance for TSS and COD. Mass of TN was reduced by 13%-24%, while TP reductions ranged from 29%-77% at four swales in Taiwan. Kercher, Jr. et al. (1983) argue that swales are preferable to traditional curb-gutter-pipe systems because they help to reduce pollutant loading and they require less land area than conventional systems.

In a modeling study of stormwater BMPs, Barrett et al. (2005) showed that expected effluent concentrations of TSS from swales were 60 mg/L, with a total load reduction of greater than 70%. However, dissolved nutrients were not reduced on a concentration basis and pollutant mass reduction was 40% for nitrate and -90% for orthophosphate. In a field study of two swales and associated vegetative filter strips located in highway medians in Texas, the authors concluded that the majority of pollutant removal occurred in the vegetative filter strips, not the swales (Barrett et al. 1998).

A study conducted in Florida examined a series of dry swales in a low impact parking lot (Rushton, 2002). The swales often added phosphorus to the stormwater. Perhaps this was due to high amounts of phosphorus present in the swale or inadvertent fertilization. However, they were able to reduce yearly flow volumes by 30%, on average (Rushton, 2001). Swales studied in Florida, Sweden, and Virginia did not adequately treat nutrients, the major pollutants of concern in North Carolina (along with sediment). All swales studied were designed to be dry. Wet swales, with some wetland characteristics, may provide improved treatment of nutrients.

Stormwater wetlands have repeatedly been shown to reduce nitrogen and phosphorus concentrations and loads from small watersheds. One wetland study has been conducted in a highway interchange (Farrel and Scheckenberger 2003) and has shown promising pollutant removal. Two stormwater wetlands were studied in North Carolina for stormwater treatment; load reduction of N species ranged from 47%-54% at one wetland and 57%-71% at the other (Line et al. 2008). Load reduction of P species ranged from 59%-76% at one wetland and -95%-70% for the other. These studies indicate that wetlands have a significant potential to reduce nitrogen and phosphorus. To date, no research has been conducted on either existing wetland swales or standard swales in the NC DOT linear right-of-way.

Few studies on the impacts of the addition of an open graded aggregate (i.e. a porous friction course) above a traditional asphalt highway have been published. A PFC is approximately 5 cm (2 in) in thickness, and is constructed by removing the fines from a traditional asphalt mixture. A study by Barrett et al. (2006) showed that the application of a PFC reduced mean EMCs for TSS from 118 mg/L to 7.6 mg/L, a 94% reduction. The same study showed a 35% reduction in TN and an 85% *increase* in TP concentrations due to the PFC application. A study in the Netherlands tested both conventional asphalt and asphalt with a PFC layer applied. TSS concentrations in the PFC-applied asphalt were 91% lower, TKN 84% lower, COD 88% lower, and Cu, Pb, and Zn ranged from 67 to 92% lower than in runoff from the conventional asphalt (Berbee et al., 1999). A similar study in Germany (Stotz and Krauth 1994) showed reductions in yearly filterable solids loads of 61%.

The goal of this research is to examine whether linear swales will significantly reduce nutrients and solids from highways and the impact of allowing swales to develop wetland conditions. Four linear swales in the right-of-way of Interstate 40 between Interstate 95 and mile marker 360 were identified for study. Secondary goals were to study roadside vegetative filter strips and the application of a porous friction course on the highway, and how these treatments might affect pollutant generation and removal.

Methods

Four linear swales were monitored along the right-of-way of Interstate 40. Two swales with hydrophytic vegetation and hydric soils (Figure 1) were each paired with a traditional dry swale (Figure 2). The first non wetland vegetated site (site NVA) is along the east bound lane of I-40 near mile marker 332. This site is paired with a wetland vegetated site located along the shoulder of the east bound lane between mile marker 332 and 333 (site VA).

Figure 1. Example of a vegetated swale with wetland characteristics.

Figure 2 Example of a vegetated swale without wetland characteristics (i.e. standard dry swale).

The second site with wetland characteristics is located along the east bound shoulder of I-40 between mile marker 353 and 354 in Sampson County (site VB) and is paired with a non wetland vegetated site (site NVB) near mile marker 360 at the boundary between Sampson County and Duplin County. The site locations are shown in Figure 3, and are represented by white stars. The effect of the vegetative filter strip (VFS) between the edge of the pavement and the swale was studied at sites NVA and NVB. At each of the four sites, a section of swale approximately 30.5 m (100 ft) long was monitored. Slot drains were installed at the edge of the pavement (Figure 4) and at the downslope end of the filter strips (Figure 5) to collect stormwater.

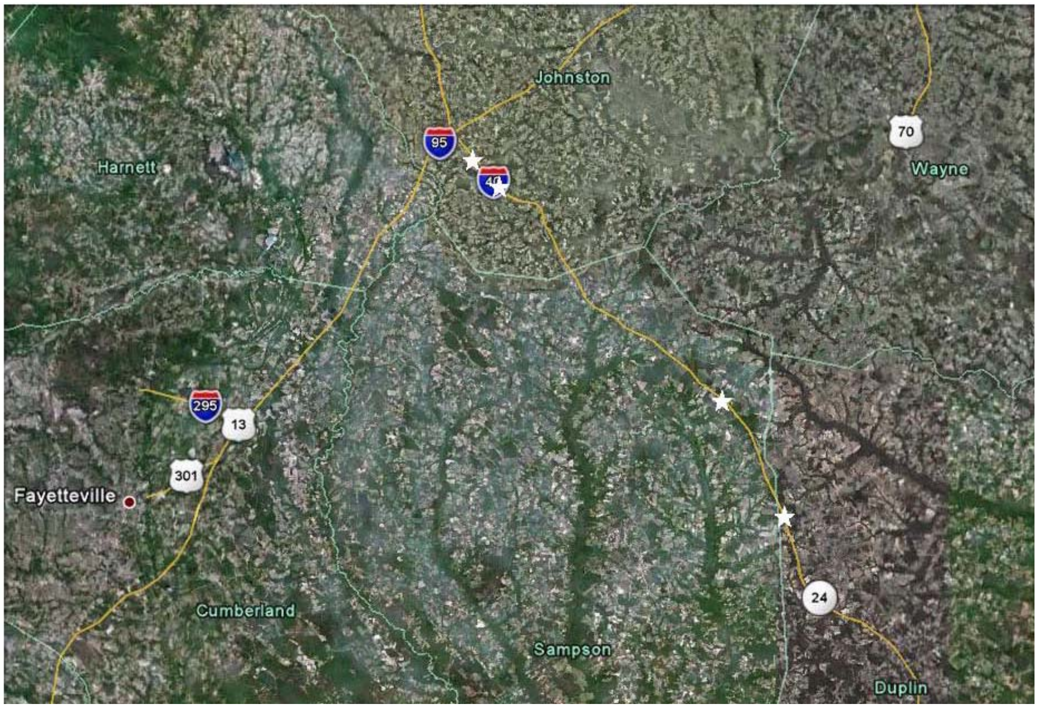

Figure 3. Swale locations along interstate 40.

Figure 4. Edge-of-pavement slot drain.

Figure 5. Downslope edge of filter strip slot drain.

Figure 6 shows a representative plan view of the monitoring design. Weir boxes with 30^o v-notch weirs were used to measure the volume of water that passed through the slot drains at the edge of the pavement and the filter strip (Figure 7). ISCO 730 bubbler modules were used to measure the depth of flow over the weirs and to calculate flow rate using the standard 30^o v-notch weir equation. The bubblers triggered ISCO 6712 automatic samplers to take flow-weighted composite samples for each storm event.

An outlet structure was installed in each swale to measure the flow rate and to enable collection of water quality samples (Figure 8). The outlet structure is comprised of 5 cm (2 in) by 60 cm (12 in) boards driven into the ground. The broad-crested portion of the weir is approximately 7.3 m (24 ft) wide, with a 30° V-notch weir in its center. ISCO 730 bubbler modules were again used to measure depth (and therefore flow rate) and trigger flow proportional sample pulls. Samples were taken from the center of the swale, approximately 1.8 m (6 ft) upslope of the outlet structure.

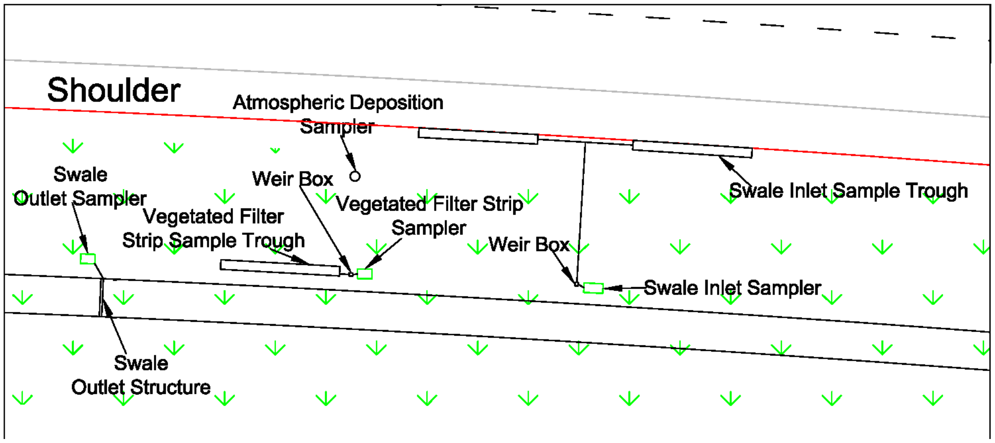

Figure 6. Representative monitoring layout for edge-of-pavement, and VFS and swale outlets.

Figure 7. Weir Box for sample collection at edge-of-pavement and VFS outlet.

Figure 8. Outlet structure for swales.

Results and Discussion

Data collection began in September of 2008, and will continue through April of 2010. To date, 21, 21, 19, and 17 storms have been collected at sites NVA, VA, VB, and

NVB, respectively. Due to the variability in rainfall depth associated with sampling from four sites located over 30 miles of highway, only seven storms have been collected at all ten sampling locations (4 sampling locations at edge-of-highway, 2 at downslope edge of VFS, and 4 at swale outlets, for a total of ten). Samples from each storm event were collected within 24 hours of the end of rainfall, and taken to the laboratory on ice. Samples were analyzed for concentrations of total Kjeldahl nitrogen (TKN), nitrate-nitrite nitrogen ($NO_{2\text{-}3}$-N), total nitrogen (TN), ammonium nitrogen (NH_4-N), organic nitrogen (Org-N), total phosphorus (TP), and total suspended solids (TSS). A summary of rainfall depths for sampled storm events at each of the four sites is presented in Table 1.

Table 1. Summary of rainfall for sampled storm events.

Rainfall Parameter	Name of Site			
	NVA	**VA**	**VB**	**NVB**
Minimum (cm)	0.84	0.79	0.81	0.89
Maximum (cm)	11.94	11.48	11.18	11.38
Median (cm)	2.96	3.35	2.64	3.57
Mean (cm)	3.65	3.92	3.97	4.44

Porous Friction Course Results

At each of the four sites, runoff samples were collected from an asphalt pavement with a porous friction course (PFC) overlay. This is the first study of these overlays for stormwater quality in North Carolina. Results are presented for the four study sites in Table 2. For comparison, effluent concentrations from traditional asphalt parking lots (Passeport and Hunt 2009), traditional asphalt highways (Barrett 1998; Barrett et al. 2006), and asphalt overlayed with PFC (Barrett et al. 2006) are also presented.

At the four study sites, mean TN EMCs from the PFC covered asphalt ranged from 1.39 mg/L to 2.38 mg/L. This is somewhat higher than the average TN EMC from 8 parking lots in North Carolina and less than two standard highways in Texas. The TN concentrations from this study were well above those (1.02 mg/L) from a PFC study in Texas (Barrett et al. 2006).

TP EMCs from the porous friction course overlay were very low at the four study sites, with mean values below 0.11 mg/L for all sites. This is lower than the average TP EMCs for other standard asphalt parking lots and highways in the literature. It is much lower than the 0.24 mg/L for asphalt covered with PFC reported in Barrett et al. (2006). That study reported greater TP concentrations from the PFC than standard asphalt. These results directly oppose the results presented herein, and may be due to a difference in the fraction of sediment bound phosphorus at the two sites.

Table 2. Mean stormwater effluent concentrations (mg/L) from highways and parking lots.

Site Location	Land Use	Data Presented	Constituent						
			TKN	NO_{2-3}-N	TN	NH_4N	Org-N	TP	TSS
NVA	Highway	Herein	0.88	0.51	1.39	0.42	0.97	0.08	11
VA	Highway	Herein	1.22	0.40	1.62	0.48	1.14	0.11	31
VB	Highway	Herein	1.28	0.68	1.95	0.58	1.37	0.10	10
NVB	Highway	Herein	1.02	1.36	2.38	0.41	1.97	0.11	11
North Carolina	Parking Lots	Passeport and Hunt (2009)	1.19	0.36	1.57	0.32	1.25	0.19	-
Texas	Highway (U.S. 183)	Barrett et al. (1998)	2.17	0.91	3.08	-	-	0.55	157
Texas	Highway (MoPac Expressway)	Barrett et al. (1998)	2.61	1.27	3.88	-	-	0.24	190
Texas	Highway without PFC	Barrett et al. (2006)	1.13	0.43	1.56	-	-	0.13	118
Texas	Highway with PFC	Barrett et al. (2006)	0.64	0.38	1.02	-	-	0.24	8

PFC overlays have been shown to reduce TSS concentrations to levels well below those of traditional highway runoff (see 8 mg/L, Barrett et al. 2006). Results from the four sites in this study were similar. Mean TSS EMCs were 11mg/L, 31 mg/L, 10 mg/L, and 11 mg/L for sites NVA, VA, VB, and NVB, respectively. These results are well below typical highway runoff TSS concentrations, which are usually between 100 mg/L and 200 mg/L (see Table 2). The PFC acts to reduce splash under wheel wells of cars and trucks, reducing TSS generation. Also, the PFC probably acts to trap the TSS in its void space.

Vegetative Filter Strip (VFS) Results

The roadside VFS has been identified as a primary location of pollutant removal in a typical asphalt highway-roadside VFS-grassed swale system (Barrett et al. 1998). However, the application of a PFC may change pollutant removal efficiency of roadside VFSs, because of the low influent concentrations from the PFC. This may be further exacerbated by the fact that the PFC and VFS share the same primary removal mechanism: sedimentation. Mean effluent concentrations and percent concentration reductions from roadside VFSs from this study and Barrett et al. (2006) are presented in Table 3. All four VFSs had approximately an 8 m width.

Table 3. Mean effluent concentrations and concentration reductions from roadside VFSs.

Mean Effluent Concentrations (mg/L)									
Site Location	Land Use	Data Presented	Constituent						
			TKN	NO_{2-3}-N	TN	NH_4N	Org-N	TP	TSS
NVA	Highway	Herein	1.35	0.44	1.79	0.34	1.44	0.24	20

NVB	Highway	Herein	1.57	0.35	1.92	0.21	1.71	0.32	38
Texas	Highway without PFC	Barrett et al. (2006)	2.15	0.27	2.42	-	-	0.29	42
Texas	Highway with PFC	Barrett et al. (2006)	2.08	0.21	2.29	-	-	0.17	33
Concentration Reductions									
NVA	Highway	Herein	-102%	5%	-58%	12%	-110%	-478%	-201%
NVB	Highway	Herein	-76%	66%	11%	-10%	2%	-211%	-392%
Texas	Highway without PFC	Barrett et al. (2006)	-91%	39%	-55%	-	-	-123%	64%
Texas	Highway with PFC	Barrett et al. (2006)	-225%	45%	-120%	-	-	11%	-328%

Effluent concentrations from the VFS were higher than edge-of-pavement concentrations for TKN, TP, and TSS for both sites NVA and NVB. Reductions in other constituent concentrations were usually less than 15%. Interestingly, all four roadside VFSs in Table 3 showed reduction of nitrate-nitrite nitrogen concentrations. This is remarkable, because conditions for denitrification do not exist in a VFS. TP concentrations were increased across the VFSs in this study, in contrast with results from the PFC in Barrett et al. (2006). The edge-of-pavement TP concentrations were extremely low in this study, possibly resulting in an irreducible concentration. TSS is exported from all VFSs that were located downslope of a PFC application in the literature and in this study. This may be due to irreducible TSS influent concentrations, which are often near 10 mg/L. In general, when a VFS is cited downslope of a PFC application, little to no benefit will be observed.

Dry and Linear Wetland Swale Results

Roadside swales are nearly ubiquitous practices used to drain highways across the U.S. and the world. However, results for nutrient removal from these practices have been mixed; presented in Table 4 are data from this study for both non-wetland swales (NVA and NVB) and wetland swales (VA and VB). Effluent concentrations from the swales are presented first, followed by concentration reduction from the edge-of-pavement (all sites) and from the downslope end of the VFS (sites NVA and NVB).

