Appendix 1

Low Impact Development for Big Box Retailers

LOW IMPACT DEVELOPMENT

for

BIG BOX RETAILERS

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I. PURPOSE

This effort was funded by an EPA Assistance Agreement funded by the Office of Water. The recommendations or outcomes of this effort may or may not reflect the views or policies of EPA. The purpose of this project is to provide large building and site footprint high volume retailers with strategies that integrate innovative and highly effective Low Impact Development (LID) stormwater management techniques into their site designs for regulatory compliance and natural resource protection at the local levels. LID is an innovative approach to stormwater management that uses decentralized, or source, controls to replicate pre-development hydrology (stormwater) conditions. This approach can be used as an alternative or enhancement for conventional end-of-pipe stormwater pond technology. This alternative tool is important because of the potential to lessen the energy impacts of large concentrated volumes of runoff from conventional end-of-pipe approaches on receiving waters as well as reducing the development footprint and long-term maintenance considerations for end-of-pipe facilities.

The Center has partnered with the Target Corporation for this effort. Target provided input on typical industry planning, design, and operational considerations as well as review for the effort. The focus of the effort is to present these concepts and techniques in an easily understood format so that a dialogue between corporate developers, local engineers, and local governments can be initiated on how to adapt and integrate these strategies and techniques into the local regulatory and watershed protection programs.

II. DOCUMENT ORGANIZATION

The document includes prototypical designs and specifications that can be incorporated into corporate design manuals and design guidance memorandums for use by facility planners, operators, and local design planners and engineers. This includes information on the effectiveness of the practices and ancillary benefits, such as heat island reduction, water conservation, and aesthetics. Information on how to calculate and demonstrate the effectiveness of the practices and in-ground case studies is included. This information can also be used to show the benefits of these practices to municipal officials and stakeholders as part of the local permit process. The document is organized into the following areas:

- *Introduction to LID Strategies and Techniques:* A brief overview of LID is provided. This includes information on LID design strategies and Best Management Practices (BMPs) that are potentially suited for Big Box retailers.
- *LID Design Strategies:* This section includes lists of potential design strategies for large footprint retailers.
- *LID Design Techniques:* The effectiveness and selection of techniques is discussed in this section. This includes information on how the techniques can be used to meet specific water quality objectives.
- *Case Studies:* Typical design situations are presented and discussed.
- *Fact Sheets:* Detailed information on technologies are presented.

III. INTRODUCTION TO LID STRATEGIES AND TECHNIQUES

The following section presents an overview of Low Impact Development (LID) approaches that are appropriate for land development activities. Comprehensive descriptions of LID strategies and design analysis tools are available in print (USEPA, 2002) and on the internet.

III.1. LID Background

Low Impact Development (LID) is a design strategy that utilizes decentralized small-scale source control structural and/or non-structural stormwater practices to meet certain technical requirements of federal, state, and local government stormwater management regulations, as well as natural resource protection and restoration goals. The goal of LID is to maintain or replicate the pre-development hydrologic regime through the use of design techniques to create a functionally equivalent hydrologic site design. Hydrologic functions of storage, infiltration and evaporation, transpiration, ground water recharge, are used to control the volume and frequency of discharges through the use of integrated and distributed micro-scale stormwater practices. This includes structural and non-structural strategies such as retention and detention areas, reduction of impervious surfaces, and the lengthening of flow paths and runoffs time. Other strategies include the preservation/protection of environmentally sensitive site features such as riparian buffers, wetlands, steep slopes, valuable (mature) trees, flood plains, woodlands, and highly permeable soils. LID has also been used to meet targeted regulatory and resource protection objectives. The ability to use “customized” small scale source controls allows the designer to select BMPs that best meet the watershed goals and objectives. This approach also allows for a treatment train approach where there are multiple opportunities to reduce pollutant loads by using a system of different techniques. TLID techniques can also be used to meet ancillary goals such as energy efficiency, community aesthetics, and potential for job training and outreach. Many LID strategies and techniques can be used to achieve Leadership in Energy and Environmental Design (LEED) credits. The LEED program is used by many organizations and communities to certify buildings as being innovative and environmentally responsible.

These controls can be integrated into many common urban land uses on both public and private property to enhance flexibility in siting stormwater controls. This creates the opportunity for partnerships to address construction and maintenance considerations.

This document provides basic templates for an initial candidate set of ten (10) LID BMPs that can be used for Big Box sites. This list was derived by evaluation different Big Box development prototypes to determine which LID BMPs could easily be incorporated into the design without significant alteration of the prototype. The goal of the document is to provide sufficient information on each practice to provide large building and site footprint high volume retailers with strategies to integrate innovative and highly effective LID stormwater management techniques into their site designs. An additional fourteen BMPS are included in Appendix B. These additional BMPs may require significant modification or may not have as an immediate impact as those included in the initial list.

Each candidate BMP listed includes a one-page brief description of the practice as well as an overview consisting of design criteria, advantages/disadvantages, and maintenance. This is followed by a detailed description of information on water quantity/quality controls, location, design and construction materials, cost, maintenance, performance and inspection, potential LEED credits, links to additional information, and issues specific to large building and site footprint high volume retailers.

III.2. Big Box Development Considerations

The “Big Box” store is a relatively new approach to retail. There are numerous configurations and approaches to the planning, design, and construction of these facilities. In many communities the construction of these facilities have significant social and economic implications. They also can have significant hydrologic impacts for the development of the site and for the inertia they can potentially create for the development of surrounding properties. Some of the basic characteristics of Big Box Development can be as follows (adapted from Columbia, 2005):

- The building typically occupies more than 50,000 square feet, with typical ranges between 90,000-200,000 sq. ft.
- Derive their profits from high sales volumes rather than price mark up
- Large windowless, rectangular single-story buildings
- Standardized facades based on corporate standards
- Reliance on auto-borne shoppers
- Highly impervious with large parking and building footprints
- No-frills site development that eschews any community or pedestrian amenities.
- Varying market niches; categories include discount department stores and warehouse clubs

The site design of Big Boxes can be classified by the type of ownership and development of the property they are located on. These are important considerations when determining what are the appropriate site design and water quality protection. This is because the owner/operator of the Big Box may or may not have significant input into the design or selection of the water quality protection strategy based on the timing of their involvement in the project and the overall contribution of the drainage from the facilities. The developments can be classified as follows:

- *Stand Alone Centers:* These facilities are typically developed by the corporation. There is typically significant flexibility in the arrangement of buildings, parking, and infrastructure. This is subject to local codes and requirements for stormwater management, open space, building density, and lot coverage. Utility and physical site opportunities and constraints also apply. Figure One shows a typical Stand Alone Center.

Figure 1 – Stand Alone Center

- *Power Centers:* This is a grouping of several stores and is usually located in a large planned development. The sites are often leased and there is often only minimal input into the overall site design. These centers are often developed over several years and much of the internal road circulation, drainage infrastructure and stormwater management are often in place to accommodate the development "pads" or sites for individual buildings. Figure Two shows a typical PowerCenter.

Figure 2 – PowerCenter

- *Infill Development:* These are sites that are located in highly urbanized areas. The buildings are either located in high rise structures at the surface level or built between several buildings and surrounded by streets and alleys. The parking is often in a garage that is shared with other users and there is minimal open space. Figure Three shows a typical Infill Center.

Figure 3 – Typical Infill Center

- *Retrofit:* This is a site where there is an existing building and infrastructure. The building is often torn down and expanded. The site may be repaved and reconstructed to accommodate circulation patterns or stormwater management regulations.

Generally Big Boxes require large impervious areas for parking and vehicular circulation, direct vehicular and pedestrian routes, separated truck loading areas, and large flat roofed building footprints. Most of the designs for these facilities are based on corporate prototypes that are designed to have predictable development costs and circulation patterns that are based on market preferences. This is essential for the successful management of the large-scale rapid construction process that many big box retailers require. The ability for a site to accommodate the basic circulation and infrastructure characteristics are often critical for the decision to build or develop a site. Modifications to the site design templates that are required to meet local codes and ordinances are given careful consideration. These design issues are often handled by a local engineering firm in order to insure the most efficient way to produce the final design and construction permit package.

III.3. Discussion of LID Opportunities for Big Boxes

Many communities have prescriptive stormwater management regulations, where there are specific runoff control rate and volume and water quality management requirements. These are often based on end-of-pipe controls for each development. In these situations the LID approach must be negotiated with the local government. The use of alternative designs are often administratively approved by waivers or modifications to the requirements. The advantages of using LID for the developer include, but are not limited to reducing the visual impact of large scale stormwater management facilities, have additional development area through the elimination of an end-of-pipe pond, utilize the landscape to provide stormwater management and reduce development costs, reduced stormwater utility fees by providing additional water quality.

Many communities are moving towards performance based standards. These can be as complex as limiting concentrations of runoff or reducing runoff volumes. LID can be used to meet these requirements by providing strategies and techniques with predictable removal efficiencies or reductions in runoff volume at the source.

In many instances, there is the requirement for additional or negotiated controls for reduction of the large-scale hydrologic and hydraulic impacts of the development. When there is the need for enhanced water quality, such as when impacts to wetlands or Waters of the U.S. occur, LID techniques can be used to meet the negotiated regulatory requirements. In large planned developments or in zoning categories where there may be the requirements for enhanced site design or environmental controls LID can be used to provide additional landscaping, visual amenities, and water quality enhancements.

III.4. LID Design Approach

The goal of LID site design is to reduce the hydrologic impact of development and to incorporate techniques that maintain or restore the site's hydrologic and hydraulic functions. The optimal LID site design minimizes runoff volume and preserves existing flow paths. This minimizes infrastructural requirements. By contrast, in conventional site design, runoff volume and energy may increase, which results in concentrated flows that require larger and more extensive stormwater infrastructure.

The requirement for efficient access and circulation is critical to the success of the Big Box development. The design elements can be broken down into *Circulation and Customer Parking, Loading Areas,* and *Building Zones.* LID techniques can be incorporated into each of these areas. Some basic design concepts and recommendations include:

- *Circulation and Customer Parking.* These are areas in the front of the building. There is usually a main drive that feeds to the parking areas. The main drive is typically located in the center of the parking lot where possible. Its function is to provide rapid access to parking and loading that is located near the entrance to the building, distribute cares to the remainder of the parking lot, and provide stacking of vehicles at the entrance to the site. There is usually green space or islands that are located on the sides of these areas to provide stacking and accommodate turning movements to the parking isles. These are often landscaped to visually enforce movements. The parking area is sized to accommodate large numbers of vehicles that are present during peak hours and holiday seasons. A significant amount of the parking area may be under utilized during most of the year, but is critical during peak seasons. Most local codes and ordinances require internal and peripheral green space for parking.

- *Loading Areas.* These areas are often located at the rear of the sides of the building. They are often screened or not visible to the building entrance or parking. The loading areas require large open unobstructed pavement areas in order to accommodate truck turning movements and trailer storage. These areas can potentially have high pollutant loads due to the number of truck visits. Employee parking may also be located in or near these areas at the rear of the store.

- *Building Zones.* This is the building and the area immediately adjacent to the building. There is usually a sidewalk immediately in front of the building. It must be wide enough to provide a safe buffer between the building and front loading/drop off area. Cart storage may also be in these areas. This area is usually minimized in order to help move people quickly into the stores. The building itself typically is constructed with a lightweight flat steel structure. The roof drains are usually connected by piping that is hung on the rafters and connected to the site storm drainage system.

III.4.1. LID Planning and Design Objectives

The following are lists of the critical planning and design objectives that can be achieved by using some basic LID that can be incorporated into the planning and design process. Each principle includes a brief description of the key concepts or elements. This list is to be used as a basic design checklist or talking points for planners and designers to communicate the critical elements with building code and planning officials, public officials, and local designers.

LID Planning

These are some basic overall LID principles that are essential for community development and watershed issues.

LID Site Design:

- reduces the impacts of development with site-appropriate, ecologically sensitive technologies,
- achieves stormwater management goals,
- creates more livable places to shop, relax, and recreate. Interesting pavement patterns and landscapes can create successful public spaces.

LID decentralized strategies and techniques are:

- customizable to meet a wide range of stormwater management objectives,
- adaptable to the physical constraints of commercial or mixed-use sites.

Integrating LID controls into site design:

- reduces the impact that development has on the hydrologic water balance,
- restores or maintains the equilibrium of the natural systems,
- reduce the need for extensive stormwater conveyance infrastructure.

Site Design Elements

The following are some of the basic site design criteria that LID strategies and techniques can be used to achieve.

Stormwater Management Objectives

Use LID stormwater controls to meet compliance goals, as well as these stormwater management objectives:

- Runoff Volume Reduction
- Peak Discharge Rate Reduction
- Water Quality Improvement – remove pollutants, reduce sediment/nutrient loads, etc.

Site Functions

- *Operations* - Reduce infrastructure maintenance requirements
- *Circulation* - Visually reinforce or provide a physical framework for vehicular and pedestrian circulation
- *Curb Appeal* - Off-site visibility, marketing, public relations

Corporate and Community Development

Use LID stormwater controls to achieve these corporate programming goals and to provide ancillary community enhancement benefits:

- *“Open Space/Park Design”* – create park-like open space, promenades, etc.,
- *Beautification/Aesthetics* – create “groves,” garden-like areas, etc…
- *Afforestation/Reforestation* – urban forest or park-like open space (“green infrastructure”)
- *Green Building* – promote green building strategies (i.e., LEED: use of recycled materials, low VOC materials, certified woods, etc.)
- *Water Conservation/Energy Conservation* –promote conservation of natural resources (water) or use of on-site renewable energy (solar, wind, etc.)
- *Public Education* – increase community awareness of conservation and ecological stewardship.

LID Site Design Components

The following is a list of the opportunities and constraints that will effect the selection of LID strategies and techniques.

Site Conditions

Suitability of LID technologies to meet stormwater objectives depends on site conditions, including:

- Soil (i.e., infiltration capacity, degree of compaction)
- Groundwater table
- Topography / Slope
- Available open space (vegetated areas)
- Vertical location of sewers and utilities
- Solar heat
- Wind patterns
- Climate and annual rainfall

Planning Codes and Ordinances

Local master plans, municipal regulations, planning codes and ordinances dictate suitability of LID technologies, including:

- Development Regulations (Zoning, Site Development, Environmental, Critical Areas, Forestry, etc.)
- Construction and Infrastructure Regulations
- Site Development and Stormwater Drainage Regulations
- Design Standards and Guidance
- Comprehensive Planning Documents
- Planning and Land Services Fees
- Reductions in Impact or Utility Fees

III.4.2. LID Design Strategies and Techniques

In order to achieve these objectives site and building design strategies for these elements must be developed. This includes a combination of site design strategies in combination with non-structural and structural BMP techniques. The use of site design strategies will reduce the hydrologic and hydraulic impacts and reduce the need for BMPs. Some basic site design strategies include:

1. Disconnect Impervious Areas/Downspout Disconnection

Runoff from connected impervious surfaces commonly flows directly to a stormwater collection system with no possibility for infiltration into the soil. Highly efficient drainage systems contribute significantly change watershed timing and increase the peak runoff rate and energy that results from the development. For example, roofs and sidewalks commonly drain onto roads, and the runoff is conveyed by the roadway curb and gutter to the nearest storm inlet. Runoff from numerous impervious drainage areas may converge, combining their volumes, peak runoff rates, and pollutant loads. Disconnection decouples roof leaders, roadways and other impervious areas from stormwater conveyance systems, allowing runoff to be collected and managed on site or dispersed into the landscape. Runoff is redirected onto pervious surfaces such as vegetated areas, reducing the amount of directly connected impervious area and potentially reducing the runoff volume and filtering out pollutants.

2. Site Minimization/Fingerprinting/Impervious Areas Reduction

Site fingerprinting, also known as minimal disturbance techniques, is a practice that minimizes ground disturbance by identifying the smallest possible land area that can practically be impacted during site development. Minimizing the amount of site clearing and grading reduces the overall hydrologic impacts of site development. Ground disturbance is typically confined to areas where structures, roads, and rights-of-way will exist after construction is complete. Development is also placed away from environmentally sensitive areas, future open space, tree save areas, future restoration areas, and temporary and permanent vegetative forest buffer zones. Existing vegetated or open space may be preserved instead of clearing a portion of the site in order to create lawn areas.

A key component of minimizing overall site impacts is reducing impervious areas (both connected and disconnected). Typical techniques include limiting roadway lengths and widths, minimizing lot setbacks (which in turn minimize driveway lengths), installing sidewalks on only one side of private roadways, and by using alternative materials such as permeable paving blocks or porous pavements.

3. Time of Concentration Practices/Surface Roughening

Time of concentration (t_c) practices, such as surface roughening, increase the time it takes for runoff to flow across a site to the drainage point or a BMP. Slowing runoff velocity potentially reduces erosion and increases the potential for infiltration. Increasing t_c is also directly related to the disconnection of impervious areas.

4. Pollution Prevention

Pollution Prevention (P2) is a general term for any activity or management action that reduces or eliminates pollutants before they are propagated downstream. The goal of P2 is to incorporate programs and techniques to keep nonpoint source (NPS) pollutants out of runoff. This helps to reduce pollutant loads entering BMPs, which enhances their performance and improves their longevity. Reduction of fertilizer, pesticide, and herbicide use and the implementation of regular street sweeping are some common P2 activities. P2 may also involve behavioral changes, such as keeping dumpster lids closed.

III.5. LID BMP Selection Criteria

Selection and sizing of BMPs depends upon a wide range of factors, including control objectives, receiving water quality, water quality parameters of interest, local (as well as federal) legislation. The importance of any of the criteria will vary from location to location, and affect the relative evaluation of overall water quality impacts projected for a big box retail location. Comprehensive selection of a BMP for use on a site depends upon:

- ability to meet regulatory requirements,
- projected system performance (pollutant removal effectiveness),
- public acceptance of the BMP,
- ability to be implemented (relative design constraints),
- institutional constraints,
- associated cost.

Proper BMP selection includes the assessment of the types of constituents found in the stormwater in order to determine the proper unit processes the BMP should employ in order to treat for those pollutants. However, it is also important to identify the sources and land areas contributing the additional stormwater volume and/or excessive loading of pollutants in order to identify source control measures, alternative development practices, and to determine BMP design and maintenance characteristics based upon identification of various land management and land use situations.

