City of Indianapolis
Department of Public Works
Green Infrastructure Supplemental Document
2015

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Executive Summary

The goal of this document is to introduce Low Impact Development (LID) techniques and the benefits (incentives), as well as to provide sufficient information (description and applicability, advantages, disadvantages, technical guidance, and cost) on each practice to demonstrate the strategies necessary to integrate innovative and highly effective LID Storm Water management techniques into design.

LID is an approach to land development that uses various land planning, design practices and technologies to simultaneously conserve and protect natural resource systems. It is an innovative multi-step Storm Water management approach that 1) utilizes thoughtful site planning and 2) manages rainfall at its source through the use of integrated and distributed micro-scale Storm Water practices (green infrastructure).

Some of the onsite Storm Water runoff reduction practices (green infrastructure) included in this document are downspout disconnection, rain barrels, cisterns, rain gardens, green roofs, roof-top storage, swales, and permeable pavement systems, among others. Several of the incentives for incorporating these techniques into design include: ancillary benefits, reduction in Storm Water sizing criteria (water quality and quantity), and a reduction in the Storm Water Utility Fee.

LID Storm Water management techniques can be used to meet supplementary goals (or in many instances other existing City regulations) in addition to meeting the Storm Water requirements. Many LID Storm Water management techniques can be integrated into urban site features (rain gardens, flow through planters, swales). A number of the generally accepted benefits from LID techniques (green infrastructure) include: cleaner water, enhanced water supplies, cleaner air, reduced urban temperatures, increased energy efficiency, infrastructure cost savings, and community benefits (quality of life).

In general, the Storm Water sizing criteria provide a strong incentive to reduce impervious cover (through LID techniques) at development and redevelopment sites (e.g., water quality and quantity). Developers could reduce the imperviousness by 20% and potentially reduce the volume of water they have to manage for quality by 30%. Reducing the curve number from 85 to 75 on a development can reduce runoff by nearly 25%. This could potentially reduce the overall cost of development.

The relationship between percent (%) impervious area and Storm Water Utility Fee is directly proportional. For a 20-acre parcel, if the site is 80% impervious the 20-year net present value of the current utility fee is approximately $102,986.44. In comparison, a reduction in imperviousness to 60% would result in a 20-year net present value of $77,239.83.

There are many incentives for incorporating LID Storm Water management techniques into Storm Water design. Developers and Municipalities, alike are realizing these benefits and have started integrating these techniques into both public and private development and redevelopment projects across the country.

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Table of Contents

1. Introduction 1
1.1. Developing the Storm Water Green Incentive Document (Credibility) 1
1.2. Change in Storm Water Design Paradigm 1
1.3. Why a Change in Design Paradigm 2
2. Low Impact Development 3
2.1. What is Low Impact Development (LID)? 3
2.2. Why use LID (Incentives)? 5
2.2.1. Incentives and Grants 5
2.2.2. Ancillary Benefits from LID Storm Water Management Techniques 8
2.2.3. Reduction in Storm Water Infrastructure Sizing 13
2.2.4. Water Quality Volume Reduction 13
2.2.5. Water Quantity Reduction 15
2.2.6. Reduction in Storm Water Utility Fee 24
2.2.7. Analysis of Storm Water Fee Incentive 24
2.2.8. Options for Small Spaces/Redevelopment Areas 26
3. Techniques to Reduce Impervious Cover 30
3.1. Rooftop Disconnection 30
3.2. Pavement Disconnection 31
3.3. Maximize Tree Canopy Over Impervious Cover 32
3.4. Install Green Roofs to Reduce Impervious Area 33
3.5. Install Permeable Pavement Systems to Reduce Impervious Area 33
4. Green Design Fact Sheets/ Design Techniques 36
4.1. Green Roofs 38
4.1.1. Green Roof Example O & M Manual 50
4.1.2. Green Roof Designer/Reviewer Checklist 53
4.2. Permeable Pavement Systems 54
4.2.1. Permeable Pavement Example O & M Manual 71
4.2.2. Permeable Pavement Designer/Reviewer Checklist 74
4.3. Rain Water Harvesting 75
4.3.1. Rain Water Harvesting Example O & M Manual 83
4.3.2 Rain Water Harvesting Designer/Reviewer Checklist 86
4.4. Filter Strips 87
4.4.1. Filter Strip Designer/Reviewer Checklist 94
4.5. Bioretention 95
4.5.1. Bioretention Example O & M Manual 112
4.5.2. Bioretention Designer/Reviewer Checklist 116
4.6. Low Impact and Retentive Grading 118
4.6.1. Low Impact and Retentive Grading Designer/Reviewer Checklist 124
4.7. Swales 126
4.7.1. Swale Designer/Reviewer Checklist 134
4.8. Subsurface Infiltration 136
4.8.1. Subsurface Infiltration Trench Designer/Reviewer Checklist 143
4.9. Inlet and Outlet Controls 144
4.9.1. Inlet and Outlet Controls Designer/Reviewer Checklist 153
4.10. Filters 155
4.10.1. Filter Designer/Reviewer Checklist 163
4.11. Subsurface Vaults 165
4.11.1. Subsurface Vault Designer/Reviewer Checklist 169
4.12. Detention Basins 171
4.12.1. Detention Basin Designer/Reviewer Checklist 180
5. Storm Water Landscape Guidance 181
5.1. Planting Recommendations / Guidelines 181

5.2. Facility Specific Landscaping Guidance 185
5.3. Native and Recommended Non-invasive Plants 191
6. Applicability and Comparison 201
6.1. Evaluation of Green Design Techniques 203
References 211

List of Figures

Figure 2.1.1: Impacts of Typical Development to the Natural Water Balance.....3
Figure 2.1.2: Green Roof Technology Chain of Benefits 10
Figure 2.1.3: Relationship Between Required Water Quality Volume Storage and Site Imperviousness (%) 14
Figure 2.1.4: SCS Solution of the Runoff Equation 16
Figure 2.1.5: Conventional Site Example 18
Figure 2.1.6: LID Site Example 19
Figure 2.1.7: Redevelopment Site Design Example Conventional vs. LID 21
Figure 2.1.7: Redevelopment Site Design Example Conventional vs. LID, cont. 22
Figure 2.1.8: New Development Site Design Example Conventional vs. LID 23
Figure 2.1.9: Redevelopment LID Water Quality Design Example 28
Figure 3.1.1: Gravel Level Spreader Connected to Filter Strip 32
Figure 3.1.2: Example Permeable Pavement System Impervious Area Reduction Technique 34
Figure 4.2.1: Permeable Paver System Cross Section 58
Figure 4.2.2: Pervious Concrete System Cross Section.....58
Figure 5.2.1: Zone of a Bioretention System 189

List of Tables

Table 2.1.1: Green Roof Cost Comparison to Conventional Roofing System and Cool Roofing System (www.greenroofs.net)....12
Table 2.1.2: Area-Weighted CN Calculation for Conventional Design....18
Table 2.1.3: Area Weighted CN Calculation for LID Design....19
Table 2.1.4: Example Storm Water Utility Fee Calculation....25
Table 3.1.1: Partial Rooftop Disconnection....31
Table 4.1.1: Green Roof Potential Application and Storm Water Regulation....39
Table 4.1.2: Engineering/Drainage Report Requirements Summary....46
Table 4.1.3: Plan Requirements....47
Table 4.1.4: O&M Manual Requirements....48
Table 4.2.1: Permeable Pavement Potential Application and Storm Water Regulation....55
Table 4.2.2: Suggested Starting Porous Pavement Design Values....61
Table 4.2.3: Required Choker Course Gradation....62
Table 4.2.4: Required Stone Storage Gradation....62
Table 4.2.5: Porous Bituminous Aggregate Gradation....63
Table 4.2.6: Engineering Report Requirements....66
Table 4.2.7: Plan Requirements....67
Table 4.2.8: O & M Manual Requirements....68
Table 4.3.1: Rain Barrel Potential Application and Storm Water Regulation....75
Table 4.3.2: Suggested Storage Design Values for Rain Barrels....78
Table 4.3.3: Engineering/Drainage Report Requirements Summary....79
Table 4.3.4: Plan Requirements....80
Table 4.3.5: O & M Manual Requirements....81
Table 4.4.1: Filter Strips Potential Application and Storm Water Regulation....88
Table 4.4.2: Suggested Starting Design Values for Filter Strip Length....90
Table 4.4.3: Suggested Maximum Velocities and Water Depths for Filter Strip Area....91
Table 4.4.4: Filter Strips Maintenance Guidelines....93
Table 4.5.1: Bioretention Potential Application and Storm Water Regulation....96
Table 4.5.2: Suggested Starting Design Values for Areas and Depths....101
Table 4.5.3: *Bioretention* Engineering/Drainage Report Requirements Summary....103
Table 4.5.4: *Microbioretention* Engineering/Drainage Report Requirements Summary....104
Table 4.5.5: *Bioretention* Plan Requirements....105
Table 4.5.6: *Microbioretention* Plan Requirements....106
Table 4.5.7: *Rain Garden* Engineering/Drainage Report Requirements Summary....107
Table 4.5.8: *Rain Garden* Plan Requirements....108
Table 4.5.9: *Bioretention, Microbioretention and Rain Garden* O & M Manual Requirements....109
Table 4.6.1: Low Impact and Retentive Grading Potential Application and Storm Water Regulation....119
Table 4.6.2: Starting Design Values for Berm Areas and Depths....121
Table 4.6.3: Berm & Grading Maintenance Guidelines....123
Table 4.7.1: Swales Potential Application and Storm Water Regulation....126
Table 4.7.2: Suggested Swale Starting Design Values....129
Table 4.7.3: Swale Maintenance Guidelines....133
Table 4.8.1: Subsurface Infiltration Potential Application and Storm Water Regulation....136

Table 4.8.2: Starting Design Values for Subsurface Infiltration Areas and Depths 139
Table 4.8.3: Subsurface Infiltration Maintenance Guidelines 142
Table 4.9.1: Inlet Maintenance Guidelines 149
Table 4.9.2: Outlet Maintenance Guidelines 152
Table 4.10.1: Filters Potential Application and Storm Water Regulation 156
Table 4.10.2: Suggested Starting Design Values for Ponding and Media Depths 160
Table 4.10.3: Filter Maintenance Guidelines.....161
Table 4.11.1: Subsurface Vaults Potential Application and Storm Water Regulation 165
Table 4.11.2: Subsurface Vaults Maintenance Guidelines 168
Table 4.12.1: Detention Basins Potential Application and Storm Water Regulation.....171
Table 4.12.2: Starting Design Parameters for Detention Basins 176
Table 4.12.3: Contour Design Parameters for Detention Basins 177
Table 4.12.4: Inlet Control and Sediment Forebay.....177
Table 4.12.5: Detention Basin Maintenance Guidelines 179
Table 5.1.1: Planting Specifications 185
Table 5.2.1: Lowest Zone (Hydrologic zones 2-4) Suggested Plants.....190
Table 5.2.2: Middle Zone (Hydrologic zones 4-5) 190
Table 5.2.3: Outer Zone (Hydrologic zones 5-6).....190
Table 5.3.1: Recommended Plant List (the excel spreadsheet is available online to download for easier use).....195
Table 6.0.1 Green Storm Water Infrastructure Land Use and Land Area Selection Matrix 201
Table 6.0.2 Effectiveness of BMPs in Meeting Storm Water Management Objectives.....202
Table 6.1.1: Evaluation of Storm Water Reduction BMPs.....207
Table 6.1.2: Cost Effectiveness of Storm Water Reduction BMPs 209

Appendices

Appendix 1: Low Impact Development for Big Box Retailers
Appendix 2: New Life Cycle Calculator Compares the Cost of Green Vegetative Roofs with Conventional Roof Systems and Life Cycle Cost Calculator-Phase 1
Appendix 3: Milwaukee Metropolitan Sewerage District (MMSD) Quicksheet 1.2
Appendix 4: Urban Watershed Forestry Manual; Part 2: Conserving and Planting Trees at Development Sites
Appendix 5: City of Indianapolis Redevelopment Site Design Example
Appendix 6: City of Indianapolis New Development Site Design Example

Attachments

Attachment 1: Guidelines for Subsurface Investigation and Infiltration Testing
Attachment 2: Green Roof Design Guidelines
Attachment 3: Permeable Pavement Systems Design Example
Attachment 4: Rain Water Harvesting Design Guidelines
Attachment 5: Bioretention Design Guidelines
Attachment 6: Swale Design Guidelines

1. Introduction

Purpose: The goal of the document is to introduce Low Impact Development (LID) techniques and benefits (incentives), as well as to provide sufficient information (description and applicability, advantages, disadvantages, technical guidance, and cost) on each practice to demonstrate the strategies necessary to integrate innovative and highly effective LID Storm Water management techniques into design. As with any practice, Storm Water management is continuously evolving. Therefore this document should be used as a benchmark, and as LID Storm Water management techniques become more prevalent in Indianapolis, new techniques and data may become available to provide further design suggestions and practices.

1.1. Developing the Storm Water Green Incentive Document (Credibility)

1) Extensive review of other cities'/states' LID techniques/Green Infrastructure and incentives was completed. The following cities'/ states' guidelines were reviewed: Chicago, Portland, Seattle, Minnesota, Milwaukee, Philadelphia, and Maryland (These documents and their URLs are referenced in the bibliography). Many of the reviewed design guidelines/green documents were authored by a consortium of experts in LID techniques including the following organizations: Natural Resources Defense Council (NRDC), `the National Association of Clean Water Agencies, the Environmental Protection Agency (EPA), the Low Impact Development Center, and Universities. The document's intent is to consolidate as many viable sources as concisely and logically as possible into one document for the City of Indianapolis. These documents were reviewed with three main focus points; 1) the city's or state's Storm Water design regulations, 2) technical design information, and 3) applicability to Indianapolis.

2) Philadelphia's and Milwaukee's Storm Water design guidelines were primarily, but not exclusively, used in developing many of the BMP fact sheets for Indianapolis. In addition, the LID technique center and EPA published a document, *LID for Big Box Retailers*, which is used for some of the design examples within this document (provided in Appendix 1). It is essential for the success of green infrastructure to keep in mind, that while some of the concepts in green design are transferable, regional conditions (rainfall intensity and patterns, evaporation, transpiration, soil properties, plant selection, etc.) are extremely crucial in the physical application of green design. Regional experts from both the private sector and academia were utilized to review the green design Fact Sheets.

1.2. Change in Storm Water Design Paradigm

A change in the design paradigm for Storm Water management is currently evolving around the world. Storm Water design was (and often, still is) put off until the last stage of development. However, Storm Water is becoming one of the first planning tools when evaluating a site and is being looked at as a valuable natural resource, not a problem to be

piped and conveyed into the nearest ditch, channel, or stream. Many developers and municipalities alike are realizing the benefits of incorporating Storm Water management into the initial planning stages and integrating various green infrastructures into both private and public development and redevelopment projects.

1.3. Why a Change in Design Paradigm

There are a number of reasons for this shift. The primary reasons are:

1) **Regulatory Changes**. Many cities and states have adopted a comprehensive watershed planning approach to further address common Storm Water management problems found across the world such as: combined sewer overflows (CSOs), stream deterioration (chemical, biological, physical, and recreational), and decreased groundwater recharge. Many cities and states have adopted not only quality and quantity design requirements, but also recharge volume, channel protection storage volume, and overbank flood protection volume requirements. Conventional Storm Water design cannot solely be used in order to meet these design criteria. LID/green infrastructure in many cases must be integrated into the design to meet these regulatory requirements.

2) **Availability of Reliable Data.** Many cities and states have been slow to adopt or accept LID techniques and the various green infrastructures into policy because of the lack of historical performance data. Cities and states do not want to rely on potentially maintenance-intensive techniques that may "fail" when the primary objective of Storm Water management has been to protect citizens from flooding. However, in the past decade there has been extensive research completed to provide scientific data on these techniques and the relatively low-maintenance requirements of most of the options. Recently the EPA has encouraged the use of green infrastructure, claiming that it can be both cost-effective and an environmentally preferable approach to reduce Storm Water runoff entering combined or separate sewer systems in combination with or in lieu of centralized hard infrastructure. (EPA, 2007)

3) **Consumer Demand.** Large corporations and companies are beginning to focus on social and environmental responsibility, allocating funds and effort to research into alternative energy sources and actions they can take to be better stewards of the environment.

2. Low Impact Development

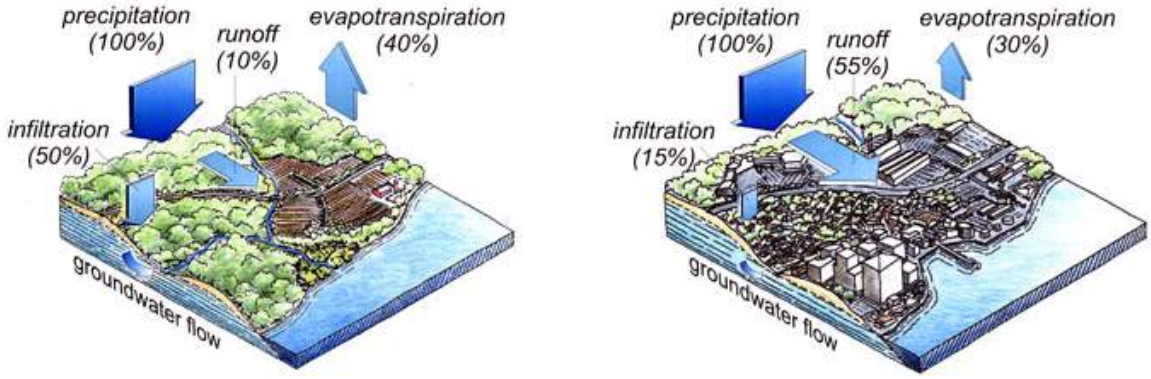
2.1. What is Low Impact Development (LID)?

LID is an approach to land development that uses various land planning techniques, design practices and technologies to simultaneously conserve and protect natural resource systems. It is an innovative multi-step Storm Water management approach that 1) utilizes thoughtful site planning and 2) manages rainfall at its source through the use of integrated and distributed micro-scale Storm Water practices.

Examples of thoughtful site planning 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. Examples of integrated and distributed micro-scale Storm Water practices include: bioretention, permeable pavers, flow through planters, disconnected downspouts, rain barrels, and green roofs, among others (refer to Section 4). Ultimately, natural hydrologic functions such as storage, infiltration, evaporation, transpiration, and groundwater recharge are used to their fullest potential to help minimize the amount of Storm Water runoff that must be managed. This helps users to control pollutants, reduce runoff volume, manage runoff timing, and address other ecological concerns.

In contrast, conventional land development techniques typically begin with clearing and grading the entire parcel, resulting in the removal of all vegetation. The next development steps traditionally include paving areas for roads and parking, building structures, and landscaping areas. This results in large amounts of impervious surface which prohibits Storm Water from infiltrating into the ground to replenish the groundwater or supply local streams and wetlands with baseflow. In order to manage the large amount of runoff generated from the impervious surface created from development, engineers then design structural Storm Water controls such as catch basins, pipes, and detention ponds.

Figure 2.1.1: Impacts of Typical Development to the Natural Water Balance



(Smart Growth Tool Kit, 2007)

Figure 2.1.1 shows the impact typical development has on the natural hydrologic cycle. As mentioned above, typical development creates large areas of impervious surface, which prevents

infiltration and subsequently generates larger runoff volumes. Under natural predevelopment conditions, more rain infiltrates through soils and percolates downward to the groundwater table.

Fact sheets and referenced attachments for a number of onsite Storm Water reduction practices are provided in Section 4.

4.1 Green Roofs: A green roof (vegetated roof/eco roof/roof garden) is a system consisting of waterproofing material, growing medium and vegetation. A green roof can be used in place of a traditional roof as a way to limit impervious site area and manage Storm Water runoff. See **Attachment 2** for design guidelines, examples and a typical detail.

4.2 Permeable Pavement Systems: Permeable Pavement provides the structural support of conventional pavement, but allows Storm Water to drain directly through the surface into the underlying stone base and soils, thereby reducing Storm Water runoff. There are permeable varieties of asphalt, concrete, and interlocking pavers. Permeable pavements are designed with an open graded stone sub-base that allows water to pass through to the native soil and provides temporary storage. See **Attachment 3** for design guidelines, examples and a typical detail.

4.3 Rain Water Harvesting: Rain barrels, cisterns, and tanks are structures designed to intercept and store runoff from rooftops. Rain barrels are used on a small scale while cisterns and tanks may be larger. See **Attachment 4** for design guidelines, examples and a typical detail.

4.4 Filter Strips: Filter Strips are densely vegetated lands that treat sheet flow Storm Water from adjacent pervious and impervious areas. They function by slowing runoff, trapping sediment and pollutants, and in some cases infiltrating a portion of the runoff into the ground.

4.5 Bioinfiltration/Bioretention/RainGarden: Bioretention areas typically are landscaping features adapted to treat Storm Water runoff. Bioretention systems are also known as Mesic Prairie Depressions, Rain Gardens, Infiltration Basins, Infiltration swales, bioretention basins, bioretention channels, tree box filters, planter boxes, or streetscapes, to name a few. Bioretention areas typically consist of a flow regulating structure, a pretreatment element, an engineered soil mix planting bed, vegetation, and an outflow regulating structure. See **Attachment 5** for design guidelines, examples and a typical detail.

4.6 Low Impact/Retentive Grading: Low Impact and Retentive Grading techniques focus on utilizing existing topography during Site layout to minimize cost. Proposing structures, roads, and other impervious surfaces along existing high ground will allow for Storm Water to drain onto adjacent Storm Water utilities with a minimum of earthwork required.

4.7 Swales: A swale is a vegetated open channel, planted with a combination of grasses and other herbaceous plants, shrubs, or trees. A traditional swale reduces peak flow at the

discharge point by increasing travel time and friction along the flow path. See **Attachment 6** for design guidelines, examples and a typical detail.

4.8 Subsurface Infiltration: Subsurface infiltration systems are designed to provide temporary below grade storage infiltration of Storm Water as it infiltrates into the ground. Dry wells, infiltration trenches and beds are a few examples of these types of systems.

4.9 Inlet and Outlet Control: Inlet and Outlet controls are the structures or landscape features that manage the flow into and out of a Storm Water management facility. Flow splitters, level spreaders, curb openings, energy dissipaters, traditional inlets, and curbless design are all examples and elements of inlet controls.

4.10 Filters: Filters are structures or excavated areas containing a layer of sand, compost, organic material, or other filter media. They reduce pollutant levels in Storm Water runoff by filtering sediments, metals, hydrocarbons, and other pollutants.

4.11 Subsurface Vaults: Subsurface Vaults are specialized underground structures designed similarly as above ground detention or retention basins. These underground basins can be utilized for groundwater recharge by allowing infiltration.

4.12 Detention Basin: Detention Basins can be a cost effective method to provide temporary storage, conveyance, and treatment of runoff when used within the context of Low Impact Development (LID) strategies. Long, linear, interconnected basins can provide the designer with an economically attractive method to provide source control of Storm Water as well as convey water without the slope and cover requirements of conventional storm sewer design.

2.2. Why use LID (Incentives)?

2.2.1. Incentives and Grants

The City has established incentive and grant programs to help encourage the use of green infrastructure. These incentives are designed to help developers offset costs of green improvements through rebates and grants and to help expedite permitting of sustainable projects. The incentives apply to both new construction and renovations. The following are descriptions of those programs that are available:

1.) **Credit Incentive Program.** The Department of Public Works has developed a system of credits for the storm water user fee imposed on the users of the Marion County Storm Water Management District's storm water system. The ability of a property owner to receive any of the credits is dependent on the property owner owning and maintaining a Department-approved BMP and providing the document required. Table 2.1 outlines the types of credits available to residential and non-residential property owners. Additional information regarding storm water credits can be found within the latest version of the City of Indianapolis Storm Water Credit Manual.