Table 4. Mean effluent concentrations and concentration reductions for wetland and dry swales.

Effluent Concentrations (mg/L)									
Site Location	**Land Use**	**Constituent**							
		TKN	**$NO_{2\text{-}3}$-N**	**TN**	**NH_4N**	**Org N**	**TP**	**TSS**	
NVA	Highway	1.13	0.44	1.57	0.12	1.45	0.10	22	
VA	Highway	0.94	0.18	1.05	0.07	0.98	0.11	21	
VB	Highway	0.89	0.26	1.15	0.09	1.06	0.08	20	
NVB	Highway	1.16	0.19	1.35	0.12	1.23	0.16	74	
Concentration Reductions from Edge-of-Pavement									

NVA	Highway	-66%	13%	-34%	71%	-91%	-116%	-135%
VA	Highway	-31%	42%	7%	78%	-25%	-70%	-48%
VB	Highway	0%	63%	29%	80%	8%	1%	-121%
NVB	Highway	-41%	78%	27%	39%	18%	-65%	-653%
Concentration Reductions from Downslope End of VFS								
NVA	Highway	-17%	27%	-8%	-79%	-16%	37%	-65%
NVB	Highway	13%	-50%	14%	-19%	14%	35%	-393%

Nitrogen species concentrations were in some cases reduced between the edge-of-pavement and the swale outlet (nitrate-nitrite nitrogen, ammonium nitrogen). However, the swale increased the concentration of most nitrogen species when compared to concentrations at the outlet of the VFS. Effluent concentrations of TN from the four swales in this study were, however, much lower than the mean effluent concentration of 2.22 mg/L from a study of a swale in Maitland, FL (Yousef et al. 1985). Effluent concentrations were also compared to ambient water quality concentrations in North Carolina that were statistically related to “good” benthos ratings (McNett et al. 2010). While none of the swales in this study had effluent concentrations below the 0.99 mg/L TN concentration for “good” benthos quality, they were easily within the 2.16 mg/L required for “fair” benthos quality. Effluent TN concentrations were lower for swales with wetland characteristics than those sites without wetland characteristics.

TP concentrations from the edge-of-pavement were low, so reductions in concentration were not observed in the swale. In both cases, the swale helped to reduce TP concentrations following large increases in concentration in the roadside VFS. TP effluent concentrations in this study were well below a published mean swale effluent concentration of 0.35 mg/L (Yousef et al. 1985). Three of the four swales studied met the benchmark of 0.11 mg/L for “good” benthos quality in North Carolina, while the fourth met the 0.22 mg/L benchmark for “fair” benthos quality (McNett et al. 2010). Trends did not suggest that wetland swales performed better than traditional dry swales for TP removal.

TSS concentrations at the edge-of-pavement were extremely low due to the application of a porous friction course. TSS was added to the stormwater by both the VFS and the swale, resulting in higher effluent concentrations from the swale than at edge-of-pavement. However, effluent swale concentrations were still low for three of the swales studied (20 mg/L, 21 mg/L, and 22 mg/L). Swale NVB had higher mean effluent concentrations (74 mg/L) due to the formation of a head cut near the upslope end of the swale.

Conclusions

NC DOT constructs and maintains hundreds of miles of existing highways in North Carolina and are constantly looking for stormwater practices to best treat runoff. In this study, the application of a porous friction course was studied as it applies to runoff quality. Additionally, a type of linear swale was studied (wetland conditions) to determine whether wetland conditions improve nutrient removal. Finally, the affect of the roadside vegetative filter strip was studied.

Effluent concentrations from the PFC for both TP and TSS were extremely low when compared to other highway runoff studies. This is most likely due to the sediment trapping ability of the PFC and due to reduced splash from tires. Due to these low concentrations, the roadside filter strips and swales increased TP and TSS concentrations. Similar to the literature, results for nutrient reductions for the swales were mixed; some nitrogen species' concentrations were reduced, while others were increased. Swale effluent quality was compared to benchmark ambient water quality; TN effluent concentrations from the swales often met "fair" benthos quality, while TP effluent concentrations met "good" water quality benchmarks in North Carolina. Results show that swales with wetland characteristics may produce lower mean effluent concentrations of TN than those without wetland characteristics. No such trend was observed for TP.

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Expanding the International Stormwater BMP Database Reporting, Monitoring and Performance Analysis Protocols to Include Low Impact Development (Part 1)

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Abstract

Low Impact Development (LID) strategies are being encouraged throughout the country as an approach to reduce potential adverse impacts of development on receiving streams. Many questions exist regarding how well various LID strategies perform in different settings, just as similar questions have been raised regarding performance of traditional stormwater best management practices (BMPs). Over a decade ago, American Society of Civil Engineers (ASCE) Urban Water Resources Research Council (UWRRC) members worked to develop a set of standardized monitoring and reporting protocols for traditional BMPs and establish a master database for the purpose of evaluating BMP performance and the factors affecting performance. This effort culminated in the International Stormwater BMP Database (www.bmpdatabase.org), which contains data for approximately 360 BMPs and continues to operate as a clearinghouse for stormwater BMP data and performance analyses.

During 2008-2009, the Stormwater BMP Database project expanded to better integrate LID into its monitoring, reporting and analysis protocols through the support of a coalition led by the Water Environment Research Foundation, the U.S. Environmental Protection Agency, the Environmental and Water Resources Institute of ASCE, the Federal Highway Administration, and the American Public Works Association.

This paper provides an overview and progress report on the LID-focused effort, including the following topics:

1. New monitoring guidance for LID studies.
2. An overview of recent changes to the stormwater BMP database to better accommodate LID studies, including LID studies at the site development level (multiple distributed controls) and individual LID techniques.
3. A summary of LID studies currently included in the database, including bioretention, green roofs, permeable pavement, biofilters and other practices.

Introduction

The International Stormwater BMP Database project began in 1996 with support from the U.S. Environmental Protection Agency (EPA) and the American Society of Civil Engineers (ASCE). The project's original long-term goal, which remains the central focus of the project, is to gather sufficient technical design and performance information to improve stormwater Best Management Practice (BMP) selection and design so that local stormwater problems can be cost-effectively addressed. EPA initially funded the project through the Urban Water Resources Research Council (UWRRC) of ASCE. In 2004, the project transitioned to a more broadly supported coalition of partners led by the Water Environment Research Foundation (WERF), including the Federal Highway Administration (FHWA), American Public Works Association (APWA), and the Environmental and Water Resources Institute (EWRI) of ASCE. During 2008-2009, a major expansion and update to the Database were completed, with emphasis on integrating Low Impact Development (LID) approaches into the BMP Database. Key tasks included:

- Holding an expert panel workshop to obtain input on a variety of LID-related tasks, including: Bill Hunt, P.E., Ph.D., North Carolina State University; Rob Traver, P.E., Ph.D., Villanova University; Rob Roseen, P.E. Ph.D., University of New Hampshire; Rich Horner, Ph.D., University of Washington; Bob Pitt, P.E., Ph.D., University of Alabama; and Ben Urbonas, P.E., Urban Water Resources Research Institute. Working with the project team, the panel input helped establish the direction for the remainder of the LID integration tasks.
- Updating the Urban Stormwater BMP Monitoring Guidance (originally issued by EPA in 2002) to include LID (available for free download at www.bmpdatabase.org).
- Adding standardized LID reporting parameters to the BMP Database at the practice level and the site-scale.
- Recategorizing (transitioning) existing LID studies into the new BMP Database categories.
- Developing volume reduction analysis protocols at the practice level and the site-scale.

These advances are discussed in a two-paper series at this EWRI LID 2010 Conference. Part 1 is the subject of this paper and is focused on an overview of the monitoring guidance, a summary of LID-related reporting protocols and a summary of LID studies currently included in the Database. Part 2 (Poresky et al. 2010) focuses on performance monitoring and data interpretation protocols for LID studies, with particular emphasis on hydrologic characterization of LID studies.

Monitoring Guidance

During the initial stages of the original BMP Database project, it became clear that better guidance was needed regarding stormwater BMP monitoring, particularly if monitoring results were to be valuable to the broader technical, management, and regulatory community. As a result, EPA and ASCE supported development of *Urban Stormwater BMP Performance Monitoring: A Guidance Manual for Meeting the National Stormwater BMP Database Requirements.* In 2008, EPA, WERF, FHWA and EWRI co-sponsored a substantive update and expansion of the monitoring manual for these purposes:

1. Improve the state of the practice by providing and enhancing a recommended set of protocols and standards for collecting, storing, analyzing, and reporting stormwater BMP monitoring data that will lead to better understanding of the function, efficiency, and design of urban stormwater BMPs.
2. Provide monitoring guidance for LID strategies at the overall site level (e.g., monitoring overall sites with multiple distributed stormwater controls).

The Manual provides guidance for all stages of BMP monitoring programs ranging from the early stages of study design to the end stages of data interpretation and reporting. Guidance is provided for monitoring a broad range of individual BMPs as well as overall site monitoring with multiple distributed BMPs, such as is the case with LID sites. The guidance pertains to both conventional and LID sites, including these topics:

- **Designing the Monitoring and Reporting Program**: A well-thought out and systematically designed monitoring program is essential to a cost-effective study design that yields meaningful results. The Manual builds upon guidance provided by EPA (2002) in its Guidance for Quality Assurance Project Plans, providing additional guidance specific to stormwater BMP monitoring and the BMP Database protocols.
- **Methods and Equipment for Stormwater BMP Monitoring:** In order to obtain high-quality data in BMP monitoring studies, it is necessary to select the proper precipitation, flow, and water quality sample collection and monitoring equipment and procedures. Information and guidance related to flow and precipitation monitoring in the context of BMP monitoring is provided, along with guidance on water quality sample collection and analysis methods. Appropriate characterization of hydrologic conditions is particularly important for LID studies where surface volume reduction is a key objective.
- **Implementing the Monitoring Program**: In order for well designed monitoring programs to result in high quality data, personnel must be properly trained, equipment properly installed, calibrated and maintained, samples correctly collected and analyzed, and data properly reported. Failures at this stage of the monitoring program can result in data that cannot be used to draw valid conclusions regarding BMP performance.
- **Data Management, Evaluation and Reporting of Results**: Once data have been collected from a monitoring program, the data need to be compiled and managed in a manner that reduces introduction of errors and enables ready access for future reference, and ideally, facilitates incorporation into the BMP Database (www.bmpdatabase.org). A strong data management and reporting system helps to ensure that studies are documented in a manner that enables long-term use of the data and transferability to the local, regional, national, and international state of the practice.
- **BMP Performance Analysis**: Over the past decade, the BMP Database project has developed recommended performance analysis approaches for BMP studies. Performance analysis methods, as well as pitfalls to avoid misleading

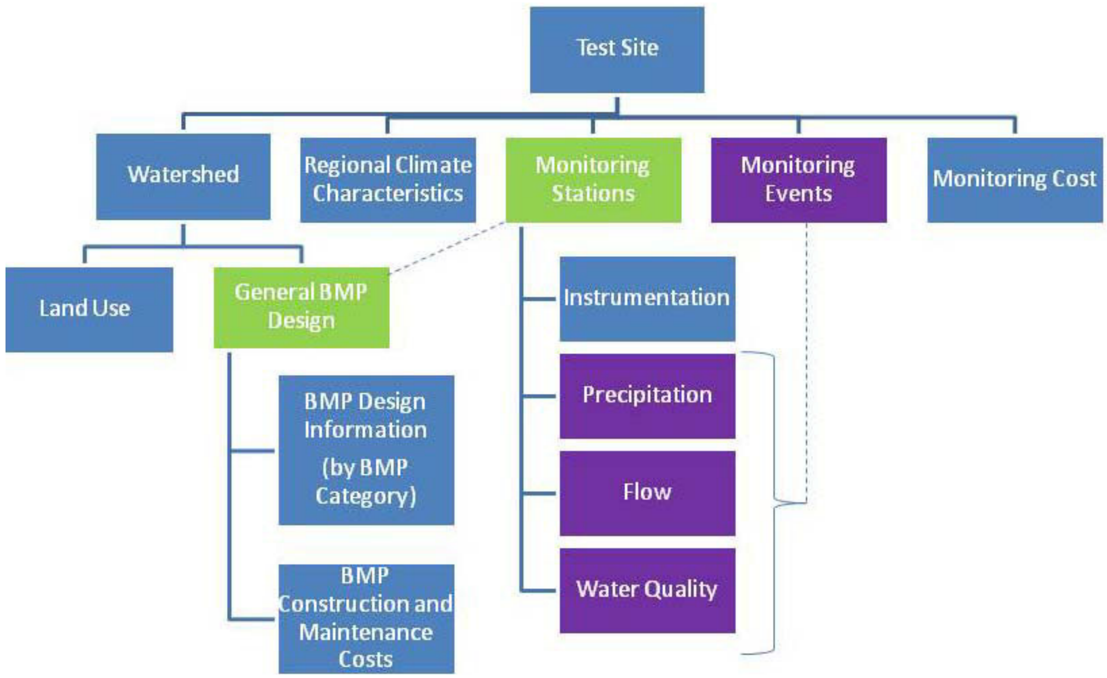
interpretation of data, are summarized, including methods currently used in the published BMP Database analysis reports, downloadable from www.bmpdatabase.org.

- **Low Impact Development(LID)/Distributed Controls Monitoring**: Building upon the concepts introduced for monitoring individual BMPs, guidance is provided on specific challenges associated with monitoring distributed controls at the site level. In these types of studies, a variety of practices such as amending soils to promote infiltration of runoff, disconnecting impervious areas, use of pervious paving materials, implementation of rain gardens on multiple lots, use of swales instead of curb and gutter, and other runoff reduction practices may be implemented. As a result, unique challenges exist in collecting and analyzing the performance of such sites. Although the state of the practice continues to evolve on this topic, the manual provides basic guidance on properly designing such studies.
- **Data Interpretation and Performance Evaluation of LID Studies**: The careful interpretation and evaluation of data is critical in reaching appropriate conclusions about volume reduction and the water quality benefits of LID. Approaches to interpret and evaluate hydrologic and water quality data, both absolutely and in comparison to conventional BMP implementations are provided. Although LID and conventional BMP studies have some similarities, there are also some key differences that warrant LID-specific guidance. A few representative differences include: LID strategies tend to emphasize reduction in volume rather than reduction in concentration; LID studies are less likely to have an "influent stream" conducive to inflow-outflow comparisons; and the time scale of monitoring required to obtain representative data may be much longer than for conventional studies.
- **LID Case Studies:** Key aspects of site-level LID studies are summarized for studies conducted in Cross Plains, WI; Burnsville, MN; Jordan Cove, CT; and Somerset, MD. All of these studies are based on a paired watershed approach incorporating a reference and test watershed, either geographically or over time.
- **Supplemental Resources on Key Topics (Appendices):** Supplemental appendices are provided on myriad statistical analysis issues, along with an appendix summarizing the data entry spreadsheet package for International Stormwater BMP Database.

BMP Database Reporting Protocols for LID Studies

Prior to 2009, the BMP Database requested a variety of information for conventional BMP studies. In 2009, a new set of data entry spreadsheets in Microsoft Excel were development to incorporated LID techniques and site-level LID studies. These spreadsheets correspond to revisions to the master database in Microsoft Access. While a complete listing of all data entry fields is beyond the scope of this short paper, the basic organization of the database is provided in Figure 1, followed by a discussion of design parameters for specific LID techniques. Watershed-level parameters are also particularly important for LID sites and are discussed in Part 2 of this two-paper series. Only minor changes have been made to the original watershed reporting parameters, which already enabled entry of reference and test watershed characteristics. Revisions to the General BMP Design Information table for all BMPs were also completed to better describe factors such as whether the BMP was installed as designed and to characterize BMP conditions during monitoring (e.g., whether clogging was present).

Figure 1. Simplified Schematic of BMP Database Elements and Relationships



In addition to General BMP Design Information identified in Figure 1, a series of tables with specific design parameters is also requested for the following BMP types:

- Site-level LID
- Bioretention
- Green Roof
- Rainwater Harvesting
- Grass Buffer
- Grass Swale
- Permeable Pavement
- Media Filter
- Infiltration Basin
- Infiltration Trench
- Wetland Channel
- Wetland Basin
- Detention Basin
- Retention Pond
- Manufactured Device
- Nonstructural Practice
- "Other"

Design data requested for the "new" LID practices, which include site-scale LID and LID practices for bioretention, green roofs and rainwater harvesting, are briefly summarized in bullet form below. Other LID practices such as grass buffers and swales and permeable pavement have been included in the BMP Database since its inception and are not repeated herein. The BMP Database website should be referenced for a complete listing of reporting parameters.