Generally, the addition of impervious area as a result of increased development leads to an increase in stormwater runoff volume, higher peak flows, higher average temperature of runoff, collection of a larger mass of pollutants (due to lack of infiltration capacity), and an increased flooding hazard for downstream waterways (Minton 2002, Lee 2002, Novotny 2003). Some impervious areas may be indirectly connected to the site drainage system by sheet flow over pervious and impervious surfaces for eventual discharge into gutters, catch basins, etc., while other areas may flow directly into the drainage system, such as roadways and roofs with attached roof drains.

Minimization of disconnected impervious area (DCIA) can be incorporated both into new design and retrofit scenarios.   The use of LID practices for new development, such as porous pavement, planter strips, and eco-roofs, all minimize impervious areas on a site, thus allowing for reduced flow rates, increased infiltration, evapotranspiration (ET), and groundwater recharge rates and therefore a reduction in the pollutant load reaching a BMP system and receiving water body. Retrofit practices, such as the disconnection or relocation of roof drains, may be possible in some older development areas, specifically low density commercial areas (Urbonas and Stahre 1993). Disconnection and relocation of roof downspouts to pervious areas allows runoff to discharge first into grass for infiltration instead of directly into the sewer system or onto the pavement or roadway area (Urbonas and Stahre 1993). This practice is not a panacea, however, since concerns over possible groundwater contamination and localized drainage problems must be addressed.

The following is a “tool box” of LID BMPs that can be incorporated into development guidance manuals. The BMPs listed below were selected because of current industry interest and knowledge of the practice that is currently being used by large-scale Big Box developments. Because of the potentially large number of LID BMPs, including modifications and variations, it is important to develop this framework so that industry and plan reviewers can determine the most appropriate technologies for each land use.

The following table provides a list of ten tools useful to large building and site footprint high volume retailers. Complete fact sheets are provided in Appendix C for each of the ten LID BMPs listed below in Table 1.

Table 1 - LID BMPS

1	Bioretention Basins (Peak and Volume)
2	Bioretention Cells (Water Quality Only)
3	Bioretention Slopes
4	Bioretention Swales
5	Water Quality Swales
6	Permeable/ Porous Pavements (Asphalt, Concrete, Blocks)
7	Tree Box Filters
8	Planter Boxes
9	Cisterns/ Rain Barrels
10	Green Roofs

The function and use of these BMP must be considered in order to use them effectively. The following tables provide a potential listing and classification of the BMPs found in the appendices. The purpose of these lists is to provide an example of the development general criteria and guidance for the selection and use of the BMPS. These are not rigid lists or classifications, but are meant to demonstrate how the BMPs can be matched up to the most appropriate use. More detailed information on the unit processes and overall use can be found in decentralized stormwater guidance documents (WERF 2006). LID stormwater controls can be classified into two different *land development* types, new development and retrofit. Table 2 shows where LID practices can potentially be incorporated into the site design. Table 3 is a representative classification scheme Table 4 categorizes these BMPs into Power Center or stand alone uses. Table 5 demonstrates the effectiveness at meeting stormwater management objectives. Table 6 shows the BMP function and unit process.

Table 2 - Potential LID BMP Locations

BMP	Circulation and Parking	Building	Loading
Cisterns		x	
Conservation (Vegetation)	x		
Downspout Disconnection		x	
Filter Strips	x		
Infiltration Beds/Trenches or Dry Wells	x		
Pocket Wetlands			
Porous Pavement	x		
Rain Gardens	x		x
Reforestation (Vegetation)	x		
Sand Filters	x		x
Soil Amendments	x		
Vegetated Roof		x	
Water Conservation		x	
Pollution Prevention			x
Tree Box Filters	x		x
Bioretention Slopes	x		x

Table 3 - Suitability of BMPs for Land Development Types

BMP	New Development	Retrofit
Cisterns	●	●
Conservation (Vegetation)	●	○
Downspout Disconnection	○	●
Filter Strips	●	●
Infiltration Beds/Trenches or Dry Wells	●	◉
Pocket Wetlands	●	●
Porous Pavement	●	◉
Rain Gardens	●	●
Reforestation (Vegetation)	●	●
Sand Filters	●	●
Soil Amendments	●	●
Tree Box Filters	●	●
Vegetated Roofs	●	●
Vegetated Swales	●	●

Key: ● Highly Suitable ◉ Moderately Suitable ○ Not Suitable

Table 4 - Suitability of BMPs for Site Layout Types

BMP	"Power Centers"	Stand-Alone
Cisterns	●	●
Conservation (Vegetation)	●	○
Downspout Disconnection	○	○
Filter Strips	●	●
Infiltration Beds/Trenches or Dry Wells	●	●
Pocket Wetlands	●	●
Porous Pavement	●	●
Rain Gardens	●	●
Reforestation (Vegetation)	●	●
Sand Filters	●	●
Soil Amendments	●	●
Tree Box Filters	●	●
Vegetated Roofs	●	●
Vegetated Swales	●	●

Key: ● Highly Suitable ◉ Moderately Suitable ○ Not Suitable

Table 5 - Effectiveness of BMPs in Meeting Stormwater Management Objectives

BMP	Volume	Peak Discharge	Water Quality
Catch Basin Sump/Vault Filters	○		○
Downspout Disconnection	◉	◉	◉
Filter Strips	○	○	◉
Infiltration Practices	◉	○	◉
Pocket Wetlands	●	●	●
Porous Pavement	●	●	◉
Rain Barrels/Cisterns*	◉	○	○
Rain Gardens	●	●	●
Sand Filters	○	○	◉
Soil Amendments	◉	◉	◉
Tree Box Filters	◉	◉	●
Vegetated Roofs	◉	●	●
Vegetated Swales	◉	◉	●

Table 6 - Functional Classification

BMP	Volume Reduction	Peak Discharge	Water Quality	Source Control	Treatment Train	Design Storm
Cisterns	●	●	●	●	●	●
Conservation (Vegetation)	●	●	●	●	●	●
Downspout	○	○	●	●	●	●

Disconnection						
Filter Strips	●	●	●	●	●	●
Infiltration Beds/Trenches or Dry Wells	●	●	●	●	●	●
Pocket Wetlands	●	●	●	●	●	●
Porous Pavement	●	●	●	●	●	●
Rain Gardens	●	●	●	●	●	●
Reforestation (Vegetation)	●	●	●	●	●	●
Sand Filters	●	●	●	●	●	●
Soil Amendments	●	●	●	●	●	●
Tree Box Filters	●	●	●	●	●	●
Vegetated Roofs	●	●	●	●	●	●
Vegetated Swales	●	●	●	●	●	●

IV. LID CASE STUDIES

The following three case studies illustrate potential scenarios where Low Impact Development LID could be used to address stormwater quality and quantity management objectives. Each scenario presents a different development or redevelopment opportunity. The objective is to use the case studies to initiate a dialogue on the potential use and issues that need to be addressed in the location, design and review process and long-term administration and maintenance. The case studies do not present the entire range of possibilities or options. These are not to be viewed as comprehensive or complete drainage calculations and site plans, but are to be used to illustrate the concepts and feasibility of the approach. General assumptions on drainage areas, drainage characteristics topography, soils, land use, and other conditions that would potentially affect the hydrologic response of the site are used. A brief description of each case study is listed below.

Case Study One: Big Box Retail
This is a stand alone Big Box Store. These sites typically are large scale changes to the land use that results in large connected impervious areas. The concept design illustrates how to disconnect and distribute the drainage into smaller management facilities to meet water quality and stormwater quantity objectives.

Summary:

- Determine feasibility for water quality control and for providing storage volume to limit the 10-yr, 24-hr peak discharge rate to the pre-development condition.

- Use NRCS TR-55 graphical peak discharge method to determine storage volume.
- Drainage area is assumed to equal site area, 22.5 ac.

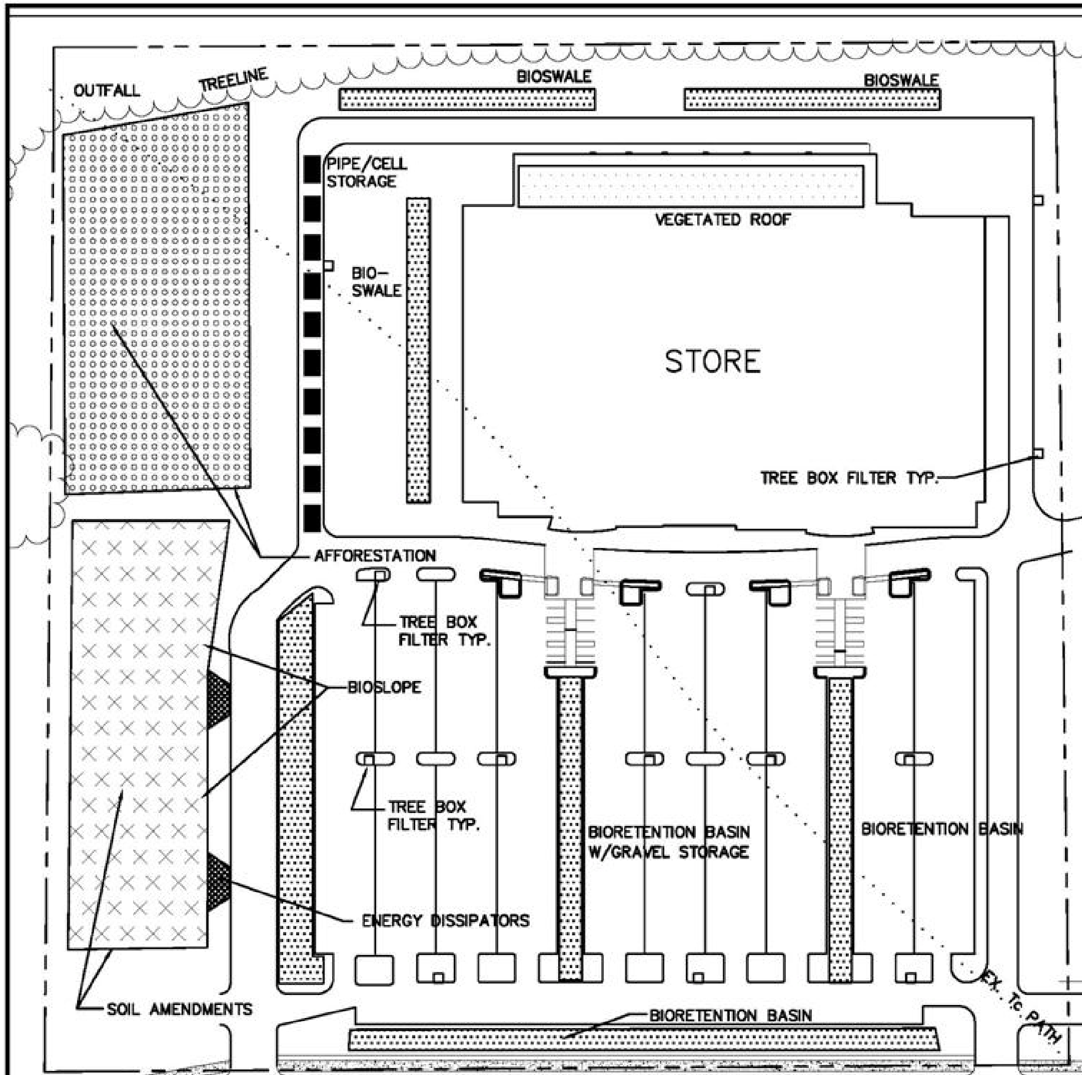
Existing Conditions
- Site is sloping from SE to NW at 2 to 5 percent.
- Moderate slope on western portion of side.
- 0.7 acres Woods and 21.8 Meadows.
- HSG C. Weighted CN is 65.
- Tc is 0.27 hours.
- Peak Discharge (CFS): 41.
- Runoff Volume (in.): 1.79.

Post-Development Conditions
- Afforestation and soil amendments on western portion of site. Increase infiltration capacity to HSG B and change in land cover.
- Conservation of woods.
- Credit bioretention areas as HSG B and Meadow.
- Weighted CN is 86.
- T_c is 0.25 hours.
- Peak Discharge (CFS): 92.
- Runoff Volume (in.): 3.65.

Results
- Detention volume: 2.1 acre feet or 1.1 inches using TR-55 graphical peak method.

BMPs
- Tree box filters provide majority of water quality control
- Green roof captures first 1" of roof runoff.
- Bioretention basins: 1.7 ac/ft storage is available.
  - Assume 6" surface storage and 1' subsurface storage is provided.
- Some bioretention basins include additional gravel underground storage.
  - 0.35 ac/ft is available in gravel storage.
- Some runoff is treated by soil amendment / bioslope areas.
- Pipes or other underground facilities provide 0.5 ac/ft storage.
- Additional storage can be provided in bioswales, amended soils, or cisterns.

Note
- See concept design on the next page.



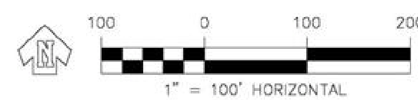
Case Study Four: Big Box Development
- Determine feasibility for water quality control and for providing storage volume to limit the 10-yr, 24-hr peak discharge rate to the pre-development condition.
- Use NRCS TR-55 graphical peak discharge method to determine storage volume.
- Drainage area is assumed to equal site area, 22.5 ac.

Existing Conditions
- Site is sloping from SE to NW at 2 to 5 percent
- Moderate slope on western portion of site
- 0.7 acres Woods and 21.8 acres Meadow
- HSG C. Weighted CN is 65
- Tc is 0.27 hours
- Peak Discharge (cfs): 41
- Runoff Volume (in.): 1.79

Post-Development Conditions
- Afforestation and soil amendments on western portion of site. Increase infiltration capacity to HSG B and change in land cover
- Conservation of woods
- Credit bioretention areas as HSG B and Meadow
- Weighted CN is 86
- Tc is 0.26 hours
- Peak Discharge (cfs): 92
- Runoff Volume (in.): 3.65

Results
- Detention volume: 2.1 acre feet or 1.1 inches using TR-55 graphical peak method

BMPs
- Tree box filters provide majority of water quality control
- Green roof captures first 1" of roof runoff (Water quality volume = first 0.5" of roof runoff.)
- Bioretention basins: 1.7 ac/ft storage is available.
  - Assume 6" surface storage and1' subsurface storage is provided.
- Some bioretention basins include additional gravel underground storage.
  - 0.35 ac/ft is available in gravel storage.
- Some runoff is treated by soil amendment / bioslope areas
- Pipes or other underground facilities provide 0.5 ac/ft storage
- Additional storage can be provided in bioswales, amended soils, or cisterns.



CASE STUDY
BIG BOX RETAIL SITE

LOW IMPACT DEVELOPMENT CASE STUDY
OCTOBER 2005

Case Study Two: Commercial Infill
This case study illustrates the potential for the retrofit of an existing strip shopping center with water quality management practices as part of a redevelopment plan. The redevelopment includes a drive through fast-food facility and a new retail strip. Stormwater quantity and quality control are provided for these areas. Retrofit of the existing impervious areas with water quality controls is also shown.

Summary:
The total site area is 20.5 acres. An existing strip mall is located on the eastern 14.75 acres.
The western 5.75 acres is being developed as a fast food drive through and small strip retail shops.
For the western 5.75 acres, demonstrate how to provide storage for the water quality volume (WQV) and to provide detention to limit the 10-yr, 2-hr peak discharge rate to the pre-development condition.
For the eastern 14.75 acres, add BMPs to provide water quality improvements and reduce runoff volume.
Assume that providing storage for 3" of runoff from the post-development impervious area will provide required detention storage for the 10-yr, 2-hr storm.

Existing Conditions
- The site drains from northeast to southwest. Slopes are from 2 to 3 percent.
- The eastern section has 8.9 acres of impervious area.
- The western section is undeveloped.

Post-Development Conditions
- The western section has 3.4 acres of impervious area.
- Soil amendments are added to 0.66 acres in the western section, increasing the area's infiltration capacity.
- 2.9 acres across the entire site are afforested.

Result – New Development
- Water quality volume = 6,200 C.F.
    - WQV = 0.5" / (12" per foot) * 3.4 acres* (43,560 S.F. per acre)
- Detention volume = 37,000 C.F.
    - Detention volume = 3" / (12" per foot) * 3.4 acres* (43,560 S.F. per acre)
- WQV is contained within the detention volume; therefore BMPs will be sized to contain the detention volume.

BMPs – New Development
- Use a combination of bioretention basins, bioswales, permeable pavement, and green roof.
- Bioretention basins and bioswales are designed so that surface ponding drains within 24 hours.
- BMPs are sized to collectively capture 3" of runoff from the post-development impervious area.

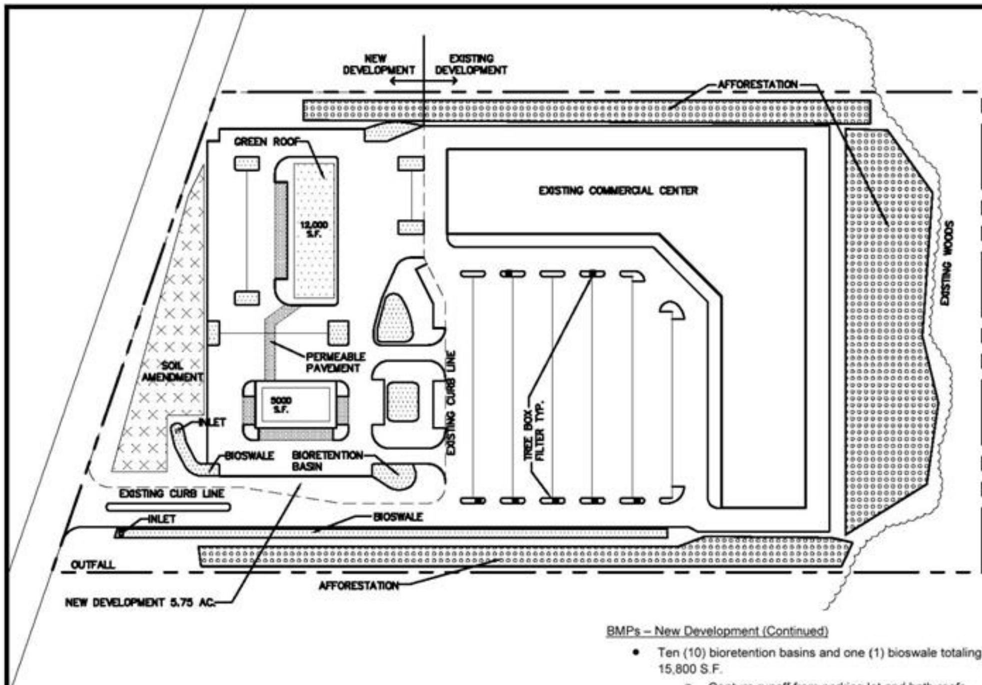
- One 11,000 S.F. green roof.
  - Covers entire 12, 000 S.F. roof of strip retail shops except utility areas and access points.
  - Assume 1.5’ storage within green roof media and no ponding.
  - Additional storage for roof runoff is provided in adjacent BMPs.
- Ten bioretention basins and one bioswale totaling 15,800 S.F.
  - Capture runoff from parking lot and both roofs.
  - Assume 6” surface storage and 1” subsurface storage is provided.
  - Paved areas are graded to drain to the nearest bioretention basin (or bioswale).
- Five section of permeable pavement totaling 8,000 S.F.
  - Capture Runoff from parking lots.
  - Assume 1.5” storage in gravel bed below permeable pavement.