Table 2.1 - Available Credits for Residential and Non-Residential Parcels

	Residential Parcels	Non-Residential Parcels		
Credit Category	**Individual Residential Parcel**	**Homeowners or Condominium Association**	**Commercial, Industrial, Mix-Use Development, Other Non-Residential**	**Public/Private School, Primary to 12**
Individual Residential Property Credit	25%			
Tier 1 Storm Water Quality and Quantity Credit		Up to 10%*	Up to 10%	Up to 10%
Tier 2 Storm Water Quality and Quantity Credit		Up to 30%*	Up to 30%	Up to 30%
Infiltrative Credit		20%*	20%	20%
Education Credit				5%
Direct Discharge Credit		Up to 50%	Up to 50%	Up to 50%
Total	**Up to 25%**	**Up to 50%**	**Up to 50%**	**Up to 50%**

*The maximum credit or combination of credits given to any one property shall be 50% for non-residential property owners and 25% for residential property owners.

2) **Green Building Incentive Program.** The green building incentive program is designed to create incentives for property owners and developers who renovate and/or construct new buildings in a sustainable manner, and is the first of its kind in Indianapolis. The program allows for building projects to receive up to a 50% rebate on all building permit fees associated with the green project. The incentive encourages building owners and developers to integrate sustainable design techniques and practices into building projects. More information is available at: http://www.indy.gov/eGov/City/DPW/SustainIndy/Green/Pages/GreenBuildingIncentiveProgram.aspx

3) **Sustainable Infrastructure Initiative.** Plans must still meet the Storm Water requirements outlined in Chapter 700 of the Storm Water Design and Construction Specifications Manual, but designs and plans that use green infrastructure techniques as defined in the Green Supplemental Document to meet those requirements will be approved by the Office Department of Code Enforcement.

Upon submittal of projects that incorporate these green techniques, permit review will be immediately processed and expedited to the greatest extent possible. This will not only encourage newcomers to utilize green infrastructure methods, but it will also reinforce the City's commitment to those already well versed in green infrastructure techniques.

In order to alert the Department of Code Enforcement staff that the project being submitted incorporates green infrastructure, each green project will require a green infrastructure checklist to accompany the green project designs. When Department of Code Enforcement staff sees the Sustainable Infrastructure checklist submitted with a project design, it will alert them that the project incorporates green infrastructure and the permit review will be immediately processed and expedited to the greatest extent possible. More information is available at:
http://www.indy.gov/eGov/City/DPW/SustainIndy/WaterLand/Pages/SustainableInfrastructure.aspx

4) **Green Infrastructure Grant Program.** The City of Indianapolis' Office of Sustainability and United Water have partnered to announce that applications are available for the Green Infrastructure Grant Program. This year, $100,000 in funding will be granted to organizations who utilize green infrastructure projects designed to improve water quality and reduce Storm Water runoff.
Maximum Grant Award: $20,000 (requires 20 percent matching contribution, match may be provided by applicant, LISC, a CDC, or another entity).
Eligible Entities: Not-for-profit organizations committed to efforts in sustainable development within Marion County, For-Profit Organizations (with approval)
More information is available at:
http://www.indy.gov/eGov/City/DPW/SustainIndy/WaterLand/GreenInfra/Pages/GreenInfrastructureGrantProgram.aspx

5) **Rain Garden and Native Planting Programs.** To promote rain gardens and native planting areas, the City of Indianapolis has established a Rain Garden Resource Center outlining supplies, customized planting plans, maintenance guidelines, permitting guidance, and more. The resource center is intended to be used by residents, businesses, developers, and institutions. Rain gardens and native planting areas can vary in size from a small rain garden in the corner of a residential lot to a large bioretention area receiving runoff from a commercial strip mall. Permitting requirements are most likely an issue only for larger projects, especially those that tie into City drainage, but the owners of all rain garden and native planting projects must check the permitting guidance. Information is available at:
www.indy.gov/eGov/City/DPW/SustainIndy/WaterLand/GreenInfra/Pages/RainGardenResources.aspx

2.2.2. Ancillary Benefits from LID Storm Water Management Techniques

LID Storm Water management techniques can be used to meet supplementary goals (or in many instances other existing City regulations) in addition to meeting the existing Storm Water requirements. A development or redevelopment site often has a required amount of green space or landscape requirements that must be met along with the Storm Water management requirements. Many LID Storm Water management techniques can be integrated into urban site features. In addition to meeting regulatory measures, some of the specific ancillary benefits from LID techniques/Green Infrastructure include (*EPA, 2007*):

Cleaner Water - Vegetation and green space reduce the amount of Storm Water runoff and, in combined systems, the volume of combined sewer overflows.

Enhanced Water Supplies - Most green infiltration approaches result in Storm Water percolation through the soil to recharge the groundwater and the base flow for streams.

Cleaner Air - Trees and vegetation improve air quality by filtering many air borne pollutants and can help reduce the amount of respiratory illness.

Reduced Urban temperatures - Summer city temperatures can average 10°F higher than nearby suburban temperatures. High temperatures are linked to higher ground level ozone concentrations. Vegetation increases shade, reduces the amount of heat absorbing materials and emits water vapor - all of which cool hot air.

Increased Energy Efficiency - Green spaces help lower ambient temperatures by shading and insulating buildings. Thereby decreasing energy needed for heating and cooling.

Community Benefits - Trees and plants improve urban aesthetics and community livability by providing recreational and wildlife areas and can raise property values.

Cost Savings - Green infrastructure may save capital costs on digging big tunnels and Storm Water ponds, operations and maintenance expenses for treatment

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. A LEED certified facility can offer competitive advantage and increase real estate value, thus improving its marketability. Appendix 1 provides a description of potential LEED credits for various Storm Water management techniques.

In general, many of the green infrastructure techniques provide the ancillary benefits listed above; specifically green roofs and their associated benefits are further identified in Figure 2.1.2

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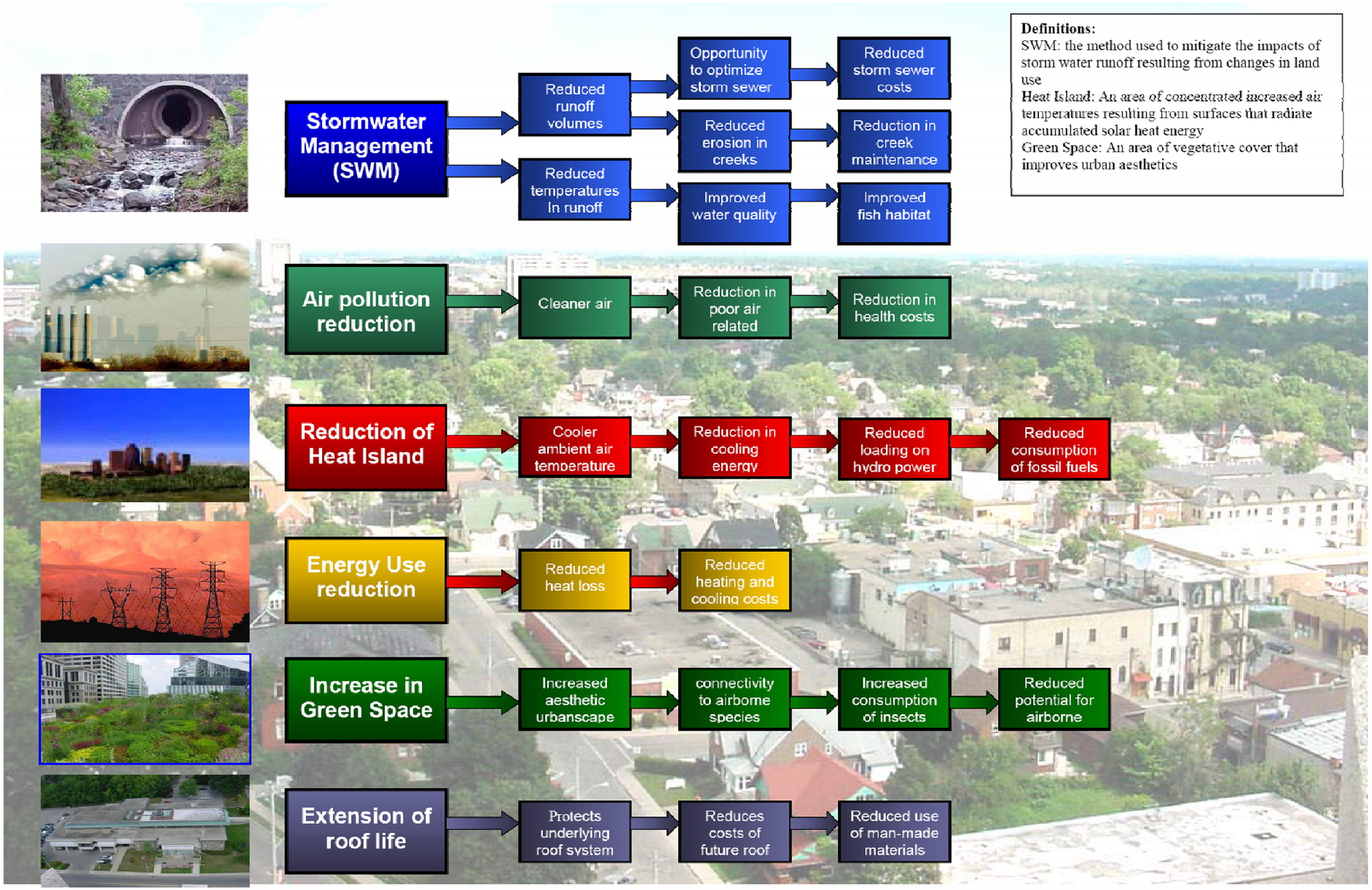
Figure 2.1.2: Green Roof Technology Chain of Benefits
(TSH Associates, 2004)



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There are many ancillary benefits associated with green roofs, supplemental to Storm Water management, as demonstrated by Figure 2.1.2. Although these benefits are well documented, there is not a wide variety of tools available to actualize these benefits monetarily. However, Green Roofs for Healthy Cities (GRHC) and the Athena Institute, with funding by TREMCO Inc, recently developed a comprehensive life cycle costing (LCC) calculator. The LCC calculator allows users to evaluate both the hard and soft costs associated with green roofs versus conventional roofing systems and cool roofing system (white roofs) over a specified time period. Provided below, in Table 2.1.1 is an example case study demonstrating this tool. In addition Appendix 2 provides a publication from TREMCO for immediate release titled *New Life Cycle Calculator Compares the Cost of Green Vegetative Roofs with Conventional Roof Systems* and an abstract titled Life Cycle Cost Calculator-Phase 1 published by Green Roofs for Healthy Cities from the 2007 Proceedings from the Greening Rooftops for Sustainable Communities Conference, Awards and Trade Show.

Table 2.1.1: Green Roof Cost Comparison to Conventional Roofing System and Cool Roofing System (www.greenroofs.net)

Common Assumptions	Input Data		
	Scenario 1	Scenario 2	Scenario 3
	Conventional Mod. Bituminous	**PVC Single Ply Cool Roof**	**Extensive Green Roof**
Project Initiation Year	2007	2007	2007
Study Period in Years	25	25	25
Applicable discount rate (%)	8	8	8
General Price Inflation Factor (%)	2.04	2.04	2.04
Thermal Fuel Energy Price Inflation Factor (%)	9	9	9
Electricity Price Inflation Factor (%)	3	3	3
Investment Data			
Investment Description	**Conventional Mod. Bituminous**	**PVC Single Ply Cool Roof**	**Extensive Green Roof**
Total Installed Capital Cost	49,728.00	41,440.00	103,600.00
Annual Electricity Energy Cost	250.00	233.00	232.00
HVAC Downsizing Capital Savings	0.00	0.00	0.00
Stormwater Control	0.00	0.00	3,850.00
Annual Maintenance Cost	761.00	557.00	306.00
Roofing Replacement Interval (in years)	16.00	12.00	25.00
Periodic Replacement Cost	48,317.00	37,140.00	491.00
Periodic Savage Value (at roof replacement)	0.00	0.00	0.00
End of Life Residual Value	16,653.00	25,548.00	23,206.00
UHI Effect Mitigation (capital cost savings)	0.00	0.00	0.00
Development Fee Reduction (capital cost savings)	0.00	0.00	2,500.00
Annual Increase in Revenue due to Roof System	0.00	0.00	2,500.00
Annual Increase in Revenue due to Productivity and Health	0.00	0.00	2,000.00
Net Capital Cost (year 0)	38,065.00	27,870.00	54,868.00
Other Annual Cost or Benefits	0.00	0.00	0.00
Financial Results Summary			
At a discount rate of (%)	8.00	8.00	8.00
NPV for study period (yrs)	-142,393.00	-136,068.00	-103,562.00
NPV at 1/3 of study period	-66,605.00	-55,014.00	-67,406.00
NPV at 2/3 of study period	-114,592.00	-101,271.00	-84,292.00
Simple Payback Period on total project investment (yrs)	Payback Period Longer than Study Period	Payback Period Longer than Study Period	Payback Period Longer than Study Period

The table above is simply an example of a tool that can be utilized when evaluating different options in project planning for a roofing system. In the example provided above, green roofs are

the most favorable option for the entire projected life of the project. However, another favorable roofing option is the PVC single ply cool roof. The PVC single ply cool roof has the best value when evaluating the project at 1/3 of the study period.

A single ply cool roof can be manufactured in a bright-white color for high solar reflectance -or albedo - and increased energy savings. White single ply membranes are highly reflective, as compared to traditional bituminous roofing material, and can help reduce the urban heat island as well as save the building owner cooling costs. Another roofing option, to help reduce the urban heat island is reflective tiles. Reflective tiles are usually made of clay or concrete, and manufactures have begun to develop pigments that reflect in the infrared. Special pigments allow roofing material to keep their traditional colors, such as brown, green, and terra cotta, while reflecting away up to 70% of the sun's energy. These products enable buyers to forego the perceived tradeoff between energy efficiency and the aesthetic concerns with a bright-white roof (EPA, 2007).

2.2.3. Reduction in Storm Water Infrastructure Sizing

In general, the Storm Water sizing criteria provide a strong incentive to reduce impervious cover at development and redevelopment sites (e.g., water quality and quantity). The following section provides examples of how the Storm Water sizing criteria, both water quality and quantity, can be used as an incentive to incorporate LID Storm Water management techniques into design.

2.2.4. Water Quality Volume Reduction

Storage requirements for WQ_v sizing criteria are directly related to impervious cover. Thus, significant reductions in impervious cover result in smaller required storage volumes and, consequently, lower BMP construction costs. Below is the WQ_v sizing criteria equation.

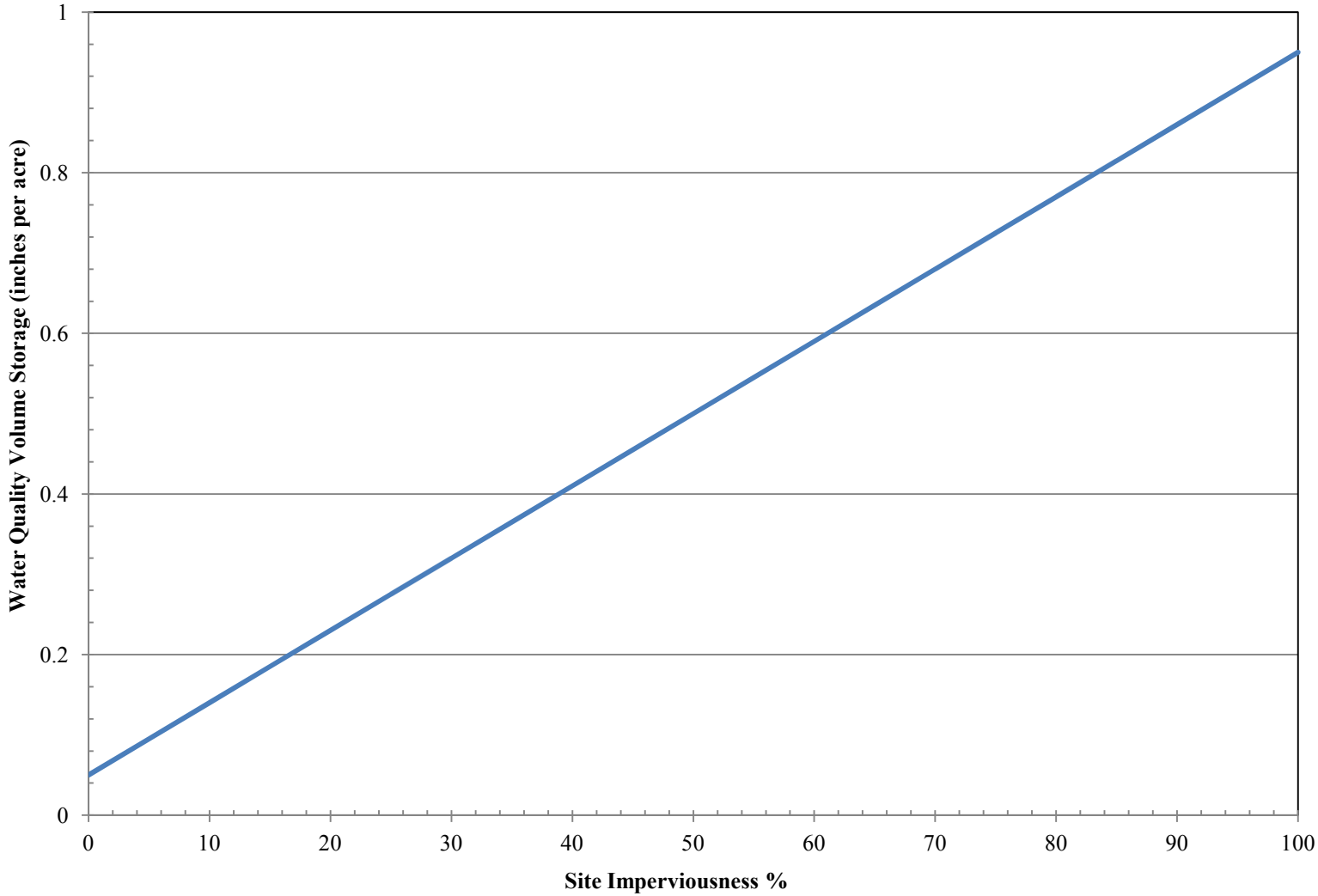
$$WQ_v = \frac{(P)(R_v)(A)}{12}$$

where:

WQ_v = water quality volume (acre-feet)
P = 1 inch of rainfall
R_v = 0.05 + 0.009(I) where I is the percent impervious cover
A = area in acres

The graphical solution to the equation is provided as Figure 2.1.3.

Figure 2.1.3: Relationship Between Required Water Quality Volume Storage and Site Imperviousness (%)



As demonstrated in Figure 2.1.3, if a developer reduces the percent (%) impervious area of a 20 acre parcel from 60% impervious to 40 % impervious by utilizing porous pavement, or other practices demonstrated in Chapter 4 (green infrastructure fact sheets) the resulting water quality volume storage to treat would be decreased from 0.59 inches/acre (11.8 inches) to 0.41 inches/acre (8.2 inches).

2.2.5. Water Quantity Reduction

A commonly used method to determine the Storm Water runoff depth for post development is the NRCS SCS curve number method. The major factors that determine the runoff curve number are the hydrologic soil group (HSG), land cover type, land treatment, hydrologic condition, and antecedent runoff condition. The NRCS (SCS) runoff equation is as follows:

$$Q_v = \frac{(P\,I_a)^2}{(P\,I_a) + S_m}$$

where:
Q_v = runoff (inches)
P = rainfall (inches)
S_m = potential maximum retention after runoff begins
I_a = initial abstraction

The SCS has found the I_a to be approximated by the following empirical equation:

$$I_a = 0.2\,S_m$$

By substituting Equation 205.02 into Equation 205.01, the following runoff equation is derived:

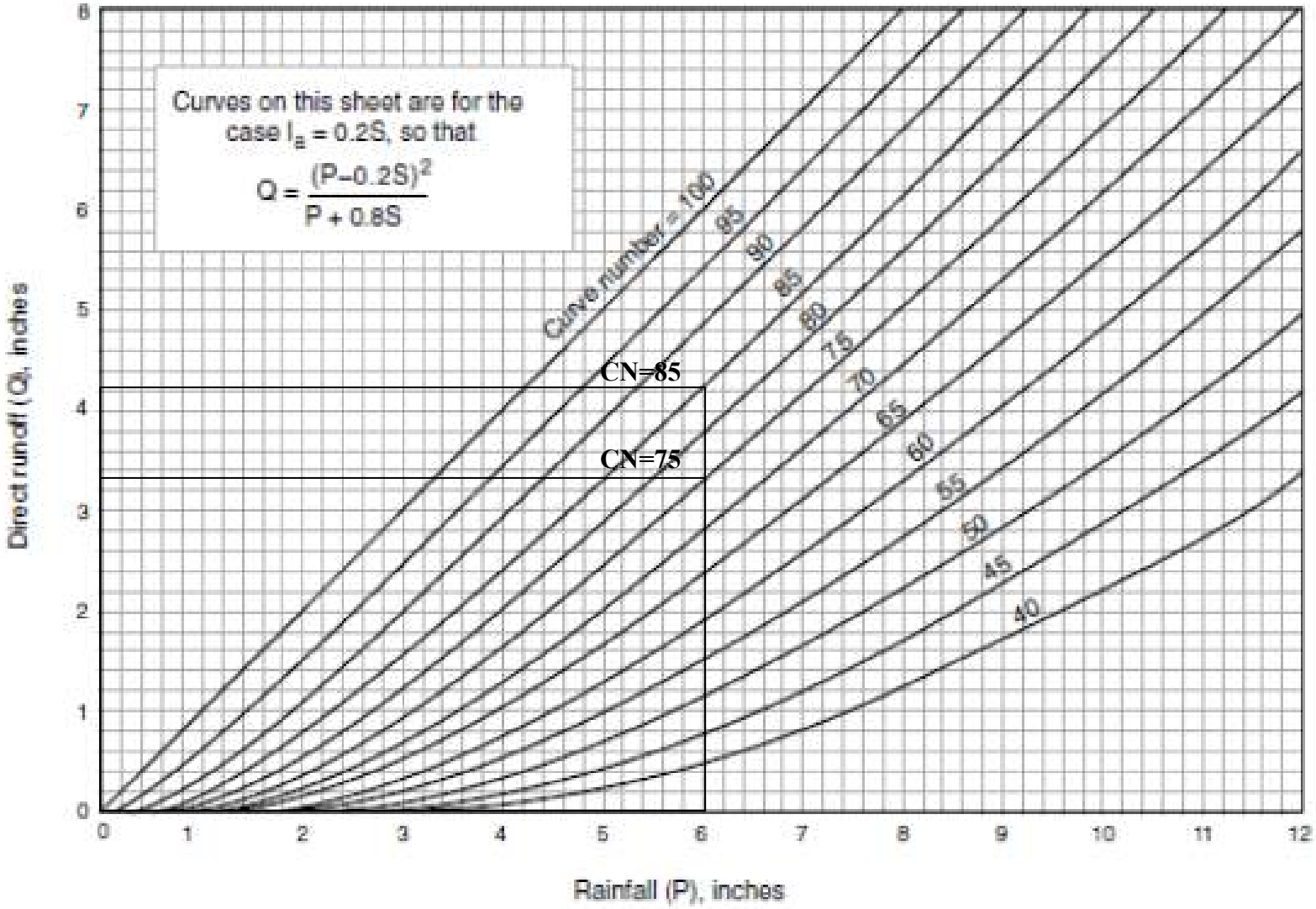
$$Q_v = \frac{(P0.2\,S_m)^2}{P + 0.8\,S_m}$$

The value of S_m is related to the soil and cover conditions of the watershed through the CN. The value of CN has a range of 0 to 100, and S_m is related to CN by the following equation:

$$S_m = (1000/CN) - 10$$

Each of the land use types is assigned a CN. The CNs are traditionally used as a factor to estimate the characteristic runoff from a land surface area as a function of the rainfall amount and pattern. A graphical solution to the runoff equation is provided in Figure 2.1.4:

Figure 2.1.4: SCS Solution of the Runoff Equation
(Source: SCS, TR-55, Second Edition, June 1986)



As demonstrated by Figure 2.1.4, approximately 4.1 inches of direct runoff would result if 5.8 inches of rainfall occurs on a watershed with a curve number of 85. In contrast, approximately 3.1 inches of direct runoff would result if the same 5.8 inches of rainfall occurs on a watershed with a curve number of 75. The amount of direct runoff (Q_v) can be reduced by lowering the CN.