Rainwater Harvesting Design Parameters

- Basic System Description (e.g., tank, cistern, or rain barrel; water source, water use, distribution system)
- Number of Units in Watershed
- Contributing Rooftop Size
- Roofing and Gutter Material Description
- Storage Volume
- Drain Time at Capacity
- Expected Long-term Capture Volume (based on computer simulation)
- Model Used for Capture Volume Simulation
- % Bypass Associated with System
- Describe Emergency Spillage (Overflow) Provision
- Describe Mosquito Prevention (if any)
- Intended Use of Captured Water (e.g., irrigation, toilet flushing, etc.)
- Can Potable Water Supplement Tank?
- Type of Irrigation System (e.g., spray, drip, hand) (if applicable)
- Reason System Selected (stormwater capture, supplement water supply, etc.)
- Comments

Green Roof Design Parameters

- Roof Type (Intensive or Extensive)
- Purpose of Roof
- Describe Green Roof
- Describe Vegetation
- Supplemental Irrigation Provided?
- Roof Media's Surface Area
- Roof Slope
- Number of Media Layers
- Type and Depth (or Thickness) of Each Media Layer
- Comments

Bioretention Design Parameters

Several types of bioretention can be entered into the bioretention design spreadsheet. These are generally categorized according to these types:

- Bioretention cell—Non-linear, not associated with conveyance.
- Off-line bioretention area—Placed next to swale at lower elevation to increase storage.
- In-line bioretention area—Linear, incorporating cell and swale characteristics for conveyance as well as retention and treatment, but low velocity.
- Sloped (weep garden) bioretention area—Behind retaining wall on relatively steep gradient.
- Sloped biodetention vegetative barrier—Placed along slope contour to retard runoff.
- Tree box filter—Enlarged planting pit, usually with drain inlet and underdrain.

Bioretention design parameters include:

- Ratio of Tributary Area to Bioretention Surface Area (hydraulic loading)
- Is Pretreatment Provided?
- Description of Pretreatment, if present
- Description of Flow Entrance
- Bioretention Surface Area
- Ponding Volume above Bioretention Media Surface
- Average Ponding Depth above Bioretention Media Surface
- General Shape of Bioretention Feature (triangle, oval, rectangle, etc.)
- Is an "Internal Water Storage Zone" Created? (via underdrain placement above bottom of media layer)
- Subsurface Storage Volume
- If subsurface storage provided, then height of outlet above bottom of bioretention media
- Bioretention Media: Natural or Amended
- Bioretention Media Depth
- Bioretention Media Design Specifications
- Bioretention Media "P" Index (Phosphorus)
- Description of Supplemental Bioretention Media Characteristics (clay content, pH, cation exchange capacity, carbon:nitrogen ratio, moisture content, metals contents, inerts content)
- Description of Vegetation Community (canopy layers and their approximate cover [stems/acre], species)
- Description of Mulch (if present)
- Surface Infiltration Rate
- Design Infiltration Rate (including safety factor for clogging)
- Is an Underdrain Provided?
- Description and Dimensions of Underdrain, if present
- Underdrain Gravel Layer Thickness, if present
- Description and Dimensions of Surface Overflow, if present
- Is a Hydraulic Restriction Layer (Liner) Provided?
- Description of Hydraulic Restriction Layer, if present
- Seasonal High Water Table Position Relative to Invert
- Comments

For LID at the site level, narrative descriptions are requested regarding the extent to which various LID practices have been implemented. The database is structured to allow detailed performance information for individual LID practices in places at the site, as well. For example, the study may include monitoring data for an individual bioretention cell within the site, as well as outflow from the watershed as a whole, compared to a reference watershed in time or space. Design parameters requested for site-scale LID are summarized in Table 1.

Table 1. Design Information for LID at Site Scale
(Primary Source: Richard Horner, University of Washington)

LID Data Element	Brief Description
Describe Site Design	Provide "big picture" of site design objectives and key design elements.
Describe Monitoring Design	Describe monitoring design relationship to design elements (to ensure proper use of data).
Method for Flood Control	Used to assess extent to which LID is used for water quality and flood control, or water quality only. Some LID sites have "hybrid" characteristics incorporating LID practices with traditional flood control approaches (e.g., are centralized detention and LID techniques).
Conservation Features	This includes preservation of existing trees, other vegetation, and soils.
Minimizing Disturbance	This includes minimizing soil excavation and compaction and vegetation disturbance.
Minimizing Building Coverage	This includes minimizing impervious rooftops and building footprints.
Minimizing Travelway Coverage	This includes constructing streets, driveways, sidewalks, and parking lot aisles to the minimum widths necessary, provided that public safety and a walkable environment for pedestrians are not compromised.
Maintaining Natural Drainage Patterns/ Designing Drainage Paths to Increase Time of Concentration	This includes measures such as: maintaining depressions and natural swales; emphasizing sheet flow instead of concentrated flow; increasing the number and lengths of flow paths; maximizing non-hardened drainage conveyances; and maximizing vegetation in areas that generate and convey runoff.
Source Controls	This includes minimizing pollutants; isolating pollutants from contact with rainfall or runoff by segregating, covering, containing, and/or enclosing pollutant-generating materials, wastes, and activities; conserving water to reduce non-stormwater discharges.
Permeable Pavements*	Permeable pavements include constructing low-traffic areas with permeable surfaces such as porous asphalt, open-graded Portland cement concrete, coarse granular materials, concrete or plastic unit pavers, and plastic grid systems. Representative applications may include driveways, patio slabs, walkways and sidewalks, trails, alleys, and overflow or otherwise lightly-used parking lots.
Natural Drainage System Elements	These include bioretention areas (rain gardens), vegetated swales, vegetated filter strips and other similar features.

LID Data Element	Brief Description
Stormwater Harvesting*	This includes use of cisterns, rain barrels or rain storage units.
Green Roof (vegetated)*	Green roofs include vegetated roofs with stormwater-related design components.
Other Site Features	Enables user to define other key site features or traditional BMPs.
List BMPs Monitored Within LID Site (as entered into BMP Database)	Relates overall LID site design to individual practices monitored and/or implemented at the site (e.g., bioretention, permeable pavement).
Estimate of Hydrologically Available Temporary Storage at Site	This information helps to normalize the relationship between source areas and storage areas, both in terms of routing and relative volume for purposes of comparing LID sites. Tabular estimates of detained, retained and excess volume for a range of storm events are beneficial in developing these estimates. A PDF providing this information can be attached separately, or this information can be summarized narratively. See Monitoring Guidance Manual for a detailed discussion.
Estimated Storage Recovery Rate in Watershed (days)	Describes the time for the LID site to recover hydrologically available temporary storage. Estimates of minimum, maximum and average recovery rates for retained and detained volumes should be provided.
Describe Key Weather Parameters During Study Period (e.g., ET, temperature)	Weather conditions can significantly affect the water balance of LID sites. Frozen soils can reduce infiltration rates; conversely, high ET can increase evapotranspiration rates. Characterization of ET, temperature and other similar factors are important in normalizing comparisons among LID sites.
Comments/Other Description	Allows user to describe other unique aspects of the site design or other general comments.

Summary of LID Techniques Currently in BMP Database

New BMP performance monitoring studies are added to the BMP Database each year, ranging from 25 to over 50 studies per year. A brief summary of BMP types included in the BMP Database, including BMPs in the new LID categories, are summarized in Table 2. LID studies include data from researchers at North Carolina State University, University of New Hampshire Stormwater Center, Villanova Urban Stormwater Partnership, Urban Drainage and Flood Control District (Denver), City of Portland Bureau of Environmental Services, and others.

Table 2. Summary of BMP Types in the Stormwater BMP Database

BMP Category	Number of Studies
Biofilter (grass swales & filter strips)	77
Bioretention	14
Detention Basin	33
Green Roof	4
Manufactured Device	63
Media Filter	28
Percolation Trench/Well	10
Permeable Pavement	14
Retention Pond	55
Wetland Basin	20
Wetland Channel	14
Subtotal Structural BMPs	**332**
Control Sites	5
Maintenance Practice (street sweeping/catchbasin cleaning)	28
Total	**365**

Conclusion

During 2008-2009, a major upgrade and expansion of the International Stormwater BMP Database was completed to integrate LID into the BMP Database monitoring guidance, reporting protocols and analysis protocols, based on input for a nationally recognized panel of experts. All materials can be downloaded from the www.bmpdatabase.org website. LID researchers are encouraged to submit their studies to expand the knowledge base available to LID practitioners and researchers.

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Low Impact Development Benefits of Level Spreader – Vegetative Filter Strip Systems

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Abstract. *Vegetative filter strips (VFS) have been employed to reduce pollutant export from agricultural watersheds for years. In order to enhance the effectiveness of VFSs, level spreaders have been employed to distribute flow evenly across the length of the upslope end of the buffer. During the past decade, level spreaders have been required in nutrient-sensitive watersheds in N.C. to reduce erosion in riparian buffers. An assessment of the performance of four level spreader – vegetative filter strip (LS-VFS) systems was conducted in the Piedmont of North Carolina. At each site, one 7.6 m (25 ft) wide grassed VFS and one 15.2 m (50 ft) wide, half grassed, half forested VFS drained highly impervious watersheds. Monitored parameters included rainfall, inflow to, and outflow from each LS-VFS system. The VFSs promoted infiltration, which resulted in a substantial decrease in flow volume and peak flow rate between the inlet and outlet of the system. To date, 58 storm events have been monitored for hydrology in Louisburg, NC. Mean flow volume was reduced by greater than 40% for both the 7.6 m and 15.2 m VFSs. Reconcentration of surface flow in the VFS was shown to substantially impair filter strip performance. These results show that a LS-VFS system can effectively reduce the hydrologic impacts of impervious surfaces.*

Twenty-one and twenty-two flow-proportional water quality samples were collected and analyzed for the Apex and Louisburg sites, respectively. Constituents monitored included TKN, NO_3+NO_2, TN, NH_4, Org-N, TP, Ortho-P, PBP, and TSS. All LS-VFS systems studied significantly reduced mean TSS concentrations ($p<0.05$), with the 7.6 m buffers reducing TSS by at more than 50% and the 15.2 m buffers reducing TSS by more than 65%. Concentrations of TKN, TN, Org-N and NH_4-N were significantly reduced ($p<0.05$) by both 15.2 m VFSs, while results were mixed for the 7.6 m VFSs. Significant pollutant mass reduction was observed ($p<0.05$) for all nine pollutant species analyzed at the Louisburg site due to infiltration in the VFSs. The effects of VFS length and/or vegetation type are very important for pollutant removal, as effluent pollutant concentrations were lower (with one exception) for the 15.2 m VFSs. Median effluent concentrations for TN and TP for the four LS-VFSs were better than fair water quality benchmarks for the Piedmont of North Carolina, but only met good water quality metrics in one-half of the studied storm events.

Keywords. level spreader, vegetative filter strip, VFS, stormwater, Low Impact Development, LID, best management practices

Introduction

Urbanization of agricultural and forested landscapes across the U.S. is occurring rapidly, often leading to environmental degradation. Construction of impervious surfaces causes changes in the hydrologic cycle, leading to increases in runoff. Additionally, urban areas provide pollutant sources that can cause impairment in water quality in urban streams, lakes, and estuaries. In order to ameliorate these issues, engineers and land use planners have designed and implemented Low Impact Development (LID) practices. LID practices include bioretention areas, cisterns (water harvesting), permeable pavement, and vegetated swales. The main purpose of these practices is to reduce runoff volumes to pre-development benchmarks. Ancillary goals of these practices include: removal of pollutants common to urban stormwater, including nitrogen, phosphorous, oil and grease, sediment, bacteria, heavy metals, and thermal pollution and improvements in urban hydrology, including mitigation of peak flows and time to peak.

One stormwater BMP that is in use in North Carolina is the level spreader - vegetated filter strip (LS-VFS) system. The term “level spreader” was first described by Smolen et al. (1988) as “a non-erosive outlet for concentrated runoff constructed to disperse flow uniformly across a slope.” A level spreader is designed to receive upslope pipe flow, and create downslope diffuse flow through a vegetated buffer or filter strip (Hathaway and Hunt, 2008). Design requirements for level spreaders have been produced in several states (IDEQ 1998; MDEP 2003; NC DENR 2007), but research on their effectiveness is inconclusive and inadequate.

Level spreaders were initially used to disperse runoff from drainage ditches through VFSs. In an early study of a LS-VFS system in Granville County, North Carolina (Franklin et al. 1992), stormwater was routed from a planted agricultural field through a wooden level spreader. Twenty nine storm events were monitored between October 1989 and July 1990. It was determined that a level spreader-forested filter zone system was effective in reducing mass loadings of NH_4-N (75%), TP (32%) and TSS (47%). Another benefit was a 36% reduction in flow volume.

Another LS-VFS study was completed at a shopping center in Virginia (Yu et al. 1993). The level spreader was 170 m long and was sized to convey 1.02 m^3/s over the spreader lip. Eight storm events during March-June of 1987 were sampled at three locations: the outlet of the watershed, at the level spreader, and at the outlet of the buffer. The removal efficiency of the level spreader-grassed buffer system was calculated using percent mass removal, with the following efficiencies: 54-84% TSS, -27-20% NO_3+NO_2, 25-40% TP, -16-50% Pb, and 47-55% Zn. The authors suggested that sedimentation and filtration were the primary methods for solids and metals removal in a VFS, while adsorption, precipitation, and plant uptake were likely the means of nutrient removal. The LS-VFS was effective in removal of particulate pollutants such as TSS, but was not as effective at removal of soluble pollutants such as nitrate-nitrite N. Removal efficiency for all pollutants increased as vegetated buffer width increased.

Another study of a level spreader-vegetated buffer system was conducted in Johnston County, North Carolina, near the intersection of NC 42 and I-40 (Line and Hunt

2009). Stormwater runoff was collected primarily from the highway (0.35 ha watershed) and conveyed through a vegetated channel to a level spreader 7.3 m in length. Buffer width was 17 m. Reductions in flow volume of 49% were observed, which led to high rates of nutrient, metals, and solids removal. Mass removal efficiencies for the level spreader-grassed buffer system were as follows: 70% total suspended solids, 11% NO_3+NO_2, 36% ammonia nitrogen, 17% total Kjeldahl nitrogen, and an 11% increase in total phosphorous.

An LS-VFS was studied in Charlotte, NC (Hunt et al. 2010). VFS area was 900 m^2, with a width of 45 m. The soils at the site were amended through the addition of course-grained particles, thereby increasing the infiltration rate and porosity of the soil. The watershed was 0.87 ha (2.15 ac) in size, and was 45% impervious. Cumulative volume reductions were 85% for this LS-VFS. This study showed the ability of LS-VFS systems to infiltrate stormwater and change the hydrologic characteristics of an urban watershed.

The four articles above offer a summary of LS-VFS performance. For ease of comparison, the following two tables summarize experimental design and results for three of the four studies. The first table is a summary of LS-VFS characteristics, along with other experimental design parameters of importance to the water quality and hydrology results from each study (Table 1).

Table 1. Summary of prior LS-VFS research.
(Adapted from authors listed in table)

Author	Year Published	Level Spreader Material	Vegetated Buffer Type	Slope of VFS (%)	# of Events	Land Use
Franklin et al.	1992	Wooden Trough	Forested (mixed pine-hardwood)	4	29	Agricultural
Yu et al.	1993	Concrete	Kentucky 31 Grass	6	8	Urban
Line and Hunt	2009	Concrete	Bermudagrass	5.2	14	Urban

An important note from Table 1 is that urban level spreader studies have been completed on grassed buffers only. Table 2 summarizes the results for pollutant removal. For comparison, the buffer width and the percent runoff volume reduction are included for each system:

Table 2: Summary of pollutant removal from LS research
(Adapted from authors listed in table)

Author	Year Published	VFS Width (m)	% Vol. Red.	% Removal NO_3+NO_2	% Removal NH_4	% Removal TKN
Franklin et al. [b]	1992	30.5	36	NM [c]	75	29
Yu et al. [b]	1993	21	NM [c]	-27	NM	NM
Yu et al. [b]	1993	45	NM	20	NM	NM
Line and Hunt [a]	2009	17	49	11	36	17

Line and Hunt [b]	2009	17	49	49	75	66
Author	% Removal TP	% Removal Ortho-P		% Removal Pb	% Removal Zn	% Removal TSS
Franklin et al. [b]	32	17		NM	NM	47
Yu et al.[b]	25	NM		-16	47	54
Yu et al. [b]	40	NM		50	55	84
Line and Hunt [a]	-11	NM		70	74	70
Line and Hunt [b]	48	NM		81	82	83

[a] These % removal values calculated as concentration reductions between inlet and outlet of the LS/VBS
[b] These % removal values calculated as load reduction between inlet and outlet of the LS/VBS
[c] Indicates that parameter was not measured for this study

Site Descriptions

Two level spreader research sites were monitored in the Piedmont region of North Carolina, where soils are characterized by moderate clay contents. The sites are located in Apex and Louisburg, NC (Figure 1).