BMPs – Remainder of Site (Existing Development)

- One 10,600 S.F. bioswale with yard inlet.
  - Capture runoff from existing roadway to improve water quality.
  - Assume 6” surface storage and 6” subsurface storage is provided.
  - Bioswale is 820’ long and 13” wide.
  - Can also provide conveyance for larger storms.
- Tree box filters provide water quality improvements for existing parking area in eastern section.

Note

- See concept design on the next page.



Case Study Three: Existing Commercial Development Retrofit

- The total site area is 20.5 acres. An existing strip mall is located on the eastern 14.75 acres.
- The western 5.75 acres is being developed as a fast food drive through and small strip retail shops.
- For the western 5.75 acres, demonstrate how to provide storage for the water quality volume (WQV) and to provide detention to limit the 10-yr. 2-hr peak discharge rate to the pre-development condition.
- For the eastern 14.75 acres, add BMPs to provide water quality improvements and reduce runoff volume.
- Assume that providing storage for 3" of runoff from the post-development impervious area will provide required detention storage for the 10-yr, 2-hr storm.
- WQV = 0.5" of runoff over the impervious area.
- Assume drainage area for western section is limited to the 5.75 acres in that section (no offsite runoff, or runoff from the eastern section)

Existing Conditions

- The site drains from northeast to southwest. Slopes are from 2 to 3 percent.
- The eastern section has 8.9 acres of impervious area.
- The western section is undeveloped.

Post-Development Conditions

- The western section has 3.4 acres of impervious area.
- Soil amendments are added to 0.66 acres in the western section, increasing the area's infiltration capacity.
- 2.9 acres across the entire site are afforested.

Result – New Development

- Water quality volume = 6,200 C.F.
  - WQV = 0.5" / (12" per foot) * 3.4 acres * (43,560 S.F. per acre)
- **Detention volume = 37,000 C.F.**
  - Detention volume = 3" / (12" per foot) * 3.4 acres * (43,560 S.F. per acre)
- WQV is contained within the detention volume; therefore, BMPs will be sized to contain the detention volume.

BMPs – New Development

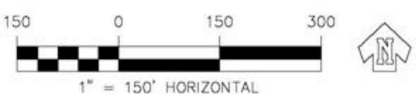
- Use a combination of bioretention basins, bioswales, permeable pavement, and green roof.
- Bioretention basins and bioswales are designed so that surface ponding drains within 24 hours.
- BMPs are sized to collectively capture 3" of runoff from the post-development impervious area.
- One (1) 11,000 S.F. green roof
  - Covers entire 12,000 S.F. roof of strip retail shops except utility areas and access points.
  - Assume 1.5" storage within green roof media and no ponding.
  - Additional storage for roof runoff is provided in adjacent BMPs.

BMPs – New Development (Continued)

- Ten (10) bioretention basins and one (1) bioswale totaling 15,800 S.F.
  - Capture runoff from parking lot and both roofs
  - Assume 6" surface storage and 1' subsurface storage is provided.
  - Paved areas are graded to drain to the nearest bioretention basin (or bioswale).
- Five (5) sections of permeable pavement totaling 8,000 S.F.
  - Capture runoff from parking lots
  - Assume 1.5' storage in gravel bed below permeable pavement.

BMPs – Remainder of Site (Existing Development)

- One (1) 10,600 S.F. bioswale with yard inlet
  - Capture runoff from existing roadway to improve water quality
  - Assume 6" surface storage and 6" subsurface storage is provided.
  - Bioswale is 820' long and 13' wide.
  - Can also provide conveyance for larger storms.
- Tree box filters provide water quality improvements for existing parking area in eastern section.



CASE STUDY
EXISTING COMMERCIAL DEVELOPMENT
RETROFIT

LOW IMPACT DEVELOPMENT CASE STUDY
OCTOBER 2005

Case Study Three: Big Box Site Development

This case study illustrates the affects of minor changes in layout at a Super Center using LID. The following shows LID storage capacity as well as volume reduction for both a 2-year 24-hour storm event and a 10-year 24-hour storm event. These retrofits use decentralized LID methods to disconnect stormwater from a centralized stormwater system and runoff. LID practices reduce stormwater peak and volume flow while improving the water quality of the runoff.

Summary:

- Determine feasibility for water quality control and for providing storage volume to limit the 10-yr, 24-hr peak discharge rate to the pre-development condition.
- Use NRCS TR-55 graphical peak discharge method to determine storage volume.
- Drainage area is assumed to equal site area, 91 ac.
- Assume 85% imperious cover and a CN of 95
- Runoff using NRCS TR-55 graphical peak discharge method for the 2-year and 10-year Type II storm is 20 ac-ft and 34ac-ft, respectively.

Retrofit Conditions:

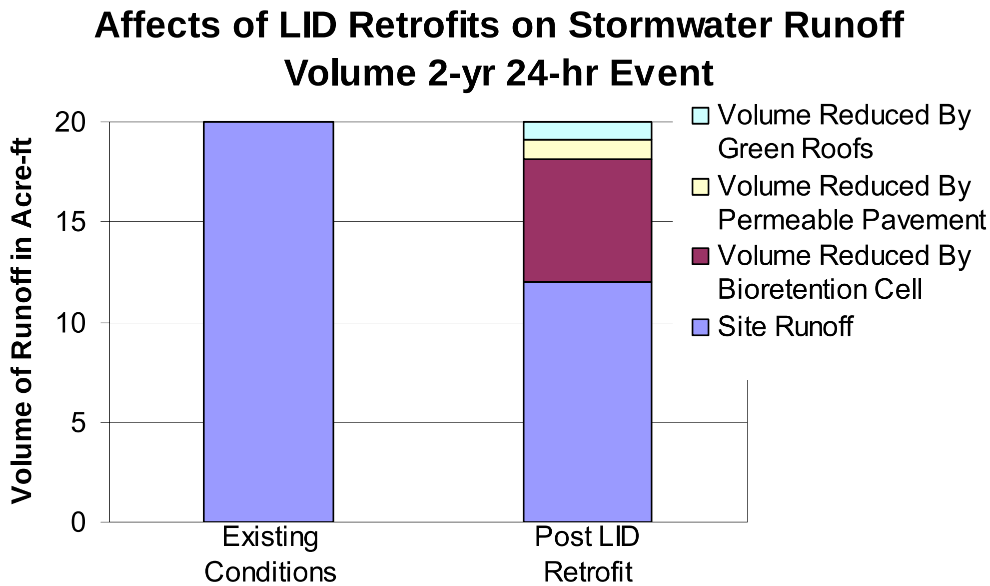
- 2.2 acres of afforestation on western portion of site. Increase infiltration capacity and change in land cover
- Conservation of woods
- Credit bioretention, permeable pavement, and green roofs areas as HSG B and Open Space

Results:

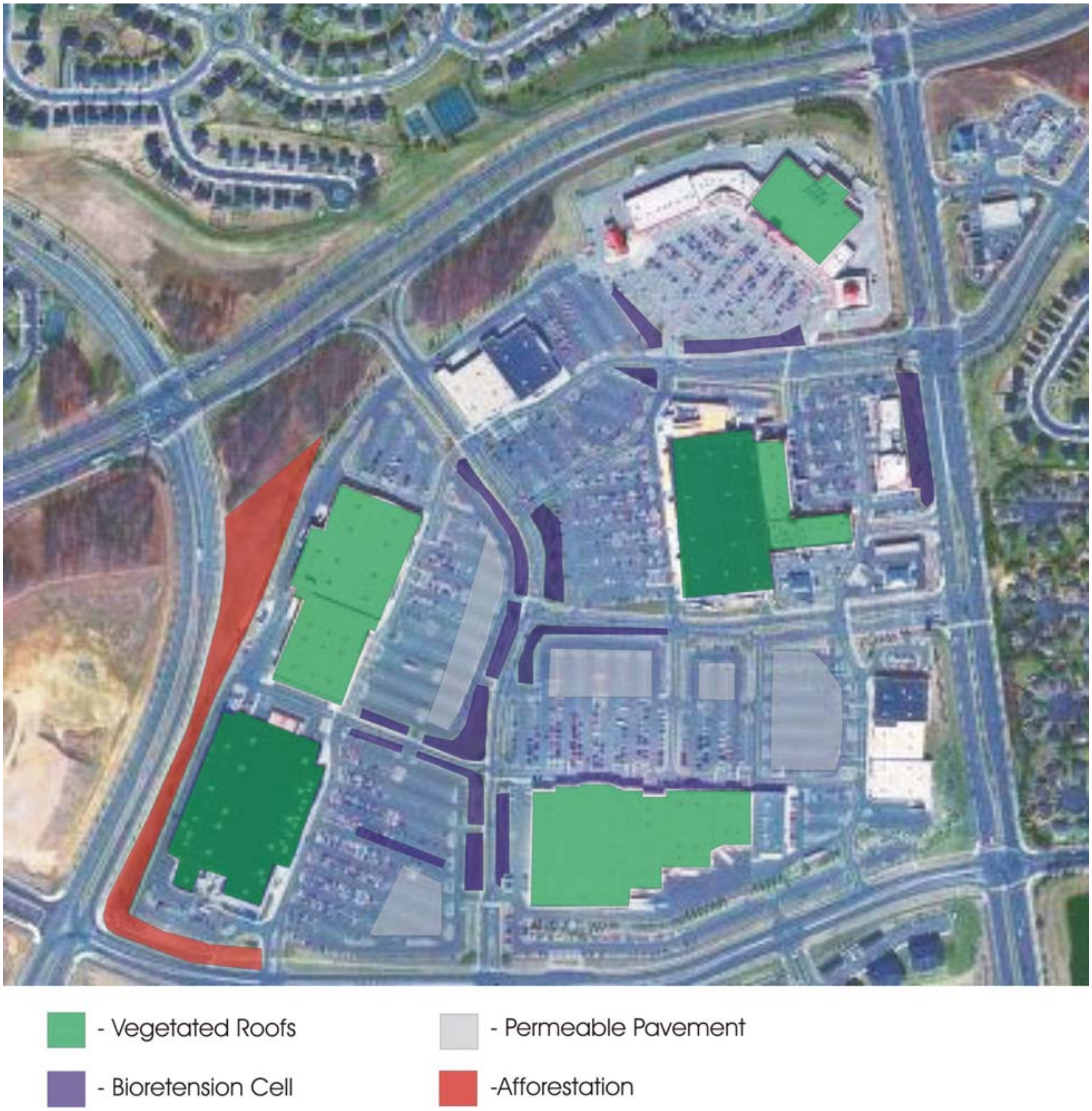
- Detention volume: 8 acre feet
- Green roofs reduce runoff volume by 17% for a 2 yr. 24 hr. storm and 9.5% for a 10 yr. 24 hr. storm.
- Green roofs, bioretention, and permeable pavers combine to offer benefits of a 23% for a 2 yr. 24 hr. storm and 15% for a 10 yr. 24 hr. storm.

BMPs:

- Green roof captures first 1" of roof runoff, 0.89 ac/ft of storage (Water quality volume = first 0.5" of roof runoff.)
- Bioretention basins: 6.1 ac/ft storage is available.
    - Assume 1' surface storage and 2.5' subsurface storage with a porosity of 0.3.
- Permeable Pavers: 1 ac/ft of subsurface storage
    - Assume subsurface storage porosity is 0.3
- Additional storage can be provided in bioswales, amended soils, or cisterns.
- Increase Time of Concentration



Affects of LID Retrofits on Stormwater Runoff Volume 2-yr 24-hr Event
Volume of Runoff in Acre-ft
20
15
10
5
0
Existing Conditions
Post LID Retrofit
Volume Reduced By Green Roofs
Volume Reduced By Permeable Pavement
Volume Reduced By Bioretention Cell
Site Runoff



Case Study Three: Big Box Site Development

V. REFERENCES

Big Box Retail Discussion. Columbia University, Graduate School of Architecture, Preservation, and Planning. Accessed November 28, 2005. http://www.columbia.edu/itc/architecture/bass/newrochelle/extra/big_box.html

Lee, J.G. and J.P. Heaney (2003). "Estimation of Urban Imperviousness and its Impacts on Storm Water Systems," *Journal of Water Resources Planning and Management*, Vol. 129, No. 5, pp. 419-426.

Minton, G. (2002). *Stormwater Treatment*, Resource Planning Associates. Seattle, WA.

Novotny, V. (2003). *Water Quality- Diffuse Pollution and Watershed Management*, John Wiley and Sons, Inc. New York, New York.

Urbonas, B.R. and P. Stahre (1993) *Stormwater: Best Management Practices and Detention for Water Quality, Drainage and CSO Management*, PTR Prentice Hall, Inc., Englewood Cliffs, NJ.

VI. APPENDIX A – Brief description of 14 additional LID BMPs

1	BMP:	Disconnect Impervious Areas/ Downspout Disconnection
	Use:	Prerequisite
	Description:	Disconnection decouples roof leaders, roadways and other impervious areas from stormwater conveyance systems, allowing runoff to be collected and managed on site or dispersed into the landscape. Runoff is redirected onto pervious surfaces such as vegetated areas, reducing the amount of directly connected impervious area and potentially reducing the runoff volume and filtering out pollutants.
	Useful Links:	Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution. http://www.nrdc.org/water/pollution/storm/stoinx.asp Milwaukee Metropolitan Sewerage District http://www.mmsd.com/projects/downspout.cfm DC Greenworks http://www.dcgreenworks.org/LID/downspout.html
2	BMP:	Fingerprinting/ Impervious Areas Reduction
	Use:	Prerequisite
	Description:	Site fingerprinting, also known as minimal disturbance techniques, is a practice that minimizes ground disturbance by identifying the smallest possible land area that can practically be impacted during site development.
	Useful Links:	Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution. http://www.nrdc.org/water/pollution/storm/stoinx.asp Center for Watershed Protection. 1998. Better Site Design: A Handbook for Changing Development Rules in Your Community. Purdue University – Long-term impacts of Land Use Change http://www.ecn.purdue.edu/runoff/documentation/impacts/minimize.htm Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters EPA 840-B-92-002 January 1993 http://www.epa.gov/owow/nps/MMGI/Chapter4/ch4-2c.html
3	BMP:	Pollution Prevention
	Use:	Prerequisite
	Description:	Pollution Prevention (P2) is a general term for any activity or management action that reduces or eliminates pollutants before they are propagated downstream. The goal of P2 is to incorporate programs and techniques to keep nonpoint source (NPS) pollutants out of runoff.
	Useful Links:	Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution. http://www.nrdc.org/water/pollution/storm/stoinx.asp Water Related Best Management Practices (BMP's) in the Landscape, Center for Sustainable Design, Mississippi State University http://www.abe.msstate.edu/Tools/csd/NRCS-BMPs/pdf/water/source/prot_sd_hazwaste.pdf United States Environmental Protection Agency Office of Water. 1999. "Combined Sewer Overflow Management Fact Sheet: Pollution Prevention." Available at http://www.epa.gov/owm/mtb/pollutna.pdf EPA Pollution Prevention Program http://www.epa.gov/p2/
4	BMP:	Reforestation/ Afforestation
	Use:	Prerequisite
	Description:	Reforestation is the planting of trees in an area that was forested in the recent past (e.g. an area that was cleared for residential development). Afforestation is planting trees in an area where they were absent for a significant period of time (e.g. an old farm field or a riparian buffer). Plantings may be seeds, seedlings, or semi-mature trees.