The designer can compute curve numbers (CN) based on the actual measured impervious area at a site using:

$$CN = \frac{(98)I + \sum (CN_P)(P)}{A}$$

Where:

CN_P = curve number for the appropriate pervious cover
I = impervious area at the site
P = pervious area at the site
A = total site area

An example of a conventional site design with the computed CN is provided below. The same site is then designed using various LID Storm Water management techniques and the resulting CN computation is provided. *(The following example problem is from the Milwaukee Metropolitan Sewerage District: Surface Water and Storm Water Rules Guidance Manual Low Impact Development Documentation 2005: Refer to Appendix 3 for further description of a LID design and review spreadsheet that allows users to quickly evaluate various LID techniques to reduce the detention requirement.)*

Figure 2.1.5: Conventional Site Example
(MMSD Low Impact Development Documentation, 2005)

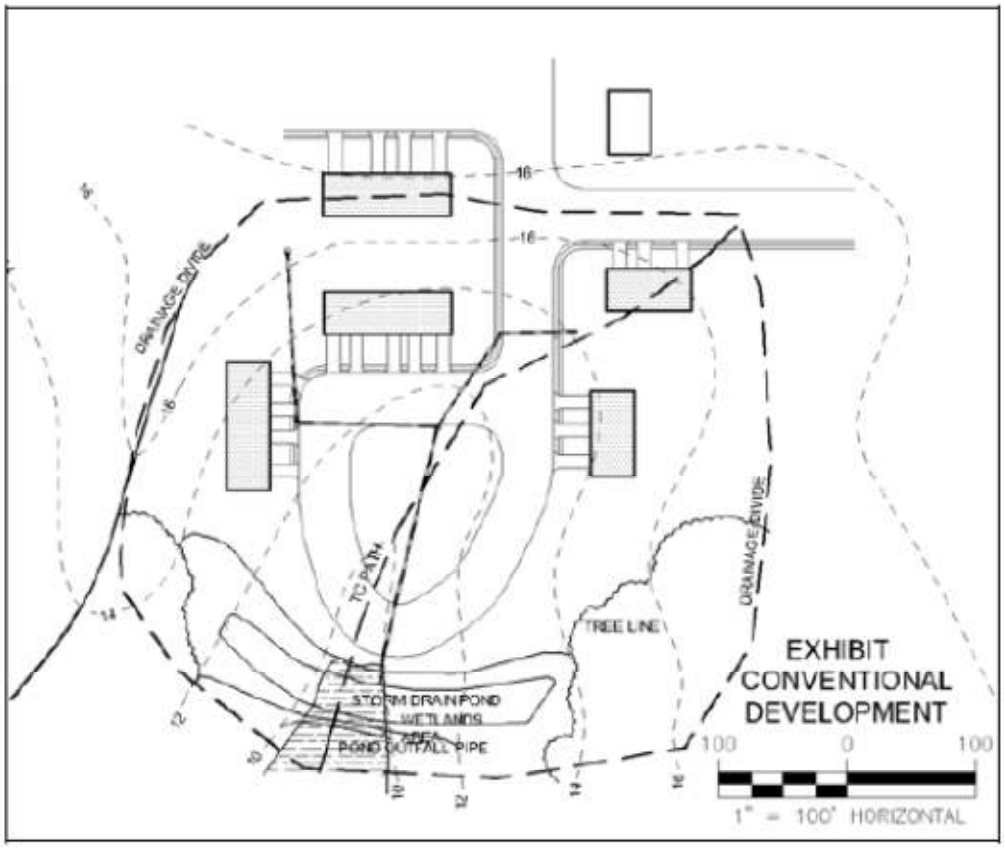


Table 2.1.2: Area-Weighted CN Calculation for Conventional Design
(MMSD Low Impact Development Documentation, 2005)

Hydrologic Soils Group	Cover Description	CN (Table 2-2 TR-55)	Area (Acres)	Product of CN x Area
B	Lawn (fair condition)	69	3.2	220.8
B	Woods, Fair	60	0.7	42.0
B	Impervious	98	2.6	254.8
			Sum of Products	**517.6**
			Divided by Drainage Area	6.5
			Weighted CN	**80**

Figure 2.1.6: LID Site Example
(MMSD Low Impact Development Documentation, 2005)

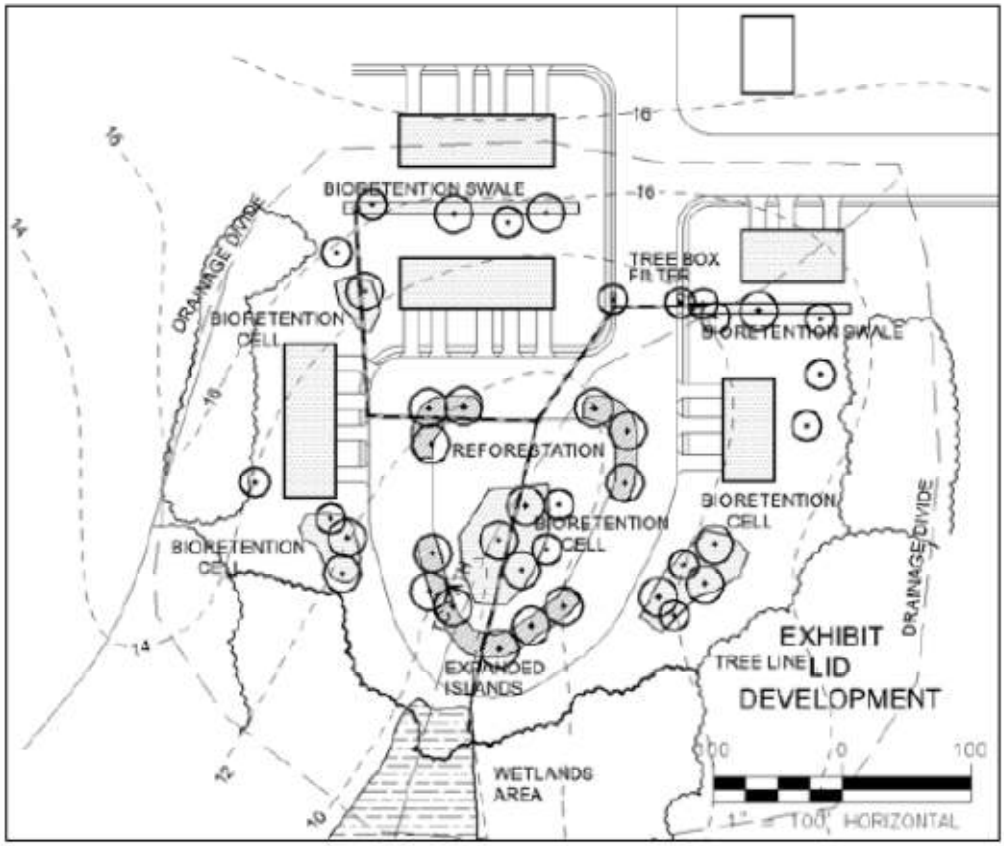


Table 2.1.3: Area Weighted CN Calculation for LID Design
(MMSD Low Impact Development Documentation, 2005)

Hydrologic Soils Group	Cover Description	CN (Table 2-2 TR-55)	Area (Acres)	Product of CN x Area
B	Lawn (good condition)	61	1.8	109.8
B	Woods, Fair	60	2.5	150.0
B	Impervious	98	2.2	215.6
			Sum of Products	**475.4**
			Divided by Drainage Area	6.5
			Weighted CN	**73**

Figures 2.1.5 and 2.1.6 demonstrate conventional and LID site plans for a 6.5 acre residential townhouse development. Tables 2.1.2 and 2.1.3 demonstrate the weighted curve number calculation for each site. The reduction in the curve number from 80 to 73, was achieved primarily by increasing the amount of wooded area. In addition several bioretention areas (rain gardens), and tree box filters were integrated into the design.

According to the standard NRCS runoff depth calculation, for a 2.57-inch storm, the lower curve number will reduce the depth of runoff from 0.9 to 0.6 inches. For this specific example, when the bioretention areas (rain gardens) that have an average ponding depth of 6 inches and a subsurface storage capacity of 3 inches, the LID spreadsheet (provided in Appendix 3), indicates that only 2.2% of the site area is needed to reduce the peak flow to a target level of 0.15 cfs/acre. Without the reduction in curve number, approximately 5.0% of the area would be needed.

Figure 2.1.7 and 2.1.8 are conceptual design examples completed to compare conventional Storm Water design with low impact development. The conceptual site design examples provide a detailed analysis for both a redevelopment and new development site consisting of: site layouts, water quality and quantity calculations, and landscape requirements for both a traditional site layout and an LID layout. The complete redevelopment and new development site reports are provided as Appendix 5 and Appendix 6, respectively.

Figure 2.1.7: Redevelopment Site Design Example Conventional vs. LID

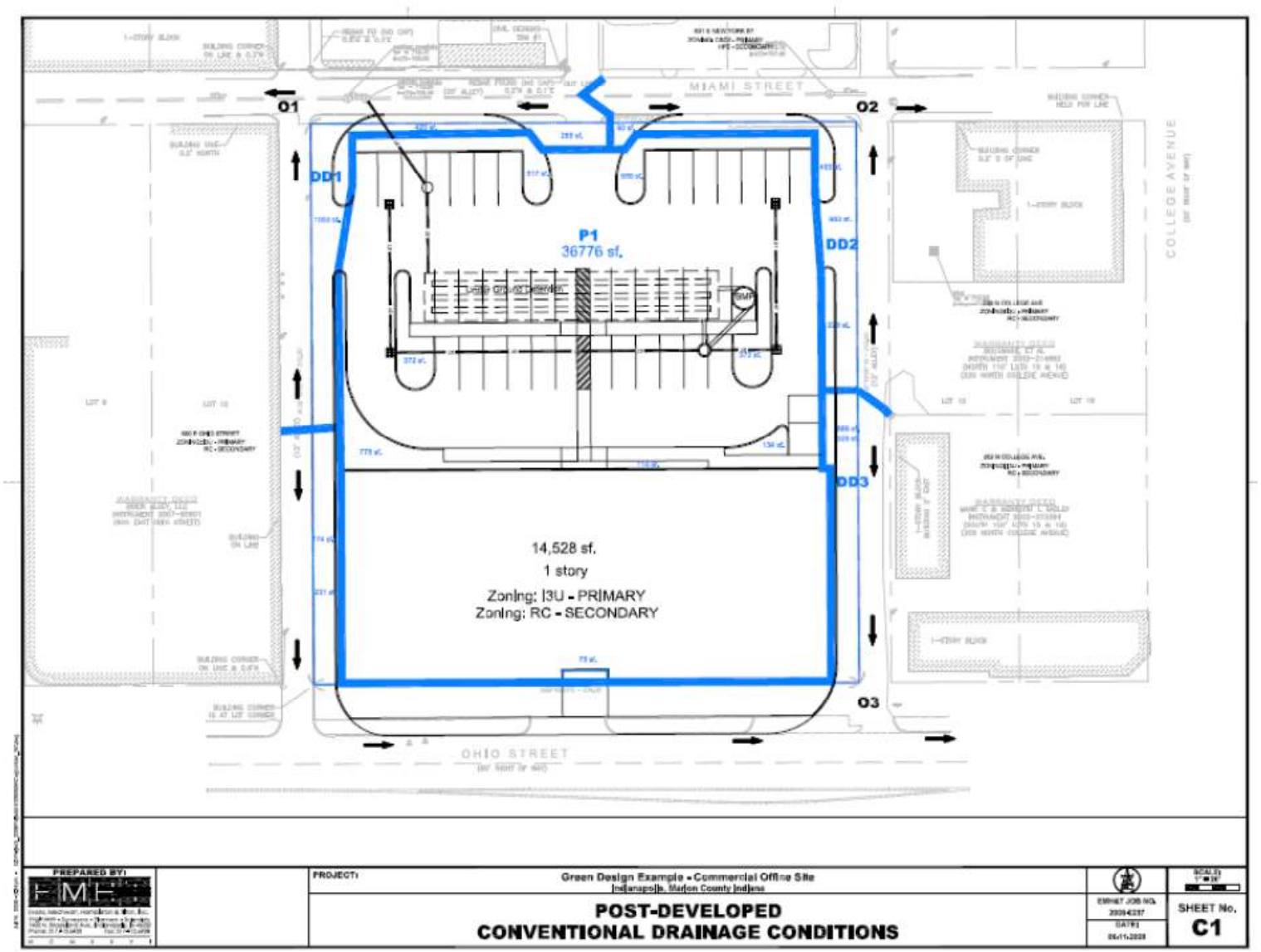


Figure 2.1.7: Redevelopment Site Design Example Conventional vs. LID, cont.

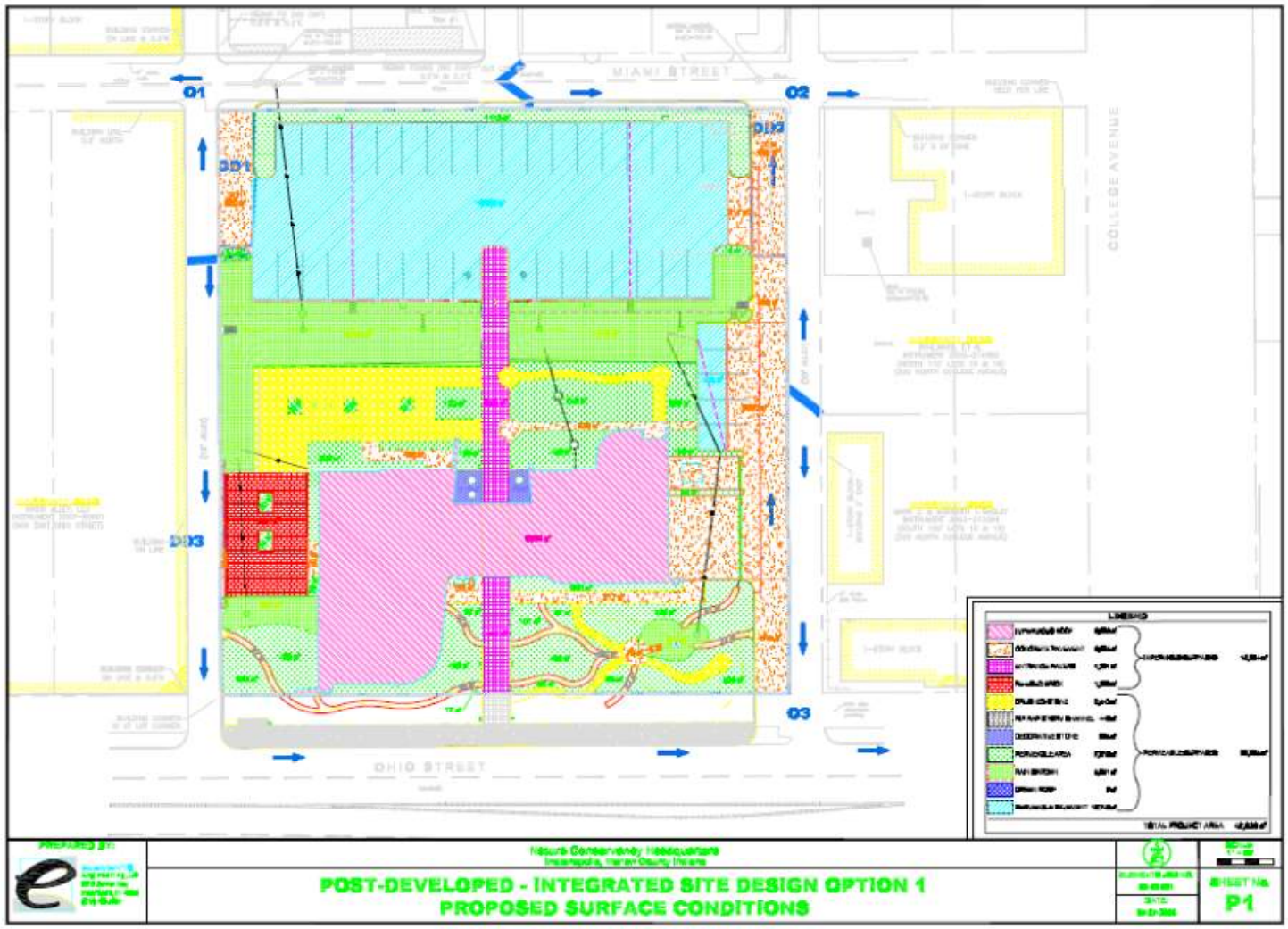
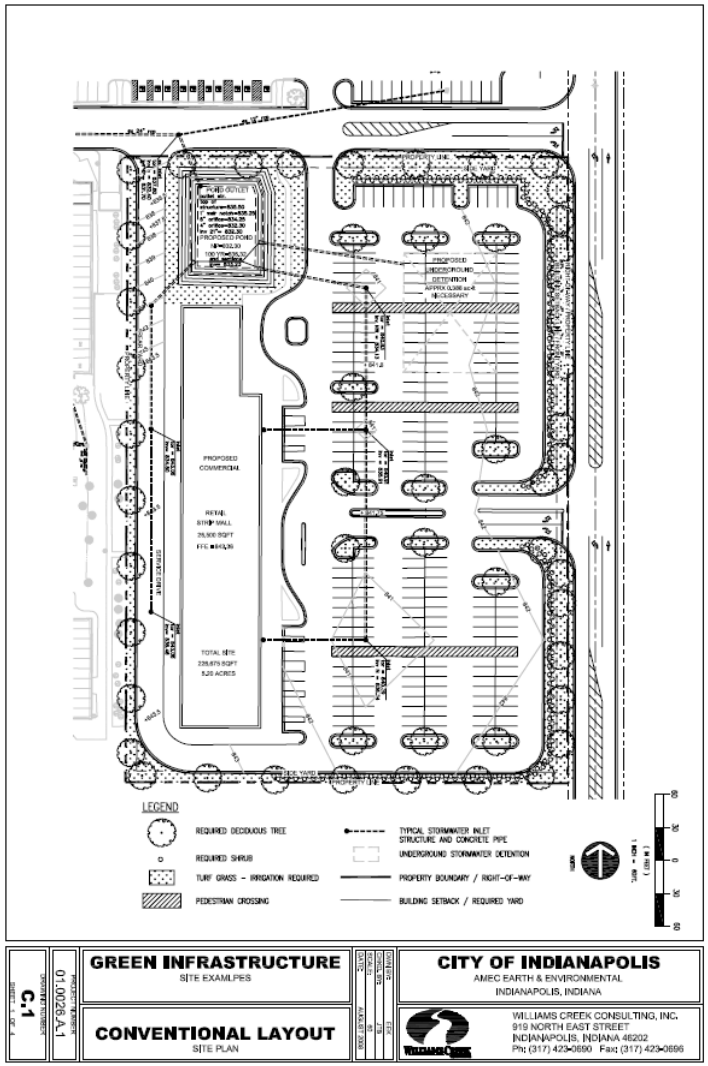
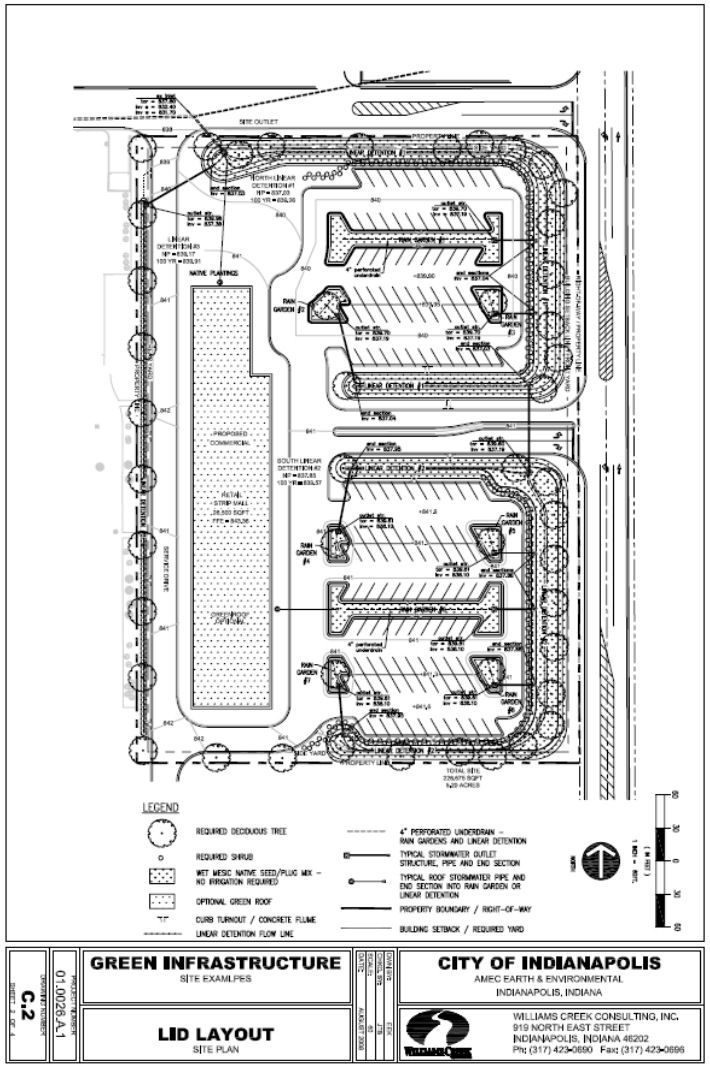


Figure 2.1.8: New Development Site Design Example Conventional vs. LID





2.2.6. Reduction in Storm Water Utility Fee

The City County Council of the City of Indianapolis - Marion County, Indiana passed General Ordinance No. 43, which created a county-wide Marion County Stormwater Management District and a stormwater management system within the Department of Public Works.

Stormwater user fees have been established on the basis of the amount of impervious surface area, as the amount of stormwater runoff a property generates is directly related to the amount of hard surface (rooftops, parking lots, driveways) on that piece of property. A statistical sampling of residential properties within the County determined that, on average, a developed single-family residential property has 2,800 square feet of impervious area. As a result, 2,800 square feet is used as the base billing unit or Equivalent Residential Unit (ERU).

Each single-family residential property is assigned a flat rate bill of one ERU. The billing rate, at the current time, applied to each ERU is $2.25 per month. Each non-residential property is then measured and its impervious surface translated into a whole number of ERUs. That number multiplied by the unit billing rate yields the monthly stormwater user fee for that particular property. The number of ERUs assigned to a non-residential property will remain constant unless any changes are made on the property that alters the amount of its impervious surface area.

By reducing the effective impervious footprint of new development or redevelopment the property owner can reduce his/her fee either directly by reduction of impervious surface or through the credit program by using BMPs that reduce the "effective" imperviousness of the site.

2.2.7. Analysis of Storm Water Fee Incentive

The use of low impact development (LID) techniques/green infrastructure is a way that property owners can reduce their impact on the City's Storm Water management system and thus reduce their Storm Water utility fees. A simple example of the financial impact of utility fees as a function of percent (%) impervious area is provided in Table 2.1.4. The costs are based on a 20 acre parcel with varying percent (%) impervious cover. The analysis provides an annual Storm Water fee and the net present value analysis for 20 years of utility fee payment (assuming a 3% discount rate). The analysis was completed based on the current utility fee of $2.25/ERU/month.