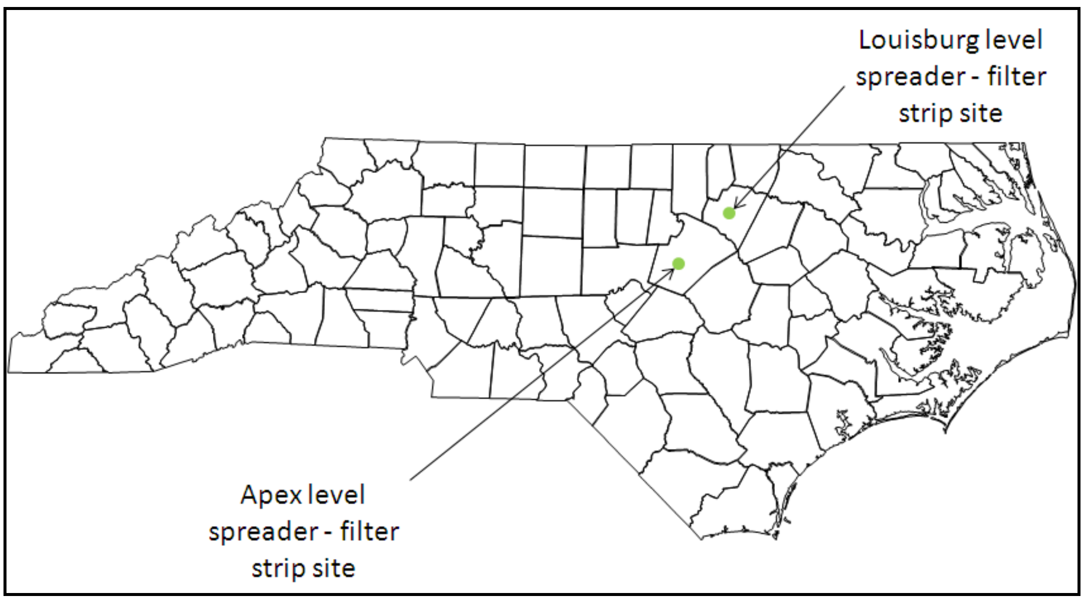

Figure 1. Locations of LS-VFS field research sites.

The Louisburg retrofit LS-VFSs were located at an emergency response center off NC Highway 56 near Louisburg, North Carolina (N 36°05'; W 78°19'). The drainage area was composed of rooftop (0.04 ha), parking lot (0.19 ha), landscaped area (0.12 ha), and portions of NC 56 (0.05 ha). Runoff from the highway, parking lot, and landscaped areas traveled by surface flow to a curb cut, where it entered a forebay. Rooftop runoff was also conveyed to the forebay.

The Apex LS-VFSs were located at Apex High School off U.S. Highway 64 (N 35°44'; W 78°50') near Apex, North Carolina. The drainage area was composed predominantly of parking lot (0.37 ha) and a few associated landscaped areas (0.05

ha). Runoff from the watershed drained to two curb cuts, where flow was conveyed via two swales to a forebay.

At each site, flow was split from the forebay to two level spreaders using two 15.2 cm (6 in) PVC pipes. Each level spreader was 3.96 m (13 ft) in length, and was constructed level across its length. During a storm event, the stage of the water increased until the forebay and swales filled, at which point water was conveyed over the level spreaders, and into one of the VFSs. The buffers differed in width and vegetation type; the first was a 7.6 m wide grassed buffer, and the second was a 15.2 m wide buffer, which was one-half grassed and one-half wooded. This experimental design was repeated at both sites. Figure 2 shows the level spreaders and associated monitoring equipment in Apex, North Carolina.

After the water passed through the buffer, the remaining surface flow was recollected in a trough downslope of the level spreader. Flow then passed from the trough to a weir box, and then discharged through a drainage pipe offsite. This monitoring setup is pictured in Figure 2, and was repeated four times, once for each of the level spreaders. Construction of the BMPs was completed in January 2008, and monitoring of the sites occurred from March 2008-March 2009.

Figure 2. Level spreader, recollection trough, and weir box.

Soil conditions contribute to the functioning of this LID practice, since it is solely dependent on infiltration as the volume reduction mechanism. The soils at both the Apex and Louisburg sites were classified as sandy loam. However, there was a tight clayey confining layer at a depth of 60 cm in Apex, which created a saturated lens during wet periods.

Materials and Methods

Monitoring was conducted at both sites to effectively measure the impacts of a LS-VFS system on water quantity and quality. Inlet hydrology at Louisburg was calculated using the curve number method. Hydrologic monitoring of outflow from the two Louisburg LS-VFSs was completed using two ISCO 730 bubbler flow meters. A 30° V-notch weir was used in each weir box. The flow module recorded stage measurements at a two minute interval. Flow rates at the outlet were calculated using the standard stage discharge relationship for a 30° V-notch weir, given below in equation 1:

$$Q=0.676*H^{2.5} \quad [1]$$

Following the calculation of flow rates, outlet flow volumes were calculated by integration of the hydrograph.

Water quality samples were taken from three locations at each site, in order to quantify concentration reductions and effluent concentrations for each buffer width. During this study, samples were analyzed for the following parameters: Total Kjeldahl nitrogen (TKN), nitrate-nitrite nitrogen (NO_3+NO_2), total nitrogen (TN), ammonium nitrogen (NH4-N), organic nitrogen (Org-N) total phosphorous (TP), orthophosphate (ortho-P), particle bound phosphorus (PBP) and total suspended solids (TSS). A total of six ISCO 6712 water quality samplers were used to take composite, flow proportional water quality samples during storm events (3 samplers at each site). The inlet sample intake at each site was located in the center of the forebay. The two outlet sample intakes at each site were located in the weir boxes, upstream of each 30° V-notch weir. The inlet water quality samples were used as a baseline for all comparisons, as they represented untreated stormwater runoff.

Hydrology Results

Monitoring of hydrologic performance of LS-VFSs at the Louisburg, NC sites occurred between March 2008 and March 2009. Fifty-eight storm events large enough to create inflow were monitored. Due to minor equipment failures, all of those storm events were not captured for both buffer lengths. Thirty-two storm events with precipitation depth <1.25 cm, fourteen events between 1.25 cm and 2.5 cm, and five events >2.5 cm were monitored. Median rainfall depth was 1.06 cm, with lower and upper extremes of 0.26 cm and 3.49 cm, respectively. Hydrologic results for this site were very promising (Figure 2). For both the 7.6 m buffer and the 15.2 m buffer, cumulative volume reductions over the yearlong study were greater than 40%. In Figure 3, mean peak flow rate reduction is plotted as a function of rainfall depth. For storm events less than 1.25 cm, this system infiltrates a substantial portion of the inflow volume, resulting in >65% peak flow reduction. However, trends indicate that as rainfall depth increases, volume reduction and peak flow reduction decrease. Therefore, a level spreader - vegetated buffer system may prove more beneficial during events with smaller precipitation depths, similar to the conclusion of Li et al. (2009) for bioretention areas.

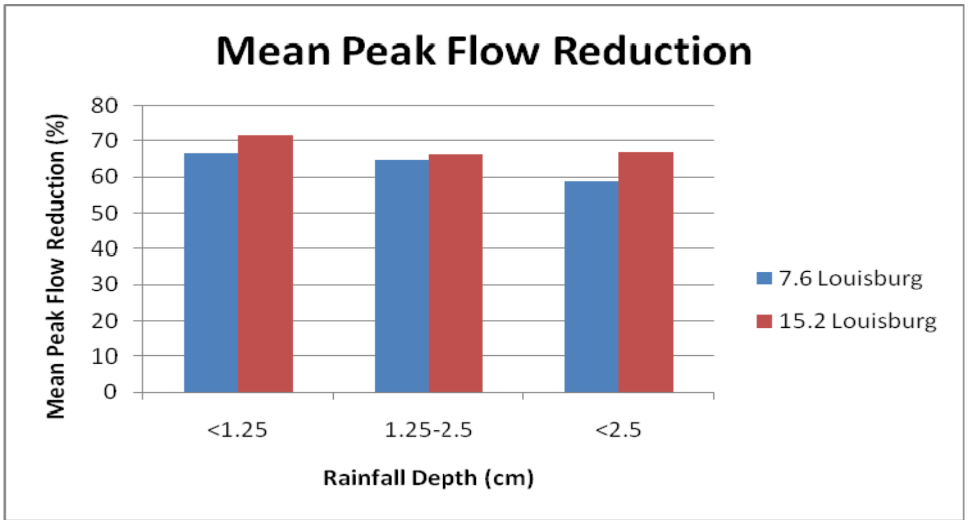

Figure 3. Hydrologic results for Louisburg, NC site.

Volume reductions were similar in magnitude for both the 7.6 m and 15.2 m buffer widths for most storm events. To demonstrate a possible cause, an effective buffer study was performed. This study involved visiting the Apex and Louisburg sites during rainfall events to survey flow paths in the VFSs. A Boolean (yes/no) measurement was taken on a 2 ft by 2 ft grid to determine whether surface flow was occurring at each point. Results are shown in Figures 4 and 5 for the 7.6 m and 15.2 m Louisburg LS-VFSs, respectively. Results are for a storm event on 2/18/09. The vertical green line in Figure 5 represents the treeline, with a wooded filter strip to the right of the line. In Figure 4, it is clear that the initially diffuse flow at the LS is maintained through the width of the buffer. In Figure 5, the diffuse flow is maintained through the grassed portion of the VFS (the first 7.6 m), but flow quickly reconcentrates once it reaches the treeline. Reconcentration causes an increase in velocity of the stormwater, which leads to reduced infiltration in the buffer. This is believed to be the reason for the decreased hydrologic performance of the 15.2 m LS-VFS in Louisburg.

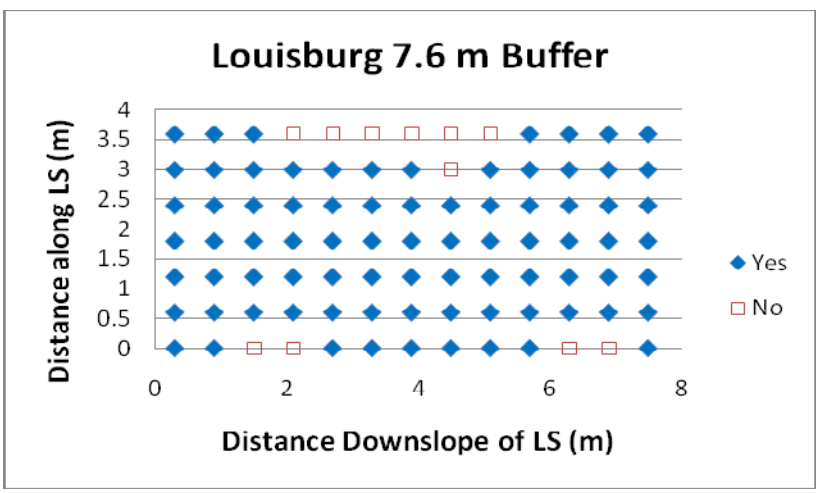

Figure 4. Effective buffer study results for 7.6 m Louisburg LS-VFS (2/18/09)

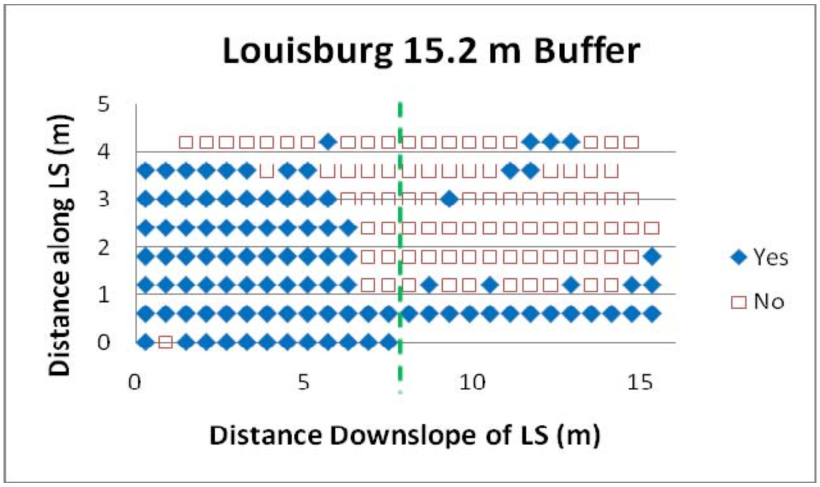

Figure 5. Effective buffer study results for 15.2 m Louisburg LS-VFS (2/18/09)

Water Quality Results

Twenty-two water quality storm events were sampled for water quality at Louisburg, while twenty-one were sampled at Apex. Mean concentration reductions between the inlet and outlet of each buffer can be seen in Figure 6:

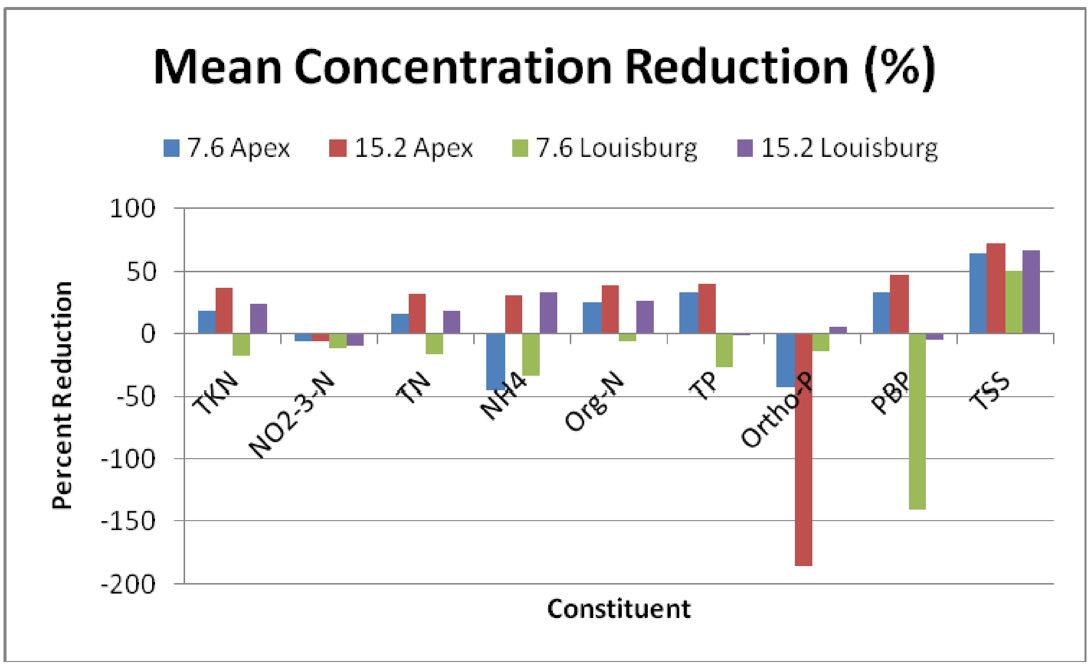

Figure 6. Percent removal results for the Apex and Louisburg LS-VFSs.

The terms "7.6" and "15.2" refer to the width of the buffer, that is, the 7.6 m (25 ft) buffer the 15.2 m (50 ft) buffer. For the 7.6 m VFS in Louisburg, no significant reductions in concentrations of nitrogen or phosphorus species were observed. TP and PBP were significantly *exported* ($p<0.05$). For the 15.2 m VFS in Louisburg, concentrations of TKN, TN, NH_4-N, Org-N, and TP were significantly reduced. Statistically significant TSS reductions were observed at both Louisburg VFSs, with 51% and 67% mean concentration reductions for the 7.6 and 15.2 m VFSs, respectively. Mean effluent concentrations were higher for the 7.6 m VFS (when compared to the 15.2 m VFS) for every constituent studied.

At Apex, concentrations of TKN, TN, NH_4-N, Org-N, TP, PBP, and TSS were significantly reduced ($p<0.05$) from the inlet to the outlet for both the 7.6 m and 15.2 m LS-VFS systems. Reductions in TSS concentration were 65% and 72% for the 7.6 m and 15.2 m LS-VFSs, respectively. TSS concentrations were also reduced in the literature, where Robinson et al. (1996) studied a 3 m buffer that removed 70% of sediment and a 9.1 m buffer that removed 85% of sediment. Mean effluent concentrations were lower for the 15.2 m buffer when compared to the 7.6 m buffer for every constituent studied except Ortho-P at the Apex site.

A new water quality metric has been introduced for use in stormwater studies in North Carolina. Ambient water quality measurements were statistically related to benthic macroinvertebrate health. For "good" benthos health, TN concentrations need to be below 0.99 mg/L and TP concentrations below 0.11 mg/L in the Piedmont of North Carolina (McNett et al. 2010). For "fair" benthos quality, TN and TP benchmarks of 2.16 mg/L and 0.22 mg/L, respectively, must be satisfied. Median concentrations from both the Apex and Louisburg sites are compared to these benchmarks in Table 3.