	Useful Links:	Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution. http://www.nrdc.org/water/pollution/storm/stoinx.asp Kentucky Division of Forestry – Reforestation Program http://www.forestry.ky.gov/programs/reforestation/ Reforestation Publications – NC State University College of Natural Resources http://www.ces.ncsu.edu/nreos/forest/reforestationpubs.htm
5	BMP:	Time of Concentration Practices/ Surface Roughening
	Use:	Secondary / Adjunct
	Description:	Time of concentration (t_c) practices, such as surface roughening, increase the time it takes for runoff to flow across a site to the drainage point or a BMP. Slowing runoff velocity potentially reduces erosion and increases the potential for infiltration. Increasing t_c is also directly related to the disconnection of impervious areas.
	Useful Links:	EPA Mid-Atlantic - National Environmental Policy Act (NEPA), LID http://www.epa.gov/reg3esd1/nepa/LID.htm New Low Impact Design: Site Planning and Design Techniques for Stormwater Management http://www.asu.edu/caed/proceedings98/Coffmn/coffmn.html
6	BMP:	Soil Amendments
	Use:	Secondary / Adjunct
	Description:	Soil amendments, which include both soil conditioners and fertilizers, make the soil more suitable for the growth of plants and increase water retention capabilities. Compost amendments and soils for water quality enhancement are also used to enhance native or disturbed and compacted soils. These measures change the physical, chemical, and biological characteristics of the soil allowing it to more effectively reduce runoff volume and filter pollutants. Soil amendments are valuable in areas with poor soils because they can help add available plant nutrients and sustain vegetative cover, reduce long-term erosion, and help reduce runoff peak volumes and discharges by absorption of rainfall and runoff.
	Useful Links:	Choosing a soil amendment, Colorado State University Cooperative Extension http://www.ext.colostate.edu/pubs/Garden/07235.html EarthWorks Soil Amendments, Inc. http://www.ewsa.com/ LID Center Soil Amendment Specification http://www.lowimpactdevelopment.org/epa03/soilamend.htm
7	BMP:	Environmentally Sensitive Landscaping
	Use:	Secondary / Adjunct
	Description:	Revegetating or landscaping a site using trees, shrubs, grasses, or other groundcover provides an opportunity to reintroduce native vegetation, which may be more disease-resistant and require less maintenance than non-native species. Long-term revegetation should only occur at sites at which future disturbance is not expected to occur.
	Useful Links:	Natural Resources Conservation Service. “Critical area planting.” Urban BMP's - Water Runoff Management. ftp://ftp-fc.sc.egov.usda.gov/WSI/UrbanBMPs/water/erosion/critareaplant.pdf Natural Resources Conservation Service. “Native revegetation - grasses, legumes, and forbs.” Urban BMP's - Water Runoff Management. ftp://ftp-fc.sc.egov.usda.gov/WSI/UrbanBMPs/water/erosion/natrevege_grasses.pdf Natural Resources Conservation Service. “Native revegetation - trees and shrubs.” Urban BMP's - Water Runoff Management. ftp://ftp-fc.sc.egov.usda.gov/WSI/UrbanBMPs/water/erosion/natrevege_trees.pdf
8	BMP:	Flow Splitters
	Use:	Secondary / Adjunct

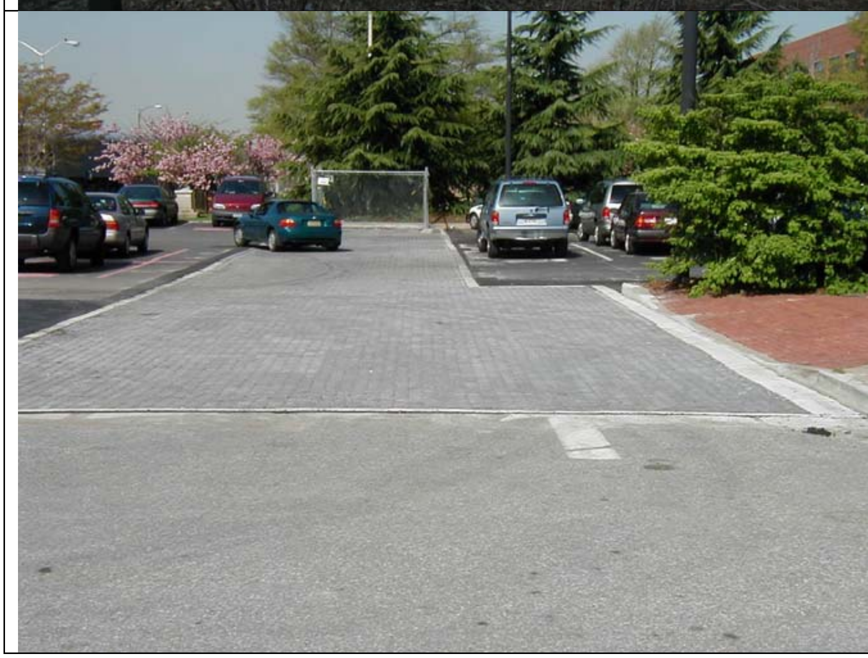
	Description:	A flow splitter allows the runoff volume from a drainage area to be split into two or more quantities ("sub-volumes"). Typically, flow splitters are used to isolate the water quality volume (WQV) in order to provide water quality treatment or manage a portion of a storm event with one or more BMPs. The WQV is typically defined as the first 0.5" to 1' of rain over the impervious drainage area. Alternately, a flow splitter can be used to divert high flows to prevent resuspension of captured pollutants in a BMP.
	Useful Links:	Split-flow Method http://www.forester.net/sw_0207_split.html Developing Split-flow Stormwater Systems http://www.epa.gov/owow/nps/natlstormwater03/11Echols.pdf Echols, S.P. 2002. Split-flow method: Introduction of a new stormwater strategy. Stormwater -The Journal for Surface Water Quality Professionals, 3(5): 16-32.
9	BMP:	Street Sweeping
	Use:	Secondary / Adjunct
	Description:	Street sweeping uses mechanical pavement cleaning practices to minimize pollutant transport to receiving water bodies. Sediment, debris, and gross particulate matter are the targeted pollutants, but removal of other pollutants can be accomplished as well. Street sweeping may also prevent pipes and outlet structures in stormwater detention facilities from becoming clogged with debris and trash. Different designs are available with typical sweepers categorized as (1) mechanical broom sweepers; (2) vacuum-assisted wet sweepers; and (3) dry vacuum sweepers. The effectiveness of street sweeping is very dependent upon when it is done and the number of dry days between storm events.
	Useful Links:	US EPA Office of Water http://www.epa.gov/owm/mtb/pollutna.pdf Low Impact Development Technologies http://www.wbdg.org/design/lidtech.php Protecting Water Quality from Urban Runoff, EPA 841-F-03-003 http://www.epa.gov/water/yearofcleanwater/docs/NPS_Urban-facts_final.pdf
10	BMP:	Dry Wells
	Use:	Limited / Occasional
	Description:	A dry well typically consists of a pit filled with large aggregate such as gravel or stone. Alternately, it may consist of a perforated drum placed in a pit and surrounded with stone. Dry wells capture and infiltrate water from roof downspouts or paved areas. The surface is typically at or just below existing grade. It may be covered by grass or other surface.
	Useful Links:	Massachusetts Low Impact Development Toolkit http://www.mapc.org/regional_planning/LID/Infiltration_trenches.html New Jersey Stormwater Best Management Practices http://www.state.nj.us/dep/watershedmgt/DOCS/BMP_DOCS/bmp2003pdfs/dec2003chap9_3.pdf Arizona Department of Environmental Quality http://www.ci.gilbert.az.us/environment/drywells.cfm
11	BMP:	Filtration Devices (Proprietary and Non-Proprietary)
	Use:	Limited / Occasional
	Description:	Filtration devices are installed in stormwater catch basins to remove mobilized pollutants before stormwater enters the collection system. These systems contain some type of filter media within a variety of configurations. Common filtration media includes fiberglass, activated carbon, and absorbent material. Geotextile materials may also be used both inside the basin or as curb inlet filters. Settling, filtration, absorption, and adsorption are the most common removal mechanisms. These devices are primarily intended to remove debris, trash, particulates, and oil and grease, but may also capture sediments.

	Useful Links:	Government of British Columbia, Ministry of Water, Land, and Air Protection: Water, Air, and Climate Branch http://wlapwww.gov.bc.ca/wat/wq/nps/BMP_Compendium/Municipal/Urban_Runoff/Treatment/Filter.htm Bioretention and LID, University of Maryland http://www.ence.umd.edu/~apdavis/Bio-research.htm
12	BMP:	Gutter Filters
	Use:	Limited / Occasional
	Description:	Gutter filters are linear pre-cast concrete gutter vaults containing gravel and finer (typically sand) filter media and an underdrain installed below grade at the curb line. They are especially useful for treating the "first flush" of roadway runoff, which contains elevated concentrations of many non-point source pollutants. A void space above the filter material captures trash and other debris that is able to pass through the surface grate while the gravel and sand filter media remove suspend solids and other pollutants. Filtered stormwater is conveyed by the underdrain from the gutter filter to the stormwater collection system. Gutter filters may be a stand-alone BMP or used in concert with other measures as part of a stormwater control strategy.
	Useful Links:	Virginia Department of Conservation and Recreation. 1999. "General intermittent sand filters." Virginia Stormwater Management Handbook, 3-12. http://www.dcr.virginia.gov/sw/docs/swm/Chapter_3-12.pdf

13	BMP:	Surface Sand Filters
	Use:	Limited / Occasional
	Description:	A sand filter is a flow-through system designed to improve water quality from impervious drainage areas by slowly filtering runoff through sand. It consists of one or more sedimentation and filtration chambers or areas to treat runoff. Pollutant removal in sand filters occurs primarily through straining and sedimentation. Treated effluent is collected by underdrain piping and discharged to the existing stormwater collection system. A sand filter occupies a small footprint compared to its drainage area. Surface and underground sand filters function similarly.
	Useful Links:	U.S. Environmental Protection Agency. 1999. Storm Water Technology Fact Sheet: Sand Filters. http://www.epa.gov/owm/mtb/sandfltr.pdf Naval Facilities Engineering Service Center. 2004. "Sand filter for treating storm water runoff." Joint Service Pollution Prevention Opportunity Handbook. http://p2library.nfesc.navy.mil/P2_Opportunity_Handbook/10-1.html Barrett, M.E. 2003. Performance, cost and maintenance requirements of Austin sand filters. Journal of Water Resources Planning and Management. May/June 2003: 234-242.
14	BMP:	Infiltration Strips (Percolation)
	Use:	Limited / Occasional
	Description:	Infiltration strips (also known as infiltration trenches, basins or galleries) are trenches that have been back-filled with stone. They collect runoff during a storm event and release it into the soil by infiltration.
	Useful Links:	US Environmental Protection Agency Office of Water. 1999. "Storm Water Technology Fact Sheet: Infiltration Trench." http://www.epa.gov/owm/mtb/infltrenc.pdf Stormwater Manager's Resource Center, Stormwater Management Fact Sheet: Infiltration Trench http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Infiltration%20Practice/Infiltration%20Trench.htm

VII. APPENDIX B – Image Gallery

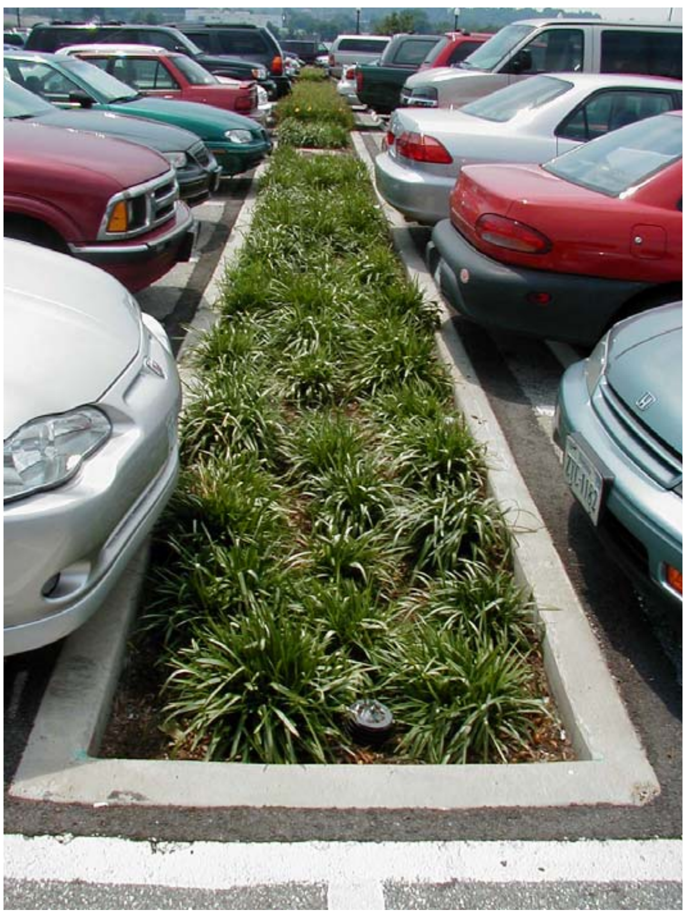
	IKEA Parking Lot ♦ Permeable Pavement ♦ Bioretention
	Super Target, Minnesota

	Safeway Parking Lot ♦ Bioretention
	Permeable Pavement

	Washington Navy Yard Bldg 166 Under Construction ♦ Permeable Pavement
	Washington Navy Yard Bldg 166 Completed ♦ Permeable Pavement

	♦ Green Roof
	♦ Bioretention Strip

- Tree Box Filter



- Bioretention Strip

VIII. APPENDIX C – Ten LID BMP Fact Sheets

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Fact sheets continue on next page.

VIII.1.Bioretention Basins

Bioretention incorporated into shopping center retrofit.
Source: LID Center

Design Criteria:

- Excavate to a minimum depth of one to three feet (deeper excavation can provide for additional storage in the soil or gravel layers, or more surface ponding)
- Cells ("rain gardens") contain grasses, perennials, shrubs, small trees and mulch
- A gravel layer provides temporary storage of stormwater, which will exit through an underdrain (if present) and/or through exfiltration into the subsoil.
- Underdrains and observation wells are recommended in areas with low subsoil permeability.
- Install surface or subsurface structure and high flow bypass to control discharge rate

Maintenance:

- Conduct routine periodic maintenance as required of any landscaped area.
- Inspect the treatment area's components and repair or replace them if necessary.
- Remove accumulated sediment and debris, replace any dead or distressed plants, and replenish mulch annually.
- Repair any eroded areas as soon as they are detected.
- The control structure should be inspected regularly for clogging and structural soundness.

Advantages:

- Useful for larger drainage areas than rain gardens
- Useful incorporated within impervious areas (e.g. parking lots, traffic medians)
- Effective for retrofit
- Enhance quality of downstream waters
- Improve landscape appearance, absorb noise, provide and wind breaks
- Maintenance needs similar to any other landscaped area

Disadvantages:

- Not appropriate where the water table is within 6 feet (1.8m) of ground level
- Not recommended for areas with steep slopes (> 20%)
- Not recommended for areas where mature tree removal would be required
- Not recommended for areas with high sediment loads
- Not appropriate where surrounding soil is unstable

Stormwater Management Suitability

Runoff Volume Reduction

Peak Discharge Rate Reduction

Water Quality

Water Quantity Controls

Bioretention basins can be used to control 2-year, 2-hour and 10-year, 2-hour storms. Drainage areas handled by bioretention basins should be small and distributed.

Stormwater can be stored through surface ponding and through storage in soil and gravel layers. Voids in these layers provide stormwater storage capacity. Depths of the layers are sized to meet storage requirements.

Exfiltration into the subsoil can potentially reduce the volume of stormwater that ultimately enters the primary stormwater conveyance system.

Volume reduction depends upon:

- available storage in the gravel layer and ponding area
- the maximum flow rate into the subsoil
- and the flow rate into the basin related to
- storm intensity

Water Quality Controls

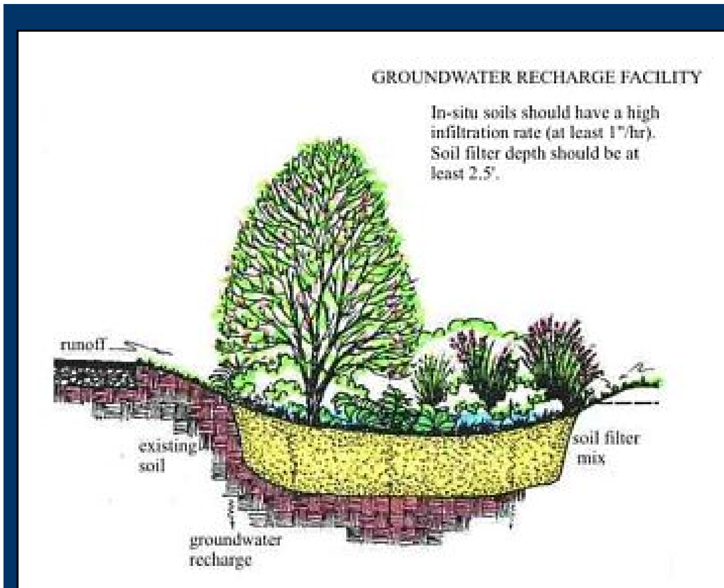
Typical phosphorus removal efficiencies for bioretention cells as follows:

- 50% removal for basins that capture 0.5” of runoff from impervious area
- 65% removal for basins that capture 1.0” of runoff from impervious area

Location

Bioretention cells can be used in commercial and industrial areas. Potential applications include median strips and parking lots.

Bioretention cells should not be located in areas of high sediment loads or where the site is not entirely stabilized.



Bioretention Cell Schematic
Source: DER - Prince Georges County, MD

Cost

The cost for a bioretention basin to treat runoff from ½ impervious acre consists of both the installation and annualized costs.

These cost calculations were based upon a bioretention basin with a surface area of 900 square feet, sized to treat the first 0.5” of runoff. A contingency of 50 percent was added to installation and replacement costs to account for additional excavation and materials needed to provide storage for larger storm events.

A bioretention basin is assumed to have a lifespan of 25 years, at which point it will be removed and replaced.

Design Construction and Materials

Bioretention basins are excavated to a depth of one (1) to three (3) feet, depending on the infiltration rate and depth to the seasonal high groundwater table or bedrock. Deeper excavation can provide more storage in soil and gravel layers or more surface ponding.

Underdrains are recommended in areas with low subsoil permeability (e.g. compacted or clay soils) or shallow soil profiles. Underdrains must tie into an adequate conveyance system. Observation wells should be installed if underdrains are used.

A gravel layer provides temporary storage of stormwater, which will exit through an underdrain (if present) and/or through exfiltration into the subsoil. If an underdrain is present, the gravel layer surrounds the underdrain pipe to minimize the chance of clogging.

The excavated area is filled with an engineered media classified as “sandy loam” or “loamy sand” that typically consists of:

- 50% sand
- 30% planting soil with minimal clay content, and
- 20% shredded hardwood mulch.

Depending on space constraints and drainage area characteristics, a pretreatment device (e.g. vegetated filter strip) can be created to intercept debris and large particles.

Item	Unit	Estimated unit cost (2005 Dollars)
Excavation	C.Y.	$8 - $10
Bioretention media	C.Y.	$40 - $60
Filter fabric	S.Y.	$1 - $5
Gravel	C.Y.	$30 - $35
Underdrain (perforated pipe 4” dia.)	L.F.	$8 - $15
Plants	Ea.	$5 - $20
Mulch	C.Y.	$30 - $35

Item	Required Cost per Year (2005 Dollars)											
	0	1	2	3	4	5	6	7	8	9	10	…	25
Installation[1]	15,000												
Mulching and Debris Removal		350	350	350	350	350	350	350	350	350	350		
Replace Vegetation		200	200	200	200	200	200	200	200	200	200		
Remove & Replace													15,000
Total Cost	**15,000**	**550**	**550**	**550**	**550**	**550**	**550**	**550**	**550**	**550**	**550**		**15,000**
Annualized Cost	$1,125 / year (includes replacement in year 25)												

[1]Developer Cost. Not included in annualized cost.

Maintenance

The primary maintenance requirement for bioretention cells is to inspect the treatment area's components and repair or replace them if necessary. Generally, maintenance is the same as the routine periodic maintenance that is required of any landscaped area

Removal of accumulated sediment and debris, replacement of any dead or stressed plants, and replenishment of the mulch layer is recommended on an annual basis. Also, any eroded areas should be repaired as soon as they are detected. The control structure should be inspected regularly for clogging and structural soundness.