Storm Water Utility Fee Calculation Example
Site Area=20 acres
Site Impervious Area=15 acres
Site Impervious Area =15 acres * 43,560 sqft/acre
Site Impervious Area =653,400 sqft
1 ERU= 2,800 sqft
1 ERU = $2.25/month
Annual Storm Water Utility Fee = (653,400 sqft/2,800 sqft) *$2.25/month *12 month
Annual Storm Water Utility Fee = $6300.64

Table 2.1.4: Example Storm Water Utility Fee Calculation

Example	
Development Area	20 Acres
Storm Water Utility Fee	$2.25/ERU/Month

%Impervious	**Storm Water Utility Fee (Annual)**	**Storm Water Utility Fee (20 year Net Present Value)**
0	$0.00	$0.00
10	$840.09	$12,873.30
20	$1,680.17	$25,746.61
30	$2,520.26	$38,619.91
40	$3,360.34	$51,493.22
50	$4,200.43	$64,366.52
60	$5,040.51	$77,239.83
70	$5,880.60	$90,113.13
80	$6,720.69	$102,986.44
90	$7,560.77	$115,859.74
100	$8,400.86	$128,733.05

The relationship between percent (%) impervious area and Storm Water utility fee is directly proportional. By decreasing the amount of impervious area at a development site, the Storm Water utility fee will subsequently be reduced. It is important for many development projects to add the Storm Water utility fee into the life cycle cost analysis for the site. Evaluating this over the projected project life will provide further incentive to the property owner to invest in the LID techniques.

2.2.8. Options for Small Spaces/Redevelopment Areas

Redevelopment of downtown properties is a significant issue for Storm Water management and combined sewer programs around the globe. In many, if not most instances, these areas are characterized by wall to wall imperviousness, undersized Storm Water infrastructure, and a growing demand to redevelop the space. In Indianapolis, redevelopment interests exist both in the downtown area and in older suburban residential and commercial areas.

Often times, there is not enough land area for traditional Storm Water management, or in many instances the land area is very valuable and developers do not want to lose the potential profits generated from the developable space. Green infrastructure techniques provide various decentralized Storm Water management methods to address these issues developers might face.

Many older suburban and commercial properties throughout Marion County are being redeveloped. These areas must also comply with the City's Storm Water regulations and are areas that would possibly benefit from incorporating LID techniques/green infrastructure.

An example of a commercial redevelopment that integrates various LID techniques/green infrastructures is provided in Figure 2.1.9 (The following design *example is from Low Impact Development for Big Box Retailers, November 2005*). 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. Storm Water quantity and quality control are provided for these areas. A retrofit of the existing impervious areas with water quality controls is also shown.

As described above, two conceptual site design examples (redevelopment and new development) demonstrating alternative configurations and multifunctional landscape areas are provided as Appendix 5 and Appendix 6. The conceptual site design examples provide a detailed analysis consisting of site layouts, water quality and quantity calculations for both a traditional site layout and an alternative LID layout.

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Figure 2.1.9: Redevelopment LID Water Quality Design Example
(Low Impact Development for Big Box Retailers, 2005)

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 predevelopment condition.
- 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 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. Slops are from 2 to 3 percent.
- The eastern section has 8.9 acres of impervious area.
- The western section is undeveloped.

Post-Development Conditions

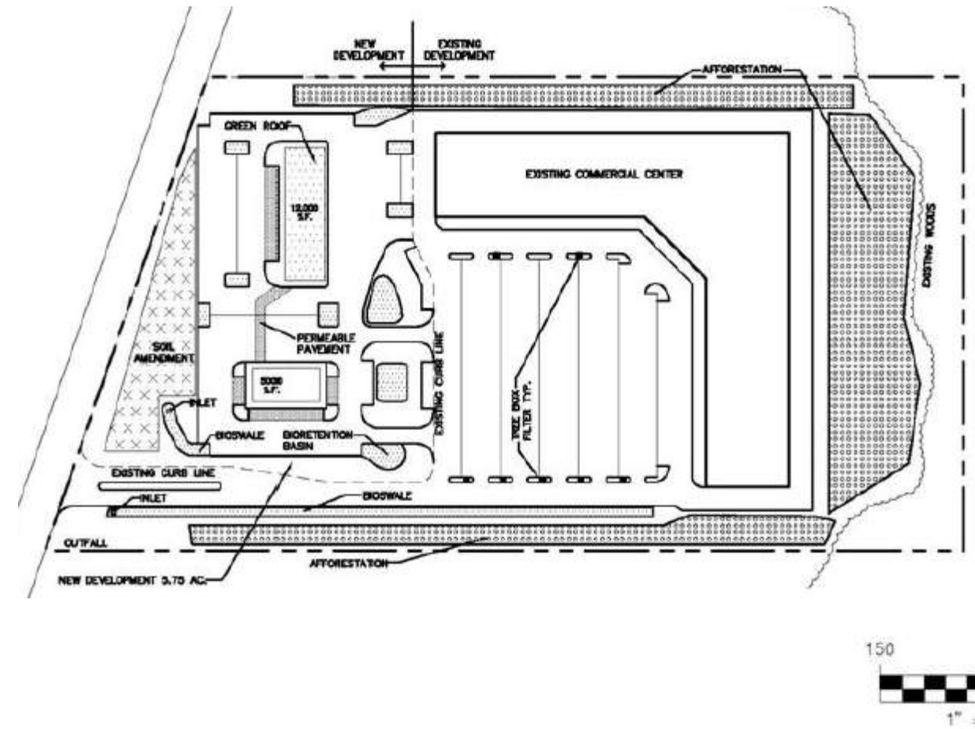
- The western section has 3.4 acres of impervious area.
- Soil amendments are added to 0.66 acres in the western section, increasing the area's infiltration capacity.
- 2.9 acres across the entire site are afforested.

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 * (43,650 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 ships except utility areas and access points.
  - Assume 1.5" storage within green roof media and no ponding.
  - Additional storage for roof runoff is provided by adjacent BMPs.



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 area 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 areas in eastern section.

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3. Techniques to Reduce Impervious Cover

As described in the previous section, both the water quality and quantity sizing equations are related to the amount of impervious cover and land surface type. It is encouraged to use thoughtful site planning techniques that include: protecting and utilizing existing site features, clustering and concentrating development, minimizing impact of disturbance, and reducing the impervious cover to be managed.

In many cases, alternative configurations for streets and parking lots can provide the same function as traditional designs with reduced impervious area. In addition, using "cupped" vs. traditional "mounded" landscaped islands, will allow for maximum use of land. Minimizing the area of rooftop and pavement and utilizing the landscaped areas at the site to be multifunctional will assist in reducing the cost of "grey' infrastructure. Two conceptual site design examples (redevelopment and new development) demonstrating alternative configurations and multifunctional landscape areas are provided as Appendix 5 and Appendix 6. The conceptual site design examples provide a detailed analysis consisting of: site layouts, water quality and quantity calculations for both a traditional site layout and an alternative layout using the above techniques.

3.1. Rooftop Disconnection

An adjustment to the total impervious surface area is permitted when the downspout is disconnected and then directed to a pervious area which allows for infiltration, filtration and increases time of concentration. Minimizing the impervious area will reduce the size and cost of structural BMPs that must be constructed. Depending on the configuration, all or a portion of the disconnected impervious area may be deducted from total imperious cover. Disconnected impervious cover may be treated as pervious when calculating Storm Water quantity and quality volumes. A rooftop is considered to be completely or partially disconnected if it meets the requirements below:

- The contributing area of rooftop to each disconnected discharge is 500 sqft or less, and
- The soil is not designated as a hydrologic soil group "D" or equivalent, and
- The overland flow path has a positive slope of 5% or less.
- Appropriate CN must be utilized when calculating the water quantity requirement.

For designs that meet these requirements, the portion of the roof that may be considered disconnected depends on the length of the overland path as designated in Table 3.1.1.

Table 3.1.1: Partial Rooftop Disconnection

Partial Rooftop Disconnection	
Length of Pervious Flow Path*	Roof Area Treated as Disconnected
(ft)	(% of contributing roof area)
0-14	0
15-29	20
30-44	40
45-59	60
60-74	80
75 or more	100
*Flow path cannot include impervious surfaces and must be at least 15 feet from any impervious surface	

(City of Philadelphia Storm Water Management Guidance Manual, 2006)

For example, consider a 1,000 sqft roof with two roof leaders each draining an area of 500 sqft. Both roof leaders discharge to a lawn. The lawn has type B soils and a slope of 3%. The distance from building to street is 70 ft, and the designer determines that roof runoff must be discharged 5 ft from the building foundation to avoid basement seepage. Therefore, the flow path is 65 ft in length. 80% of the roof area may be considered disconnected and treated as pervious cover when calculating Storm Water management requirements. Disconnection of the roof leaders will significantly reduce the size and cost of Storm Water management facilities at this site.

3.2. Pavement Disconnection

An adjustment to the total impervious surface area is permitted when pavement runoff is directed to a pervious area which allows for infiltration, filtration and increased time of concentration. This method is generally applicable to small or narrow pavement structures such as driveways and narrow pathways through otherwise pervious areas (e.g., a bike path through a park). For structures that meet the requirements, all of the disconnected impervious area may be deducted from the total impervious cover for water quality calculations. However, appropriate CN values listed in Table 205-02 of the City of Indianapolis Stormwater Design and Construction Specifications Manual must be used when performing water *quantity* calculations. Pavement is disconnected if it meets the requirements below:

- The contributing flow path over impervious cover is no more than 75 feet, and
- The length of overland flow is greater than or equal to the contributing length, and
- The soil is not designated as hydrologic soil group “D” or equivalent, and
- The slope of the contributing impervious area is 5% or less, and
- The slope of the overland flow path is 5% or less.

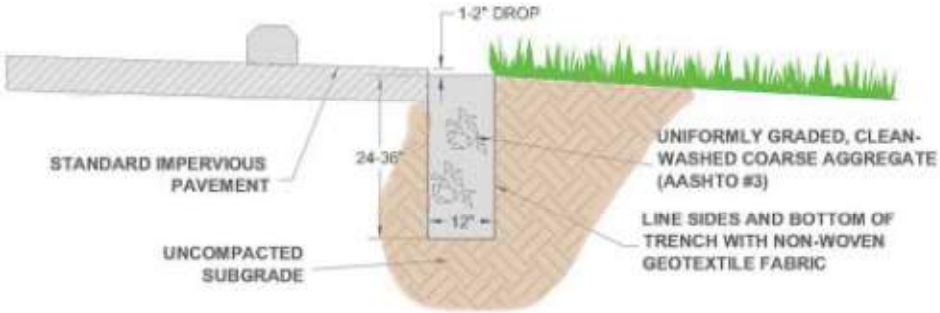
If discharge is concentrated at one or more discrete points, no more than 1,000 sqft may discharge to any one point. In addition, a gravel strip, level spreader, or other spreading device is required for concentrated discharges. For non-concentrated discharges along the entire edge of pavement, this requirement is waived; however, there must be provisions for the establishment of

vegetation along the pavement edge and temporary stabilization of the area until vegetation becomes established.

For example, in Figure 3.1.1, concentrated runoff from a small parking lot drainage area is directed towards a gravel level spreader which is connected to a filter strip that is part of a larger overall Storm Water treatment system. The level spreader ensures that the runoff entering the filter strip has sheet flow characteristics which aids in the filter strip's effectiveness. Since a flow spreader was installed to handle concentrated runoff, this small parking lot would be considered disconnected.

Note: Filter strips are recommended as only a viable Storm Water management pretreatment option. Filter strips are recommended for use as pretreatment for many intensive structural controls.

Figure 3.1.1: Gravel Level Spreader Connected to Filter Strip



(City of Philadelphia Storm Water Management Guidance Manual, 2006)

3.3. Maximize Tree Canopy Over Impervious Cover

An adjustment to the total impervious surface area is permitted when new or existing tree canopy, appropriate for the site, extends over the impervious cover. Under these circumstances, a portion of impervious cover under tree canopy may be treated as disconnected and deducted from total impervious cover. A curve number of 93 may be used when calculating the water quantity requirements. The tree species must be appropriate for the site. To be eligible for the reduction:

- New trees planted must be planted within 10 feet of ground level impervious area within the limits of earth disturbance.
- New deciduous trees must be at least 2-inch caliper and new evergreen trees must be at least 6 feet tall to be eligible for the reduction.
- A 100 sqft impervious area reduction is permitted for each new tree.
- The maximum reduction permitted, including new and existing trees is 25% of ground level impervious area within the limits of earth disturbance, unless the width of impervious surface area is 10 ft. Up to 100% of narrow impervious areas (i.e. sidewalks and paths) may be disconnected through the application of tree credits.

For further information on specific strategies to incorporate trees into the design of development sites refer to Appendix 4, Urban Watershed Forestry Manual; Part 2: Conserving and Planting Trees at Development Sites.

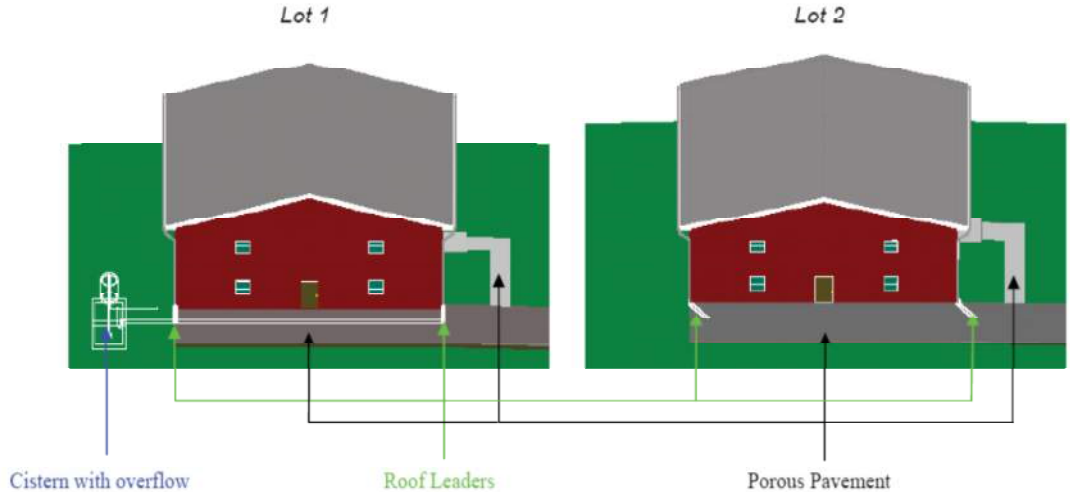
3.4. Install Green Roofs to Reduce Impervious Area

An adjustment to the total impervious surface area is permitted when a green roof is installed on a building. The design, construction, and operation and maintenance agreement must meet the requirements specified by Fact Sheet 4.1. To encourage this emerging technology, the impervious area reduction is permitted equal to the entire area of the green roof. However, since a green roof is not a zero discharges system, the remaining site design must safely convey roof runoff to a designated location. Appropriate CN values must be utilized when performing water quantity calculations. See **Attachment 2** for the appropriate CN values.

3.5. Install Permeable Pavement Systems to Reduce Impervious Area

An adjustment to the total impervious surface area may be permitted when a permeable pavement system is properly designed and installed on the site such that it does not create any areas of concentrated infiltration. Permeable pavement systems, including pervious concrete, porous asphalt, and permeable pavers with at least 40% void space; and other approved porous structural surfaces can be considered to be disconnected if they receive direct rainfall only and are underlain by a #8 crushed stone infiltration bed that is at least 8 inches deep. Permeable pavement systems must meet the requirements specified by the following permeable pavement system Fact Sheet 4.2, including completion of field verified permeability rates by a licensed engineer, geologist, or soil scientist. If the porous surface receives runoff from adjacent conventional pavement surfaces or if the roof or other runoff is directed into the subsurface storage bed, the porous pavement/infiltration bed system will be considered a structural BMP and the porous surface will be considered to be impervious surface this is demonstrated in Figure 3.1.2. A CN value of 98 must be utilized when performing water quantity calculations with the stone below the pavement considered as storage. See **Attachment 3** for example design calculations.

Figure 3.1.2: Example Permeable Pavement System Impervious Area Reduction Technique
(City of Philadelphia Storm Water Management Guidance Manual, 2006)



Roof Area (same for both houses): 25 x 20 x 2 = 1,000 ft^2
Driveway and Sidewalk Area (same for both houses): (60 x 90) + (4 x 19.5) + (5 x5) = 643 ft^2
Impervious Area before Disconnection (same for both houses): (Roof Area + Driveway and Sidewalk Area) = 1,643 ft^2

(City of Philadelphia Storm Water Management Guidance Manual, 2006)

The home on lot 1 has disconnected both the roof, by the use of a cistern with an over flow for larger precipitation events, and the pavement, by use of the porous pavement. The home on lot 2 has also disconnected the roof. However, the roof was disconnected by the use of the porous pavement, since the downspouts run directly into the gravel storage bed of the porous pavement; the porous pavement is considered a structural BMP and is still considered to be impervious area.

Impervious Area of Lot 1 After Disconnection: 0 ft^2 (since roof leaders are disconnected to a cistern)
Impervious Area of Lot 2 After Disconnection: 643 ft^2 (since roof leaders discharge directly into porous pavement)

(City of Philadelphia Storm Water Management Guidance Manual, 2006

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4. Green Design Fact Sheets/ Design Techniques

The Fact Sheets were reviewed and updated by a design/review group comprised of local designers (Williams Creek Consulting, Evans, Mechwart, Hambleton, and Tilton Engineering (EMH&T), and Elements Engineering, Inc., in addition various plan review staff from the City of Indianapolis were involved in the review of these documents. Local nurseries, including Spence Restoration Nursery and JF New, were used to review the Recommended Plant Lists.

These documents were created to provide an educational overview, key elements, potential applications, materials, recommended design procedures, construction guidelines, and maintenance guidelines for the following Storm Water management techniques.

4.1 Green Roofs
4.2 Permeable Pavement Systems
4.3 Rain Water Harvesting
4.4 Swales
4.5 Bioinfiltration/Bioretention/RainGarden
4.6 Low Impact and Retentive Grading
4.7 Swales
4.8 Subsurface Infiltration
4.9 Inlet and Outlet Controls
4.10 Filters
4.11 Subsurface Vaults
4.12 Detention Basins

This Manual has been revised as of July 2015. Revisions were made to provide further technical material to support the Storm Water management techniques. To provide further technical guidance, the following attachments have been included:

Attachment 1: Guidelines for Subsurface Investigation and Infiltration Testing
Attachment 2: Green Roof Design Guidelines
Attachment 3: Permeable Pavement Systems Design Guidelines
Attachment 4: Rain Water Harvesting Design Guidelines
Attachment 5: Bioretention Design Guidelines
Attachment 6: Swale Design Guidelines

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4.1. Green Roofs

A green roof (vegetated roof/eco roof/roof garden) is a system consisting of waterproofing material, growing medium and vegetation. A green roof can be used in place of a traditional roof as a way to limit impervious site area and reduce Storm Water runoff. The green roof design should attempt to mimic pre-developed site hydrology, reducing post-developed peak runoff rates to near pre-developed rates. Green roofs also help mitigate runoff temperatures by keeping roofs cool and retaining much of the runoff from typical storm events. Although many green roofs consist of lightweight growing medium and low-growing succulent vegetation, other more heavily planted systems are possible; in either case the design should be self-sustaining.

The structural support must be sufficient to hold the additional weight of the green roof. Greater flexibility and options are available for new buildings than for reroofing existing buildings, however retrofits are possible. For retrofit projects, an architect, structural engineer, or roof consultant can determine the condition of the existing building structure and what might be needed to support a green roof. Alterations might include additional decking, roof trusses, joists, columns, and/or foundations. Generally, the building structure must be adequate to hold an additional 15 to 25 pounds per square-foot (psf) saturated weight, depending on the vegetation and growth medium that will be used (in addition to live load requirements). An existing rock ballast roof may be structurally sufficient to hold a 10-15 psf green roof (ballast typically weigh 10-15psf).

Two additional alternatives, to the traditional bituminous roofing material, are a single ply cool roof and reflective tiles. White single ply membranes are highly reflective, as compared to traditional bituminous roofing material, and can help reduce the urban heat island effect as well as save the building owner cooling costs. Reflective tiles are usually made of clay or concrete, and manufactures have begun to develop pigments that reflect in the infrared. Special pigments allow roofing material to keep their traditional colors, such as brown, green, and terra cotta, while reflecting away up to 70% of the sun's energy. These products enable buyers to forego the perceived tradeoff between energy efficiency and the aesthetic concerns with a bright-white roof (EPA, 2007). It should be noted that these alternatives do not provide storm water quantity or quality benefits.

Key Elements:

- Green Roofs must be designed in accordance with applicable city, state, and federal building codes and a drainage system and overflow to an approved conveyance and discharge location must be designed in accordance to the Storm Water Design and Construction Specifications Manual.
- Internal drainage, including provisions to cover and protect deck drains, must anticipate the need to manage large rainfall events without inundating the cover.
- Green roofs with engineered growing medium of at least 3 inches in depth can be considered more pervious in Storm Water design calculations for the WQv sizing equation than a standard roof.
- Providing urban green space, aesthetically pleasing views, and habitat.
- May reduce utilities such as heating and cooling costs.
- Can extend roof life by two to three times.
- Improve air quality by filtering dust particles.
- LEED points.

Table 4.1.1: Green Roof Potential Application and Storm Water Regulation

Potential applications			Storm Water regulations		
				Infiltration	No Infiltration
Residential Subdivision:	Yes		Water Quality Benefit:	No	Yes
Commercial:	Yes		Volume Reduction:	No	Yes
Ultra Urban:	Yes		Attenuation Benefit:	No	Yes
Industrial:	Yes				
Retrofit:	Yes				
Highway Road:	No				

Acceptable forms of pre-treatment

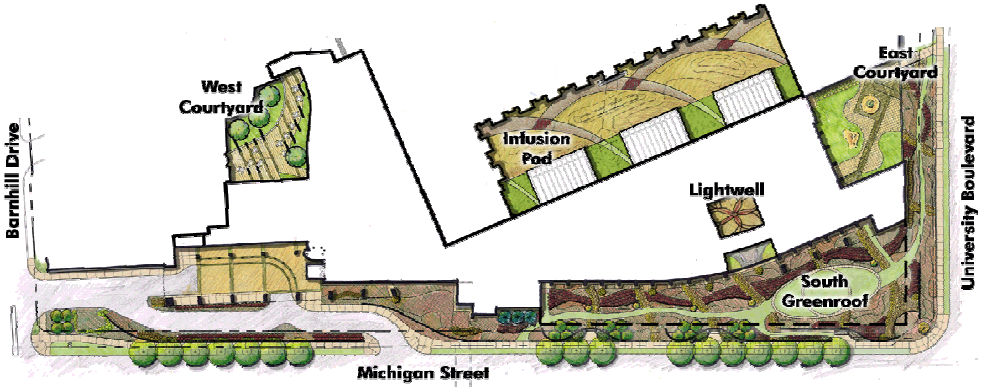
N/A

Green Roofs in the Urban Landscape

Unlike conventional roofing, green roofs promote retention and evapotranspiration of precipitation. This Storm Water management technique is very effective in reducing the volume and velocity of Storm Water runoff from roofs.

Green roofs can be installed on many types of roofs, from small slanting roofs to large commercial flat roofs. The maximum acceptable pitch for conventional green roofs is 25%, unless documentation is provided for runoff control on a steeper slope. Green roofs are an ideal option for new buildings that are taking long term cost savings and energy conservation into consideration. Many existing buildings can also be retrofitted with green roofs if structurally capable.

Although green roofs are more expensive than conventional roofs initially, they provide long term benefits and costs savings. A green roof's underlying waterproofing can extend the life of a roof two to three times by protecting the roof from mechanical damage, shielding the roof from UV radiation, and buffering temperature extremes. Green roofs also reduce energy costs by providing insulation and absorbing/reflecting excess heat and light. The roof slowly absorbs energy from the sun during the day and releases it as the air cools, thereby reducing heating and cooling costs. The benefits will be greatest during the summer months, and low buildings will see the greatest benefits. Green roofs also reduce the urban heat island effect by providing evaporative cooling and can improve air quality by filtering dust particles.