Table 3. Comparison of median outlet concentrations to benthic macroinvertebrate indicator benchmarks for the Piedmont of North Carolina.

Site	TN		TP	
	No. of Events Exceeding[1] "Good"	No. of Events Exceeding "Fair"	No. of Events Exceeding "Good"	No. of Events Exceeding "Fair"
Apex Inlet	14	4	14	4
7.6A Outlet	11	2	7	2
15.2A Outlet	10	1	5	1
Louisburg Inlet	8	2	11	7
7.6L Outlet	12	2	16	6
15.2L Outlet	7	1	16	2

[1] "Exceeding" means the concentration was higher, or worse, than the target water quality benchmark.

At Apex, a greater number of storms at the inlet had concentrations worse than the "good" and "fair" limits than at either of the VFS outlets. This shows that water quality was improving through the VFS. Also, the wider filter strip had fewer events exceeding benchmark concentrations. Trends were not as obvious at Louisburg. Events exceeding "fair" benchmarks decreased with increased VFS length. The increase in events exceeding "good" benchmarks for the 7.6L VFS was due to slight increases in TN and TP concentrations for this buffer.

As shown in Figure 7, LS-VFS can have a substantial impact on water quality when mass removal of pollutants is considered. Results are shown for the 7.6 m and 15.2 m VFSs in Louisburg for all constituents studied.

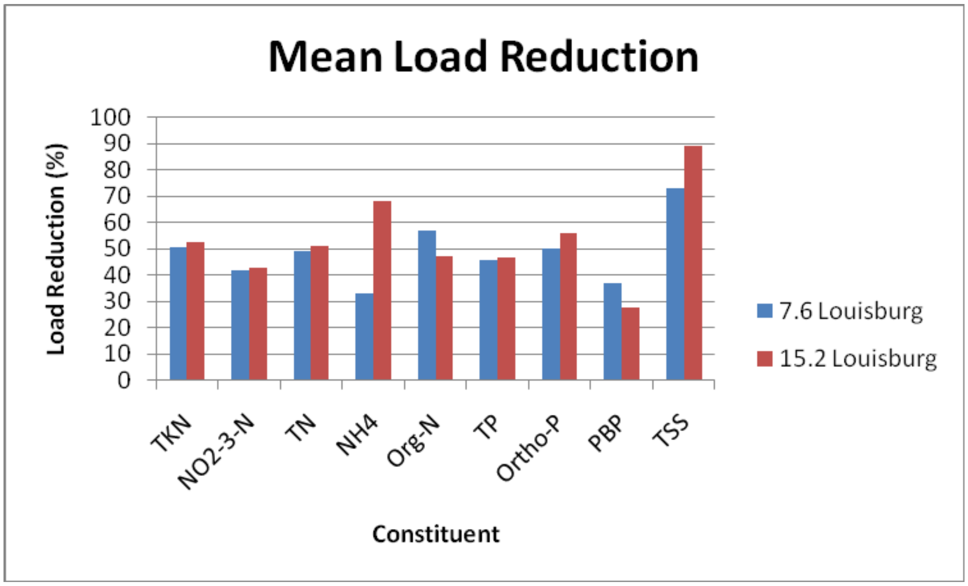

Figure 7. Mean pollutant mass removal results.

For all pollutants and VFS widths at the Louisburg site, reductions in pollutant mass were statistically significant ($p<0.05$). This is due primarily to volume reductions in the VFSs. In every case except Org-N and PBP, the wider buffer reduced the mass of pollutant to a greater extent. The mean effluent loads produced by the 7.6 m and 15.2 m VFSs were statistically different ($p<0.05$) for TSS and NH_4-N. However, in most cases for nitrogen and phosphorus species, the difference in load reductions is small between the 7.6 m and 15.2 m VFSs. This is probably due to reconcentration of surface flow in the wooded portion of the 15.2 m VFS. The microtopography surrounding trees causes diffuse flow to reconcentrate, leading to increased flow velocity, and less time for pollutant removal and infiltration to occur. Overall, the results summarized above are very promising, and show that this system can be used to effectively remove pollutants on a mass basis before they enter downstream rivers, lakes, or estuaries.

Conclusions

Four LS-VFS systems were studied in urban areas of the Piedmont of North Carolina. Results indicated that properly designed, installed, and maintained LS-VFS systems can function to improve urban hydrology and water quality. Infiltration in the VFS reduced stormwater volumes during small storm events. As rainfall depth increased, flow volume mitigation decreased, as the in situ soil became saturated. TSS was reduced by more than 50% for 7.6 m VFSs and more than 65% for 15.2 m VFSs. Mean effluent concentrations for the 7.6 m VFS were higher than those for the corresponding 15.2 m VFS, except for one pollutant at Apex. This highlighted the importance of VFS width for pollutant removal. Median effluent concentrations of LS-VFS systems had TN and TP concentrations that met indicators of "fair" benthos health. Only 50% of storm events studied met benchmarks for "good" benthos quality in the Piedmont of North Carolina. This is probably due to the fact that LS-VFS systems are primarily sedimentation systems; if particle bound pollutant concentrations are low, their performance will suffer. Pollutant load reductions of between 40-70% were observed for all nitrogen species at Louisburg. For phosphorous species, mass reductions varied between 27% and 47%. Mean load reductions of TSS for the 7.6 m and 15.2 m VFSs, respectively, were 73% and 89%. These systems are relatively easy to design and install, and have relatively minimal construction and maintenance costs. For these reasons, the LS-VFS can be a beneficial management practice for the stormwater quality designer. Results show that a level spreader - vegetated buffer system is a viable LID practice for the management of urban stormwater runoff.

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ATTACHMENT D

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Florida-Friendly Landscaping™ Pattern Book:

Sample plant lists and designs for four Florida regions

USDA HARDINESS ZONES 10A, 10B, AND 11, SOUTH FLORIDA

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TABLE 1. GROUPS A1, A2, A3: FRONT ENTRIES/PATIOS, SIDEWALKS/WALKWAYS, MAILBOXES/UTILITIES		
Characteristics: Low growing and compact, colorful, medium/ coarse texture, bold forms, clean growth habit, unique shape, overhead branching, soft foliage, clumping/mounding		
	SUN	**SHADE**
SHRUBS		
Small	*Allamanda schottii* (Bush Allamanda) *Euryops chrysanthemoides* (African Bush Daisy) *Ficus microcarpa* 'Green Island' (Green Island Ficus) *Hamelia patens* 'Compacta' (Dwarf Firebush) *Ilex vomitoria* 'Nana' (Dwarf Yaupon Holly)* *Pittosporum tobira* 'Wheeler's Dwarf' (Dwarf Pittosporum) *Podocarpus* 'Pringles' (Dwarf Podocarpus) *Rhaphiolepis indica* 'Dwarf' (Dwarf Indian Hawthorn) Rosa spp. (Knockout® Rose) *Vaccinium darrowii* (Darwin's Blueberry)* *Viburnum obovatum* 'Densa' (Dwarf Walter's Viburnum)*	*Ficus microcarpa* 'Green Island' (Green Island Ficus) *Ilex vomitoria* 'Nana' (Dwarf Yaupon Holly)* *Philodendron* 'Xanadu' (Xanadu) *Pittosporum tobira* 'Wheeler's Dwarf' (Dwarf Pittosporum) *Podocarpus* 'Pringles' (Dwarf Podocarpus) *Psychotria nervosa* 'Nana' (Dwarf Coffee)* *Rhaphiolepis indica* 'Dwarf' (Dwarf Indian Hawthorn) *Sabal minor* (Dwarf Palmetto)*
Medium	*Argusia gnaphalodes* (Sea Lavender)* *Capparis cynophallophora* (Jamaican Caper)* *Duranta erecta* 'Gold Mound' (Dwarf Golden Dewdrop) *Galphimia gracilis* (Thryallis) *Jasmine multiflorum* (Downy Jasmine) *Jatropha integerrima* (Jatropha) *Lyonia ferruginea* (Rusty Lyonia)* *Myrcianthes fragrans* 'Compacta' (Dwarf Simpson's Stopper)* *Myrica cerifera* 'Pumila' (Dwarf Wax Myrtle)* *Pittosporum tobira* (Pittosporum) *Senna mexicana* 'Chapmanii' (Bahama Cassia)* *Sophora tomentosa* (Necklace Pod)* *Suriana maritima* (Bay Cedar)*	*Ilex cornuta* 'Burfordii Nana' (Dwarf Burford Holly) *Myrcianthes fragrans* 'Compacta' (Dwarf Simpson's Stopper)* *Philodendron* 'Selloum' (Split-leaf Philodendron) *Philodendron* 'Xanadu' (Xanadu) *Pittosporum tobira* (Pittosporum) *Podocarpus macrophyllus* (Podocarpus) *Rhaphiolepsis indica* (Indian Hawthorn)

TABLE 1. GROUPS A1, A2, A3: FRONT ENTRIES/PATIOS, SIDEWALKS/WALKWAYS, MAILBOXES/UTILITIES		
	SUN	**SHADE**
GROUNDCOVERS		
	Agapanthus spp. (Lily of the Nile) *Aptenia cordifolia* (Baby Sun Rose) *Arachis glabrata* (Perennial Peanut) *Bulbine* spp. (Bulbine) *Dietes vegeta (vegeta = D. iridioides)* (African Iris) *Ernodea littoralis* (Beach Creeper)* *Evolvulus glomeratus* (Blue Daze) *Gaillardia pulchella* (Blanket Flower)* *Helianthus debilis* (Beach Sunflower)* *Hemerocallis* spp. (Daylily) *Ipomoea imperati* (Beach Morning Glory)* *Iva imbricata* (Beach Elder)* *Lantana montevidensis* (Trailing Lantana)* *Licania michauxii* (Gopher Apple)* *Liriope muscari* (Monkey Grass) *Mimosa strigillosa* (Sunshine Mimosa)* *Ophiopogon japonica* (Mondo Grass) *Phyla nodiflora* (Fogfruit)* *Salvia misella* (Creeping Sage)* *Sesuvium portulacastrum* (Seaside Purslane)* *Tulbaghia vioilacea* (Society Garlic) *Zamia pumila (pumila = Z. floridana)* (Coontie)*	*Ajuga reptans* (Ajuga) *Crytomium falcatum* (Holly Fern) *Dianella* spp. (Flax Lily) *Dietes vegeta (vegeta = D. iridioides)* (African Iris) *Liriope muscari* (Monkey Grass) *Ophiopogon japonica* (Mondo Grass) *Osmunda cinnamomea* (Cinnamon Fern)* *Woodwardia areolata* (Netted Chain Fern)* *Zamia pumila (pumila = Z. floridana)* (Coontie)*
*Florida native plant **Also see table of wildflowers and ornamental grasses		
SPECIMEN TREES		
Small	*Ardisia escallonioides* (Marlberry)* *Baccharis halimifolia* (Salt Bush)* *Callistemon* spp. (Bottlebrush) *Citharexylum spinosum* (Fiddlewood)* *Cordia boissieri* (White Geiger)* *Cornus foemina* (Swamp Dogwood)* *Ilex vomitoria* 'Pendula' (Weeping Yaupon Holly)* *Ilex vomitoria* (Yaupon Holly)* *Ilex x attenuata* 'Savannah' (Savannah Holly) *Jatropha integerrima* (Jatropha) *Ligustrum japonicum* (Privet) *Myrica cerifera* (Wax Myrtle)* *Myrcianthes fragrans* (Simpson's Stopper)* *Pseudophoenix sargentii* (Buccaneer Palm)* *Senna polyphylla* (Desert Cassia)*	*Ardisia escallonioides* (Marlberry)* *Cornus foemina* (Swamp Dogwood)* *Ilex cassine* (Dahoon Holly)* *Ilex opaca* var. *arenicola* (Scrub Holly)* *Ilex x attenuata* 'Savannah' (Savannah Holly) *Ilex vomitoria* (Yaupon Holly)* *Ilex vomitoria* 'Pendula' (Weeping Yaupon Holly)* *Ligustrum japonicum* (Privet) *Myrcianthes fragrans* (Simpson's Stopper)*

TABLE 1. GROUPS A1, A2, A3: FRONT ENTRIES/PATIOS, SIDEWALKS/WALKWAYS, MAILBOXES/UTILITIES		
	SUN	**SHADE**
SPECIMEN TREES		
Medium	*Chionanthus virginicus* (Fringe Tree)* *Gordonia lasianthus* (Loblolly Bay)* *Ilex cassine* (Dahoon Holly)* *Juniperus virginiana* (Red Cedar)* *Morus rubra* (Mulberry)* *Parkinsonia aculeata* (Jerusalem Thorn) *Podocarpus gracilior* (Fern Leaf Podocarpus) *Quercus geminata* (Sand Live Oak)* *Tabebuia argentea* (Yellow Trumpet Tree) *Ulmus alata* (Winged Elm)* *Ulmus americana* 'Floridana' (Florida Elm)*	*Chionanthus virginicus* (Fringe Tree)* *Gordonia lasianthus* (Loblolly Bay)* *Ilex cassine* (Dahoon Holly)* *Magnolia virginiana* (Sweet Bay)* *Podocarpus gracilior* (Fern Leaf Podocarpus)
Large	*Acer rubrum* (Red Maple)* *Conocarpus erectus* 'Sericeus' (Silver Buttonwood)* *Pinus elliottii* var. *densa* (South Florida Slash Pine)* *Quercus virginiana* (Live Oak)* *Taxodium ascendens* (Pond Cypress)* *Taxodium distichum* (Bald Cypress)*	
*Florida native plant		

TABLE 2. GROUPS B1 AND B2: UNDER WINDOWS AND ALONG WALLS		
Characteristics: Medium/ tall shrubs, soft/ fine texture, loose foliage, flexible branches, no thorns, easy to trim		
	SUN	**SHADE**
SHRUBS		
Medium	*Ardisia escallonioides* (Marlberry)* *Argusia gnaphalodes* (Sea Lavender)* *Callicarpa americana* (Beautyberry)* *Capparis cynophallophora* (Jamaican Caper)* *Erythrina herbacea* (Coral Bean)* *Eugenia foetida* (Stopper)* *Euryops chrysanthemoides* (African Bush Daisy) *Forestiera segregata* (Florida Privet)* *Hamelia patens* 'Compacta' (Dwarf Firebush) *Ilex vomitoria* 'Nana' (Dwarf Yaupon Holly)* *Lycium carolinianum* (Christmasberry)* *Lyonia ferruginea* (Rusty Lyonia)* *Myrcianthes fragrans* 'Compacta' (Dwarf Simpson's Stopper)* *Myrica cerifera* 'Pumila' (Dwarf Wax Myrtle)* *Podocarpus* 'Pringles' (Dwarf Podocarpus) *Psychotria sulzneri* (Shiny Coffee)* *Rapanea punctata* (Myrisine)* *Rhaphiolepis indica* (Indian Hawthorn) *Rosa* spp. (Knockout® Rose) *Senna mexicana* 'Chapmanii' (Bahama Cassia)* *Sophora tomentosa* (Necklace Pod)* *Suriana maritima* (Bay Cedar)* *Vaccinium darrowii* (Darwin's Blueberry)* *Viburnum obovatum* 'Densa' (Dwarf Walter's Viburnum)*	*Ardisia escallonioides* (Marlberry)* *Callicarpa americana* (Beautyberry)* *Cephalanthus occidentalis* (Buttonbush)* *Erythrina herbacea* (Coral Bean)* *Hamelia patens* 'Compacta' (Dwarf Firebush) *Illicium parviflorum* (Anise)* *Itea virginica* (Sweet Spire)* *Myrcianthes fragrans* 'Compacta' (Dwarf Simpson's Stopper)* *Podocarpus* 'Pringles' (Dwarf Podocarpus) *Rapanea punctata* (Myrisine)* *Rhaphiolepis indica* (Indian Hawthorn)
Tall	*Capparis cynophallophora* (Jamaican Caper)* *Cephalanthus occidentalis* (Buttonbush)* *Coccoloba uvifera* (Seagrape)* *Hamelia patens* (Firebush)* *Illicium parviflorum* (Anise)* *Ligustrum japonicum* (Privet) *Myrcianthes fragrans* (Simpson's Stopper)* *Myrica cerifera* (Wax Myrtle)* *Podocarpus macrophyllus* (Podocarpus) *Vaccinium arboreum* (Sparkleberry)* *Viburnum odoratissimum* (Sweet Viburnum) *Viburnum suspensum* (Sandankwa Viburnum)	*Ardisia escallonioides* (Marlberry)* *Cephalanthus occidentalis* (Buttonbush)* *Hamelia patens* (Firebush)* *Illicium parviflorum* (Anise)* *Ligustrum japonicum* (Privet) *Myrcianthes fragrans* (Simpson's Stopper)* *Podocarpus macrophyllus* (Podocarpus) *Psychotria bahamensis* (Bahama Coffee)* *Viburnum odoratissimum* (Sweet Viburnum) *Viburnum suspensum* (Sandankwa Viburnum)
* Florida native plant		