Potential LEED Credits

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)

Other: Sustainable Sites – Credit 7 "Landscape & Exterior Design to Reduce Heat Islands" (1-2 Points)
Water Efficiency – Credit 1 "Water Efficient Landscaping" (1-2 Points)
Innovation & Design Process (1-4 Points)

Links to Additional Information

USEPA Office of Water
http://www.epa.gov/OW-OWM.html/mtb/biortn.pdf

Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution.
http://www.nrdc.org/water/pollution/storm/stoinx.asp

United States Environmental Protection Agency, 2000: Bioretention applications: Inglewood Demonstration Project, Largo, Maryland, and Florida Aquarium, Tampa, Florida. Office of Water, Washington, D.C., EPA-841-B-00-005A

U.S. Environmental Protection Agency, 1995: Maryland developer grows 'Rain Gardens' to control residential runoff. Nonpoint Source News-Notes, 42 (August/September)
http://www.epa.gov/NewsNotes/issue42/urbrnf.html

Performance and Inspection

To ensure proper performance, visually inspect that stormwater is infiltrating properly into each bioretention cell. Water standing in a bioretention cell for more than 48 hours indicates operational problems.

Corrective measures include inspection for and removal of sediments, typically by backflushing.

Samples of bioretention media should be assessed if there is poor infiltration to determine the condition of the media (e.g. clay content).

Replacement of the bioretention media may be required to restore the flow rate through the cell. First, applying soil amendments can be attempted to restore permeability.

Perform inspection:

- annually in spring
- after severe weather events (e.g. hurricanes)

VIII.2.Bioretention Cells

Bioretention cell in a commercialr parking lot
Source: LID Center, Inc

Design Criteria:

- **Excavated to a minimum depth of one to three feet (deeper excavation can provide for additional storage in the soil or gravel layers, or more surface ponding)**
- **Cells, or "rain gardens," contain grasses and perennials, shrubs, and small trees**
- **A gravel layer provides temporary storage of stormwater, which will exit through an underdrain (if present) and/or through exfiltration into the subsoil.**
- **Underdrains are recommended in areas with low subsoil permeability. Observation (cleanout) wells should also be installed, if underdrains are used.**

Maintenance:

- **Conduct routine periodic maintenance as required of any landscaped area.**
- **Inspect the treatment area's components and repair or replace them if necessary.**
- **Remove accumulated sediment and debris, replace any dead or distressed plants, and replenish the mulch layer on an annual basis.**
- **Repair any eroded areas as soon as they are detected.**

Advantages:

- **Useful for small drainage areas**
- **Useful in impervious areas (e.g. parking lots, traffic medians)**
- **Effective for retrofit**
- **Enhance the quality of downstream water bodies**
- **Improve landscape appearance, absorb noise, provide shade and wind breaks**
- **Maintenance needs similar to any other landscaped area**

Disadvantages:

- **Not recommended for areas where mature tree removal would be required**
- **Not recommended for areas with high sediment loads**
- **Not appropriate where the surrounding soil stratum is unstable**
- **Not applicable for large drainage areas**

Stormwater Management Suitability

Runoff Volume Reduction

Water Quality

Water Quantity Controls

Stormwater in excess of the water quality volume (WQV: see section below) can be detained by allowing additional ponding and/or subsurface storage in the bioretention cell, thereby reducing the runoff volume and peak discharge rate. Voids in the soil and gravel layers provide stormwater storage capacity.

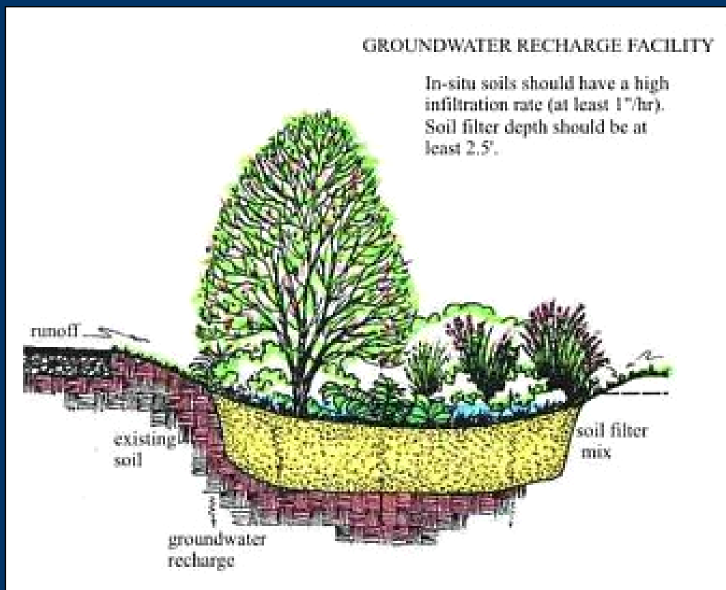
The depth of the gravel layer may be increased to add storage capacity. Exfiltration into the subsoil can reduce the volume of stormwater that ultimately enters the conveyance system.
Volume reduction depends on the available detention storage in the gravel layer and ponding area. It also is a function of the flow rate into the cell and the maximum flow rate into the subsoil. These factors are related to the storm intensity and drainage area size.

Water Quality Controls

The water quality volume (WQV) is typically defined as the first one-half to one inch of runoff from impervious areas.

Typical phosphorus removal efficiencies for bioretention cells as follows:

- 50% removal for cells that capture 0.5" of runoff from an impervious area
- 65% removal for cells that capture 1.0" of runoff from an impervious area



Bioretention Cell Schematic
Source: DER - Prince Georges County, MD

Location

Bioretention cells can be used in commercial and industrial areas. Potential applications include median strips, parking lots, and swales.

Bioretention cells should not be located in areas of high sediment loads or where the site is not entirely stabilized.

Cost

Cost of a bioretention cell to treat runoff from ½ impervious acre consists of both installation costs and annualized costs.

Cost calculations were based upon a bioretention cell with a surface area of 900 square feet, sized to treat the first 0.5” of runoff.

A bioretention cell is assumed to have a lifespan of 25 years, at which point it would be removed and replaced.

Design Construction and Materials

Bioretention cells are excavated to a depth of one (1) to three (3) feet, depending on the infiltration rate and depth to the seasonal high groundwater table or bedrock. Deeper excavation can provide for more storage in soil or gravel layers.

Underdrains are recommended in areas with low subsoil permeability (e.g. compacted or clay soils) or shallow soil profiles. Underdrains must tie into an adequate conveyance system. Observation wells should be installed if underdrains are used.

A gravel layer provides temporary storage of runoff which may exit through an underdrain and/or through exfiltration into the subsoil. If an underdrain is present, the gravel layer surrounds the underdrain pipe to minimize the chance of clogging.
The excavated area is then filled with an engineered media classified as “sandy loam” or “loamy sand” that typically consists of:

- 50% sand
- 30% planting soil with minimal clay content, and
- 20% shredded hardwood mulch.

The area is then mulched and planted with shrubs, perennials, grasses, and small trees. The cell must provide for bypass flow into an inlet or overflow weir.

Bioretention cells typically consist of the cost components below.

Item	Unit	Estimated unit cost (2005 Dollars)
Excavation	C.Y.	$8 - $10
Bioretention media	C.Y.	$40 - $60
Filter fabric	S.Y.	$1 - $5
Gravel	C.Y.	$30 - $35
Underdrain (perforated pipe 4” dia.)	L.F.	$8 - $15
Plants	Ea.	$5 - $20
Mulch	C.Y.	$30 - $35

Item	Required Cost per Year (2005 Dollars)											
	0	1	2	3	4	5	6	7	8	9	10	…	25
Installation[1]	10,000												
Mulching and Debris Removal		350	350	350	350	350	350	350	350	350	350		
Replace Vegetation		200	200	200	200	200	200	200	200	200	200		
Remove & Replace													10,000
Total Cost	**10,000**	**550**	**550**	**550**	**550**	**550**	**550**	**550**	**550**	**550**	**550**		**10,000**
Annualized Cost	$925 / year (includes replacement in year 25)												

[1]Developer Cost. Not included in annualized cost.

Maintenance

The primary maintenance requirement for bioretention cells is to inspect the treatment area's components and repair or replace them if necessary. Generally, maintenance is the same as the routine periodic maintenance that is required of any landscaped area

Removal of accumulated sediment and debris, replacement of any dead or stressed plants, and replenishment of the mulch layer is recommended on an annual basis. Also, any eroded areas should be repaired as soon as they are detected.

Potential LEED Credits

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)

Other: Sustainable Sites – Credit 7 "Landscape & Exterior Design to Reduce Heat Islands" (1-2 Points)

Water Efficiency – Credit 1 "Water Efficient Landscaping" (1-2 Points)

Innovation & Design Process (1-4 Points)

Links to Additional Information

USEPA Office of Water
http://www.epa.gov/OW-OWM.html/mtb/biortn.pdf

Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution.
http://www.nrdc.org/water/pollution/storm/stoinx.asp

United States Environmental Protection Agency, 2000: Bioretention applications: Inglewood Demonstration Project, Largo, Maryland, and Florida Aquarium, Tampa, Florida. Office of Water, Washington, D.C., EPA-841-B-00-005A

U.S. Environmental Protection Agency, 1995: Maryland developer grows 'Rain Gardens' to control residential runoff. Nonpoint Source News-Notes, 42 (August/September)
http://www.epa.gov/NewsNotes/issue42/urbrnf.html

Performance and Inspection

To ensure proper performance, visually inspect that stormwater is infiltrating properly into each bioretention cell. Water standing in a bioretention cell for more than 48 hours indicates operational problems.

Corrective measures include inspection for and removal of sediments, typically by backflushing.

Samples of bioretention media should be assessed if there is poor infiltration to determine the condition of the media (e.g. clay content).

Replacement of the bioretention media may be required to restore the flow rate through the cell. First, applying soil amendments can be attempted to restore permeability.

Perform Inspection:

- annually in spring
- after severe weather events (e.g. hurricanes)

VIII.3.Bioretention Slopes

Highway median: potential bioslope location
Source: LID Center

Design Criteria:

- **Construct a bioslope along the entire length of the sloped edge of its drainage area, having a width sufficient to provide treatment for the drainage area runoff**
- **Cover slope with an ecology mix soil having a minimum depth of one foot**
- **Install a gravel level spreader between the impervious surface and the slope**
- **Install a vegetated filter strip between the gravel and the bioslope, if pre-treatment is desired or needed**
- **Install a gravel underdrain trench and pipe at the base of the slope for temporary storage of stormwater.**
- **Plant (seed) the slope with grasses**

Maintenance:

- **Periodically remove debris accumulated on the gravel level spreader.**
- **Mow the grass filter strip with a retractable –arm mower to avoid compaction of the ecology mix.**
- **Reseed bare areas annually.**
- **Repair any eroded areas as soon as they are detected.**
- **Conduct periodic sampling and testing to assess adequate ongoing permeability of the ecology mix.**

Advantages:

- **Useful for medians and side slopes of access roads/sites**
- **Useful along edges of elevated impervious areas (e.g. parking lots)**
- **Effective for retrofit of standard fill slopes**
- **Enhance quality of downstream waters**
- **Reduce runoff volume and pollutant loads**

Disadvantages:

- **Not recommended for unstable slopes or those steeper than 4:1 (rise : run)**
- **Runoff must flow onto the bioslope via sheet flow only**
- **Bioslopes cannot handle high velocity and high discharge flows.**
- **Bioslopes are susceptible to erosion**
- **Requires specialized mowing equipment (retractable arm) to avoid compaction**

Stormwater Management Suitability

Runoff Volume Reduction

Peak Discharge Rate Reduction

Water Quality

Water Quantity Controls

Bioslope design is based on the ability of a slope area to absorb and treat a specified storm intensity. This assumed design rainfall intensity typically relates to the maximum anticipated intensity of the water quality storm event.

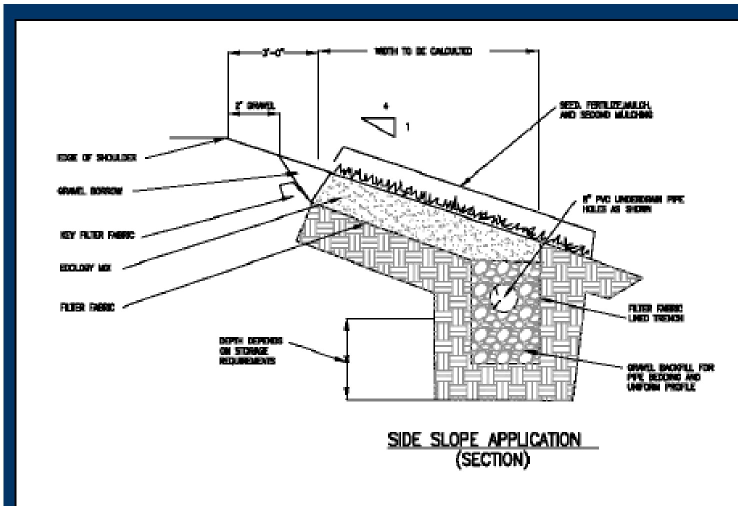
For storms with an intensity greater than the design rainfall intensity, some runoff will not be captured and infiltrated, but will flow over the surface of the bioslope. Stormwater not captured by the bioslope can be detained through additional (sub)surface storage at the base of the bioslope.

A ponding area or gravel storage bed (infiltration trench) can be constructed at the slope base to store excess runoff. It is important to emphasize that storm intensity, not rainfall depth, will determine the volume of "excess" stormwater that will need to be stored at the base of the bioslope. For the bioslope itself and the auxiliary storage area, the permeability of the subsoil will determine whether captured runoff will exfiltrate into the subsoil or flow into an underdrain connected to a conventional conveyance system.

Additional subsurface storage can be provided within the bioslope itself by enlarging the gravel underdrain trench. This can be used to store water that would otherwise flow directly into the underdrain pipe.

Water Quality Controls

Research conducted by the Washington State Department of Transportation has found that bioslopes can remove 60 percent of phosphorus, 77 percent of metals, and 88 percent of total suspended solids (TSS) contained in stormwater runoff from a water quality storm event.



Bioslope Cross-Section
Source: Washington State Highway Runoff Manual

Location

Bioslopes are appropriate for use on medians and side slopes of access roads or sites but cannot be used where the side slope exceeds 4:1 (rise : run) or on unstable slopes.

To avoid erosion, stormwater must run onto the bioslope via sheet flow only. High velocity and high discharge flows must be diverted to conveyance channels.

Cost

The cost for a bioslope to treat runoff from ½ impervious acre is consists of both the installation and annualized costs.

These cost calculations were based upon a bioslope with a surface area of 3,000 square feet.

A bioslope is assumed to have a lifespan of 25 years, at which point it would be removed and replaced.

Design Construction and Materials

Bioslopes consist of a gravel level spreader next to the pavement to evenly distribute flows and trap sediments; an optional vegetated filter strip to provide additional pretreatment if space allows; an ecology mix bed which provides the majority of water quality improvement; and an optional gravel underdrain trench and pipe.

Underdrains may be needed on Hydrologic Soil Group (HSG) C and D soils. Observation/cleanout wells should be installed, if underdrains are used. Soil amendments may be used in the filter strip to increase its permeability.

When sizing a bioslope for its drainage area, the long-term flow rate through the ecology mix must be at least as great as the design peak discharge rate from the drainage area. Include a 50 percent safety factor when assigning a long-term conductivity rate to the ecology mix.
Basic bioslope dimensions are given below.

- The bioslope should be as long as the drainage area it is intended to treat and should run parallel along the sloped edge of the drainage area (e.g. roadway).
- The bioslope width must be sufficient to provide treatment for the adjacent drainage area.
- Dual bioslopes must be at least two feet (2') wide.
- The ecology mix soil bed should be one foot (1') deep or greater.
- The side slope of the bioslope should be no steeper than 4H:1V.
    - The gravel level spreader should be at least one foot (1') wide and at least 18 inches deep.
    - The gravel underdrain trench should be at least two feet (2') wide.

Item	Unit	Estimated unit cost (2005 Dollars)
Level spreader (gravel)	C.Y.	$30 - $35
Filter fabric	S.Y.	$1 - $5
Underdrain trench (gravel)	C.Y.	$30 - $35
Underdrain (perforated pipe 8" dia.)	L.F.	$8 - $15
Grass seed or sod	M.S.F.	$15 - $20
Ecology mix	C.Y.	$40 - $60

The ecology mix consists of the following components (per WSDOT standards).

Item	Required Cost per Year (2005 Dollars)											
	0	1	2	3	4	5	6	7	8	9	10	…	25
Installation[1]	10,000												
Mowing		150	150	150	150	150	150	150	150	150	150		
Reseeding		50	50	50	50	50	50	50	50	50	50		
Remove & Replace													10,000
Total Cost	**10,000**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**		**10,000**
Annualized Cost	$600 / year (includes replacement in year 25)												

[1]Developer Cost. Not included in annualized cost.

Maintenance

Periodically remove any debris that has accumulated on the gravel level spreader and mow the grass filter strip. Use a retractable-arm mower to avoid compaction of the ecology mix. Both activities can be incorporated into regular maintenance activities.

Reseed bare areas annually. Conductivity tests may be used periodically to determine whether the permeability of the ecology mix decreases over time.

Potential LEED Credits

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)

Other: Sustainable Sites – Credit 7 "Landscape & Exterior Design to Reduce Heat Islands" (1-2 Points)
Water Efficiency – Credit 1 "Water Efficient Landscaping" (1-2 Points)
Innovation & Design Process (1-4 Points)

Links to Additional Information

USEPA Office of Water
http://www.epa.gov/OW-OWM.html/mtb/biortn.pdf

Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution.
http://www.nrdc.org/water/pollution/storm/stoinx.asp

United States Environmental Protection Agency, 2000: Bioretention applications: Inglewood Demonstration Project, Largo, Maryland, and Florida Aquarium, Tampa, Florida. Office of Water, Washington, D.C., EPA-841-B-00-005A

U.S. Environmental Protection Agency, 1995: Maryland developer grows 'Rain Gardens' to control residential runoff. Nonpoint Source News-Notes, 42 (August/September)
http://www.epa.gov/NewsNotes/issue42/urbrnf.html

Performance and Inspection

To ensure proper performance, visually inspect that stormwater is infiltrating properly into the bioslope. Problems are indicated by channelized flow down the slope or rill formation.

Corrective measures include inspection for accumulated sediments around the level spreader and their removal, if necessary.

If infiltration is poor, samples of the ecology mix should be assessed to determine the condition of the ecology mix. The mix may need to be replaced if it has deteriorated.