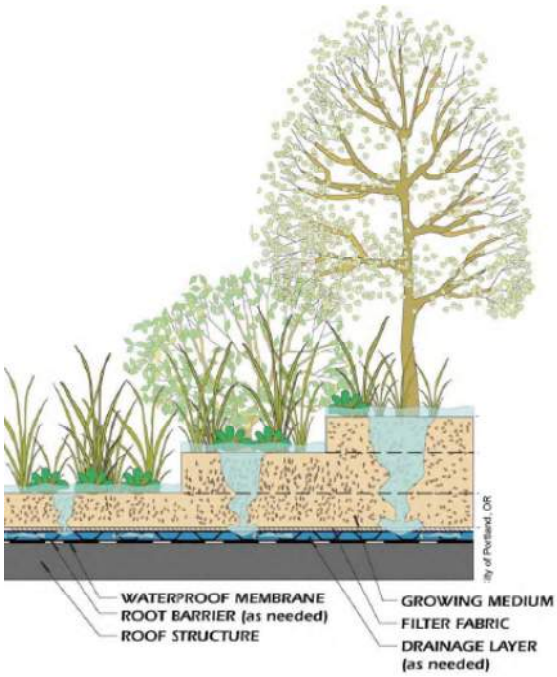


MICHIGAN STREET AND UNIVERSITY BOULEVARD: INDIANAPOLIS IU MELVIN BREN SIMON CANCER CENTER

Components of a Green Roof

There are three basic types of green roofs (GRHC, 2008). An extensive green roof system is 6 inches or less in depth, and has a water saturation weight of 10-35 lbs/ft². It usually has limited accessibility and is planted with drought-tolerant succulent plants and grasses. A semi-intensive green roof contains material 25% above or below 6 inches. It may be partially accessible, has a water saturation weight of up to 50 lbs/ft² and has potential for greater plant diversity than an extensive roof. An intensive green roof is deeper than 6 inches and typically has a water saturation weight between 50-300 lbs/ft². These roofs are usually accessible to others besides maintenance and allow for great plant diversity. Each green roof project is unique, given the purpose of the building, its architecture and the preferences of its owner and end user. However, green roof systems are typically comprised of the same components:

- Plant material
- Growing medium
- Filter fabric
- Drainage layer
- Insulation (optional)
- Waterproof membrane/root barrier
- Roof structure



TYPICAL COMPONENTS OF A GREEN ROOF

In addition to the three primary green roof categories, there are two main approaches to installing green roofs; these are classified as Modular and Loose Laid. Each of these categories includes a variety of specific construction methods and system design approaches.

MODULAR GREEN ROOF SYSTEM INSTALLATION

DEARBORN, MI-FORD ROUGE CENTER COMPLEX-10-AC GREEN ROOF –PART OF A 600-AC STORM WATER MANAGEMENT SYSTEM AT A BROWNFIELD SITE

PLANT MATERIAL

Plant Material

The plant material chosen for green roofs is designed to take up much of the water that falls on the roof during a storm event and be drought tolerant. Plant material also collects dust, creates oxygen, releases moisture, and provides evaporative cooling. Plant selection is very important to the sustainability of the roof. The extensive green roof should reach 90% growth coverage within two years. The following criteria should be taken into consideration when selecting vegetation for the green roof:

- Drought tolerant, requiring little or no irrigation after establishment
- Self-sustaining, without the need for fertilizers, pesticides, or herbicides
- Able to withstand heat, cold, and high winds
- Very low-maintenance, needing little or no mowing or trimming
- Perennial or self-sowing
- Fire resistant

SEDUM MIX

A mix of sedum/succulent plant communities is recommended because they possess many of these attributes. Herbs, forbs, grasses and other low groundcovers can also be used to provide additional benefits and aesthetics, however these plants may need more watering and maintenance to survive and keep their appearance. Refer to Green Roof Plants by Snodgrass and Snodgrass for a comprehensive list of plants suitable for green roofs.

Growing Medium

The growing medium is a critical element of Storm Water storage and detention on a green roof, and provides a buffer between the roof structure and vegetation for root development. Storage is provided by a green roof primarily through water held in tension in the growing medium pores. The growing medium in an extensive green roof should be a lightweight mineral material with a minimum of organic material and should stand up to freeze/thaw cycles. Semi-intensive and intensive roofs may have organic material and/or sand added to the mineral material. Organic material should not contain peat, because of its nonrenewable nature and burning potential, nor animal waste, which can leach pollutants into Storm Water and may eventually leave the site. The engineered material should be Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL) approved. The FLL is further described in the Materials section.

KENTUCKY SANITATION DISTRICT1-DEMONSTRATION SITE

CROSS SECTION-GROWING MEDIUM

Filter Fabric

An engineered, non woven filter fabric prevents fine soil particles from passing into the drainage layer of the green roof system.

Drainage Layer

The drainage layer is a lightweight granular medium and/or plastic material resembling egg cartons set beneath the planting medium. The drainage layer needs to provide a balance between water retention and root aeration and is a critical component of the Storm Water retention function. An approved discharge location should be identified for every green roof and drain(s) provided.

Waterproof Membrane/Root Barrier

To maintain structural integrity of the roof, a waterproof material is laid above the roof structure. Some waterproofing materials are inherently root resistant, whereas others require an additional root barrier. It is important that the membrane be of high quality as it will be labor intensive to replace once the green roof components are in place.

Roof Structure

The load capacity of a roof structure must be taken into account when considering the installation of a green roof. Extensive green roofs typically weigh between 15 and 25 psf and are compatible with wood or steel decks. Intensive green roof weigh more than 50 psf and typically require concrete supporting decks.

Recommended Design Procedure

- Early communication between the design team (developer, civil engineer, structural engineer, architect, landscape architect, planner, roofer etc) is extremely important in the design procedure.
- Investigate the feasibility of the installation of a green roof. A structural engineer should verify that the roof will support the weight of the green roof system. It is important to consider the saturated weight of the roof in the design calculations.

- Determine the portion of roof that will have a green roof. Typically 10% or less of the green roof is composed of non-vegetated components such as gravel ballast, pavers for maintenance access, etc.
- Extensive green roofs that have an engineered growing medium of at least 3 inches thick can be permitted as water quality volume reduction equal to the entire area of the green roof.
- Although green roofs are not considered as impervious surfaces when determining Storm Water management requirements, they are not zero discharge systems. The roof drainage system and the remainder of the site drainage system must safely convey roof runoff
- Develop a planting plan based on the thickness of the planting media.
- Complete construction plans and specifications.
- For additional design information, refer to **Green Roof Design Guidelines (Attachment 2)**.

Materials

Presently (2010), the only widely-accepted, established standards for green roof construction are those developed in Germany by the Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL). The FLL guidelines include industry standard tests for the weight, moisture, nutrient content, and grain-size distribution of growing media. FLL also certifies laboratories to conduct critical tests, such as the root penetration resistance of waterproofing membranes. These guidelines are available in English translation directly from FLL. There is also an American Standard Testing Methods (ASTM) task group that is developing comprehensive American standards for green roof installation. Since guidelines are constantly being upgraded and approved, the engineer is responsible for verifying that the design materials meet all current standards at the time of design.

Materials for green roofs will vary somewhat depending on the media thickness, intended uses, and desired appearance. The specifications provided below focus on those for a 3-inch extensive green roof system.

Plant Material

- Green roof plantings should be able to withstand heat, cold, and high winds. After establishment, the plants should be self-sustaining and tolerant of drought conditions.
- For extensive green roofs, about half of the plants should be varieties of sedums. To ensure diversity and viability, at least four different species of sedum should be used. For an extensive green roof, the remainder of the plants should be herbs, meadow grasses, or meadow flowers, depending on the desired appearance.
- *Sedum sarmentosum* also known as star sedum, gold moss, stringy stonecrop, or graveyard moss and *Sedum hispanico* are known to be invasive and should be avoided.
- Green roofs should include a significant percentage of evergreen plants to minimize erosion in winter months.
- When fully established, the selected plantings should thoroughly cover (90% or more), the growing medium.

Growing Medium

- Green roof growing medium should be a lightweight mineral material with a minimum of organic material and should meet the following standards
  - Non-Capillary Pore Space at Field Capacity, 0.333 bar: $\geq$ 15% (vol)
  - Moisture Content at Field Capacity: $\geq$ 12% (volume)
  - Maximum water retention: $\geq$ 30% (volume)
- The nutrients shall be initially incorporated in the formulation of a suitable mix for the support of the specified plant materials.

Filter Fabric

Filter or separation fabric shall allow root penetration, but prevent the growth medium from passing through into the drainage layer. The fabric should be a non-woven polypropylene geotextile.

Drainage Layer

- Drainage layer shall be used to provide conveyance of excess water in the green roof system. The layer shall meet the following specifications:
  - Abrasion resistance (ASTM-C131-96): $\leq$ 25 % loss
  - Soundness (ASTM-C88 or T103 or T103-91): $\leq$ 5% loss

- Porosity (ASTM-C29): ≤ 25% loss
- Grain size distribution (ASTM-C136)
    - Percent Passing US#18 sieve: ≤ 1%
    - Percent Passing ¼-inch sieve: ≤ 30%
    - Percent Passing 3/8-inch sieve: ≤ 80%

Waterproof Membrane/Root Barrier

- PVC, EPDM, and thermal polyolefin (TPO) are inherently root resistant; other common waterproofing materials might require a root barrier between waterproofing and vegetative cover. PVC has been shown to release toxins in some situations and should be avoided if other alternatives are available.

- Avoid using herbicides to prevent root penetration of waterproofing.

Irrigation System

- It is recommended that extensive systems be designed to not require irrigation.

- When using an irrigation system pipes should not be placed directly on the waterproof membrane, but on a protection board or among the growing medium to avoid damage to the system from pressure and pipe movement.

Roof Structure

- Typical roof structure should have structural stability inspected by a Structural Engineer.

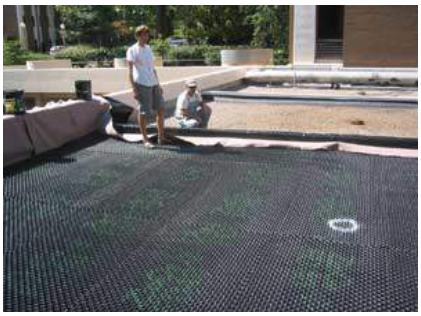
Construction Guidelines

- A safety program is one of the most important considerations for anyone that will be building a green roof. All governmental fall and safety protection regulations must be followed.
- Pre construction meeting/training for all trades involved in the installation of a green roof is critical to the success of a green roof due to the number of trades involved.
- Contractors should be trained for green roof installation and have a thorough understanding of the overall system that they are installing. Contractors must be aware of the roof access points, load bearing points, material storage requirements, mode of transportation of materials to the jobsite, and scheduling of materials.
- Apply waterproof membrane and inspect for any irregularities that would interfere with its elemental function within the green roof system.
- The waterproof membrane should be protected when exposed to increased moisture levels from construction and in work traffic zones. Membrane protection should be a mandatory requirement of installation for the period of time it is exposed during staging and installation of overburden, i.e. all layers above the membrane. All membrane layers should have enough strength to cope with the weight of construction equipment. The following are membrane protection techniques:
- Restrictions of traffic on membrane
- Physical protection
- Phased construction

- When the waterproofing membrane is installed it must be tested to ensure that there are no leaks, after which it should be continuously protected.

FLOOD TEST

- The design professional is responsible for deciding the best method to test the integrity of the waterproofing membrane. The most common method used is flood testing. A flood test typically involves the following steps:
  - Temporary blockage of drain system
  - Area covered with 2" water for 24 to 48 hours
  - Inspection of the underside of test area for water infiltration
  - Careful removal of water from the site so as not to stress the drainage system



DRAINAGE LAYER

DRAINAGE MAT

- Install drainage layer, taking care to protect the waterproof membrane from damage.
- Test the drainage system.
- Install the filter fabric or separation layer over entire drainage layer.
- Install growing medium component as specified.
- Establish vegetation in the spring for best results, sedums can be established from fresh cutting that are broadcast onto the growing medium.
- In May/June or September/October, sedum plugs can be established by planting them 1 foot on center.
- Perennials can be seeded, except during summer months.
- A biodegradable or photodegradable wind barrier or hydromulch may be used to prevent erosion during the establishment period. It generally takes about two growing seasons for full establishment.

GROWING MEDIUM

PLANTING

Maintenance Guidelines

All facility components, including plant material, growing medium, filter fabric, drainage layer, waterproof membranes, and roof structure should be inspected for proper operations, integrity of the waterproofing, and structural stability throughout the life of the green roof. Detailed maintenance guidelines and a recommended schedule of inspection and maintenance can be found in the Example Green Roof Operation and Maintenance (O & M) Manual.

- Fertilization is not necessary and fertilizers should not be applied, unless there is a documented need. If it is determined that fertilization is required to restore function of the green roof vegetation, the exact fertilization requirements should be determined by testing, and the minimum quantity of fertilizer should be applied to restore function. Fertilizers containing phosphorus should not be used unless testing indicates it is needed.
- During the plant establishment period, maintenance staff should conduct 3-4 visits to conduct basic weeding, fertilization, and in-fill planting. Thereafter, only two annual visits for inspection and light weeding should be required (irrigated assemblies will require more intensive maintenance).
- Spill prevention measures from mechanical systems located on roofs should be exercised when handling substances that can contaminate storm water.
- If the structure/property where the green roof exists is likely to change hands, a plaque or similar element should be placed on and/or near the roof stating the manufacturer of the green roof elements so warranty details and other information best relayed by the manufacturer are easily obtained.

Table 4.1.2: Engineering / Drainage Report Requirements Summary

Item	Required
Storage Volume Calculations	Yes
Emergency Overflow Calculations	Yes
Water Quality Volume Calculations (if system is part of the stormwater quality management system)	Yes
Water Quantity Volume Calculations (if system is part of the stormwater quantity management system)	Yes
Structural Engineer's Certification (for Retrofits)	Yes

Table 4.1.3: Plan Requirements

Item	Required
Profile Detail of Proposed Green Roof Showing:	
Soil Depth	Yes
Impermeable membrane	Yes
Filter Fabric	Yes
Soil Specifications	Yes
Drainage Layer	Yes
Area Map Showing Area Covered by Proposed Green Roof	Yes
Plant Specifications	Yes
Filter Fabric Specifications	Yes
Center Coordinates of Green Roof (in State Plane Coordinates) on Cover Sheet Summary Table	Yes

Table 4.1.3: Plan Requirements 1

Table 4.1.4: O & M Manual Requirements

Item	Required
Tabular Inspection Schedule	Yes
Site Diagram with Green Roof Area	Yes
Inspection Checklist	Yes
Narrative description of Inspection Procedure including:	Yes
Startup Maintenance	Yes
Fertilizer Guidance	Yes
Plant Coverage Minimum Requirement (90%)	Yes
Emergency Overflow System Inspection	Yes
Wind and Rain Erosion Inspection	Yes
Weeding	Yes
Self-Inspection Yearly Certification	Yes

4.1.1. Green Roof Example O & M Manual

Green Roof – O & M Manual

Owner Name
Address of Property
Owner Contact Name and Phone Number

BMP Narrative:
Regular inspection and maintenance is critical to the effectiveness of a green roof. It is the responsibility of the property owner to maintain all Storm Water facilities in accordance with the minimum design standards required by the City of Indianapolis and this Operations & Maintenance Manual. All facility components, including plant material, growing medium, filter fabric, drainage layer, waterproof membranes, and roof structure should be inspected for proper operations, integrity of the waterproofing, and structural stability throughout the life of the green roof. The local jurisdiction has the authority to impose additional maintenance required where deemed necessary. The city has the right to inspect the system and to require replacement if it fails or is a threat to public safety. If maintenance does not correct the problem, full or partial replacement may be required.

Green Roofs shall be in accordance with the following inspection and maintenance criteria:

Inspection Activities	**Suggested Frequency**
• Inspect to ensure that the green roof was installed and working properly. • Inspect areas for potential erosion or damage to vegetation.	Post-construction
• Inspect foundation for any leaks and structural deficiencies. • Inspect overflow devices (pipes and inlets) for obstructions or debris that would prevent proper drainage when filtration capacity is exceeded.	Annually and after large storm events
• Inspect for ponding. • Inspect for dead or stressed vegetation. • Inspect for tall or sun scorched grass. • Inspect for weeds. • Inspect mechanical equipment for leaks and spills.	As needed
Maintenance Activities	**Suggested Frequency**
• Repair any leaks or structural deficiencies. • Contact manufacturer for repair or replacement of membrane. • Remove any sediment and plant debris from clogged outlets.	As needed
• Drain inlet pipe should be cleared when soil substrate, vegetation, debris or other materials clog the drain inlet. • Plant material should be maintained to provide **90%** coverage. • Weeds should be pulled manually, and removed regularly and not allowed to accumulate. • If necessary during the establishment period (initial 18 months), irrigation can be provided by hand watering or automatic sprinkler system. • Report any mechanical equipment leaks and spills, proper spill prevention should be exercised.	As needed
• Growing medium should be inspected for evidence of erosion from wind or water. If erosion channels are evident, they can be stabilized with additional growth medium must be similar to the original specified material.	Quarterly

Address of property

Inspector:
Date:
Time:
Weather: Rainfall over previous 2-3 days? Site conditions:
Owner change since last inspection?: Y N

Mark items in the table below using the following key:

- **X** Needs immediate attention
- **–** Not Applicable
- ✓ Okay
- **?** Clarification Required

Green Roof Components:

Items Inspected	Checked		Maintenance Needed		Inspection Frequency
STRUCTURAL COMPONENTS:	Y	N	Y	N	**A**
1. Foundation checks (e.g. are there any leaks or structural deficiencies)?					
2. Tears or perforation of membrane (contact manufacturer for repair or replacement)?					
3. Clogged outlets (remove any sediment and plant debris if necessary)?					
4. Standing water present (all facilities shall drain within 24 to 48 hours. Record time/date, weather, and site conditions when ponding occurs)?					
VEGETATION: (plant material shall cover 90% of the facility)					**M, AMS**
5. Dead or stressed vegetation?					
6. Tall or sun scorched grass?					
7. Weeds?					
GROWING/FILTER MEDIUM:					**M, AMS**
8. Exposed soils?					
9. Gullies?					
10. Ponding?					
OTHER					**A**
11. Are mechanical units free of leaks and spills?					
12. Is there any threat to Public Health? (e.g mosquito larvae or rats)					
13. Other (describe)?					

Inspection Frequency Key A= Annual, M= Monthly, AMS= After Major Storm

COMMENTS:

OVERALL CONDITION OF FACILITY:
In accordance with approved design plans? Y / N

In accordance with As Built plans? Y / N
Area of roof covered by green roof on plans = _____
Area of roof covered at time of inspection = _____

Maintenance required as detailed above?Y / N

Compliance with other consent conditions? Y / N

Comments: _____
_____

Dates by which maintenance must be completed: _____ / ___ / ____

Dates by which outstanding information as per consent conditions is required by: _____ / ___ / ____

Inspector's signature: _____

Owner/Engineer/Agent's signature: _____

Owner/Engineer/Agent's name printed: _____

4.1.2. Green Roof Designer/Reviewer Checklist

Item	Yes	No	N/A	Notes
Load and structural capacity analyzed?				
Waterproofing layer and protection adequate?				
Leak protection system provided?				
Internal drainage capacity for large storms provided?				
Appropriate growing medium?				
Appropriate drainage media and/or layer?				
Geotextile/filter fabric specified?				
Good detailing (flashings, penetrations, drains, gravel edges, etc.)?				
Slope stability provided, if necessary?				
Appropriate vegetation selected?				
Appropriate drainage location provided?				
Plant establishment (temporary irrigation/fertilization) procedures provided?				
Erosion control / wind protection provided?				

4.2. Permeable Pavement Systems

Permeable Pavement provides the structural support of conventional pavement, but allows Storm Water to drain directly through the surface into the underlying stone base then to an underdrain or soils (where the soil type allows for infiltration), thereby reducing Storm Water runoff. There are permeable varieties of asphalt, concrete, and interlocking pavers. Permeable pavements are designed with an open graded stone sub-base that allows water to pass through to the native soil and/or provides temporary storage. Some of the benefits to using permeable pavements include: a reduction in the amount of storm pipes and inlet structures required; the ability to have more parking areas built to accessible slopes (due to flatter grades achievable with porous surfaces); improved growing conditions of plant material in landscape islands due to air and water available through porous surface; pedestrian safety due to improved winter and wet weather pavement conditions.

KEEP INDIANAPOLIS BEAUTIFUL HEADQUARTERS: 1029 FLETCHER AVE. INDIANAPOLIS, IN- INTEGRATED STORM WATER MANAGEMENT- FEATURES PERVIOUS CONCRETE, CISTERN AND RAIN GARDENS TO MEET STORM WATER REGULATIONS

Key Elements of Permeable Pavement:

- Porous structural surface with high infiltration rate.
- Porous surface and #8 stone sub-base suitable for design traffic loads. Can be used on most travel surfaces with slopes less than 5%.
- Uncompacted, level sub-grade allows infiltration of Storm Water.
- Open-graded #8 stone aggregate sub-base provides storage.
- Additional storage and control structures can be incorporated to meet flood control.
- Positive overflow prevents system flooding.

Table 4.2.1: Permeable Pavement Potential Application and Storm Water Regulation

Potential applications			Storm Water regulations		
				Infiltration	No Infiltration
Residential Subdivision:	Yes		Water Quality Benefit	Yes*	No
Commercial:	Yes		Volume Reduction	Yes	No
Ultra Urban:	Yes		Attenuation Benefit	Yes	Yes
Industrial:	Yes				
Retrofit:	Yes				
Highway Road:	Limited, only where approved by DPW				

*If all design storms are captured and infiltrated

Acceptable Forms of Pre-treatment

N/A

Permeable Pavement in the Urban Landscape

Permeable pavement systems can be used to promote infiltration of Storm Water runoff or detain runoff. When designed to infiltrate, this technique is very effective in reducing the volume of Storm Water entering a sewer system and is being studied for its effectiveness for removing pollutants. During a rain event, Storm Water flows through the porous surface, drains into the crushed stone sub-base beneath the pavement, and remains stored until Storm Water can infiltrate into the soil or, in the case of detention, until it can be released in a controlled manner to an "adequate" drainage outlet. Porous asphalt and concrete mixes are similar to their impervious counterparts, but do not include the finer grade particles. Interlocking pavers may have openings that are filled with stone to create a porous surface.

PERMEABLE PAVER SYSTEM APPLICATION-BRENTWOOD SCHOOL-PLAINFIELD, IN

Permeable pavement systems are suitable for any type of development. They are especially well suited for parking lots, walkways, sidewalks, basketball courts, and playgrounds. Proper training of owner, users and maintenance staff will help to prolong the life of the system.

PERVIOUS CONCRETE APPLICATION-PURDUE UNIVERSITY-WEST LAFAYETTE, IN

Alternate for Paved Surfaces

Almost any surface that is traditionally paved with an impervious surface can be converted to a porous pavement system. Porous surfaces are particularly useful in high density areas where there is limited space for other Storm Water management systems. Porous pavement can be used for parking lots, basketball courts, playgrounds, plazas, sidewalks and trails. Interlocking porous pavers can be used to provide an interesting aesthetic alternative to traditional paving. Porous pavement can be designed to meet the loading requirements for most parking lots and travel surfaces. However, for lots or loading areas that receive a high volume of heavy traffic and/or turning movements (as in a restaurant drive-thru lane), porous pavement can be used for parking stalls and conventional pavement for travel lanes and loading areas. In this case the impervious surfaces could be graded toward the porous surfaces.

PERMEABLE PAVER SYSTEM APPLICATION-MORTON ARBORETUM- CHICAGO, IL

It should be noted that porous pavement may not be used within the public right-of-way without approval of the DPW.