TABLE 3. GROUPS C1 AND C2: ALONG PROPERTY LINES AND FENCES		
Characteristics: Dense foliage, upright form, evergreen, sturdy, fast growing		
	SUN	**SHADE**
SHRUBS		
Medium	*Allamanda schottii* (Bush Allamanda) *Eugenia foetida* (Stopper)* *Ilex cornuta* 'Burfordii Nana' (Dwarf Burford Holly) *Podocarpus* 'Pringles' (Dwarf Podocarpus)	*Callicarpa americana* (Beautyberry)* *Podocarpus* 'Pringles' (Dwarf Podocarpus) *Psychotria nervosa* (Wild Coffee)* *Rapanea punctata* (Myrsine)*
Tall	*Chrysobalanus icaco* (Cocoplum)* *Coccoloba uvifera* (Seagrape)* *Forestiera segregate* (Florida Privet)* *Ilex vomitoria* (Yaupon Holly)* *Illicium parviflorum* (Anise)* *Ligustrum japonicum* (Privet) *Myrcianthes fragrans* (Simpson's Stopper)* *Myrica cerifera* (Wax Myrtle)* *Podocarpus gracilior* (Fern Leaf Podocarpus) *Podocarpus macrophyllus* (Podocarpus) *Viburnum obovatum* (Walter's Viburnum)* *Viburnum odoratissimum* (Sweet Viburnum) *Viburnum suspensum* (Sandankwa Viburnum)	*Agarista populifolia* (Pipestem)* *Ardisia escallonoides* (Marlberry)* *Illicium parviflorum* (Anise)* *Ligustrum japonicum* (Privet) *Myrcianthes fragrans* (Simpson's Stopper)* *Podocarpus gracilior* (Fern Leaf Podocarpus) *Podocarpus macrophyllus* (Podocarpus) *Viburnum odoratissimum* (Sweet Viburnum) *Viburnum suspensum* (Sandankwa Viburnum)
VINES		
	Bignonia capreolata (Cross Vine)* *Campsis radicans* (Trumpet Vine)* *Lonicera sempervirens* (Coral Honeysuckle)* *Pandorea jasminoides* (Pandorea Vine) *Pentalinon luteum* (Native Allamanda Vine)*	*Bignonia capreolata* (Cross Vine)* *Campsis radicans* (Trumpet Vine)* *Lonicera sempervirens* (Coral Honeysuckle)*
* Florida native plant		

TABLE 4. GROUP D: UNDER TREES		
Characteristics: Shallow roots, vines/spreading		
	SUN	**SHADE**
GROUNDCOVERS		
	Agapanthus spp. (Lily of the Nile) *Aptenia cordifolia* (Baby Sun Rose) *Arachis glabrata* (Perennial Peanut) *Bulbine* spp. (Bulbine) *Dietes vegeta (vegeta = D. iridioides)* (African Iris) *Ernodea littoralis* (Beach Creeper)* *Evoluvlous glomeratus* (Blue Daze) *Gaillardia pulchella* (Blanket Flower)* *Helianthus debilis* (Dune Sunflower)* *Hemerocallis* spp. (Daylily) *Ipomoea imperati* (Beach Morning Glory)* *Ipomoea pes-caprae* (Railroad Vine)* *Iva imbricata* (Beach Elder)* *Licania michauxii* (Gopher Apple)* *Mimosa strigillosa* (Sunshine Mimosa)* *Phyla nodiflora* (Fogfruit)* *Salvia misella* (Creeping Sage)* *Sesuvium portulacastrum* (Seaside Purslane)* *Tulbaghia violacea* (Society Garlic)	*Ajuga reptans* (Ajuga) *Blechnum serrulatum* (Swamp Fern)* *Crytomium falcatum* (Holly Fern) *Dianella* spp. (Flax Lily) *Liriope muscari* (Monkey Grass) *Mitchella repens* (Partridgeberry)* *Ophiopogon japonica* (Mondo Grass) *Osmunda cinnamomea* (Cinnamon Fern)* *Trachelospermum asiaticum* (Asiatic Jasmine) *Woodwardia areolata* (Netted Chain Fern)*
VINES		
	Bignonia capreolata (Cross Vine)* *Campsis radicans* (Trumpet Vine)* *Lonicera sempervirens* (Coral Honeysuckle)* *Passiflora incarnata* (Passion Flower)* *Pentalinon luteum* (Yellow Mandevilla)* *Symphyotrichum carolinianum* (Climbing Aster)*	*Bignonia capreolata* (Cross Vine)* *Campsis radicans* (Trumpet Vine)* *Lonicera sempervirens* (Coral Honeysuckle)* *Passiflora incarnata* (Passion Flower)*
*Florida native plant		

TABLE 5. GROUP E: SPECIALTY GARDENS – RAIN GARDENS, WATER EDGE, AND BUTTERFLY GARDENS

Specialty Gardens – Rain Gardens/Downspouts

Characteristics: Wet feet, small size, groundcover, clumping, water movement

	SUN	SHADE
GROUNDCOVERS		
	Arachis glabrata (Perennial Peanut) *Hymenocallis latifolia* (Spider Lily)* *Phyla nodiflora* (Fogfruit)* *Sisyrinchium angustifolium* (Blue-eyed Grass) * *Spartina bakeri* (Sand Cordgrass)* *Spartina patens* (Saltmeadow Cordgrass)* *Tulbaghia violacea* (Society Garlic)	*Hymenocallis latifolia* (Spider Lily)*

*Florida native plant

**Also see table of wildflowers and ornamental grasses

Specialty Gardens – Water Edge

Characteristics: Wet feet, small size, groundcover, clumping, water movement

GROUNDCOVERS		
	Arachis glabrata (Perennial Peanut) *Hymenocallis latifolia* (Spider Lily)* *Phyla nodiflora* (Fogfruit)* *Sisyrinchium angustifolium* (Blue-eyed Grass)* *Spartina bakeri* (Sand Cordgrass)* *Spartina patens* (Saltmeadow Cordgrass)* *Tulbaghia violacea* (Society Garlic)	*Hymenocallis latifolia* (Spider Lily)*

*Florida native plant

**Also see table of wildflowers and ornamental grasses

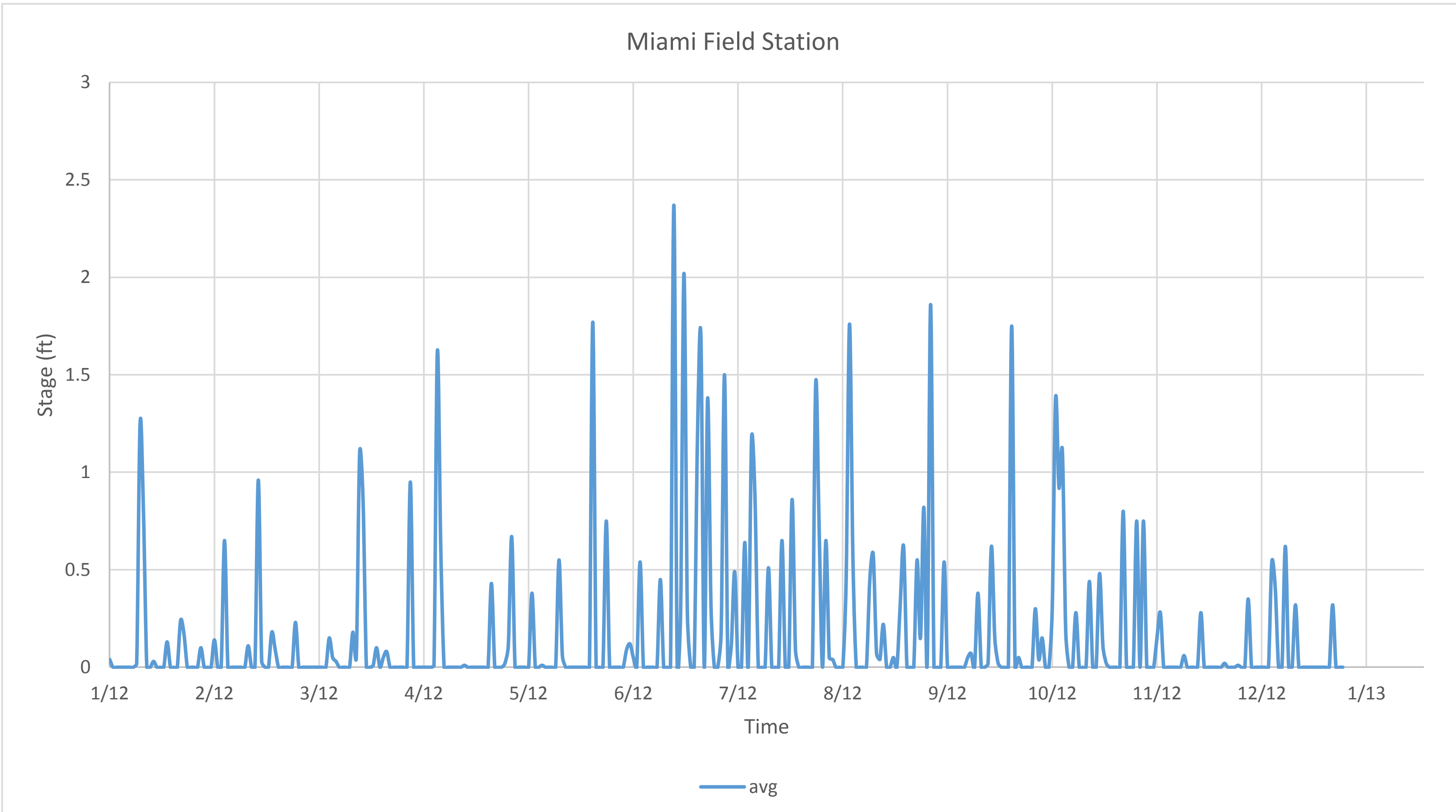
TABLE 5. GROUP E: SPECIALTY GARDENS – RAIN GARDENS, WATER EDGE, AND BUTTERFLY GARDENS		
Specialty Gardens – Butterfly Characteristics: Bright colors (reds, yellows, and purples), a variety of heights, larval host plants and adult nectar sources		
	SUN	**SHADE**
	Ardisia escallonioides (Marlberry)* *Capparis cynophallophora* (Jamaican Caper)* *Eugenia foetida* (Stopper)* *Hamelia patens* 'Compacta' (Dwarf Firebush) *Phyla nodiflora* (Fogfruit)* *Psychotria nervosa* (Wild Coffee)* *Senna mexicana* 'Chapmanii' (Bahama Cassia)* *Sophora tomentosa* (Necklace Pod)* *Vaccinium arboreum* (Sparkleberry)* *Vaccinium darrowii* (Darwin's Blueberry)* *Zamia pumila (pumila = Z. floridana)* (Coontie)*	*Ardisia escallonioides* (Marlberry)* *Psychotria nervosa* (Wild Coffee)* *Vaccinium arboreum* (Sparkleberry)* *Zamia pumila (pumila = Z. floridana)* (Coontie)*
VINES		
	Passiflora incarnata (Passion Flower)*	*Passiflora incarnata* (Passion Flower)* *Passiflora suberosa* (Corkystemmed Passion Flower)*
*Florida native plant		

TABLE 6. WILDFLOWERS AND GRASSES		
Characteristics: Bright colors (reds, yellows, and purples), a variety of heights, larval host plants and adult nectar sources		
	SUN	**SHADE**
	Ageratum littorale (Beach Mistflower)* *Asclepias perennis* (Swamp Milkweed)* *Asclepias tuberose* (Milkweed)* *Berlandiera subacaulis* (Green Eyes)* *Conradina* spp. (Scrub Mint)* *Coreopsis leavenworthii* (Tickseed)* *Eragrostis elliottii* (Lovegrass)* *Eragrostis spectabilis* (Purple Lovegrass)* *Helianthus debilis* (Dune Sunflower)* *Lantana involucrata* (Wild Sage)* *Liatris* spp. (Blazing Star)* *Muhlenbergia capillaris* (Muhly Grass)* *Pentas lanceolata* (Pentas) *Polymnia uvedalia* (Bear's Foot)* *Salvia coccinea* (Red Sage)* *Solidago sempervirens* (Seaside Goldenrod)* *Solidago stricta* (Slender Goldenrod)* *Tripsacum floridanum* (Florida Gamagrass)* *Uniola paniculata* (Sea Oats)* *Vernonia angustifolia* (Ironweed)*	
*Florida native plant		

ATTACHMENT E

	Low Impact Development Integrated Management Practices (IMPs) & Design Consideration Matrix				
	Advantages	Disadvantages	Space Required	Maintenance	Proximity to building Foundation
Bioretention or Rain Garden	Uses landscape areas (native species) on lots to hold and infiltrate stormwater	Required pretreatment for significant volume (parking lots & commercial areas)	Minimum surface area range: 50 to 200 ft^2. Minimum length to width ratio 2:1	Low Requirement (routine landscape maintenance)	Minimum distance of 10 ft down gradient from buildings and foundations recommended
Tree Box Filters or Infiltration Planters	Small-scale variation of Bioretention areas. The box performs as a filter (bottom open) and / or detention BMP (bottom closed). Reduce volume of runoff, offer multiple habitat and aesthetic benefits, reduce heat island effects	Avoid soil compaction. Composition of soil must be evaluated, and usually amended with organic matter to improve moisture retention and microbial action. Provision for overflow or diversion of high flows must be included	In an urban setting, typical 4'x10'x3' tree box. Volume of soil must be considered carefully. Reduction of soil will directly impact the potential size of the tree	Low Requirement (routine landscape maintenance)	Minimum distance of 10 ft down gradient from buildings and foundations recommended
Vegetated Swales (grass, infiltration, wet)	Dry swales provide quantity and quality control by facilitating stormwater infiltration. Wet Swales uses residence time and natural growth to reduce peak discharge and provide water quality treatment	Must be sized to convey the peak discharge of the design storm. Permeability of the soil will determine whether a dry or wet swale can be used	Top width to depth ratio of the cross section equal to or greater than 6:1 or side slopes equal to or flatter than 3H:1V	Low Requirement (routine landscape maintenance)	Minimum distance of 10 ft down gradient from buildings and foundations recommended
Filter Strips Vegetated Buffers	Close-growing vegetation planted between pollutant source and a downstream receiving water body	Maximum drainage area to filter strips is limited by the overland flow limits of 150 feet for pervious & 75 feet for impervious surfaces	Minimum length of 15 to 20 ft.	Low Requirement (routine landscape maintenance)	Minimum distance of 10 ft down gradient from buildings and foundations recommended
Infiltration Trench	Stormwater is directed into the trench and is stored until it can be infiltrated into the soil. Very adaptable IMP & the most effective, makes it ideal for small urban drainage areas	To extend the life cycle some sort of pretreatment should be included in their design like vegetated filter strips or grassed swales.	Minimum surface area range: 8 to 20 ft^2. Minimum length to width ratio 2:1	Moderate to high requirement. Periodic monitoring.	Minimum distance of 10 ft down gradient from buildings and foundations recommended
Rain Barrels	Low-cost, effective and easily maintainable. Provides permanent storage for a design volume. Can be used to store runoff for later reuse for lawn and garden watering	Design should be incorporated into the lot's landscaping plan or patio or decking design to be aesthetically acceptable	The size of the rain barrels is a function of the rooftop surface area that drains to the barrel & the inches of rainfall to be stored	Low Requirement	Rain barrels can be located beneath each downspout
Cisterns	Roof water management devices that provide retention storage volume in underground storage tanks. Also provide opportunity for water conservation & reducing water utility costs	Due to the size of rooftops and amount of imperviousness of the drainage area, increased runoff volume & peak discharge rates for commercial or industrial sites may require larger-capacity cisterns	Premanufactured residential use cisterns come in sizes ranging from 100 to 1,400 gallons	Low requirement. They should be located for easy maintenance or replacement	Individual cisterns can be located beneath each downspout, or storage volume can be provided in one large, common cistern
Permeable Pavement	Retention system that should be used as part of a treatment train to reduce stormwater volume and pollutant load from parking lots and similar areas. Increases usable/developable space	Potential challenges including poorly draining soils, areas subject to high traffic volume regardless of wheel loads, areas of frequent turning moves. Areas for high potential of hazardous material spills. Potential for tripping hazards by pedestrians. Higher construction cost	Includes subsoil, sub-base, and the pervious pavement. Treatment volume to achieve the efficiency shall be determined based of percentage of directly connected impervious areas (DCIA) and weighted curve number for non-DCIA areas	Moderate to high requirement. Periodic vacuum sweeping is recommended annually and whenever the vertical hydraulic conductivity is less than 2.0 inches per hour or less than the permitted design percolation rate	Ideal locations are parking lots, driveways and areas with light traffic. Sidewalks and bike paths.
Detention Ponds	Dry detention ponds detain a portion of urban runoff for a short period of time using a fixed opening to regulate outflow at a specified rate. Wet detention ponds are designed to maintain a permanent pool of water and temporarily store urban runoff until it is released at a controlled rate. Hydraulic holding times are relatively short, such as hours or days.	Must maintain a permanent pool, cannot be constructed in areas with insufficient precipitation, or highly permeable soils. A pond aerator is necessary to avoid stagnation	The permanent pool size shall be sized to provide a resident time that achieves the required nutrient removal efficiency. Maximum depth shall be no greater than 12 feet.	Low to moderate requirements. Ensure proper drainage, aerobic functioning & aeration, & vegetative health. Remove sediment, trash and debris	Ideal location downstream of catchment and runoff, usually constructed at the lowest point of the site
Retention Ponds	Retention systems rely on absorption of runoff to treat urban runoff discharges. Water is percolated through soils, where filtration and biological action remove pollutants.	A large concern is the re-suspension of settled materials, requiring periodic sediment, debris, and pollutant removal. Where groundwater requires protection, retention systems may not be appropriate.	The required treatment volume to achieve the necessary efficiency shall be determined based on the percentage directly connected impervious areas (DCIA) and the weighted curve number for non-DCIA areas	Low to moderate requirement. Regular trash and intermittent sediment removal, pollutants accumulate in soil and may require soil amendments and clean out	Ideal location downstream of catchment and runoff, upstream from off-site stormwater management systems