Perform inspection:

- annually in spring
- after severe weather events (e.g. hurricanes)

VIII.4.Bioretention Swales

Bioretention Swale
Source: Portland BES

Advantages:

- Useful incorporated with linear impervious areas (e.g. roads)
- Improve on standard grassed swales by affording greater infiltration, water retention, nutrient/ pollutant removal
- Effective for retrofit
- Enhance quality of downstream waters, as well as reducing runoff volume and peak runoff rate
- Improve roadway corridor appearance

Disadvantages:

- Not recommended for areas where the slope in the direction of flow exceeds 5 percent due to risk of erosive velocities
- Not appropriate where the water table is within 6 feet (1.8m) of ground level
- Not appropriate where surrounding soil is unstable
- Not recommended for areas with high sediment loads

Design Criteria:

- Depth shall be one (1) to three (3) feet, minimum (greater depth can provide more storage in soil or gravel layers or more surface ponding)
- Contains mulch, grasses and herbaceous annuals and perennials (typically natives)and special bioretention media
- A gravel layer provides temporary storage of stormwater, which will exit through an underdrain (if present) and/or through exfiltration into the subsoil.
- Underdrains are recommended in areas with low subsoil permeability. Observation (cleanout) wells should also be installed.
- Use inlets or overflow weirs for bypass flow, check dams for encouraging sheet flow

Maintenance:

- Conduct routine periodic maintenance including mowing (to design flow depth), verifying hydraulic efficiency of the channel, insuring dense, healthy cover
- Inspect the treatment area's components and repair or replace them if necessary.
- Remove accumulated sediment and debris, replace any dead or distressed plants, and replenish mulch annually.
- Repair any eroded areas as soon as they are detected. Reseed bare areas.

Stormwater Management Suitability

Runoff Volume Reduction

Peak Discharge Rate Reduction

Water Quality

Water Quantity Controls

Any volume of stormwater in excess of the water quality volume (WQV) can be detained by providing additional ponding and/or subsurface storage in the bioswale, thereby reducing the runoff volume and peak discharge rate.

The voids in the soil and gravel layers provide storage capacity. Additional storage may be provided by increasing the depth of the gravel layer. Exfiltration into the subsoil can potentially reduce the volume of stormwater that ultimately enters the conveyance system.

Volume reduction depends upon:

- available storage in the gravel layer and ponding area
- the maximum flow rate into the subsoil
- the flow rate into the basin related to
  - storm intensity
  - drainage area size

A bioswale's cross-section can be sized to provide conveyance for any given design storm, as required by applicable regulations.

Water Quality Controls

Phosphorus removal efficiency data specific to bioswales is not available. Similarities in design and function of swales to bioretention cells (see Section 2.2) allow phosphorus removal efficiencies for bioretention cells to be used as a reference for bioswales.

Therefore, bioswale phosphorus removal efficiencies are:

- 50 percent for swales that capture 0.5" runoff from the impervious area
- 65 percent for swales that capture 1.0" runoff from impervious the area

Location

Bioswales can be used in commercial and industrial areas. Use of pre-treatment BMPs in conjunction with bioswales may be advisable. Sediment capturing devices such as filter strips and vegetated filters are examples of these optional techniques.
Bioswales generally should not be located where there are high sediment loads or soils are not entirely stabilized.

Bioswale Maintenance
Source: LID Center

Cost

The cost for a bioswale to treat runoff from ½ impervious acre consists of both the installation and annualized costs.

Cost calculations were based upon a bioswale design having a surface area of 900 square feet.

A bioswale is assumed to have a lifespan of 25 years, at which point it would be removed and replaced.

Design Construction and Materials

Bioswales are excavated to a minimum depth of one (1) to three (3) feet, depending on the infiltration rate and depth to the seasonal high groundwater table or bedrock. Deeper excavation can provide for additional storage in the soil or gravel layers.

Underdrains are recommended in areas with low subsoil permeability (e.g. compacted or clay soils) or shallow soil profiles. Underdrains must tie into an adequate conveyance system. Observation/ cleanout wells should also be installed if underdrains are used.

A gravel layer provides temporary storage of stormwater, which will exit through an underdrain (if present) and/or through exfiltration into the subsoil.
If an underdrain is present, the gravel layer surrounds the underdrain pipe to minimize clogging. The excavated area is then filled with an engineered media classified as "sandy loam" or "loamy sand" that consists of:

- 50% sand
- 30% planting soil with minimal clay content, and
- 20% shredded hardwood mulch.

The swale area is then seeded to provide a plant community of warm season grasses, herbaceous annuals and flowering perennials.

The swale must provide for bypass flow into an inlet or overflow weir. Check dams may be used to act as flow spreaders to encourage sheet flow.
Bioswale slopes should be no greater than 5 percent. Gentle slopes and reduced velocities are critical to ensuring a stable, non-erosive swale.

Item	Unit	Estimated unit cost (2005 Dollars)
Excavation	C.Y.	$8 - $10
Grading	S.Y.	$0.10 - $0.15
Bioretention media	C.Y.	$40 - $60
Filter fabric	S.F.	$0.70 - $1.00
Underdrain trench (gravel)	C.Y.	$30 - $35
Underdrain (perforated pipe 8" dia.)	L.F.	$15 - $20
Seed	S.F.	$1 - $2

Item	Required Cost per Year (2005 Dollars)											
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**…**	**25**
Installation[1]	10,000												
Mowing		100	100	100	100	100	100	100	100	100	100		
Reseeding / Replanting		100	100	100	100	100	100	100	100	100	100		
Remove & Replace													10,000
Total Cost	**10,000**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**		**10,000**
Annualized Cost	$600 / year (includes replacement in year 25)												

[1]Developer Cost. Not included in annualized cost.

Maintenance

The primary maintenance requirement for bioswales includes routine inspections targeted at maintaining hydraulic efficiency of the channel, the treatment effectiveness of the bioretention components, and a dense, healthy vegetative cover. Inspections should also target erosion of the swale channel bottom.

Maintenance activities should include periodic mowing (with grass never cut shorter than the design flow depth), clearing of debris and blockages, and sediment removal. Reseed bare areas annually.

Potential LEED Credits

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)

Other: Sustainable Sites – Credit 7 "Landscape & Exterior Design to Reduce Heat Islands" (1-2 Points)
Water Efficiency – Credit 1 "Water Efficient Landscaping" (1-2 Points)
Innovation & Design Process (1-4 Points)

Links to Additional Information

USEPA Office of Water
http://www.epa.gov/OW-OWM.html/mtb/biortn.pdf

Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution.
http://www.nrdc.org/water/pollution/storm/stoinx.asp

United States Environmental Protection Agency, 2000: Bioretention applications: Inglewood Demonstration Project, Largo, Maryland, and Florida Aquarium, Tampa, Florida. Office of Water, Washington, D.C., EPA-841-B-00-005A

U.S. Environmental Protection Agency, 1995: Maryland developer grows 'Rain Gardens' to control residential runoff. Nonpoint Source News-Notes, 42 (August/September)
http://www.epa.gov/NewsNotes/issue42/urbrnf.html

Performance and Inspection

To ensure proper performance, visually inspect that stormwater is infiltrating properly and is being conveyed through the length of the bioswale. Water standing in a bioswale for more than 48 hours indicates operational problems.

Corrective measures include inspection for and removal of sediments, typically by backflushing.

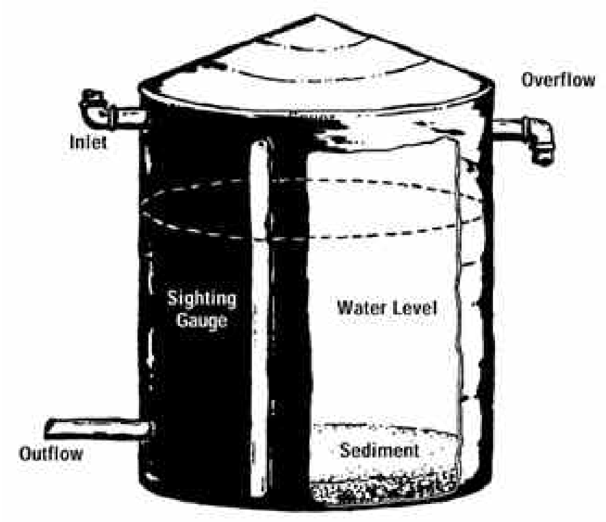
Samples of bioretention media should be assessed if there is poor infiltration to determine the condition of the media (e.g. clay content).

Replacement of the bioretention media may be required to restore the flow rate through the cell. First, applying soil amendments can be attempted to restore permeability.

Perform inspection:

- annually in spring
- after severe weather events (e.g. hurricanes)

VIII.5.Cisterns / Rainbarrels



Schematic of Cistern. Source: Texas Water Development Board- Rainwater Harvesting

Design Criteria:

- Rainwater catchment systems (RWCS) store roof runoff for reuse.
- Cisterns may store up to 10,000 gallons of stormwater runoff. Prefabricated systems offer greater reliability and ease of integration with plumbing systems. These can be placed on rooftops and drained by gravity. If installed in a basement, pumping is required. An overflow to the sanitary sewer should also be provided.
- Rain barrels typically store less than 100 gallons of runoff. Homemade rain barrels can be easily constructed from readily available materials.

Maintenance:

- Rain Barrels
  Inspect each unit and its components seasonally and after major rain events for clogging.
  Replace minor parts as needed.

- Cisterns
  Inspect for clogging and structural soundness - and test water quality - twice each year. Repair as needed.
  Remove accumulated sediment once annually.

Advantages:

- Allows capture and reuse of roof runoff – relatively clean, naturally "soft" water, free of most sediment and dissolved salts
- Reduces runoff volume, as well as peak discharge rate for small, frequent rain events
- Reduces potable water consumption:
  - landscape irrigation
  - HVAC coolant
  - toilet flushing
- Affords water quantity and quality control where space is scarce and land values are premium
- Effective for urban retrofit sites

Disadvantages:

- Unless provided in large quantities, rain barrels may not be able to handle the water quality volume (WQV)
- Regulatory and administrative obstacles may preclude the re-use of cistern water. This may reduce the attractiveness and feasibility of this BMP given space needs and costs.

Stormwater Management Suitability

Runoff Volume Reduction

Peak Discharge Rate Reduction

Water Quality

Water Quantity Controls

For any storm, the runoff volume will be reduced by an amount equal to the empty volume of the RWCS, which may be less than the total storage capacity. The peak discharge rate may be delayed or reduced, depending on captured volume.

Rain barrel sizing is relatively simple. Rain barrels usually store between 55 and 130 gallons and may be connected in series. Space constraints and frequency and volume of irrigation will determine the number of rain barrels used for a rooftop.

Cistern sizing depends on the water demand and on the collection volume: in other words, an analysis of the water input and output. Storage in addition to the WQV (water quality volume) may be needed if cistern water is not completely drawn down between storms. Per capita use of cistern water (e.g. toilet flushes per person per day) can be used to calculate the demand, i.e. the cistern outflow rate.

Water Quality Controls

Typically, to be considered a water quality BMP, a RWCS must collect the water quality volume (WQV), which is the first 0.5" of rainfall (NVPDC). Unless provided in large quantities, rain barrels may be unable to meet this requirement.

For all RWCS, settling of sediments will contribute to water quality improvements (however, resuspension during subsequent storms may be a concern). Additional pollutant removal ability will depend on the ultimate use of the water.

Since rain barrel water is typically used for landscape irrigation, pollutant removal rates approximate those of infiltration BMPs (see 2.2, bioretention cells). The same holds true for cistern water used for landscape irrigation.

If cistern water is used for toilet flushing or other applications in which it will ultimately be discharged to the sanitary sewer, the pollutant removal rate is the same as that of the wastewater treatment plant (WWTP). This efficiency is 95 to 100 percent for phosphorus and many other pollutants.

Location

RWCS can be used on any building site with sufficient space and structural capacity where there will be a reliable end use for collected rainwater. Cisterns may be installed for any land use. Rain barrels are often, but not exclusively, used for residential applications due to their small capacity.

Cost

Cost calculations were developed assuming the first 0.5” of rainfall is captured.
Cost for a large cistern to treat runoff from ½ impervious acre consists of installation and annualized costs.

For similar capacity, a series of 53 rain barrels (130 gal/each) would be required. Their primary purpose would be to increase visibility of the system in order to raise public awareness of stormwater issues.

Both cisterns and rain barrels are assumed to have a lifespan of 25 years, at which point they would be removed and replaced.

Design Construction and Materials

Cisterns and rain barrels may be constructed from available parts, but prefabricated systems may offer more reliability and greater ease of integration with the building’s plumbing system. If adequate structural capacity exists, cisterns can be placed on rooftops and be drained by gravity. Another common installation location is a basement, in which case pumping is needed. Flow splitters can be used to divert the WQV to the cistern. An overflow to the sanitary sewer should also be provided.

If cisterns are used to supplement a building’s potable plumbing system, a parallel plumbing system will need to be installed. The installation cost depends on the size and purpose of the system and will need to be considered in any cost-benefit analysis. Safety measures must be taken to ensure that cistern water not be used for potable purposes. Besides a parallel plumbing system, such measures include warning signs and lockable faucets.

Cistern/Rain Barrel Type	Small system	Large system
Galvanized steel	$225 → 200 gal.	$950 → 2000 gal.
Polyethylene	$150 → 130 gal.	$1100 → 1800 gal.
Fiberglass	$660 → 350 gal.	$10,000 → 10K gal.
Fiberglass/steel composite	$300 → 300 gal.	$10,000 → 5K gal.
Ferro-cement	Varies by location	Varies by location

Item	Required Cost per Year – Cistern[2] (2005 Dollars)											
	0	1	2	3	4	5	6	7	8	9	10	…	25
Installation[1]	13,000												
Debris Removal		250	250	250	250	250	250	250	250	250	250		
Replace Parts				500			500			500			
Water Quality Tests		500	500	500	500	500	500	500	500	500			
Remove & Replace													13,000
Total Cost	**13,000**	**550**	**550**	**550**	**550**	**550**	**550**	**550**	**550**	**550**	**550**		**13,000**
Annualized Cost	$1,400 / year (includes replacement in year 25)												

[1]Developer Cost (assumes 10,000 gallon fiberglass cistern). Not included in annualized cost.
[2]Comparable capacity using rain barrels results in installed cost of $7,950 and annualized costs of $720 including replacement.

Maintenance

Maintenance requirements for rain barrels are minimal. Each unit and its attachments should be inspected for clogging several times a year and after major storms. Minor parts such as spigots, screens, downspouts or leaders may need to be replaced periodically.

Cisterns should undergo water quality assessments (i.e. sediment, fecal coliform, bacteria, and heavy metals) and inspections for clogging and structural soundness twice each year. Accumulated sediment should be removed once annually. Costs associated with inspection and repair of the distribution system (parallel plumbing) are widely variable.

Potential LEED Credits

Primary: Water Efficiency – Credit 1 "Water Efficient Landscaping" (1-2 Points)
Water Efficiency – Credit 3 "Water Efficient Landscaping" (1-2 Points)
Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)

Other: Innovative & Design Process (1-4 Points)

Innovation & Design Process (1-4 Points)

Links to Additional Information

Downspout Disconnection in Toronto,
www.city.toronto.on.ca/watereff/downspot.htm

Rainwater harvesting from Rooftop catchments
www.oas.org/usde/publications/Unit/oea59e/ch10.htm

Tanks Direct, Above ground and underground storage for water, petroleum, and chemical applications
www.storagetanks.com

The Texas Water Development Board-Rainwater Harvesting
www.twdb.state.tx.us/assistance/conservation/Rain.htm

Performance and Inspection

Inspect rain barrels once each season) and after extreme weather events, checking connections (e.g. inflow and outflow hoses) when removing debris.

Inspect cisterns twice each year for structural soundness; one of these times may coincide with annual sediment removal.

If there is a parallel plumbing system, it can be inspected at the same time as the conventional plumbing system.

Rain Barrel
Source: District of Columbia Water & Sewer Authority

VIII.6.Water Quality Swales

Grassed Swale
Source: LID Center

Advantages:

- Useful for small drainage areas with low stormwater velocities
- Use existing natural low areas to treat stormwater
- Can be sized to convey any design storm required
- Reduce stormwater volume
- Enhance quality of downstream waters
- Reduce runoff velocity
- Minimal maintenance requirements

Disadvantages:

- Not applicable to large drainage areas in excess of 10 acres (much smaller areas are recommended)
- Not recommended for areas with slopes greater than 5% or where velocities exceed 3 to 4 feet per second --- without the use of check dams
- Not applicable where soil infiltration rates are less than 0.3 inches per hour

Design Criteria:

- Broad, shallow channel vegetated along bottom and sides with grasses designed to accommodate peak flow of design storm
- Side slopes must be 3:1 (rise : run) or less
- Slope in flow direction must be 5 percent or less
- Grass along sides of channel is kept at a height greater than the maximum design stormwater volume
- Soils must have a minimum permeability rate of 0.27 inches per hour (SCS A/B soils groups) or be improved with amendments
- An optional gravel layer can provide storage of stormwater in excess of WQV; engineered soil can improve filtration

Maintenance:

- Conduct routine periodic maintenance that is required of any grassed area: mow, weed, water, aerate and reseed.
- Maintain grass height equal or greater to the design flow depth.
- Minimize or eliminate us of fertilizers, herbicides, and pesticides.
- Remove sediment and debris after severe storm events.
- Inspect swales (and check dams) for erosion and repair and reseed as needed.

Stormwater Management Suitability

Runoff Volume Reduction

Peak Discharge Rate Reduction

Water Quality

Water Quantity Controls

Any volume of stormwater in excess of the WQV can be detained by providing additional ponding and/or subsurface storage in the swale, thereby reducing the runoff volume and peak discharge rate. The voids in the soil and gravel layers provide stormwater storage capacity.

The depth of the gravel layer may be increased to add additional storage. Exfiltration into the subsoil can potentially reduce the volume of stormwater that ultimately enters the conveyance system.

Volume reduction depends on:

- available detention storage in the gravel layer and ponding area,
- the maximum flow rate into the subsoil,
- the flow rate into the swale,
  - storm intensity
  - drainage area size.

The cross-section of a water quality swale can be sized to provide conveyance for any given design storm, as required.

Water Quality Controls

Phosphorus removal efficiency is 15 percent if existing subsoil underlies the swale. However, the rate is 35 percent if an engineered soil mixture is used. Pollutant load reductions are achieved due to decreased volume of stormwater runoff.