Direct connection of roof leaders and/or inlets

The stone sub-base storage of permeable pavement systems can be designed with extra capacity, and roof leaders and inlets from adjacent impervious areas can be tied into the sub-base to capture additional runoff. These stone beds can be sized to accommodate runoff from rooftops via direct connection or to supplement other Storm Water Best Management Practices (BMPs). Pretreatment (sumped inlet with hood) may be necessary to prevent particulate materials from these surfaces from clogging the sub-base of the porous pavement system. All permeable pavement systems must include a positive overflow.

Direction of Impervious Runoff to Permeable Pavement System

Adjacent impervious surfaces can be graded so that the flow from the impervious area flows over the porous pavement and into the sub-base storage below if sufficient capacity is created. Typically, it is recommended that the impervious area does not exceed 3 times the area of the porous pavement receiving the runoff.

**PERMEABLE PAVEMENT SYSTEM-
INTERCARE-INDIANAPOLIS, INDIANA**

**PERMEABLE PAVER SYSTEM-
ELMHURST COLLEGE-ELMHURST
ILLINOIS-**

**PERVIOUS CONCRETE DRAINAGE IMPROVEMENT- PURDUE
UNIVERSITY- WEST LAFAYETTE IN**

Components of a Permeable Pavement System

Different porous surfaces are used for porous pavement systems, but all rely on the same primary components:

- Inflow/Surfacing
- Storage
- Infiltration/Outflow

Figure 4.2.1: Permeable Paver System Cross Section

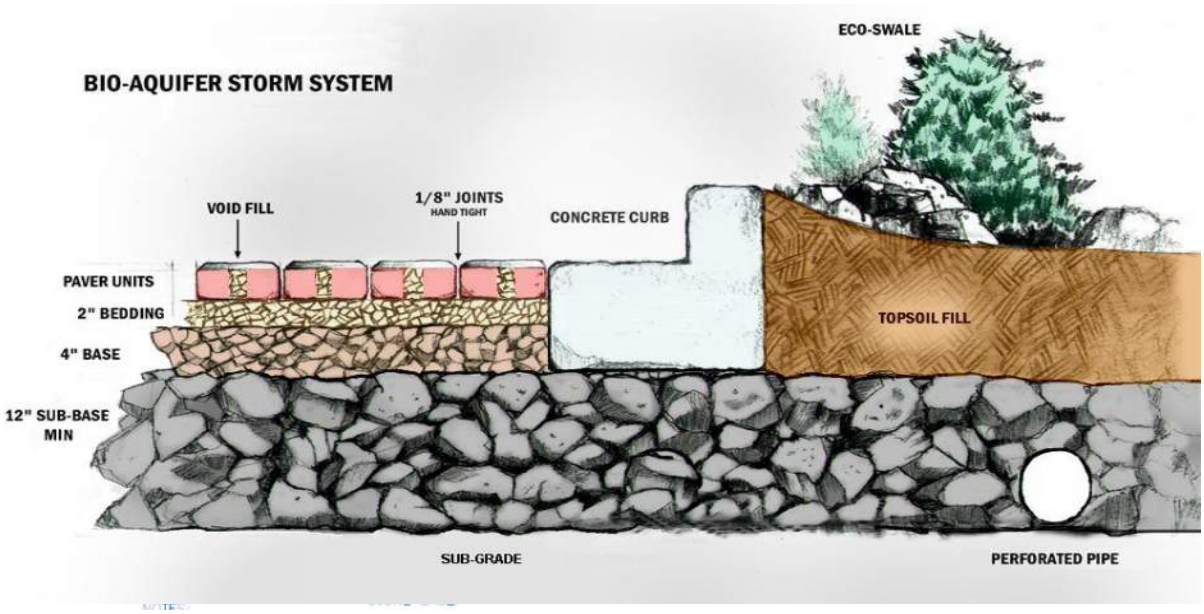
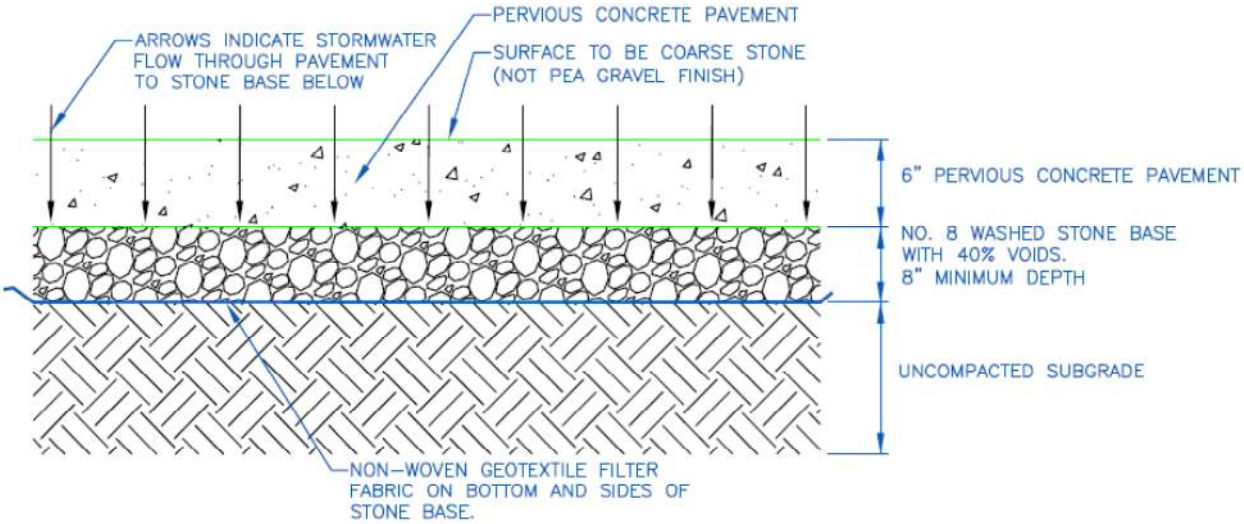


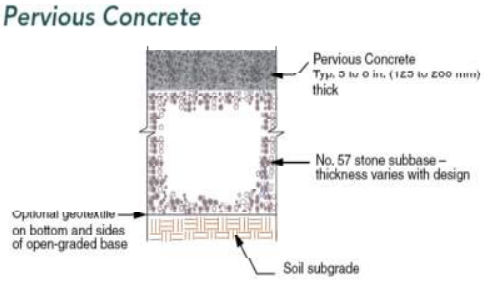
Figure 4.2.2: Pervious Concrete System Cross Section



Inflow/Surfacing

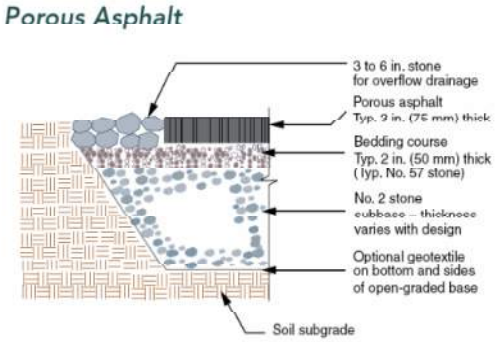
There are many different types of structural surface materials that allow water to flow through void spaces within the material. Any of these alternatives serve as a form of conveyance and filtration for the storage bed below. Several of the most commonly used porous structural surfaces are described below, but this does not represent an exhaustive list of the porous surfaces appropriate for Storm Water management applications.

Porous concrete (a/k/a Portland Cement, Pervious Concrete, or PCPC)



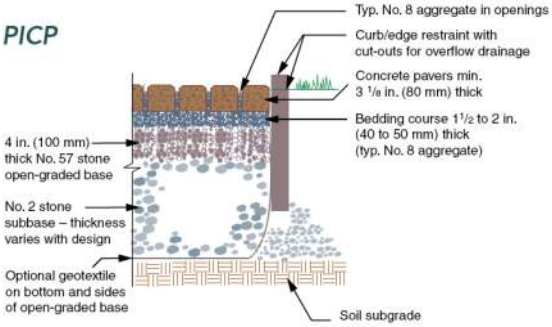
Porous concrete was developed in the U.S. by the Florida Concrete Association in the 1970s. While its early applications remained in Florida and other southern areas, the last ten years have seen an increase in the use of porous concrete in freeze-thaw regions. According to the ACI Committee Report 522R-06, the term "pervious concrete" typically describes a zero-slump, open graded material consisting of Portland cement, coarse aggregate, little or no fine aggregate, admixtures and water. Porous concrete is produced by substantially reducing the number of fines in the mix in order to establish voids for drainage. Porous concrete has a coarser appearance than its conventional counterpart.

Porous asphalt



Porous asphalt pavement was first developed in the 1970s and consists of standard bituminous asphalt in which the fines have been screened and reduced, allowing water to pass through very small voids. Recent research in open-graded mixes for highway application has led to additional improvements in porous asphalt through the use of additives and binders. Porous asphalt is very similar in appearance to conventional, impervious asphalt.

Permeable pavers



Permeable pavers are interlocking units (often concrete) with openings that can be filled with a pervious material such as gravel. These units are often very attractive and are especially well suited to plazas, patios, small parking areas, etc. There are also plastic grids that can be filled with gravel to create a fully gravel surface that is not as susceptible to rutting and compaction as traditional gravel lots. Gravel used in interlocking concrete pavers or plastic grid systems must be well graded to ensure permeability.

Reinforced turf

Reinforced turf consists of interlocking structural units with openings that can be filled with soil for the growth of turf grass and are suitable for traffic loads and parking. They are often used in overflow or event parking as well as emergency access for fire trucks. Reinforced turf grids are made of concrete or plastic and are underlain by a stone and/or a sand drainage system for Storm Water management. While both plastic and concrete units perform well for Storm Water management and traffic needs, plastic units may provide better turf establishment and longevity, largely because the plastic will not absorb water and diminish soil moisture conditions. The grids protect the root structure of the grass and minimize the impact on the grass by traffic loads.

Storage

In addition to distributing mechanical loads, coarse aggregate laid beneath porous surfaces is designed to store Storm Water prior to infiltration into soils or discharging to a Storm Water BMP. The aggregate is wrapped in a non-woven geotextile to prevent migration of soil into the storage bed and resultant clogging. In porous asphalt and porous paver applications, the storage bed also has a choker course of smaller aggregate to separate the storage bed from the surface course. The storage bed can be designed to manage runoff from areas other than the porous surface above it, or can be designed with additional storage and control structures that meet the parameters required within the Storm Water Design and Construction Specifications Manual. Currently, the approval of a pervious concrete / porous pavement system requires an underdrain with infiltration allowed only when the underlying soils permit.

Infiltration/Outflow

Positive overflow must be provided for porous pavement systems. Positive overflow conveys runoff from larger storms out of the system, prevents flooding and prevents water from standing within the porous structural surface which minimizes freeze-thaw impacts. One solution for a positive overflow is a stone buffer along the edges of a porous pavement lot. The stone, typically river rock or a stone with aesthetic value, is connected to the stone sub-base below the pavement to allow a path for excess water to flow out of the system. The stone should allow positive overflow to occur at an elevation below the structural surface. A perforated pipe system can also convey water from the storage bed to an outflow structure. The storage bed and outflow structure should be designed to meet the detention requirements of the Storm Water Design and Construction Specifications Manual. Inlets can be used to provide positive overflow if additional rate control is not necessary. More information about large underground storage systems can be found in the Subsurface Infiltration Fact Sheet.

SIDE BY SIDE COMPARISON OF STANDARD ASPHALT WITH POROUS ASPHALT

Recommended Design Procedure

Design of porous pavement systems is critical if they are to function properly and efficiently. The area and shape are dependent on the site design, and selection of the surface material is dependent on intended site uses and desired appearance. The depth of the stone base can be adjusted depending on the management objectives, total drainage area, traffic load, and soil characteristics. The following design procedures are general guidelines that designers can follow.

- Determine if site is acceptable for use of porous pavements.
- In order to properly design the porous pavement system, a curve number or runoff coefficient must be established for the pavement. Current standards require that the standard pavement CN of 98 or runoff coefficient of 0.85 be used with the stone base utilized for detention requirements.
- Porous pavement should be designed as a detention system. The outlet control will be the underdrain and / or infiltration rate of the underlying soil. Standard detention calculations per Chapter 300 should be used for determining the depth of the stone base for the volume.
- Current standards require that water quality be addressed separately from the porous pavement system as porous pavement has not been accepted as a water quality practice.

Siting for Porous Pavements

Porous pavements are not suited for every site. Site evaluation is critical for the success of porous pavement. Porous pavements should not be used until the site has met the minimum standards required for their use. Some minimum standards are:

- High water table depth to bottom of stone storage layer must be 2 feet or greater.
- For optimal performance locate systems on well-drained permeable soils with field verified permeability rates. A geotechnical report / analysis is required when infiltration will be utilized. The report must document the soil infiltration rate and the seasonal high water table.
- Land surrounding and draining to the pavement doesn't exceed 20% slope.
- Minimum setback of 100 feet from wells used to supply drinking water or as required by local agency. Not recommended for use in well-head protection zones without an "impermeable" liner and a positive connection to an "acceptable" storm water outlet.
- Minimum setback of 10 feet from down-gradient of building foundations or as required by building code.
- Determine the detention and water quality requirements on the site. See the Storm Water Design and Construction Specifications Manual for more information.
- Create a Conceptual Site Plan for the entire site and determine what portion of the detention/retention sizing requirements porous pavement will meet.
- Investigate the feasibility of infiltration in the area proposed for a porous pavement (hotspot investigation, infiltration test, and geotechnical analysis). More information is provided in **Attachment 3**.
- Create a conceptual design for the porous pavement system.

Table 4.2.2: Suggested Starting Porous Pavement Design Values	
Area (surface area and infiltration area)	Largest feasible on site
Choker/Aggregate Bed Depth	8-36 inches

- Estimate the total storage volume and adjust area and/or depths as needed to provide required storage. Assume a void ratio of approximately 40% for #8 washed stone.
- Design system with a level bottom; use a terraced system on slopes. Provide a positive slope for the bottom if the underlying soils have a high clay content or low permeability in general.
- Using infiltration area and the saturated vertical infiltration rate of the native soil, estimate how long the stored volume will take to drain. The maximum drain down time for the entire storage volume is 72 hours, but the Engineer may choose a shorter time based on site conditions and Owner preference. If storage does not drain in the time allowed, adjust aggregate depth and/or surface area. Adjust the design until the volume and drainage time constraints are met. Ensure that the storage volume does not occur within the porous structural surface, but is entirely contained within the stone sub-base below it. Underdrains placed at the top of the aggregate bed can serve to minimize or prevent standing water in the structural surface. Also refer to **Permeable Pavement Systems Design Guidelines (Attachment 3)**.
- Per City of Indianapolis requirements, at least one underdrain shall be used for all porous pavement systems. Additional underdrains may be required based on layout and individual site conditions.
- Design distribution and overflow piping to minimize chance of clogging.
- Check that any release rate requirements (including release through any underdrain) are met by the system as designed. Typically, the underdrain pipe can be set at an elevation higher than the stone bottom to allow detention within the stone. See the Storm Water Design and Construction Specifications Manual.

- Design adequate Storm Water quality BMP(s) downstream of the porous pavement to treat the water quality volume per the Storm Water Design and Construction Specifications Manual.
- Complete construction plans and specifications.

Materials

Subsurface Storage Beds

- All aggregates within infiltration beds shall meet the following:

1. Uniformly graded, crushed, washed coarse aggregate
2. Maximum wash loss of 0.5%
3. Minimum Durability Index of 35
4. Maximum abrasion of 10% for 100 revolutions and maximum of 50% for 500 revolutions.

- Choker course aggregate, where needed, shall meet the specifications of AASHTO No. 57.
- Storage stone should meet the specifications of AASHTO No. 3. Additional storage materials are further discussed in the Subsurface Infiltration Fact Sheet.

Table 4.2.3: Required Choker Course Gradation

U.S. Standard Sieve Size	Percent passing
1 ½" (37.5 mm)	100
1" (25 mm)	95 - 100
½" (19 mm)	25-60
4 (4.75 mm)	0 - 10
8 (2.36 mm)	0 - 5

Table 4.2.4: Required Stone Storage Gradation

U.S. Standard Sieve Size	Percent passing
2 ½" (63 mm)	100
2" (50 mm)	95 - 100

Porous pavement mix designs are often 'local' to a region as aggregate properties vary depending on the region. Also, advances in mix designs of porous pavements continue to evolve. Therefore, the information listed below for porous asphalt and pervious concrete pavements should be used as a foundation for the mix designs and local suppliers should be consulted to finalize the mix design for the project.

Porous Concrete

- Portland Cement Type I, II or III conforming to ASTM C 150 or Portland Cement Type IP or IS conforming to ASTM C 595.

- No. 8 coarse aggregate (3/8 to No. 16) per ASTM C 33 or No. 89 coarse aggregate (3/8 to no. 50) per ASTM D 448.

- As mentioned above, due to the variations in aggregate, mix designs for pervious concrete vary in the different regions of the country. There is no ideal mix that will produce the same result in all locations. Local concrete suppliers who are certified to produce pervious concrete can provide a mix design that will meet the desired pavement performance. Typically for pervious concrete pavements in central Indiana the:
    - water/cement ratio varies from 0.26 to 0.40
    - concrete mixture void content varies from 15% to 25%
    - cement content is 350 lbs/cubic yard minimum for vehicular traffic loading
    - use of a hydration stabilizing admixture (HSA) is strongly recommended

Test pours are recommended to ensure adequate strength, porosity and appearance of the pervious concrete.

The Indiana Ready Mixed Concrete Association has a system of certifying installers for pervious concrete. The certified installers are listed on their website at www.irmca.com. Only certified installers shall be used for the pervious concrete installations which are to serve as Storm Water infrastructure and detention facilities.

Porous Bituminous Asphalt

- Bituminous surface shall be laid with a bituminous mix of 5.75% to 6% by weight dry aggregate. In accordance with ASTM D6390, drain down of the binder shall be no greater than 0.3%. Aggregate grain in the asphalt shall be a minimum 90% crushed material and have the following gradation.

Table 4.2.5: Porous Bituminous Aggregate Gradation

U.S. Standard Sieve Size	Percent passing
½ (12.5 mm)	100
3/8” (9.5 mm)	92 - 98
4 (4.75 mm)	34 - 40
8 (2.36 mm)	14 - 20
16 (1.18 mm	7 - 13
30 (0.60 mm	0-4
200 (0.075 mm)	0-2

- Neat asphalt binder modified with an elastomeric polymer to produce a binder meeting the requirements of PG 76-22 as specified in AASHTO MP-1. The elastomer polymer shall be styrene-butadiene-styrene (SBS), or approved equal, applied at a rate of 3% by weight of the total binder.
- Hydrated lime should be added at a dosage rate of 1% by weight of the total dry aggregate to mixes containing granite. Hydrated lime shall meet the requirements of ASTM C 977. The additive must be able to prevent the separation of the asphalt binder from the aggregate and achieve a required tensile strength ratio (TSR) of at least 80% on the asphalt mix when tested in accordance with AASHTO T 283. The asphaltic mix shall be tested for its resistance to stripping by water in accordance with ASTM D-1664. If the estimated coating area is not above 95 percent, anti-stripping agents shall be added to the asphalt.

- The asphaltic mix shall be tested for its resistance to stripping by water in accordance with ASTM D-3625. If the estimated coating area is not above 95 percent, anti-stripping agents shall be added to the asphalt.

Paver and Grid Systems

- Paver and grid systems shall conform to manufacturer specifications.

- A minimum flow through rate of 5 in/hr or a void percentage of no less than 10%.

Non-Woven Geotextile

- Geotextile shall consist of needled non-woven polypropylene fibers and meet the following properties:

    - Grab Tensile Strength (ASTM-D4632) ≥ 120 lbs
    - Mullen Burst Strength (ASTM-D3786) ≥ 225 psi
    - Flow Rate (ASTM-D4491) ≥ 95 gal/min/ft^2
    - UV Resistance after 500 hrs (ASTM-D4355) ≥ 70%
    - Heat-set or heat-calendared fabrics are not permitted

Pipe

- Distribution pipe within bed shall be continuously perforated and have a smooth interior with a minimum inside diameter of 6-inches. High-density polyethylene (HDPE) pipe shall meet the specifications of AASHTO M252, Type S or AASHTO M294, Type S.

Construction Guidelines

General Guidelines for all Porous Pavements

The construction guidelines for the installation of the subsurface infiltration beds are applicable to all porous pavement systems. Guidelines are also provided specifically for pervious concrete and porous asphalt.

SUBBASE EXCAVATION AND CONSTRUCTION

- Areas for porous pavement systems shall be clearly marked before any site work begins to avoid soil disturbance and compaction during construction.

- An on-site pre-construction conference is recommended in order to inform the contractor and subcontractors of the special precautions that are required when working around porous pavements. This includes landscape crews, as the improper placement of mulch onto the porous pavement could result in localized clogging. During the pre-construction conference, the porous pavement siting requirements should be reviewed to ensure that no adverse impacts could occur to surrounding properties (basements, etc.).

- Identify the sources of Storm Water point discharges that could drain toward the pavement surface (roof leaders, etc.). Provide a bypass for these Storm Water sources during the placement and curing period of the porous pavement.

- Excavate porous pavement subsurface area to proposed depth. Where erosion of subgrade has caused accumulation of fine materials and/or surface ponding, this material shall be removed with light equipment and the underlying soils scarified to a minimum depth of 6 inches with a York rake or equivalent and light tractor.

- Existing subgrade shall NOT be compacted or subject to excessive construction equipment prior to placement of geotextile and stone bed. If it is essential that equipment be used in the excavated area, all equipment must be approved by the Engineer. Use of equipment with narrow tracks or tires, rubber tires with large lugs, or high pressure tires will cause excessive compaction and shall not be used.

- Bring subgrade of stone infiltration bed to line, grade, and elevations indicated in the Drawings. Fill and lightly regrade any areas damaged by erosion, ponding, or traffic compaction before placing the stone. The bottom of the infiltration bed shall be at a level grade.

- Place geotextile and recharge bed aggregate immediately after approval of subgrade preparation to prevent accumulation of debris or sediment. Prevent runoff and sediment from entering the storage bed during the placement of the geotextile and aggregate bed.

- Place geotextile in accordance with manufacturer's standards and recommendations. Adjacent strips of filter fabric shall overlap a minimum of 16 inches. Fabric shall be secured at least 4 feet outside of bed. This edge strip should remain in place until all bare soils contiguous to beds are stabilized and vegetated. As the site is fully stabilized, excess geotextile can be cut back to the edge of the bed.

- Install aggregate course in lifts of 6-8 inches. Compact each layer with equipment, keeping equipment movement over storage bed subgrades to a minimum. Install aggregate to grades indicated on the drawings.

- After placement and appropriate curing of structural pavement surface (7 days for pervious concrete and 48 hours minimum for porous asphalt hardening), test infiltration ability by applying clean water at a rate of at least 5 gpm over surface. The water applied to the surface should infiltrate without creating puddles or runoff.

- Do not use the porous pavement area for equipment or materials storage; no soil shall be deposited on porous pavement surfaces.

Guidelines for Installation of Pervious Concrete

- Pervious concrete pavement shall be installed by certified contractors only.

- A pre-paving conference with the contractor and engineer is recommended one week prior to beginning placement of pervious concrete. It is recommended that the contractor have the pervious concrete supplier, the foreman and the entire concrete crew that will form and place the concrete in attendance at this meeting.

- Once placed, the pervious concrete shall remain <u>covered and undisturbed</u> for seven (7) days. The covering should be a waterproof polyethylene sheeting with a minimum thickness of 6 mil. This curing period is essential for adequate strength and durability.

- The use of signage is encouraged during the seven day period to minimize the potential damage to the curing concrete occurring from pedestrian traffic.

Guidelines for Installation of Porous Asphalt

- Install and compact choker course aggregate evenly over surface of stone bed. Choker base course shall be sufficient to allow for even placement of asphalt, but no thicker than 1-inch in depth.

- Appropriate vehicles with smooth, clean dump beds shall be used to transport the asphalt mix to the site. Control cooling of asphalt by covering mix. Porous asphalt mix shall not be stored for more than 90 minutes before placement.