Average Continuous Rainfall Distribution



Date		Average	Total	
1/1/12		0.04	60.11	
1/2/12		0		
1/3/12		0		
1/4/12		0		
1/5/12		0		
1/6/12		0		
1/7/12		0		
1/8/12		0		
1/9/12		0.02		
1/10/12		1.25		
1/11/12		0.8		
1/12/12		0		
1/13/12		0		
1/14/12		0.03		
1/15/12		0		
1/16/12		0		
1/17/12		0		
1/18/12		0.13		
1/19/12		0		
1/20/12		0		
1/21/12		0		
1/22/12		0.24		
1/23/12		0.17		
1/24/12		0		
1/25/12		0		
1/26/12		0		
1/27/12		0		
1/28/12		0.1		
1/29/12		0		
1/30/12		0		
1/31/12		0		
2/1/12		0.14		
2/2/12		0		
2/3/12		0		
2/4/12		0.65		
2/5/12		0		
2/6/12		0		
2/7/12		0		
2/8/12		0		
2/9/12		0		
2/10/12		0		
2/11/12		0.11		
2/12/12		0		
2/13/12		0		
2/14/12		0.96		
2/15/12		0.03		
2/16/12		0		
2/17/12		0		
2/18/12		0.18		
2/19/12		0.09		
2/20/12		0		
2/21/12		0		

Date		Average	Total	
2/22/12		0		
2/23/12		0		
2/24/12		0		
2/25/12		0.23		
2/26/12		0		
2/27/12		0		
2/28/12		0		
2/29/12		0		
3/1/12		0		
3/2/12		0		
3/3/12		0		
3/4/12		0		
3/5/12		0		
3/6/12		0.15		
3/7/12		0.05		
3/8/12		0.03		
3/9/12		0		
3/10/12		0		
3/11/12		0		
3/12/12		0		
3/13/12		0.18		
3/14/12		0.05		
3/15/12		1.1		
3/16/12		0.86		
3/17/12		0		
3/18/12		0		
3/19/12		0.01		
3/20/12		0.1		
3/21/12		0		
3/22/12		0.05		
3/23/12		0.08		
3/24/12		0		
3/25/12		0		
3/26/12		0		
3/27/12		0		
3/28/12		0		
3/29/12		0		
3/30/12		0.95		
3/31/12		0		
4/1/12		0		
4/2/12		0		
4/3/12		0		
4/4/12		0		
4/5/12		0		
4/6/12		0.01		
4/7/12		1.62		
4/8/12		0.62		
4/9/12		0		
4/10/12		0		
4/11/12		0		
4/12/12		0		
4/13/12		0		

Date		**Average**	Total	
4/14/12		0		
4/15/12		0.01		
4/16/12		0		
4/17/12		0		
4/18/12		0		
4/19/12		0		
4/20/12		0		
4/21/12		0		
4/22/12		0		
4/23/12		0.43		
4/24/12		0		
4/25/12		0		
4/26/12		0		
4/27/12		0.02		
4/28/12		0.11		
4/29/12		0.67		
4/30/12		0		
5/1/12		0		
5/2/12		0		
5/3/12		0		
5/4/12		0		
5/5/12		0.38		
5/6/12		0		
5/7/12		0		
5/8/12		0.01		
5/9/12		0		
5/10/12		0		
5/11/12		0		
5/12/12		0		
5/13/12		0.55		
5/14/12		0.06		
5/15/12		0		
5/16/12		0		
5/17/12		0		
5/18/12		0		
5/19/12		0		
5/20/12		0		
5/21/12		0		
5/22/12		0		
5/23/12		1.77		
5/24/12		0		
5/25/12		0		
5/26/12		0		
5/27/12		0.75		
5/28/12		0		
5/29/12		0		
5/30/12		0		
5/31/12		0		
6/1/12		0		
6/2/12		0.09		
6/3/12		0.12		
6/4/12		0.05		

Date		**Average**	Total	
6/5/12		0		
6/6/12		0.54		
6/7/12		0		
6/8/12		0		
6/9/12		0		
6/10/12		0		
6/11/12		0		
6/12/12		0.45		
6/13/12		0		
6/14/12		0		
6/15/12		0		
6/16/12		2.37		
6/17/12		0		
6/18/12		0.28		
6/19/12		2.02		
6/20/12		0.28		
6/21/12		0		
6/22/12		0		
6/23/12		1.19		
6/24/12		1.7		
6/25/12		0		
6/26/12		1.38		
6/27/12		0.31		
6/28/12		0		
6/29/12		0		
6/30/12		0.18		
7/1/12		1.5		
7/2/12		0		
7/3/12		0.11		
7/4/12		0.49		
7/5/12		0		
7/6/12		0		
7/7/12		0.64		
7/8/12		0		
7/9/12		1.17		
7/10/12		0.88		
7/11/12		0		
7/12/12		0		
7/13/12		0		
7/14/12		0.51		
7/15/12		0		
7/16/12		0		
7/17/12		0		
7/18/12		0.65		
7/19/12		0		
7/20/12		0		
7/21/12		0.86		
7/22/12		0.09		
7/23/12		0		
7/24/12		0		
7/25/12		0		
7/26/12		0		

Date		**Average**	Total	
7/27/12		0		
7/28/12		1.46		
7/29/12		0.72		
7/30/12		0		
7/31/12		0.65		
8/1/12		0.05		
8/2/12		0.04		
8/3/12		0		
8/4/12		0		
8/5/12		0		
8/6/12		0.45		
8/7/12		1.76		
8/8/12		0.56		
8/9/12		0		
8/10/12		0		
8/11/12		0		
8/12/12		0		
8/13/12		0.45		
8/14/12		0.58		
8/15/12		0.07		
8/16/12		0.04		
8/17/12		0.22		
8/18/12		0		
8/19/12		0		
8/20/12		0.05		
8/21/12		0		
8/22/12		0.32		
8/23/12		0.62		
8/24/12		0		
8/25/12		0		
8/26/12		0		
8/27/12		0.55		
8/28/12		0.15		
8/29/12		0.82		
8/30/12		0.02		
8/31/12		1.86		
9/1/12		0		
9/2/12		0		
9/3/12		0		
9/4/12		0.54		
9/5/12		0		
9/6/12		0		
9/7/12		0		
9/8/12		0		
9/9/12		0		
9/10/12		0		
9/11/12		0.05		
9/12/12		0.07		
9/13/12		0		
9/14/12		0.38		
9/15/12		0		
9/16/12		0		

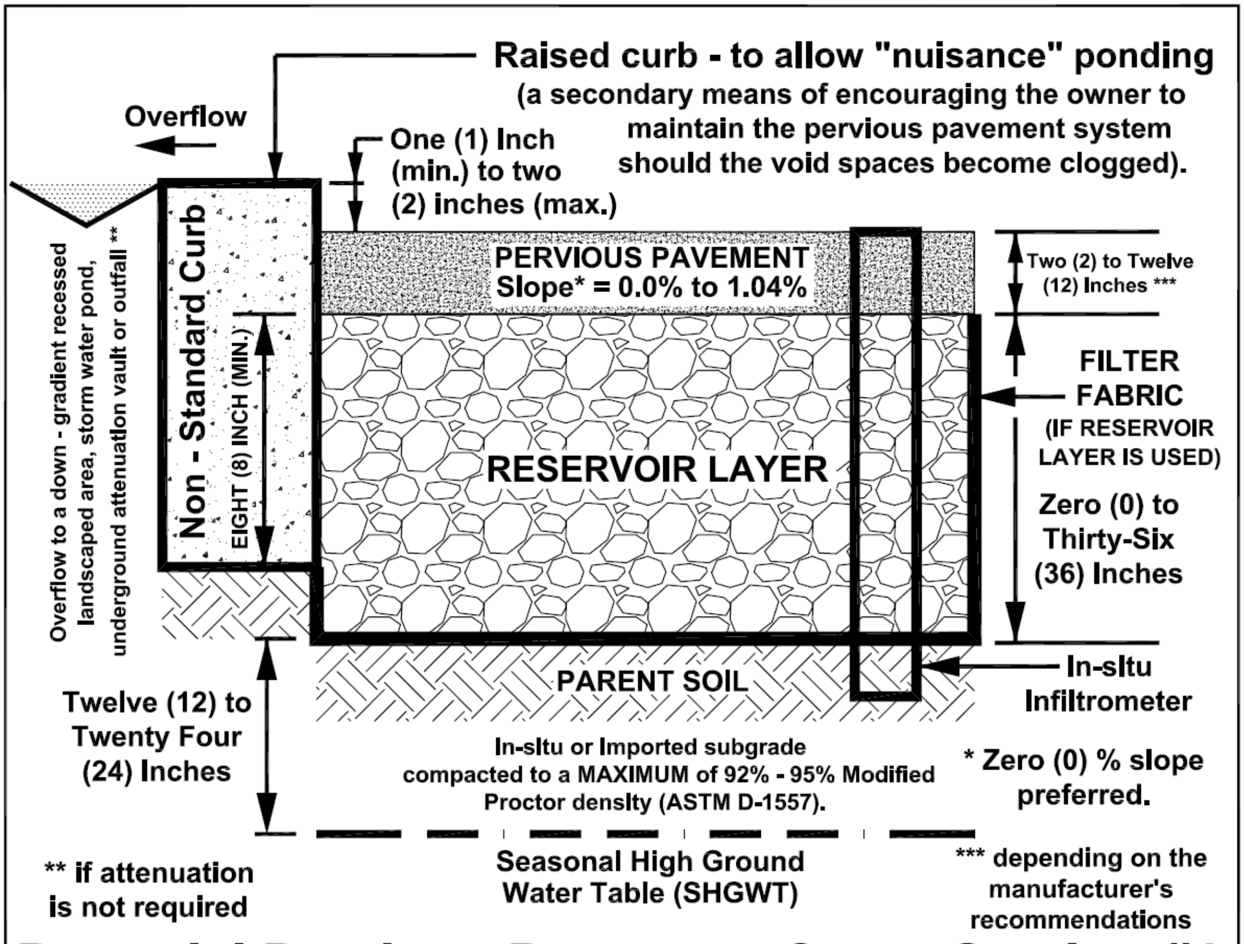
Date		Average	Total	
9/17/12		0.02		
9/18/12		0.62		
9/19/12		0.15		
9/20/12		0.02		
9/21/12		0		
9/22/12		0		
9/23/12		0		
9/24/12		1.75		
9/25/12		0		
9/26/12		0.05		
9/27/12		0		
9/28/12		0		
9/29/12		0		
9/30/12		0		
10/1/12		0.3		
10/2/12		0.04		
10/3/12		0.15		
10/4/12		0		
10/5/12		0		
10/6/12		0.3		
10/7/12		1.38		
10/8/12		0.92		
10/9/12		1.11		
10/10/12		0.18		
10/11/12		0		
10/12/12		0		
10/13/12		0.28		
10/14/12		0		
10/15/12		0		
10/16/12		0		
10/17/12		0.44		
10/18/12		0		
10/19/12		0		
10/20/12		0.48		
10/21/12		0.11		
10/22/12		0.02		
10/23/12		0		
10/24/12		0		
10/25/12		0		
10/26/12		0		
10/27/12		0.8		
10/28/12		0		
10/29/12		0		
10/30/12		0		
10/31/12		0.75		
11/1/12		0		
11/2/12		0.75		
11/3/12		0		
11/4/12		0		
11/5/12		0		
11/6/12		0.15		
11/7/12		0.28		

Date		**Average**	Total	
11/8/12		0		
11/9/12		0		
11/10/12		0		
11/11/12		0		
11/12/12		0		
11/13/12		0		
11/14/12		0.06		
11/15/12		0		
11/16/12		0		
11/17/12		0		
11/18/12		0		
11/19/12		0.28		
11/20/12		0		
11/21/12		0		
11/22/12		0		
11/23/12		0		
11/24/12		0		
11/25/12		0		
11/26/12		0.02		
11/27/12		0		
11/28/12		0		
11/29/12		0		
11/30/12		0.01		
12/1/12		0		
12/2/12		0		
12/3/12		0.35		
12/4/12		0		
12/5/12		0		
12/6/12		0		
12/7/12		0		
12/8/12		0		
12/9/12		0		
12/10/12		0.54		
12/11/12		0.41		
12/12/12		0		
12/13/12		0		
12/14/12		0.62		
12/15/12		0		
12/16/12		0		
12/17/12		0.32		
12/18/12		0		
12/19/12		0		
12/20/12		0		
12/21/12		0		
12/22/12		0		
12/23/12		0		
12/24/12		0		
12/25/12		0		
12/26/12		0		
12/27/12		0		
12/28/12		0.32		
12/29/12		0		