Pollutant removal occurs in grassed swales through two mechanisms. Vegetation in the channel removes large and coarse particulates and sediment from stormwater. Pollutants are also removed by aerobic decomposition and chemical precipitation that occurs within the soil matrix while stormwater is infiltrating.

Location

Grassed swales should only be used where soils have infiltration rates of more than 0.3 inches per hour. Suitability of grassed swales depends on soil type, slope, imperviousness of the contributing watershed, dimensions and slope of the grassed swale system.

In general, grassed swales can be used to manage runoff from drainage areas that are less than 10 acres in size (although smaller areas are recommended), with slopes 5 percent or less, or velocities greater than 3 to 4 feet per second.

Grassed Swale
Source: VA DCR
PERMISSION PENDING

Cost

The cost for a water quality swale to treat runoff from ½ impervious acre consists of both the installation and annualized costs.

Cost calculations were based upon a water quality swale with a surface area of 900 square feet.

A water quality swale is assumed to have a lifespan of 25 years, at which point it would be removed and replaced.

Design Construction and Materials

Swale capacity should be able to accommodate the peak flow from the design storm. Soil Conservation Service (USDA-SCS) hydrologic group A and B soils are required for grassed swales unless a permeability rate of 0.27 inches per hour or greater can be achieved. Soil amendments can be used to increase permeability.

The side slopes of the swale shall be no steeper than 3:1(rise:run) and longitudinal slopes shall be 5 percent or less. Check dams may be used to increase the overall detention time provided by the system.

Grass should be selected and installed in order to ensure swale stability and to provide sufficient surface roughness and filtering. Grassed swales typically consist of the component listed below.

Item	Unit	Estimated unit cost (2005 Dollars)
Grading	S.Y.	$0.10 - $0.15
Erosion control material	S.Y.	$1 - $2
Sod	S.F.	$2 - $4
Grass seed	S.F.	$1 - $2

Item	Required Cost per Year (2005 Dollars)											
	0	1	2	3	4	5	6	7	8	9	10	…	25
Installation[1]	6,000												
Mowing		100	100	100	100	100	100	100	100	100	100		
Reseeding		50	50	50	50	50	50	50	50	50	50		
Aeration		50	50	50	50	50	50	50	50	50	50		
Remove & Replace													6,000
Total Cost	**6,000**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**		**6,000**
Annualized Cost	$425 / year (includes replacement in year 25)												

[1]Developer Cost. Not included in annualized cost.

Maintenance

Maintenance activities include periodic mowing (grass must be cut equal to or higher than the design flow depth), weed control, watering during drought conditions, reseeding of bare areas, and clearing of debris and blockages. Significant storm events can cause sediment to accumulate. Swales must be inspected regularly for signs of erosion (especially at the edges of check dams) and for sediment deposition.

Minimize or avoid using fertilizers and pesticides. Fertilizers should only be used to aid required reseeding. Grass cover should be thick and reseeded as necessary. Periodically, swales should be aerated and debris should be removed. Vehicular traffic or parking must not be allowed on or around swales to avoid compacting soils.

Potential LEED Credits

Primary: Sustainable Sites – Credit 6 “Stormwater Management” (1-2 Points)

Other: Sustainable Sites – Credit 7 “Landscape & Exterior Design to Reduce Heat Islands” (1-2 Points)
Water Efficiency – Credit 1 “Water Efficient Landscaping” (1-2 Points)
Innovation & Design Process (1-4 Points)

Links to Additional Information

USEPA Office of Water
http://www.epa.gov/OW-OWM.html/mtb/vegswale.pdf

Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution.
http://www.nrdc.org/water/pollution/storm/stoinx.asp

United States Environmental Protection Agency, 2000: Bioretention applications: Inglewood Demonstration Project, Largo, Maryland, and Florida Aquarium, Tampa, Florida. Office of Water, Washington, D.C., EPA-841-B-00-005A

U.S. Environmental Protection Agency, 1995: Maryland developer grows 'Rain Gardens' to control residential runoff. Nonpoint Source News-Notes, 42 (August/September)
http://www.epa.gov/NewsNotes/issue42/urbrnf.html

Performance and Inspection

To ensure proper performance, visually inspect that stormwater is being conveyed through the entire water quality swale. Water standing in a water quality swale for more than 24 hours indicates operational problems.

If excessive ponding is observed, a swale should be inspected for any accumulated sediments. Any blockages should be removed.

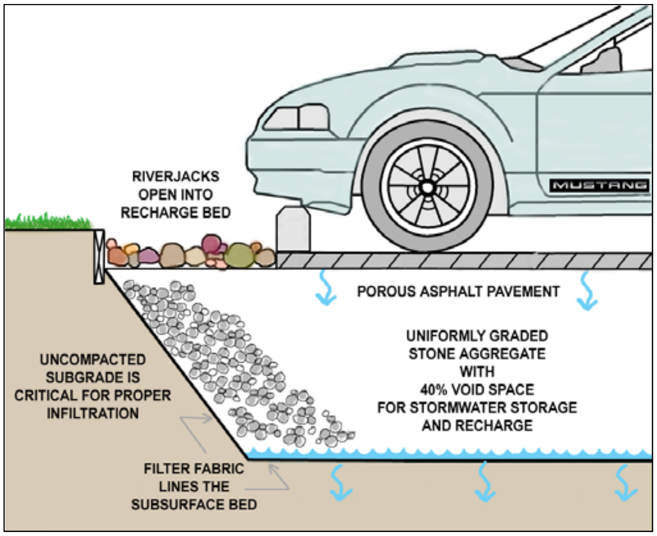
Aeration of a swale should be done every other year to maintain the function of the soils and aid infiltration. Annual inspections should be conducted to determine water infiltration and conveyance.

Reseeding or resodding may be required if the grass becomes diseased or damaged.

Perform inspection:

- annually in spring
- after severe weather events (e.g. hurricanes)

VIII.7.Permeable / Porous Pavement



Permeable pavement cross-section
Source: Cahill and Associates

Design Criteria:

- **Asphalt or concrete with reduced fines and a special binder allowing water to pass through voids OR paving blocks installed with gaps between units that are filled with aggregate or soil and turf grass**
- **Porous paving is underlain with a subbase of aggregate comprised two layers:**
  - **Upper layer – fines**
  - **Lower layer – coarse aggregate**
    - **structural support**
    - **reservoir**
- **Geotextile fabric separates aggregate layers from the soil below**
- **Underdrains and cleanouts may be needed where infiltration rates are low**

Maintenance:

- **Primary Goal –**
  Prevent clogging of voids by fine sediment particles
  - **Vacuum pavement three (3) to four (4) times annually**
  - **DO NOT pressure wash pavement (forces particles deep into voids)**
  - **DO NOT apply abrasive materials as treatment for snow/ice safety hazards**
- **Inspect regularly for clogging as well as structural soundness.**

Advantages:

- **Useful in parking lots, driveways, road shoulders and paths**
- **Uses site features that cause stormwater management problems as part of a creative solution**
- **Conserves space allocated to storm-water management**
- **Effective for retrofit**
- **Enhance quality of downstream waters by decreasing runoff volume and peak discharge, as well as filtering pollutants and aiding recharge of groundwater**

Disadvantages:

- **Only feasible in areas level enough for vehicular and pedestrian uses**
- **Without adequate training, personnel can permanently damage structures**
- **Not feasible where sediment loads can not be controlled**
- **Not appropriate where the seasonal groundwater table – or bedrock - is within two (2) to four (4) feet of the bottom of the infiltration trench**

Stormwater Management Suitability

Runoff Volume Reduction

Peak Discharge Rate Reduction

Water Quality

Water Quality Controls

Pollutant loads can be cut by decreasing stormwater volume discharged through the subbase aggregate and by increasing infiltration into substrate. The first method of calculating load reduction is to calculate the volume of stormwater retained in the aggregate subbase. Further reduction of pollutant loads requires analysis of other pollutant removal mechanisms.

If stormwater is able to infiltrate into the soil, pollutants will further adsorb and be absorbed by soil particles. Other processes such as aerobic decomposition and chemical precipitation will also decrease pollutants within the soil matrix. Sand layers below the aggregate may provide water quality treatment.

A determination of pollutant load reductions will require an analysis of adsorption and absorption rates for soluble pollutants as well as rates of decomposition and precipitation.

Reductions in particulates and suspended solids can be achieved by physical removal when filtering through subbase aggregate.

Nitrogen removals depend greatly upon stormwater infiltrating into the soil where microbial conversion of nitrogen is able to occur.

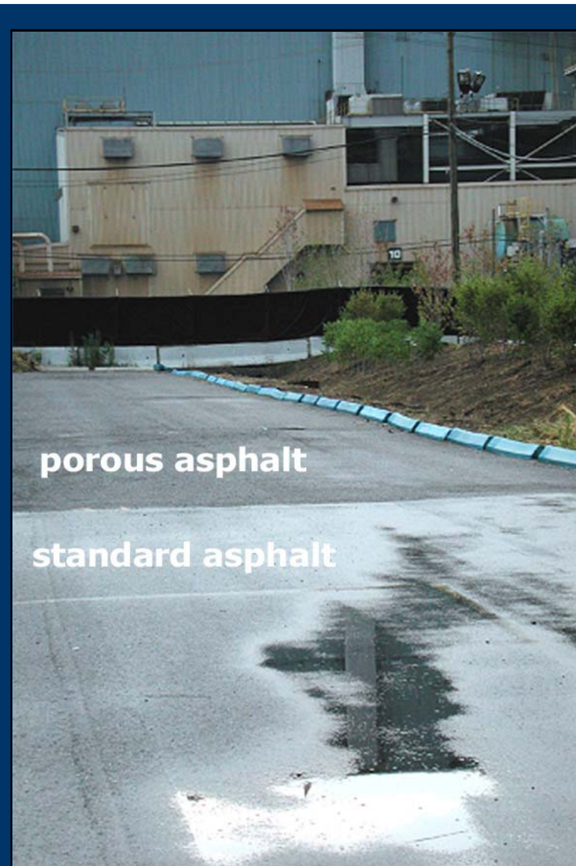
Water Quantity Controls

Porous pavements reduce stormwater runoff volume and peak discharge rates by providing a storage reservoir and an opportunity for subsurface infiltration. Stormwater volumes greater than WQV potentially can be stored.

Determining the reduction in stormwater volume requires determining the flow rate through the pavement, the response to the storm event, the volumetric storage area in the aggregate subbase, and the release rate. The interstitial voids provide stormwater storage. Permeability of surrounding soils adds storage capacity based upon infiltration rate. The depth of the aggregate subbase may be increased to add additional storage. The maximum depth of the aggregate subbase will be a function of the retention time desired, porosity of the selected aggregate, and soil infiltration rate.

Location

Permeable pavements may be used for parking lots, driveways, road shoulders and pedestrian paths. Such paving should not be used in areas with the potential for spills, such as gas stations or loading docks. Permeable pavement should not be used for roadways with traffic heavier or more frequent than that on residential roads.



Drainage in both types of pavement
Source: Cahill and Associates

Cost

The cost for porous or permeable pavement to treat runoff from ½ impervious acre consists of installation and annualized costs. Cost calculations were based upon permeable pavement being installed on 10% of a ½ acre parking lot.

Permeable pavement is assumed to have a lifespan of 25 years, at which point it would be removed and replaced.

Design Construction and Materials

Construction of permeable asphalt and concrete will be similar to that of conventional pavements. Installation of paving blocks may require additional labor costs for hand placement. Similar materials and construction techniques are required for permeable and conventional pavements.

The largest difference is the depth of the aggregate subbase and the addition of the geotextile material. Permeable pavement systems typically consist of the following components.

Perforated underdrains may be used when constructing permeable pavement in areas where soil infiltration rates are low. Observation/cleanout wells must be installed if underdrains are used. A clearance of at least two (2) to four (4) feet must be maintained between the bottom of the infiltration trench and the seasonal high groundwater table or bedrock, depending on site conditions.

Preventing overland runoff from flowing across permeable paving decreases sediment loading and maximizes lifespan and performance of the paving. This can be accomplished through the use of a perimeter berm or filter strip.

Item	Unit	Estimate unit cost (2005 dollars)
Excavation	C.Y.	$8 - $10
Porous asphalt	S.F.	$0.50 - $1.00
Porous concrete	S.F.	$2.00 - $6.50
Concrete paving blocks	S.F.	$5 - $10
Aggregate	C.Y.	$30 - $35
Geotextile fabric	S.F.	$0.70 - $1.00

Item	Required Cost per Year (2005 Dollars)											
	0	1	2	3	4	5	6	7	8	9	10	…	25
Installation[1]	12,000												
Vacuum Sediment		500	500	500	500	500	500	500	500	500	500		
Remove & Replace													12,000
Total Cost	**12,000**	**500**	**500**	**500**	**500**	**500**	**500**	**500**	**500**	**500**	**500**		**12,000**
Annualized Cost	$950 / year (includes replacement in year 25)												

[1]Developer Cost. Not included in annualized cost.

Maintenance

The main goal of a maintenance program for porous or permeable paving surfaces is to prevent clogging by fine sediment particles. Vacuum the pavement three (3) to four (4) times annually, depending on the average sediment loading.

DO NOT pressure wash the permeable/porous pavements, as this may force particles deeper into the pavement where it can no longer be removed by vacuuming.

Abrasive materials for snow treatment, such as sand, should be prohibited in order to prevent clogging of paving voids. Settlement of paving block systems may require resetting. Cracks and settlement in asphalt or concrete may require cutting and replacing the pavement section.

Potential LEED Credits

Primary: Sustainable Sites – Credit 7.1 "Landscape & Exterior Design to Reduce Heat Islands" (1 Point)
Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)
Other: Innovation & Design Process (1-4 Points)

Links to Additional Information

USEPA Office of Water
http://www.epa.gov/owow/nps/pavements.pdf

LID Urban Design Tools
http://www.lid-stormwater.net/permeable_pavers/permpavers_benefits.htm

Performance and Inspection

To ensure proper performance, visually inspect that stormwater is infiltrating properly and is not ponding on the surface of the porous or permeable pavement.

Standing water on such pavement may indicate clogging of open void spaces. Annual visual inspections should be conducted to check for accumulated sediments.

Routine vacuuming should prevent clogging. If voids are clogged, vacuuming is necessary.
If this treatment does not restore permeability, the pavement might be clogged beyond repair and may need to be replaced.

VIII.8.Planter Box

Planter Box
Source: LID Center

Advantages:

- Effective as part of an overall disconnection strategy in urban areas
- Provide capacity to store and filter runoff
- Enhance quality of downstream water bodies
- Offer "green space" in densely developed environments
- Stormwater provides resources to plantings effectively at low cost enhancing viability
- Effective for retrofit

Disadvantages:

- Space needed for planter boxes may not be available in all situations within the urban environments where they are most cost effective
- High attrition rates for plantings in stressful urban settings may necessitate vigilant maintenance and higher costs than less complex alternatives such as cisterns

Design Criteria:

- **Elevated structures intercept, store and filter stormwater from routed downspouts**
- **Planter boxes are constructed of materials capable of containing runoff and echoing the environment; the architecture and/or streetscape**
- **Planter boxes contain:**
  - **aggregate substrate**
  - **soil matrix**
  - **mulch**
  - **herbaceous plants, shrubs and/or small trees**
- **Underdrains and observation wells are recommended to avoid overflow in the event of heavy wet weather**

Maintenance:

- **Inspect planter boxes for structural integrity and clogging on a regular basis**
- **Backflush the underdrain in the event that obstructions are found during inspection**
- **Inspect the soil matrix and aggregate substrate to evaluate root growth and to verify channel formation is not occurring**
- **Turn or till soil matrix if infiltration becomes slowed due to soil compaction**
- **Identify damaged components and repair or replace, if needed.**

Stormwater Management Suitability

Runoff Volume Reduction

Peak Discharge Rate Reduction

Water Quality

Water Quality Controls

Water quality benefits are similar to those for bioretention cells. Phosphorus removal is achieved at the rate of 50 percent for the first one-half inch (0.5”) of runoff that enters the planter box from impervious areas.

Planter boxes contribute to pollutant load reductions by minimizing the volume of stormwater generated. Rainfall is retained and stored in the special soil matrix and substrate. Rainfall is intercepted by plants which evapo-transpire moisture.

Concentrations of pollutants will also be reduced as stormwater infiltrates through planter box soil. Pollutants adsorb and are absorbed by the soil particles. Aerobic decomposition and chemical precipitation will also decrease concentrations of pollutants within the soil matrix.

Determination of pollutant load reductions requires an analysis of adsorption and absorption rates for soluble pollutants, as well as decomposition and precipitation rates.

Reductions of suspended solids and particulates are achieved by physical removal when runoff is filtered through the aggregate.

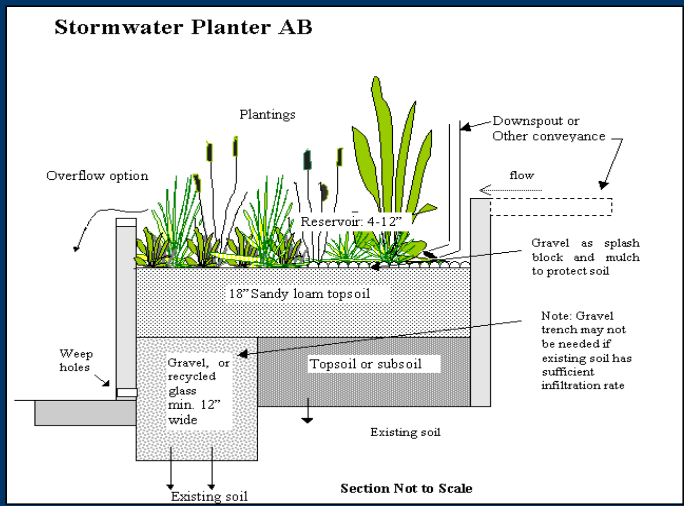
Water Quantity Controls

Routing stormwater to planter boxes can reduce runoff volume and the rate of peak discharge by providing temporary ponding capacity, in addition to sub-surface soil storage.

Additional storage can be provided by constructing a gravel storage bed below the planting soil, similar to gravel layers in bioretention cells.

Location

Planter boxes are most commonly used in urban areas adjacent to buildings and along sidewalks. Locations close to roof downspouts are preferable when used as part of a downspout disconnection program.



Planter Box Schematic
Source: LID Center

Cost

The cost for a planter box system to treat runoff from ½ impervious acre is comprised of both installation cost and annualized costs. These calculations were based upon a planter box system with a total surface area of 500 ft^2.