- The porous bituminous surface course shall be laid in one lift directly over the storage bed and stone base course and compacted to a 2½-inch finished thickness.

- Compaction of the surface course shall take place when the surface is cool enough to resist a 10-ton roller. One or two passes is all that is required for proper compaction. More rolling could cause a reduction in the surface porosity and permeability, which is unacceptable

- After rolling asphalt, no vehicular traffic is permitted on the surface until cooling and hardening has taken place (minimum 48 hours).

- The use of signage is encouraged during the seven day period to minimize the potential damage to the fresh asphalt occurring from pedestrian traffic.

Maintenance

As with most Storm Water management facilities, porous pavement systems require regular maintenance to extend their life. Detailed maintenance guidelines and a recommended schedule of inspection and maintenance can be found in the Example Permeable Pavement O & M Manual.

Sediment Control

Superficial dirt does not necessarily clog the voids in porous surfaces. However, dirt that is ground in repeatedly by tires can lead to clogging. Therefore, trucks or other heavy vehicles should be prevented from tracking or spilling dirt onto the pavement. Furthermore, all construction or hazardous materials carriers should be prohibited from entering a porous pavement lot. Also, by providing a 'rumble strip' surface at the entrance of a porous parking lot, the debris from tires can be isolated and later collected to avoid potential clogging of the entire lot.

Winter Maintenance

Winter maintenance for a porous parking lot may be necessary, but is usually less intensive than that required for a standard asphalt lot. By its very nature, a porous pavement system with subsurface aggregate bed has better snow and ice melting characteristics than standard pavement. Once snow and ice melt, they flow through the porous pavement rather than refreezing. Therefore, ice and light snow accumulation are generally not as problematic. However, snow will accumulate during heavier storms. Abrasives such as sand or cinders shall not be applied on or adjacent to the porous pavement. Snow plowing is acceptable, provided it is done carefully (i.e. by setting the blade about one inch higher than usual or using a rubber tipped blade. Salt is not recommended for use as a deicer on the porous pavement. Non-toxic, organic deicers applied either as blended, magnesium chloride-based liquid products or as pretreated salt, are preferable. Any deicing materials should be used in moderation.

Repairs

Potholes are not common; though settling might occur if a soft spot in the subgrade is not removed during construction. Damaged areas that are smaller than 50 square feet can be patched with a porous or standard asphalt mix, depending on the location within the porous area. In many cases the loss of porous surface will be insignificant. If an area greater than 50 square feet is in need of repair, approval of patch type must

be sought from either the engineer or owner. Porous pavement must never be seal coated under any circumstances. Any required repair of drainage structures should be done promptly to ensure continued proper functioning of the system.

Note:

Design of permeable pavement systems are not limited to the examples shown within this text. Successful Storm Water management plans will combine appropriate materials and designs specific to each site.

Table 4.2.6: Engineering Report Requirements

Item	Infiltration / Detention Design	Detention-Only Design
Soil Infiltration Rate and Seasonal High Water Table Elevation Documentation	Report by Geotechnical Engineer or Registered Soil Scientist Required	Not Required
Storage Volume Calculations using 40% Void Space	Yes	Yes
Runoff, Storage, Outlet and Drain-Down Time Calculations	Yes	Yes
Overflow Calculations	Yes	Yes
Discussion of Local Water wells, and / or Wellhead Protection Zones	Yes	Yes

Table 4.2.7: Plan Requirements

Item	Infiltration Design	Detention-Only Design
Watershed Delineation (i.e. area served by the porous pavement) (Impervious area served may not exceed 3x area of porous pavement)	Yes	Yes
Plan View with Porous Pavement Area delineated and Labeled	Yes	Yes
Cross-Section Detail Showing Depth of Pavement, Choker Layer and Storage Layer	Yes	Yes
Detail and Location of Warning Sign ('Pervious Pavement - No Construction Equipment")	Yes	Yes
Plan View Showing Underdrain location and Outlet	Yes	Yes
Plan View Showing Location of Water Quality System	Not Required	Yes
Location of Overflow	Yes	Yes
Location of Local Waterwells-	Yes	Yes
Center Coordinates (in State Plane Coordinates) on Cover Sheet Summary Table	Yes	Yes

Table 4.2.8: O & M Manual Requirements

Item	Infiltration Design	Detention-Only Design
Owner Name, Address, Phone Number, email, etc.	Yes	Yes
Water Quality Unit Maintenance per Chapter 700	Not Required	Yes
Site Map with Porous Pavement Delineated and Labeled	Yes	Yes
Tabular Inspection Table	Yes	Yes
Inspection Checklist	Yes	Yes
Narrative Describing Repair Procedures / Requirements for the Porous Pavement	Yes	Yes
Inspection of Pretreatment Systems	Yes	Yes

Green Infrastructure Checklist

Permeable Pavements:

Site requirements for use:

- High water table depth to bottom of stone storage layer must be 2' or greater. (This is to prevent high water table from filling up detention storage area in stone.)
- If buildings adjacent to pavement have basements, make sure that the porous pavement is a minimum of 10' from the building/basement. Also, depending on soil type, a waterproof membrane may be needed on the side adjacent to the building. This should be evaluated on a case by case basis.
- If adjacent buildings don't have basements, the porous pavement should be located a minimum of 5' from the building.

Design Considerations:

- Slope of porous pavement can be flatter than traditional pavement. This helps the stone bed below it to be most efficiently used for Storm Water storage. Some slope is recommended to allow for positive drainage if pavement clogs in some areas.
- Size detention basin (stone base below pavement) based on Storm Water flow entering pavement. For #8 washed stone base, the void area in the stone is typically 40% of the stone volume. The stone must be wrapped in geotextile to ensure that voids in stone remain open for water storage and don't get clogged over time. The contractor can provide a sample of the stone to verify the void space for the stone used if needed.
- **No storage of Storm Water on top of the pavement** (as is allowed with traditional pavement).
- **No storage of Storm Water within porous pavement section**. The design must include a positive overflow from the stone bed to prevent water backing up into pavement section. (This is to prevent issues with freeze-thaw.) This could be an underdrain pipe or simply the stone base exposed so it can overflow to the lawn.
- It is recommended to discharge the overflow from the pavement stone base into a rain garden or bioretention area to improve water quality.
- If soils are adequate for infiltration there might not be runoff from the pavement (if all of it infiltrates). In this case (which is likely rare, but possible) there is no water quality volume or required treatment since there is no runoff.

Construction Considerations:

- Qualified contractors are a MUST. This means that their crew must have experience placing the pavement, not just the foreman.
- When using Portland Cement Pervious Concrete (PCPC) the pavement must remain covered for 7 days during the curing period. During this time it is critical that any Storm Water be diverted from the pavement – especially roof leaders that contribute point discharges.
- Erosion control is a must - any sediment laden water shall not be allowed to flow onto the porous pavement.
- No mulch or landscaping storage shall be allowed on the pavement as it could clog the pores of the pavement and thereby reduce its ability to convey and store Storm Water.
- The pavement should be tested after construction by pouring water over it to see if there are any areas that need to be cleaned or repaired due to construction activities.

4.2.1. Permeable Pavement Example O & M Manual

Permeable Pavement – O & M Manual

Owner Name
Address of Property
Owner Contact Name and Phone Number

BMP Narrative:
Regular inspection and maintenance is critical to the effective use of porous pavement. It is the responsibility of the property owner to maintain all Storm Water facilities in accordance with the minimum design standards required by the City of Indianapolis and this Operations & Maintenance Manual. The local jurisdiction has the authority to impose additional maintenance required where deemed necessary. The city has the right to inspect the system and to require replacement if it fails or is a threat to public safety. Portland Cement Pervious Concrete Pavement (PCPC) is considered to be failing if water can be seen standing on it or in it (within the concrete pavement section), unless the storm event is above a 100-year event. If maintenance does not correct the problem, full or partial replacement may be required.
Porous pavement shall be in accordance with the following inspection and maintenance criteria:

Inspection Activities	**Minimum Frequency**
• Inspect to ensure that pavement was installed and working properly. • Inspect areas for potential erosion or damage to vegetation.	Post-construction
• Visibly inspect porous pavement surface after major storm event for evidence of sediment, debris (e.g., mulch, leaves, trash, etc.), ponding of water, oil-dripping accumulations, clogging of pores and other damage. • Inspect overflow devices (pipes and inlets) for obstructions or debris that would prevent proper drainage when filtration capacity is exceeded. • Ensure that the contributing area upstream of the porous pavement is free of sediment and debris.	Annually and after large storm events
• Verify that the porous pavement dewaters between storms.	Monthly
• Inspect the surface for structural integrity. Inspect for evidence of deterioration or spalling.	Annually
Maintenance Activities	**Minimum Frequency**
• Remove excess sediment from construction area and stabilize adjacent areas with vegetation.	Post-construction
• Prevent soil from being washed onto pavement by ensuring that adjacent areas are stabilized. Keep landscape areas well maintained with lawn clippings removed to prevent clogging pavement. • Rake and remove fallen leaves and debris from deciduous trees and shrubs to reduce the risk of clogging. • Remove debris and clear obstructions from overflow devices (pipes and inlets).	Annually, as needed
• Vacuum sweep porous concrete pavement (with proper disposal of removed material), followed by high pressure hosing (when needed) to free pores on the surface.	2-3 times per year or more frequent as needed.
• If ponding persists, clogged concrete pavement must be repaired or replaced.	If failure exists

Address of property

Inspector:
Date:
Time:
Weather: Rainfall over previous 2-3 days? Site conditions:
Owner change since last inspection?: Y N

Mark items in the table below using the following key:

- **X** Needs immediate attention
- **–** Not Applicable
- ✓ Okay
- **?** Clarification Required

Porous Pavement Components:

Items Inspected	Checked		Maintenance Needed		Inspection Frequency
PAVEMENT SURFACE	Y	N	Y	N	**M**
1. Signs of clogging (e.g. standing water)?					
2. Debris (mulch, trash) accumulation?					
3. Sediment accumulation?					
4. Standing water present?					
ADJACENT AREAS					**A, AMS**
5. Erosion from underdrain?					
6. Exposed soil in areas discharging or adjacent to the porous pavement area?					
7. Is porous pavement adversely affected by any adjacent site feature?					
DEWATERING					**A, AMS**
8. Does runoff discharge from pavement area 24 to 72 hours after the end of a storm event?					
OUTLETS/OVERFLOW SPILLWAY					**A, AMS**
9. Is outlet for storm sewer system free from debris and in good working order?					
OTHER					**A**
10. Have there been complaints from residents?					
11. Public hazards noted?					
12. Other (describe)?					

Inspection Frequency Key A= Annual, M= Monthly, AMS= After Major Storm

Notes:

1. **Sand, cinders or other abrasives should not be used on or adjacent to the porous pavement.**
2. **Signage indicating no heavy or construction traffic permitted should be posted.**
3. **Porous pavement must not be seal coated.**

COMMENTS:

OVERALL CONDITION OF FACILITY:

In accordance with approved design plans? Y / N

In accordance with As Built plans? Y / N

Maintenance required as detailed above? Y / N

Compliance with other consent conditions? Y / N

Comments: _____

_____

Dates by which maintenance must be completed: ____/ ___ / ___

Dates by which outstanding information as per consent conditions is required by: ____ / ___ / _____

Inspector's signature: _____

Owner/Engineer/Agent's signature: _____

Owner/Agent's name printed: _____

4.2.2. Permeable Pavement Designer/Reviewer Checklist

Type of pervious pavement(s) proposed: _____

Source of mix design or material source: _____

Item	Yes	No	N/A	Notes
Appropriate application of pervious pavement (e.g., use, traffic loading, slopes)?				
Infiltration rates measured?				
Soil permeability acceptable?				
If not, appropriate underdrain provided?				
Adequate separations from wells, structures, etc.?				
Natural, uncompacted soils specified for base?				
Level infiltration area (bed bottom)?				
Excavation in pervious pavement areas				
Hotspots/pretreatment considered?				
Storage depth limited to 8-36”?				
Drawdown time less than 72 hours?				
Positive overflow from system?				
Erosion and Sedimentation control?				
Feasible construction process and sequence?				
Geotextile specified?				
Clean, washed, open-graded aggregate specified?				
Properly designed/specified pervious pavement surface?				
Maintenance accounted for and plan provided?				
Signage provided to prevent construction traffic and compaction?				

4.3. Rain Water Harvesting

Rain barrels, cisterns, and tanks are structures designed to intercept and store runoff from rooftops and other limited access surfaces (e.g. no transportation access). Rain barrels are used on a small scale while cisterns and tanks may be larger. These systems may be above or below ground, and they may drain by gravity or be pumped. Stored water may be slowly released to a pervious area, used for irrigation, or plumbed into buildings per code for use inside. *These techniques only serve as an effective Storm Water control function if the stored water is emptied between most storms, freeing up storage volume for the next storm.*

Key elements:

- Storage devices designed to capture small, frequent storm events with opportunity for larger storm volume capture.
- Storage techniques may include rain barrels, underground concrete or prefabricated tanks, above ground vertical storage tanks, or other systems.
- Systems must provide for storage, overflow or bypass of large storm events per local the City of Indianapolis Storm Water Design and Construction Specifications Manual.
- Placement of storage elements higher than areas where water will be reused may reduce or eliminate pumping needs.
- For effective Storm Water control, water must be used or discharged before the next storm event (i.e. <72 hours).
- Most effective when designed to meet a specific water need for reuse.

Table 4.3.1: Rain Barrel Potential Application and Storm Water Regulation

Potential applications			Storm Water regulations				
				Infiltration		No Infiltration	
Residential Subdivision:	Yes			RB	Cistern	RB	Cistern
Commercial:	Yes		Water Quality Benefit	Yes	Yes	Yes	Yes
Ultra Urban:	Limited		Volume Reduction	Yes	Yes	Yes	Yes
Industrial:	Yes		Attenuation Benefit	Yes	Yes	Yes	Yes
Retrofit:	Yes						
Highway Road:	No		Level of Benefit dependent on design criteria				

Acceptable forms of pre-treatment

- Screens
- First Flush bypass

Rain Barrels, Cisterns, and Tanks in the Urban Landscape

Rain barrels, cisterns, and other tanks are storage devices meant to promote detention of Storm Water runoff. Collectively or alone, these systems can be effective at preventing large volumes of Storm Water from entering the sewer system. Rain barrels, cisterns, and vertical storage are suitable where there is a use and need for the stored water or where there are areas to which water can be slowly released between storms. Rain harvesting storage can be used with existing buildings, new development, and redevelopment areas. Each of these areas can incorporate these systems into their Storm Water management plan. The design of these systems can be flexible due to the numerous design opportunities to capture and reuse Storm Water. The application and use of rain barrels, cisterns, or other tank storage systems are not limited to the examples provided below.

Rain Barrels on Individual Homes

The most common use of rain barrels is connection of one roof leader (downspout) to a single barrel on a residential property. Stored water can provide irrigation for a garden or can be released slowly to a lawn. Barrels can either be purchased or can be built by the homeowner. They are ideal for gardeners and concerned citizens who want to manage Storm Water without a large initial investment. They are also an easy retrofit. A design professional and Storm Water design calculations are typically not needed. The labor and installation can generally be performed by the property owner or handyman. The materials necessary are generally low cost and can be found at local retail hardware or plumbing supply stores.

Large Surface Tanks

Surface tanks may be larger than rain barrels but serve the same function. They can be integrated into sites where a significant water need exists or rain harvesting and reuse is desired. They may drain by gravity or be pumped. These typically need design professional assistance for more complex water collection and delivery system design. Typically need to be installed to local code by a certified and bonded plumbing or construction contractor.

Subsurface Storage and Water Reuse

Subsurface systems can be larger and more elaborate than rain barrels. These systems are typically pumped and may be used to supply water for building use or for irrigation systems. Because the cisterns are below the surface, they do not interfere with the landscape. These systems have higher initial costs than rain barrels and are ideal for commercial and institutional sites.

Water Features in Public and Institutional Landscapes

Architectural designs have incorporated water storage into site design. Features such as water fountains and ponds capture Storm Water from design storms to provide a water sources for these landscape features. These typically need design professional assistance for more complex water collection and delivery system design. Typically need to be installed to local code by a certified and bonded plumbing or construction contractor.

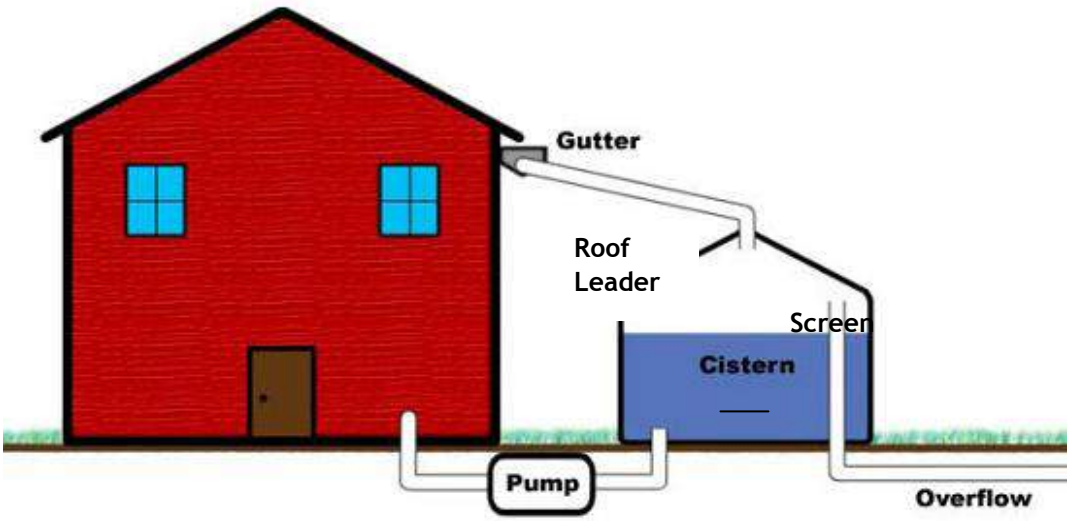
Reusing Storm Water for Indoor Use

Roof runoff can be captured and stored for reuse for residential, commercial or industrial needs. Roof runoff used in toilets does not need to meet potable water standards, but care must be used in plumbing to the building. Potable re-use systems for harvested rain water must comply with local plumbing and health codes. Supplementary and/or backup potable water systems must be maintained separately with all appropriate backflow prevention protection.

Components of Rain Barrels, Cisterns, and Tanks

Rain barrels, cisterns, and tanks all require the following basic components:

- a roof leader or other means of conveying roof runoff to the storage element,
- a screen to prevent debris and mosquitoes from entering,
- a storage element,
- a slow release mechanism or pump, a reuse opportunity, or infiltration area, and
- an overflow mechanism to bypass larger storms, after the storage element has filled.



Roof Leader

The gutter and roof leader system collects rooftop runoff and conveys it to the rain barrel, cistern, or other storage element. In most cases conventional roof leaders and downspouts can be used for this purpose.

Screen

A screen keeps leaves and other debris from entering and clogging the storage element. A screen also prevents mosquitoes from breeding in the storage element. A screen is typically placed at the end of the roof leader, before flow enters the rain barrel or cistern. A leaf strainer may also be placed where the gutter connects to the roof leader.

Storage Element

The storage element is the barrel, cistern, or tank itself. Rain barrels are typically made of plastic. Underground cisterns may be poured concrete or prefabricated plastic tanks similar to septic tanks. Proprietary products that store water in a variety of structures are also available. Tanks larger than rain barrels may be used above or below ground.

Slow Release Mechanism or Pump

For the storage element to serve its Storm Water control function, it must be partially or completely drained between most wet weather events. Rain barrels are typically drained in one of two ways: manually by means of a spigot similar to ordinary outside water faucets; and, the continual, slow release using a soaker hose to a garden or infiltration area. Larger surface tanks may drain by gravity or may be pumped. Subsurface systems and systems where Storm Water is reused for needs other than irrigation are typically pumped.

Overflow Mechanism

The storage capacity of rain barrels, cisterns, and other tanks may be exceeded in large storms. In rain barrels, a flexible hose is provided at an elevation near the top of the barrel. The diameter of the hose is at least equal in size to the roof leader to allow runoff to flow unimpeded during large events. The overflow from cisterns and larger tanks can occur through a weir, pipe, or other mechanism.

Table 4.3.2: Suggested Storage Design Values for Rain Barrels	
Rain Barrel	50 - 150 gallons
Cistern	500 - 7,000 gallons
Larger Above Ground Tank	3,000 - 12,000 gallons

Siting Procedure Recommendation

Identify opportunities and areas where water can be reused for irrigation, released to an infiltration area, or meet indoor use needs. Estimate the rate at which water can be reused. If the process of reuse is proposed to meet the Water Quality requirement, check the local Storm Water design codes and ordinances. For irrigation or garden use, determine the water needs of the plants; an assumption of 1 inch per week over the soil area may be used for approximate results. Identify potential infiltration areas where water may be discharged to at a slow rate. Refer to **Rain Water Harvesting Design Guidelines (Attachment 4)** for additional design information.

Rain Barrels

- Identify roof leaders where rain barrels can be installed.

- Decide whether to purchase a commercial rain barrel or to construct your own rain barrel.

- Choose between a faucet and a soaker hose. Position the outlet as low on the barrel as the design will allow to maximize storage volume. It is recommended that the design allow retention of 2 inches at the bottom of the barrel to help trap sediment and provide stability.

- Consider elevating the barrel by placing it on a stable platform (ie. cinder blocks) to increase water pressure at ground level.

- It is easiest to install soaker hoses on the ground surface. The hoses can then be easily reconfigured and moved whenever necessary. However, underground soaker hoses provide greater irrigation benefits for gardens, because the water does not evaporate. If buried, soaker hoses should be placed 2-4 inches under soil or 1-2 inches under mulch. Soaker hoses that are buried too deep can be difficult to monitor and are more prone to damage from root growth. Solid hose can be use if desired location of soaker hose is away from rain barrel.

- If emptying the barrel manually, develop a plan so that it is partially or completely emptied on average every 3 to 4 days. This is necessary so that the entire storage capacity is available at the beginning of most storms.

- Position the overflow hose to discharge larger storms. The overflow should be discharged to an area protected from erosion. At a minimum, direct the overflow to the same location as the roof leader before placing rain barrel.

Cisterns (Subsurface or Surface)

- Identify which roof leaders can drain to the cistern, and the area of roof draining to each leader.

- Estimate the storage needed. A rough estimate may be obtained by performing a weekly water balance of rainfall and water reuse. Depending on the complexity of system and/or intended reuse options, a Design Professional may need to be contracted to perform more rigorous analysis in order to best meet water demand needs.

- Design to local codes and ordinances, preparing complete construction plans and specifications.

Materials and Construction Guidelines
Rain Barrels

- Rain barrels are commonly pre-fabricated structures constructed with plastic, wood or steel.

- The container should be made of an opaque material to prevent algae growth in the stored water.

- Debris screen to keep leaves and other debris from entering and clogging the storage element.

Cisterns

Cisterns may be constructed of fiberglass, concrete, plastic, brick, or other materials.

Maintenance

As with most Storm Water management systems, cisterns and rain barrels require regular inspection and maintenance to insure their functionality and to extend their life. Detailed maintenance guidelines and a recommended schedule of inspection and maintenance can be found in the Example Cistern/Rain Barrel O & M Manual.