Date		Average	Total	
12/30/12		0		
12/31/12		0		

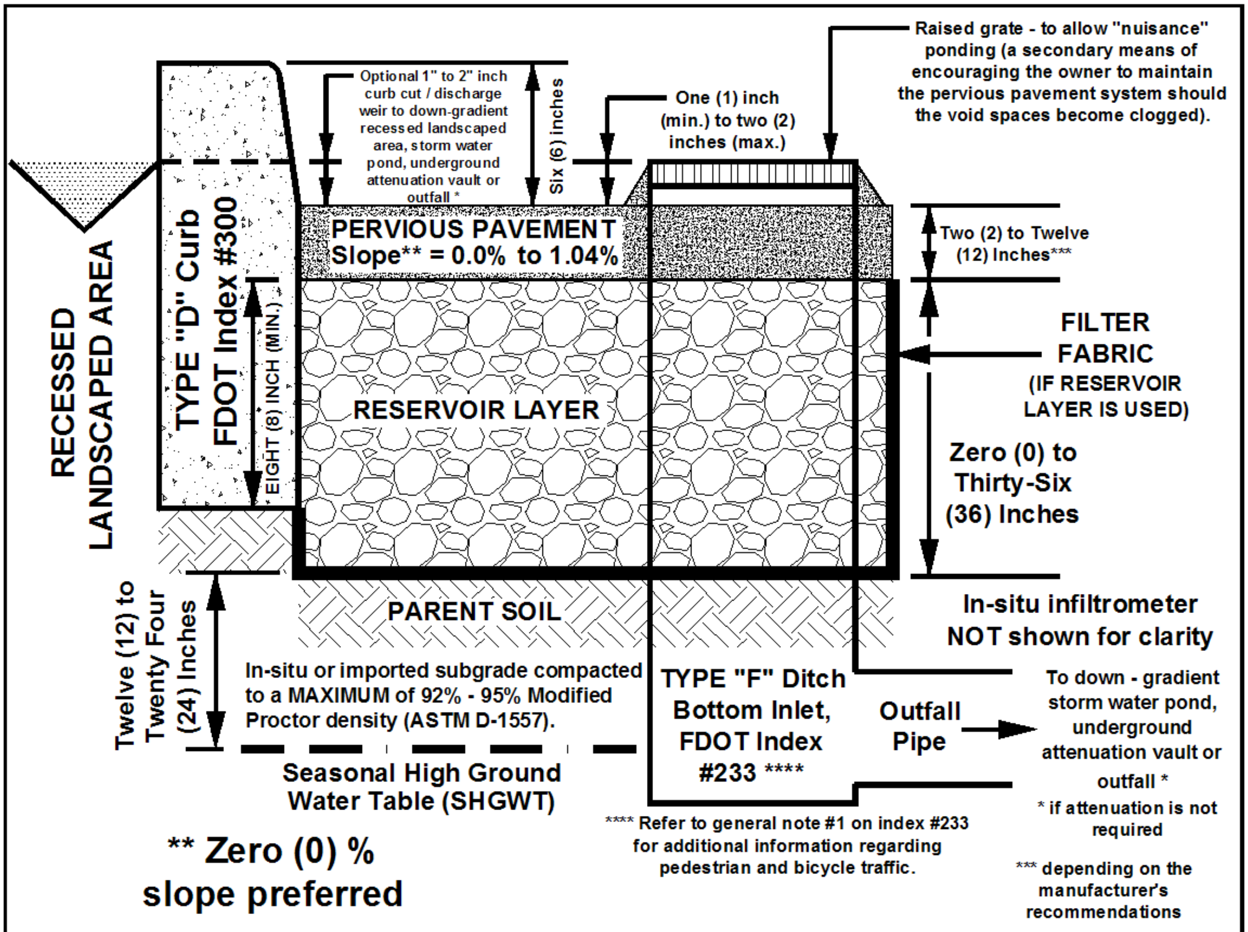
ATTACHMENT G

PERVIOUS PAVEMENT SYSTEM CROSS SECTION #1



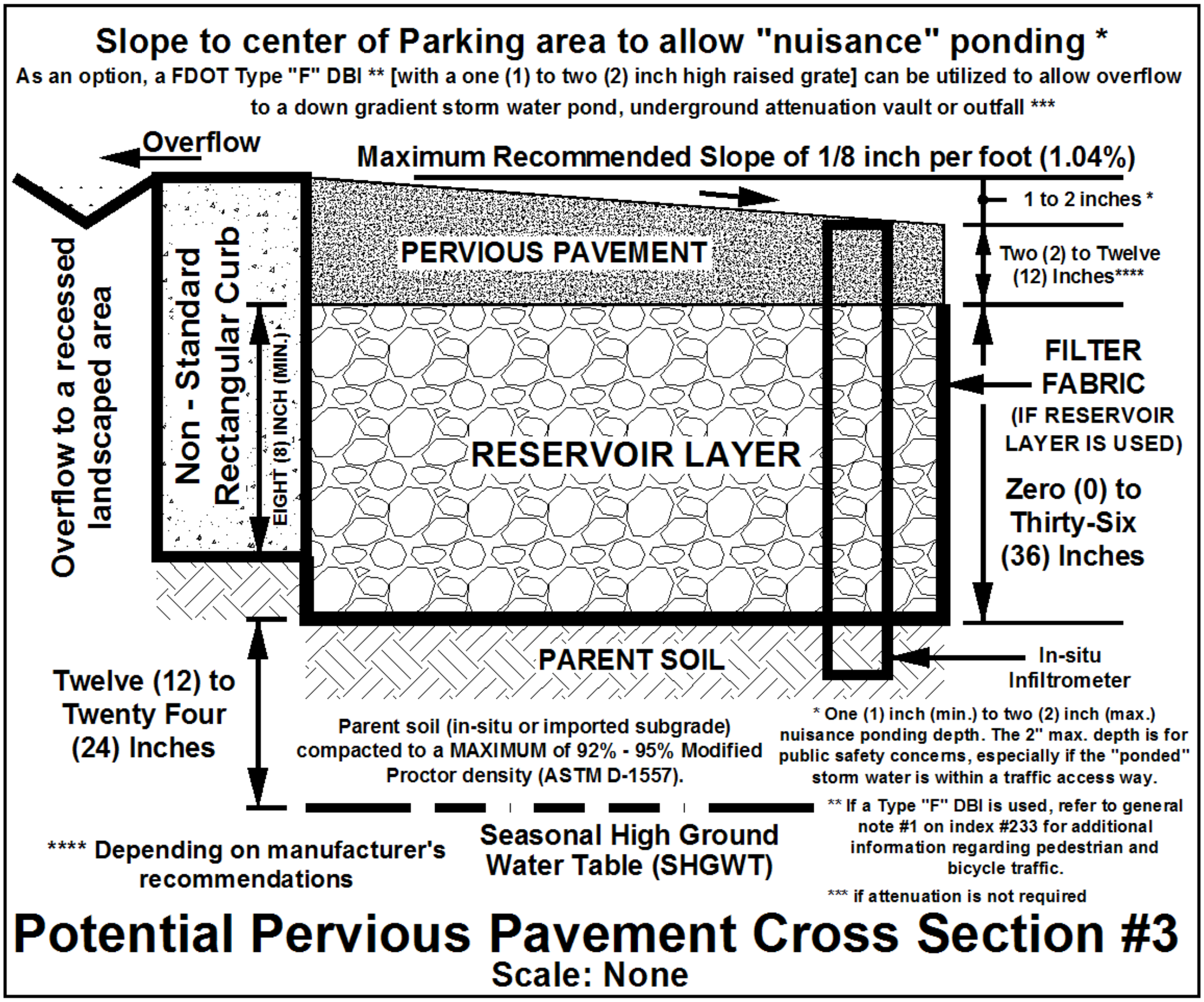
Potential Pervious Pavement Cross Section #1
Scale: None

PERVIOUS PAVEMENT SYSTEM CROSS SECTION #2



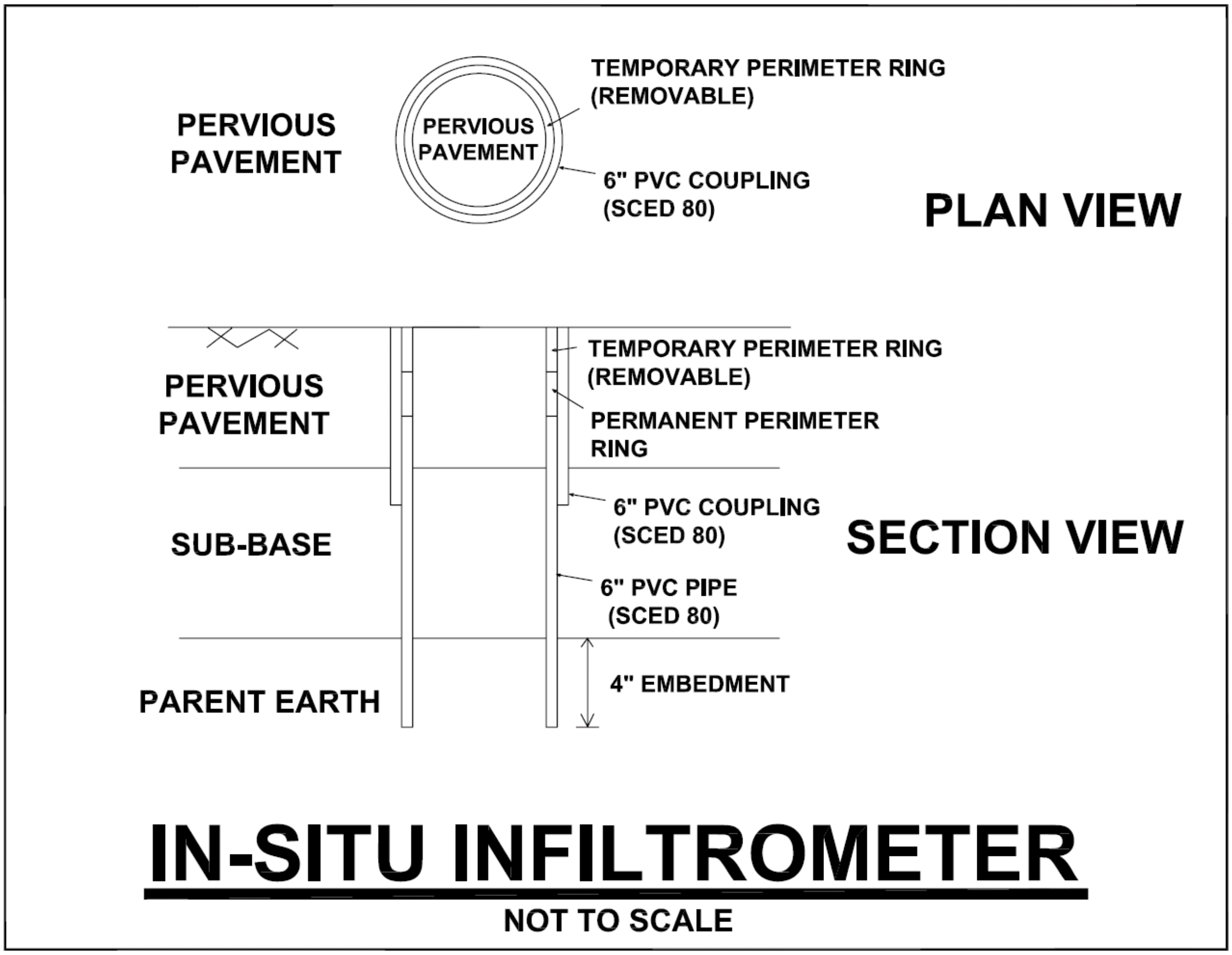
Potential Pervious Pavement Cross Section #2
Scale: None

PERVIOUS PAVEMENT SYSTEM CROSS SECTION #3

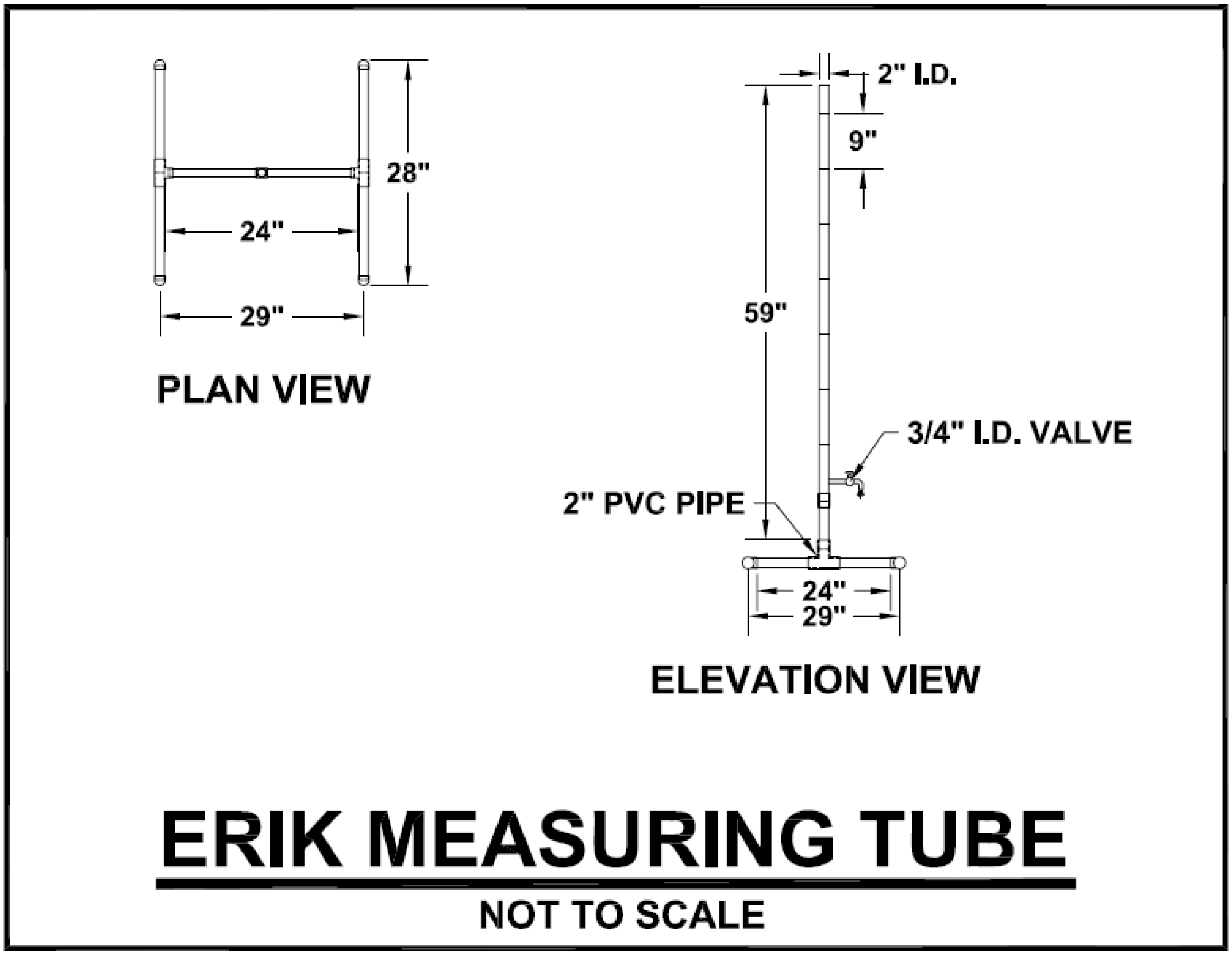


PLAN VIEW OF ERIK IN-SITU INFILTROMETER

(Embedded Ring Infiltration Kit)

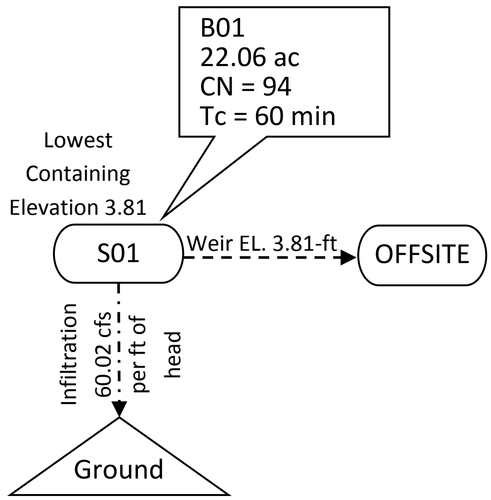


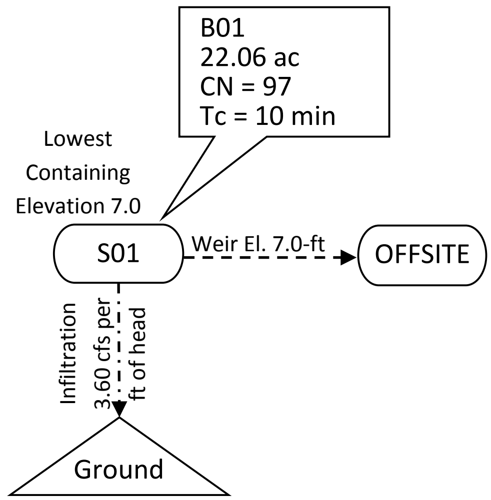
ERIK Measuring Tube



ATTACHMENT H

Pre-Development – Existing Condition




B01
22.06 ac
CN = 97
Tc = 10 min
Lowest
Containing
Elevation 7.0
S01
Weir El. 7.0-ft
OFFSITE
Infiltration
3.60 cfs per
ft of head
Ground

Article XIV. Rainwater HARVESTING FACILITIES

Secs. 7 4-871. Structural rainwater harvesting facilities allowed.

All buildings are allowed to incorporate structural rainwater harvesting facilities such as cisterns and rain barrels. Existing buildings may also be retrofitted with these types of facilities. Encroachment into side setback areas by up to 50 percent and rear setback to within five feet of the property line may be permitted if necessary upon approval of the planning and zoning director.
(Ord. No. 2013-37, § 2, 12-3-2014)

Secs. 74-872-74-875. Reserved.

ARTICLE XV. ENERGY-EFFICIENT LIGHTING FOR COMMERCIAL BUILDINGS AND SITES

Sec. 74-876. LED lighting.
All commercial buildings and associated sites shall utilize LED lighting fixtures for all external lighting.
(Ord. No. 2013-37, § 2, 12-3-2014)

Secs. 74-877-74-880. Reserved.

ARTICLE XVI. LOW IMPACT DEVELOPMENT PRACTICES

Sec. 74-881. Low impact development (LID) practices.

New buildings and redevelopment sites must make every effort to incorporate the following low impact development (LID) practices into project design, site and building plans:

(a) Identify and preserve sensitive areas that affect site hydrology.
(b) Evaluate potential site development options to reduce, minimize and disconnect total impervious area.
(c) Employ integrated management practices (IMPs) to allow for distributed control of stormwater throughout entire site.
(d) First minimize and then mitigate the hydrologic impacts of land use activities at or close to the source of generation.
(e) Integrate stormwater controls into multifunctional landscape features such as bioretention cells where runoff can be micromanaged and controlled at the source.
(f) Limit clearing and grading to minimize hydrologic impacts on existing site land cover.
(g) Use site drainage and hydrology as a design element.
(h) Modify and increase drainage flow path.

(Ord. No. 2013-37, § 2, 12-3-2014)