A planter box is assumed to have a lifespan of 25 years, at which point it would be removed and replaced.

Design Construction and Materials

Planter boxes may be constructed of any durable material. When abutting a building, planter boxes are often made from materials used in the building's construction. They also might be constructed of concrete or other materials used in the nearby streetscape. Stand-alone units might be metal or fiberglass, or other appropriate materials.

An appropriate soil mix is needed to ensure adequate plant growth and vitality. Native plants are often preferred in order to maximize plant viability and to ease maintenance.

Underdrains can be installed to connect planter boxes to a runoff conveyance system. Observation/ clean-out wells should be installed if underdrains are used.

Item	Unit	Estimated unit cost (2005 Dollars)
Planter box construction (concrete)	C.Y.	$75 - $125
Vegetation planting	Ea.	$5 - $20
Soil media	C.Y.	$15 - $25
Underdrain - perforated pipe (4" dia.)	L.F.	$8 - $12

Item	Required Cost per Year (2005 Dollars)												
	0	1	2	3	4	5	6	7	8	9	10	…	25
Installation[1]	4,000												
Mulching, Weeding, and Debris Removal		300	300	300	300	300	300	300	300	300	300		
Replace Vegetation		100	100	100	100	100	100	100	100	100	100		
Concrete Repair						500					500		
Remove & Replace													4,000
Total Cost	**4,000**	**400**	**400**	**400**	**400**	**900**	**400**	**400**	**400**	**400**	**900**		**4,000**
Annualized Cost	$625/ year (includes replacement in year 25)												

[1]Developer Cost. Not included in annualized cost.

Maintenance

Maintenance activities entail routine inspections of the planter box structure and the underdrain. Soil matrix and substrate also need to be inspected to evaluate root growth and channel formation.

The soil media may need to be tilled to improve infiltration. Plants may need to be replaced. Back-flushing the underdrain may be able to remove obstructions. If these efforts are unsuccessful, the soil media and underdrain may need to be removed and replaced.

Potential LEED Credits

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)
Sustainable Sites – Credit 7 "Landscape & Exterior Design to Reduce Heat Islands" (1-2 Points)
Water Efficiency – Credit 1 "Water Efficient Landscaping" (1-2 Points)

Other: Water Efficiency – Credit 3 "Water Use Reduction" (1-2 Points)
Innovation & Design Process (1-4 Points)

Links to Additional Information

Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution.
http://www.nrdc.org/water/pollution/storm/stoinx.asp

Achieving Sustainable Site Design through Low Impact Development Practices, Whole Building Design Guide
http://www.wbdg.org/design/lidsitedesign.php

Planter Boxes - City of Sandy Oregon
http://www.ci.sandy.or.us/pw/Storm/Planter_boxes.htm

Performance and Inspection

To ensure proper performance, visually inspect that stormwater is infiltrating properly into the planter box soil matrix and that there is discharge from the underdrain during heavy wet weather events. Ponding of rainwater in a planter box for more than 24 hours indicates operational problems.

If excessive ponding is observed, corrective measures include inspecting the soil matrix for signs of compaction, as well as the underdrain for signs of clogging.

VIII.9.Tree Box Filters

Tree box filter at the Pentagon
Source: LID Center

Design Criteria:

- Tree box filters resemble typical urban street tree planters are installed below grade along a curb line. They consists of:
  - A pre-cast concrete box
  - Bioretention soil or growth media
  - A tree or shrub
- A standard curb inlet is set downstream from tree box filters. High volumes of stormwater will bypass the tree box filter, if full, and flow directly to the inlet.
- Plants should be selected based on local recommendations for street trees highly tolerant of high stress conditions. Natives are preferred.

Maintenance:

- Periodic, regular removal of trash and debris is required, preferably at least seasonally and after severe storm events
- Replenishment of the mulch layer is recommended once or twice annually.
- Inspect the tree box regularly for clogging and flush via the cleanout, if needed.
- During extreme droughts, water the tree or shrub just as any other landscape plants.

Advantages:

- Provide shade and shelter, absorb noise, filter air pollutants and improve the aesthetic value of urban landscapes
- Effective for retrofit
- Enhance quality of downstream waters
- Relatively small units can treat large areas (comparatively) and their runoff volumes

Disadvantages:

- Among LID practices and technology, tree box filters are one of the more expensive alternatives
- Tree box filters are effective for capture of the WQV (water quality volume) for only small, frequently occurring storms --- they cannot handle larger volumes, nor can they detain WQV for extended periods
- Additional storage systems are required downstream for large flow volumes --- with added installation and upkeep costs

Stormwater Management Suitability

Runoff Volume Reduction

Peak Discharge Rate Reduction

Water Quality

Water Quantity Controls

Tree box filters can reduce the runoff volume and peak discharge rate for small, frequently-occurring storms by capturing the water quality volume (WQV). They are not intended to capture volumes larger than the WQV, or to detain the WQV for extended periods of time. Volumes larger than the WQV can be detained in a subsurface storage system downstream --- such as a gravel bed.

Water Quality Controls

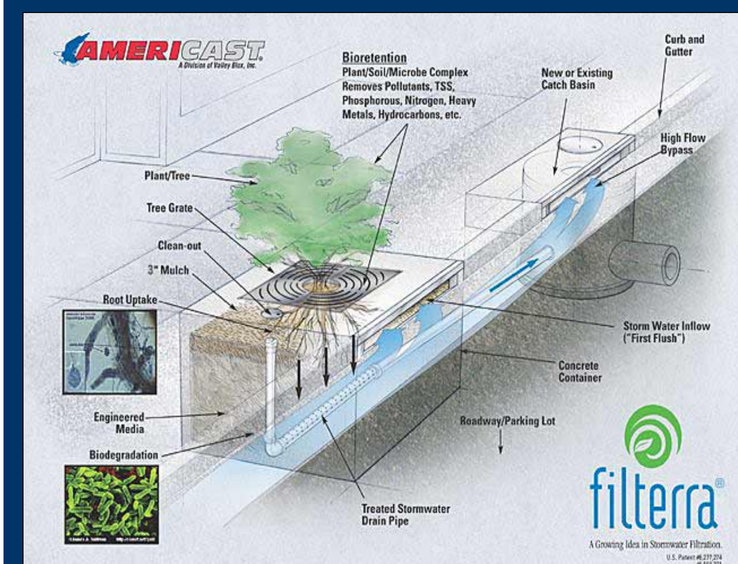
Tree box filters remove pollutants through the same biological, chemical, and physical mechanisms as bioretention cells.

Pollutant	Expected removal
Total suspended solids	85%
Total phosphorous	74%
Total nitrogen	68%
Total metals	82%

Source: Virginia Stormwater Minimum Standard 3.11C

Location

Tree box filters can receive stormwater runoff from streets and parking lots, as long as a downstream inlet or outfall is present. All land uses are suitable.



Tree box filter schematic
Source: Americast
PERMISSION PENDING

Cost

The cost for a tree box filter to treat runoff from ½ impervious acre is comprised of both the installation cost and annualized costs. These cost calculations were based upon installing two (2) 6' x 6' tree box filters.

A tree box filter is assumed to have a lifespan of 25 years, at which point it would be removed and replaced.

A tree box filter this size costs approximately $8,000, including two (2) years of maintenance, filter material, and plants. Installation costs about $1500 per unit for a total of $9500.

Annual maintenance is $500 per unit when performed by the manufacturer, but only $100 per unit if tended by the owner/operator.

Design Construction and Materials

To treat 90 percent of the annual runoff volume, the surface area of a tree box filter should be approximately 0.33 percent of the drainage area. Tree boxes must be regularly spaced along the length of a corridor to meet the annual treatment target. A curb inlet must be located downstream of the tree fox filter(s) to intercept bypass flow.

Tree box filters are off-line devices and should never be placed in a sump position (i.e. at a low point). Instead, runoff should flow *across* the inlet. Also, tree box filters are intended for intermittent flows and must not be used as larger event detention devices.

Tree box filters consist of a pre-cast concrete container, a mulch layer, bioretention media, observation and cleanout pipes, underdrain pipes, and a single tree or large shrub. A decorative grate is typically used to protect the device and the plant, as well as to intercept large debris. Pretreatment under normal conditions is not necessary.

Item	Required Cost per Year (2005 Dollars)											
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**…**	**25**
Installation[1]	19,000												
Mulching and Debris Removal		150	150	150	150	150	150	150	150	150	150		
Replace Vegetation						250					250		
Remove & Replace													19,000
Total Cost	**19,000**	**150**	**150**	**150**	**150**	**300**	**150**	**150**	**150**	**150**	**300**		**19,000**
Annualized Cost	$950 / year (includes replacement in year 25)												

[1]Developer Cost. Not included in annualized cost.

Maintenance

Maintenance of tree box filters typically entails annual inspection and regular removal of trash and debris. Mulch will need to be replenished one (1) to two (2) times per year. The cleanout pipe can be used to flush the system if the underdrain becomes clogged.

During extreme droughts, the tree or shrub may need supplemental water just as any other landscape plants. In these high stress environments, plants may need to be replaced every few years (5 years is the interval assumed for this cost estimate).

Potential LEED Credits

Primary: N/A

Other: Innovation & Design Process (1-4 Points)

Links to Additional Information

Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution.
http://www.nrdc.org/water/pollution/storm/stoinx.asp

Sizing of Tree Box Filters - LID Stormwater
http://www.lid-stormwater.net/treebox/treeboxfilter_sizing.htm

LID Technologies, Whole Building Design Guide
http://www.wbdg.org/design/lidtech.php

Americast Filterra
http://www.americastusa.com/filterra.html

Performance and Inspection

To ensure proper performance, visually inspect each tree box filter to verify that stormwater is infiltrating properly. Excessive volumes of stormwater bypassing a tree box filter may indicate operational problems.

Corrective measures to restore performance include further detailed inspection to uncover accumulated sediments and debris and, then, removal, if needed.

In instances where the condition of the soil media has significantly degraded, the media and vegetation should be removed and replaced.

Inspection and maintenance should occur on an annual or semi-annual basis.

VIII.10.Green Roofs

Extensive green roof in Baltimore, MD
Source: Katrin Scholz-Barth Consulting.

Design Criteria:

- **Extensive green roofs are low profile and lightweight: thin sheaths of soils, mosses, sedums, herbs and other perennials**
- **Intensive green roofs use a greater depth of growth media and sturdier structures to support trees, shrubs and activity areas**
- **Green roofs consist of several layers:**
  - **Waterproof membrane***
  - **Root barrier**
  - **Insulation layer**
  - **Drainage layer**
  - **Growth medium**
  - **Vegetation**

Leak detection is optional

Maintenance:

- **Properly installed green roofs require little upkeep beyond typical conventional roofs**
- **Periodic weeding, as well as soil and plant replenishment are the primary upkeep tasks for extensive green roofs**
- **Intensive green roofs require more structural as well as horticultural upkeep**
- **EFVM systems are recommended for intensive green roofs in case leaks need to be discovered and repaired**
- **Conditions of draught or high wind may require supplemental watering/irrigation**

Advantages:

- **Reduce roof runoff volume**
- **Reduce runoff pollutant loads**
- **More durable than conventional roofs**
- ***Extensive* greenroofs are useful for retrofits**
- ***Intensive* greenroofs provide valuable urban open space**
- **Insulating properties absorb noise, reduce energy use/loss and ameliorate urban heat island effects --- resolving many urban issues simultaneously**

Disadvantages:

- **Among LID practices and technology, green roofs are one of the most expensive alternatives**
- **Designing green roofs requires uncommon professional expertise and additional design costs**
- **Maintenance of green roofs requires some degree of specialized training**

Stormwater Management Suitability

Runoff Volume Reduction

Peak Discharge Rate Reduction

Water Quality

Water Quantity Controls

Green roofs store rainwater in their soil layer, reducing the volume and peak discharge rate of roof runoff. The storage capacity can be estimated using the equation below.
Equation 1:
*Storage volume = (green roof area) * (soil depth) * (soil porosity)*

This equation is based on the fundamental principle of soil porosity and provides a general guideline for estimating storage capacity. More complex calculations can be used for further detailed analysis.
Green roofs are generally sized to store the water quality volume (WQV):
the first 0.5" of rainfall.

Additional soil depth can be used to increase a green roof's storage capacity.

Part of the stormwater will be retained on the roof and lost to evapo-transpiration. Part of the stormwater will percolate through the drainage layer and become surface runoff. The water retention capacity of the soil medium is dependent upon both the properties of the medium and characteristics of the vegetative cover, as well as climactic conditions.

Water Quality Controls

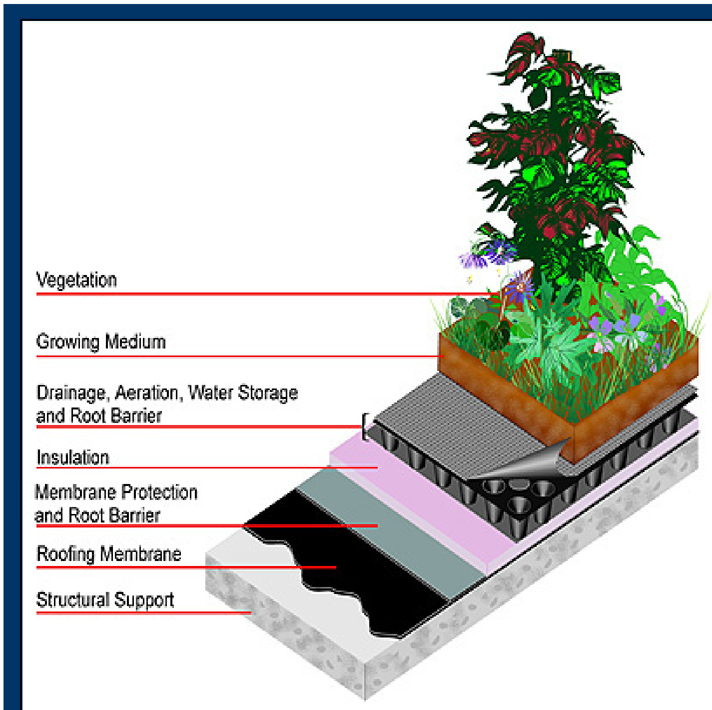
No conclusive water quality information can be presented at this time; research in this area is ongoing.

More Information:
Green Roofs for Healthy Cities
http://www.greenroofs.org/

Third Annual Greening Rooftops for Sustainable Communities Conference, Awards, & Trade Show, May 4th - 6th, 2005 - Washington, D.C.
http://www.greenroofs.org/washington/index.php

Location

Green roofs can be placed on any residential, commercial, or industrial roof surface that is not reserved for patio or utility access.



Extensive green roof cross-section
Source: American Wick Drain Corp.

Cost

Costs for ***extensive*** green roofs are $15 to $20 per square foot for all use types (e.g. high density residential or commercial/industrial). These costs include all green roof components, including waterproof membrane, growth medium, and plants.

The highest costs of green roof construction are the growth medium components and plants. Costs are higher if plants are placed individually rather than installed as vegetated mats.

Costs are given for an ***extensive*** green roof. The cost for a ½ acre (21780 ft^2) extensive green roof consists of both installation costs and annualized costs.

A green roof is assumed to have a lifespan of 25 years, at which point it would be removed and replaced.

Design Construction and Materials

Green roofs consist of several layers. Beginning with the bottom layer, they consist of a waterproof membrane, a root barrier, an insulation layer, a drainage layer, growing medium, and vegetation. A drainage layer is needed for flat roofs but may not be necessary for sloped roofs. A leak detection system below the membrane is optional.

Deciding whether to construct an intensive or extensive roof may be influenced by the property owner's desired maintenance level and by the roof's structural capacity. Soil depth is another design variable and determines water storage capacity. Plants recommended for use on green roofs are hardy, self-sustaining, drought-resistant plants.

Often, plants of the Sedum and Delosperma (common succulents) genuses are used for extensive green roofs. Many species ane varieties are available from a wide array of vendors.

Item	Required Cost per Year (2005 Dollars)												
	0	1	2	3	4	5	6	7	8	9	10	…	25
Installation[1]	250,000												
Weeding		500	500	500	500	500	500	500	500	500	500		
Infill with cuttings[2]						6000					6000		
Soil replenishment						1000					1000		
Remove & Replace													250,000
Total Cost	**250,000**	**500**	**500**	**500**	**500**	**7500**	**500**	**500**	**500**	**500**	**7500**		**250,000**
Annualized Cost	$11,600 / year (includes replacement in year 25). Excluding replacement: $1,600 / year												

[1]Developer Cost. Not included in annualized cost.

[2]Assume 5% of area needs replanting, and a density of 2 plugs per square foot.

Maintenance

Once a properly installed green roof is established, its maintenance requirements are generally minimal. The main requirements for ***extensive*** roofs are weeding, as well as periodic soil and plant replenishment. More structural and horticultural maintenance is required for ***intensive*** roofs because plantings are typically heavier and more elaborate.

Corrective actions for green roofs are generally localized repairs. Leaks need to be quickly repaired, if they should be detected. An electric leak survey (i.e. Electrical Field Vector Mapping) can be performed to locate leaks in the membrane. More complex green roof systems have monitoring devices installed with the waterproof membrane.
Long periods of drought or loss of soil to high winds may require replacement of growth media or replanting. If drought becomes an issue, corrective actions include installing an irrigation system or scheduling supplemental watering.

Potential LEED Credits

Primary: Sustainable Sites – Credit 7.2 "Landscape & Exterior Design to Reduce Heat Islands" (1 Point)
Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)
Water Efficiency – Credit 1 "Water Efficient Landscaping" (1-2 Points)
Other: Innovation & Design Process (1-4 Points)

Links to Additional Information

Natural Resources Defense Council, 2001: Stormwater Strategies: Community Responses to Runoff Pollution.
http://www.nrdc.org/water/pollution/storm/stoinx.asp

Green Roofs for Healthy Cities
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http://www.greenroofs.org/washington/index.php

Resource Portal for Green Roofs
http://www.greenroofs.com/

Performance and Inspection

Soil stability and plant vitality are keys to the function of green roofs. Green roofs should be inspected annually for loss of growth medium due to erosion and to asssure plant health. However, wind or water erosion should not be a major concern because the plants' dense root structures provide stabilization. If any erosion should occur, add soil, replant, and install temporary erosion control fabric. Replace dead plants as needed.

Note: if slow-growing plants are selected, more than a single growing season may be needed to achieve full growth.