Technical Design Requirements Summary Tables

Table 4.3.3: Engineering / Drainage Report Requirements Summary

Item	Required
Runoff Calculations (for Cisterns and Storage Tanks)	Yes
Storage Volume Calculations (for Cisterns and Storage Tanks)	Yes
Drain Down Time (72 hrs max) for Systems Designed as Part of the Stormwater Quantity or Quality System	Yes
Inflow / Outflow pipe size calculations (10-yr minimum) (for Cisterns and Storage Tanks)	Yes
Emergency Overflow Calculations (for Cisterns and Storage Tanks)	Yes
Water Quality Volume Calculations (if system is part of the stormwater quality management system)	Yes
Water Quantity Volume Calculations (if system is part of the stormwater quantity management system)	Yes

Table 4.3.4: Plan Requirements

Item	Required
Detail of Storage System Showing:	Yes
Dimensions	Yes
Inlet and Outlet	Yes
Location of Screens or other Pretreatment	Yes
Backfill	Yes
Basin Map Showing Area Served by Storage System	Yes
Pretreatment Detail (e.g. screen opening size and location)	Yes
Easements (If Storage System is Part of the Water Quantity or Quality System)	Yes
Center Coordinates of Storage Tank (in State Plane Coordinates) on Cover Sheet Summary Table	Yes

Table 4.3.5: O & M Manual Requirements

Item	Required
Tabular Inspection Schedule	Yes
Site Diagram with Storage System Location and Details of Areas to be Inspected	Yes
Inspection Checklist	Yes
Narrative description of Inspection Procedure including:	Yes
Sediment Gauging	Yes
Pretreatment Inspection	Yes
Emergency Overflow System	Yes
Note to Drain Storage System Prior to Winter if Freezing Possible*	Yes

*Systems drained for winter may not qualify as a water quantity or quality practice.

4.3.1. Rain Water Harvesting Example O & M Manual

Rain Water Harvesting – O & M Manual

Owner Name
Address of Property
Owner Contact Name and Phone Number

BMP Narrative:
Regular inspection and maintenance is critical to the effective use of a cistern/rain barrel. It is the responsibility of the property owner to maintain all Storm Water facilities in accordance with the minimum design standards required by the City of Indianapolis and this Operations & Maintenance Manual. The local jurisdiction has the authority to impose additional maintenance required where deemed necessary. The city has the right to inspect the system and to require replacement if it fails or is a threat to public safety. If maintenance does not correct the problem, full or partial replacement may be required.
Cisterns/Rain Barrels shall be in accordance with the following inspection and maintenance criteria:

Inspection Activities	**Suggested Frequency**
• Inspect to ensure that cistern/rain barrel was installed and working properly. • Certification shall be required that the constructed system meets the conditions specified on the approved plans. • Certification regarding the water tightness of the underground storage tank is required after its installation.	Post-construction
• Leaf screens, gutters, and downspouts should be inspected and cleaned to prevent clogging. • Inspect overflow device for obstructions or debris that would prevent proper drainage when storage capacity is exceeded. • Inspect to ensure overflow runoff is safely conveyed to a stable outfall that causes no problems to down gradient properties. • Dewatering in between rain events so that the required storage volume is available. • Inspect for presence of mosquito larvae.	Annually and after large storm events
• Inspect all fittings and valves for water tightness seal.	Monthly
• Above-ground systems should be disconnected, drained, and cleaned at the start of the Winter season.	Annually
Maintenance Activities	**Suggested Frequency**
• Clean leaf screens, gutters, and downspouts. • Replace overflow device if any obstructions or debris prevent proper drainage when storage capacity is exceeded. • If overflow runoff is not safely conveyed to a stable outfall and/or signs of erosion exist, stabilize and remedy problem. • Dewater in between rain events so that the required storage volume is available and sediment is removed. • Replace any system components that are not performing properly.	Annually, as needed
• Above-ground systems should be disconnected, drained, and cleaned at the start of the Winter season.	Annually

Address of property

Inspector:
Date:
Time:
Weather: Rainfall over previous 2-3 days? Site conditions:
Owner change since last inspection?: Y N

Mark items in the table below using the following key:

- **X** Needs immediate attention
- **–** Not Applicable
- ✓ Okay
- **?** Clarification Required

Cistern Components:

Items Inspected	Checked		Maintenance Needed		Inspection Frequency
SYSTEM COMPONENTS	Y	N	Y	N	**A, AMS**
1. Signs of clogging (e.g. screens, gutters, downspouts)?					
2. Debris accumulation?					
3. Sediment accumulation?					
4. Standing water present around base?					
5. Are valves and fittings watertight?					
ADJACENT AREAS/OVERFLOW SPILLWAY					**A, AMS**
6. Is overflow outlet clean of debris?					
7. Erosion from overflow path?					
8. Signs of water ponding?					
9. Is outlet for storm sewer system free from debris and in good working order?					
DEWATERING					**A**
10. When was Cistern/Rain Barrel Last Drained?					
OTHER					**A**
11. Physical appearance of water, any odor?					
12. Are mosquito larvae present?					
13. Have there been complaints from residents?					
14. Public hazards noted?					
15. Other (describe)?					

Inspection Frequency Key A= Annual, M= Monthly, AMS= After Major Storm

COMMENTS:

OVERALL CONDITION OF FACILITY:

In accordance with approved design plans? Y / N

In accordance with As Built plans? Y / N

Maintenance required as detailed above? Y / N

Compliance with other consent conditions? Y / N

Comments: _____

_____

Dates by which maintenance must be completed: ____/ ___ / ___

Dates by which outstanding information as per consent conditions is required by: ____ / ___ / _____

Inspector's signature: _____

Owner/Engineer/Agent's signature: _____

Owner/Engineer/Agent's name printed: _____

4.3.2 Rain Water Harvesting Designer/Reviewer Checklist

Type and size (gallons) of storage system provided: _____

Item	Yes	No	N/A	Notes
Capture area defined and calculations performed?				
Pretreatment provided to prevent debris/sediment from entering storage system?				
Water use identified and calculations performed?				
If the use is seasonal, has off-season operation been considered?				
Draw-down time considered?				
Is storage system located optimally for the use?				
Is a pump required?				
If so, has an adequate pump system been developed?				
Acceptable overflow provided?				
Winter operation (protection from freezing) considered?				
Observation/clean-out port provided?				
Maintenance accounted for and plan provided?				

4.4. Filter Strips

Filter Strips are densely vegetated lands that treat sheet flow Storm Water from adjacent pervious and impervious areas. They function by slowing runoff, trapping sediment and pollutants, and in some cases infiltrating a portion of the runoff into the ground. To be effective, they require the presence of sheet flow across the entire strip. Since they can be incorporated into landscaped areas, filter strips can provide dual functionality to satisfy Storm Water pre-treatment and landscape requirements in one location. Filter strips are a sensible and cost-effective Storm Water management pretreatment option applicable to a variety of development sites including roads and highways.

Key elements:

Filter Strips must be designed within parameters required by the <u>Indianapolis Storm Water Design and Construction Specifications Manual</u>.

- Filters strips are only considered a viable pretreatment option for other BMPs and do not provide adequate pollutant removal benefits to act as a stand-alone BMP.
- Sheet flow across the vegetated filter strip is mandatory for proper filter strip function.
- Filter strip length is a function of slope, vegetation type, soil type, drainage area, and desired amount of pretreatment. See Table 4.4.2 for filter strip length criteria, as common terminology for filter strips uses the word 'length' for what would normally be considered the width as well as the length. A unit width of filter strip is assumed, with the length being the dimension parallel to the flow path. The length dimension is specified with respect to the flow path in both parallel and perpendicular directions.
- Level spreading devices are recommended to provide uniform sheet flow conditions at the interface of the filter strip and the adjacent land cover.
- The longest flow path to a filter strip, without the installation of energy dissipaters and/ or flow spreaders, is 75 feet for impervious ground covers and 150 feet for pervious ground covers. (See Chapter 700, Section 702.06 for additional requirements)
- Filter strip slope should never exceed 10%. Slopes less than 6% are generally preferred. Slopes greater than 2% are recommended to promote positive drainage flow to and through the filter strip.
- Maximum contributing drainage area is less than 5 acres, and should also never exceed a drainage area to filter strip area ratio of 6:1.
- Maximum contributing drainage area slope is generally recommended to be less than 5%, unless energy dissipation and/or flow spreaders are provided.
- Construction of filter strips shall entail as little disturbance to existing vegetation at the site as possible.

- Use of native plants within filter strips can serve to stabilize soils to prevent erosion. This is most beneficial in areas along stream banks and shorelines.

Table 4.4.1: Filter Strips Potential Application and Storm Water Regulation

Potential applications			Storm Water regulations		
				Infiltration	No Infiltration
Residential Subdivision:	Yes		Water Quality Benefit	No	Yes
Commercial:	Yes*		Volume Reduction	No	No
Ultra Urban:	Limited*		Attenuation Benefit	No	No
Industrial:	Limited*				
Retrofit:	Yes				
Highway Road:	Yes				

Acceptable forms of pre-treatment

N/A

Filter Strips in the Urban Landscape

Filter strips are effective at slowing runoff velocities, removing pollutant loads, and promoting infiltration of runoff produced by both impervious and pervious areas. Filter strips are suitable for many types of development projects. Filter strips can be used as pretreatment facilities for other BMPs in residential, commercial, and light industrial development; roads and highways; and parking lots.

FILTER STRIP IN FORESTED AREA

Filter strips are recommended for use as a pretreatment component of other BMPs including but not limited to: bioretention, constructed wetlands, detention, filters, ponds/wet basins, porous pavement, and vegetated swales. The use of a properly maintained filter strip extends the life of the associated BMPs and decreases its hydraulic residence time. It also increases the amount of time before these structures need maintenance.

Components of a Filter Strip System

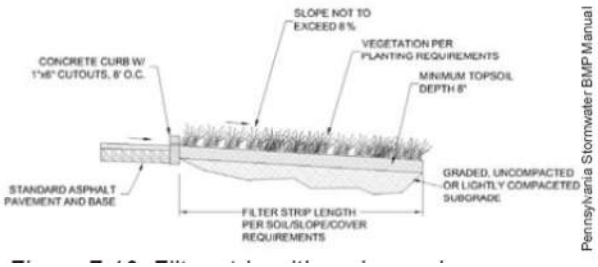
Inlet Control

Filter strips are typically combined with a level spreader or flow control device. A flow control device functions to lessen the flow energy of Storm Water prior to entering the filter strip area. Filter strips function best when flows are evenly distributed over their width. Concentrated flows can have an erosive effect that can damage the filter strip by short circuiting it and rendering the strip ineffective. Curb openings combined with a gravel level spreader are a common type of flow control. See Section 4.9: Inlet and Outlet Controls for more information. Slotted or depressed curbs installed at a level grade at the edge of the impervious area should ensure a well distributed flow to the filter strip. These slotted openings should be spaced along the length of the curb.

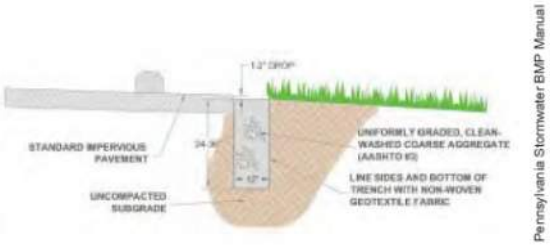
FILTER STRIP PROVIDING PRETREATMENT FROM A PARKING LOT TO A BIORETENTION SYSTEM

Vegetation

The vegetation for filter strips may be comprised of turf grasses, meadow grasses, shrubs, and native vegetation. It can include trees or indigenous areas of woods and vegetation. Vegetation adds aesthetic value as well as water quality benefits. The use of indigenous vegetated areas that have surface features that disperse runoff is encouraged, as the use of these areas will also reduce overall site disturbance and soil compaction. Native vegetation also helps to minimize erosion by stabilizing the soil with the deep root structure common in native plants. The use of turf grasses will increase the required length of the filter strip compared to other vegetation options. See Chapter 5: Storm Water Landscape Guidance.



FILTER STRIP WITH CURB OPENING



FILTER STRIP WITH GRAVEL TRENCH LEVEL SPREADER

Retentive Grading

Filter strip effectiveness may be enhanced by installing retentive grading perpendicular to the flow path. A pervious berm allows for a greater reduction in both runoff velocity and volume, thus improving pollutant removal capabilities by providing a temporary (very shallow) ponded area. The berm should be constructed according to the design provided in Section 4.6: Berms and Retentive Grading.

Check Dams

Filter strips with slopes that exceed 6% should implement check dams to encourage ponding and prevent scour and erosion of the filter strip area. More information on check dams is available in Section 4.9: Inlet and Outlet Controls.

CHECK DAMS: NOTE CHANNEL STORAGE CAPACITY CREATED BY CHECK DAMS. NOTCHED CENTER ALLOWS SAFE OVERFLOW WITHOUT SCOUR AROUND SIDES

Recommended Design Procedure

- Determine the Water Quality and Quantity requirements for the site per the Storm Water Design and Construction Specifications Manual.

- Create a Conceptual Site Plan for the entire site and determine what portion of the sizing requirements filter strips will accommodate (for pretreatment purposes).

- Investigate the feasibility of infiltration according to soil and vegetative conditions in the area proposed for the filter strip. If infiltration is feasible, determine the saturated vertical infiltration rate. Refer to **Attachment 1**, **Guidelines for Infiltration Practices** for soil infiltrating testing guidelines.

- Examine size and slope of the drainage area. The maximum contributing drainage area to a filter strip area shall never exceed 5 acres, and should also never exceed a drainage area to filter strip area ratio of 6:1.

- If the slope of the filter strip parallel to the proposed flow path is ≥ 5%, energy dissipater and/or flow spreaders must be installed.

- Design an inlet control to meet energy dissipation requirements. See Section 4.9: Inlet and Outlet Controls.

- A flow spreader which stretches the entire length (perpendicular to flow path) of the contributing drainage area should be designed to limit flow velocity to prevent erosion and to spread the flow equally across the filter strip. If necessary, a bypass should be installed to prevent excessive, damaging flows.

- Create a conceptual design for the pretreatment filter strip.

Table 4.4.2: Suggested Starting Design Values for Filter Strip Length	
Strip Length Perpendicular to Flow Path	Largest feasible on site
Strip Length Parallel to Flow Path	10* - 150 feet
*The minimum pretreatment filter strip value is based on the length of the receiving flow path. The graph below shows how the minimum length requirement changes as both flow path and filter strip slope change.	

- Determine the longest flow path length for the contributing drainage area.

- For contributing drainage areas with flow paths < 30 feet use the following graph to help determine the filter strip length parallel to the flow path.

- For filter strips with contributing flow paths > 30 feet, use the suggested flow characteristics for maximum velocity and depth as design restrictions. When choosing an initial filter strip length (parallel to flow), the suggested minimum starting design value is 10 feet.

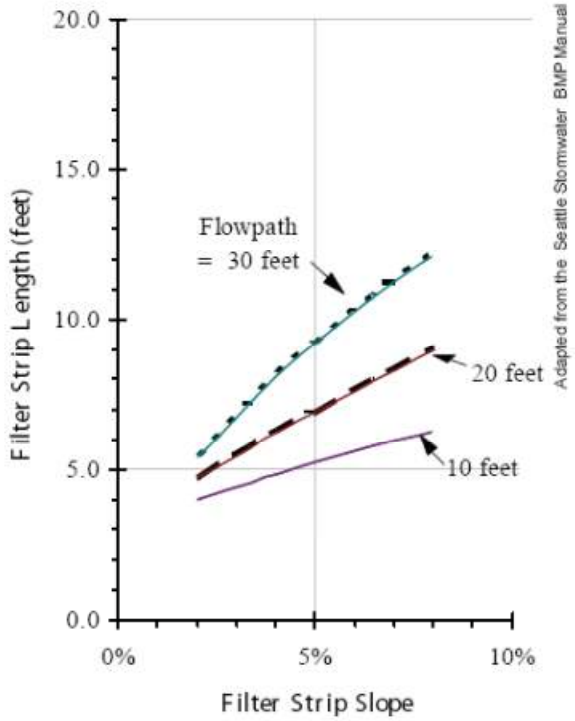


Table 4.4.3: Suggested Maximum Velocities and Water Depths for Filter Strip Area	
Maximum Velocity (ft/s)	1.0, Less than 0.5 preferred
Maximum Water Depth (in.)	1.0, Less than 0.5 preferred
The values for both maximum Velocity and Water depth were taken from the US DOT Storm Water Best Management Practices (BMPs) in an Ultra-Urban Setting: Selection and Monitoring and the Seattle BMP Manual.	

- Adjust filter strip design characteristics to provide desired amount of pretreatment.

- When considering retentive grading, use the infiltration area and the saturated vertical infiltration rate of the native soil to estimate how long the surface ponding will take to drain. The maximum drain down time for the ponded volume is 72 hours, but a drain down time of 24 - 48 hours is recommended. If ponded water does not drain in the time allowed, adjust water surface depth, soil depth, and/or surface area. Adjust the design until the volume and drainage time constraints are met.

- All retentive grading techniques should encourage soil stabilization and erosion control with vegetative growth. See Section 4.6: Low Impact and Retentive Grading.

- Choose plants and trees appropriate and compatible with the site conditions and local landscape requirements. See Chapter 5: Storm Water Landscape Guidance.
- Filter strips may not be used in high use areas unless precautions are taken to minimize disturbance (i.e. signage, placement of sidewalks or paths to minimize disturbance of the filter strip). Educational signage is encouraged and may be required in the Operations & Maintenance Manual to ensure that the owner understands the purpose of the filter strip (to avoid future mowing and removal).

- Determine final contours of the filter strip.

- Complete construction plans and specifications.

Materials

All material/ plant specifications should appear on the plans.

- Recommendations for plant materials and soils can be found in Chapter 5: Storm Water Landscape Guidance.

Construction Guidelines

- Areas for filter strips shall be clearly marked before any site work begins to avoid soil disturbance and compaction during construction.

- In areas where soil is compacted, tilling to depths of 12-18 inches is necessary. A minimum of 6 inches of top soil must be added into the tilled soil column, and small trees and shrubs with capabilities for deep root penetrations should be introduced to maximize the soil infiltrative capacity. Chapter 5: Storm Water Landscape Guidance, for more specification on soil types and preferred plantings.

- Provide erosion and sedimentation control protection on the site such that construction runoff is directed away from the proposed filter strip location.

- Complete site elevation and retentive grading, if proposed. Stabilize the soil disturbed within the limit of earth disturbance.

- Install energy dissipaters and flow spreaders. Refer to Section 4.9 Inlet and Outlet Controls for more detailed construction information.

- The slope (parallel to the flow path) of the top of the filter strip, after the flow spreading device, shall be less than 1 % and gradually increase to designed value to protect from erosion and undermining of the control device.

- Construct inlet protection as specified in the design.

- Seed and plant vegetation (plants, shrubs, and trees) as indicated on the plans and specifications listed in Chapter 5: Storm Water Landscape Guidance.

- Once site vegetation is stabilized, remove erosion and sediment control protection.

Maintenance Guidelines

All areas of the filter strip should be inspected after significant storm events for ponding that exceeds maximum depth and duration guidelines. Corrective measures should be taken when excessive ponding occurs. An Operations & Maintenance Manual should be included in the design documents to instruct the owner/operator of the maintenance required to maintain the filter strip functioning in accordance with the design.

Table 4.4.4: Filter Strips Maintenance Guidelines		
	Activity	Schedule
	Mowing and/or trimming of vegetation (not applicable to all filter strips). Filter strips that need mowing are to be cut to a height no less than 4 inches. Greater than 5 inches is preferred.	As needed
	Inspect all vegetated strip components expected to receive and/or trap debris and sediment for clogging and excessive debris and sediment accumulation; remove sediment during dry periods.	Quarterly
	Vegetated areas should be inspected for erosion, scour, and unwanted growth. This should be removed with minimum disruption to the planting soil bed and remaining vegetation. Inspect all level spreading devices for trapped sediment and flow spreading abilities. Remove sediment and correct grading and flow channels during dry periods.	Biannually
	Maintain records of all inspections and maintenance activity.	Ongoing

- When correcting grading of a flow spreading device, use proper erosion and sediment control precautions in the concentrated area of disturbance to ensure protection of the remaining potion of the filter.

- Disturbance to filter strips should be minimal during maintenance. At no time should any vehicle be driven on the filter strip. In addition, foot traffic should be kept to a minimum.

- If the filter strip is of the type that needs mowing (i.e., turf grass and possibly other native grasses), the lightest possible mowing equipment (i.e., push mowers, not riding mowers) should be used. The filter strip should be mowed perpendicular to the flow path (however not exactly the same path every mowing) to prevent any erosion and scour due to channeling of flow in the maintenance depressions.

- When establishing or restoring vegetation, biweekly inspections of vegetation health should be performed during the first growing season or until the vegetation is established. For more information on vegetative maintenance, refer to Chapter 5: Storm Water Landscape Guidance.

- Bi-weekly inspections of erosion control and flow spreading devices should be performed until soil settlement and vegetative establishment has occurred.

Note:
Design of filter strips are not limited to the examples shown within this text. Successful Storm Water management plans will combine appropriate materials and designs specific to each site

4.4.1. Filter Strip Designer/Reviewer Checklist

Item	Yes	No	N/A	Notes
Sheet flow provided?				
Recommended slope ranges followed?				
Appropriate length for soil, vegetation, and slope?				
Slope of drainage area below five percent?				
If not, is energy dissipation provided?				
Length/area of incoming drainage appropriately limited?				
Receiving vegetation considered?				
Located in undisturbed virgin soil?				
If not, will soil be properly compacted and stabilized?				
Appropriate vegetation selected for stabilization?				
Feasible construction process and sequence?				
Soil compaction avoided or mitigated?				
Erosion and sedimentation control provided to protect filter strip.				

4.5. Bioretention, Micro-bioretention and Rain Gardens

Bioretention

Bioretention areas typically are landscaping features adapted to treat Storm Water runoff. Bioretention systems are also known as Mesic Prairie Depressions, Rain Gardens, Infiltration Basins, Infiltration Swales, bioretention basins, micro-bioretention systems, bioretention channels, tree box filters, planter boxes, or streetscapes, to name a few. Bioretention areas typically consist of a flow regulating structure, a pretreatment element, an engineered soil mix planting bed, vegetation, and an outflow regulating structure. Bioretention systems provide both water quality and quantity Storm Water management opportunities.

Bioretention systems are flexible, adaptable and versatile Storm Water management facilities that are effective for new development as well as highly urban re-development situations. Bioretention can readily adapt to a site by modifying the conventional "mounded landscape" philosophy to that of a shallow landscape "cup" depression. Such landscape depression storage and treatment areas fit readily into: parking lot islands; small pockets of open areas; residential, commercial and industrial campus landscaping; and, urban and suburban green spaces and corridors.

Bioretention works by routing Storm Water runoff into shallow, landscaped depressions. These landscaped depressions are designed to hold and remove many of the pollutants in a manner similar to natural ecosystems. During storm events, runoff ponds above the mulch and Engineered Soil Mix in the system. Runoff from larger storms is generally diverted past the facility to the storm drain system. The runoff remaining in the bioretention facility filters through the Engineered Soil Mix. The filtered runoff can either be designed to enhance groundwater infiltration or can be collected in an underdrain and discharged per local Storm Water management requirements.

Key elements:

- Storm Water management design intended to replicate a site's pre-developed natural hydrologic processes through runoff storage and filtration.
- Flexible in size and configuration; can be used for a wide variety of applications. Can be used for Water Quality Volume (WQv) requirements for most local ordinances.
- Water Quality and Quantity volume that drains down in no more than 48 hours.
- Engineered Soil Mix that provides Storm Water treatment through filtration while enhancing plant growth.
- Native and/or ornamental vegetation that provide evapotranspiration of Storm Water, pollutant filtration, and an aesthetically designed landscape area.
- Flood control bypass system for runoff in excess of designed filtration capacity.
- Maintenance of Engineered Soil Mix and vegetation is required.

Highlights:

- Contributes to enhanced air quality, water quality and can assist in directly reducing urban heat island impacts.
- Can improve property value through attractive landscaping.

Effectiveness

- Structural Storm Water management practices such as bioretention can be used to achieve four broad resource protection goals. These include flood control, channel protection, ground water recharge, and pollutant removal. Bioretention systems tend to behave similarly to swales; their pollutant removal rates are relatively high.

SEATTLE STREET EDGE ALTERNATIVES (SEA)

Table 4.5.1: Bioretention Potential Application and Storm Water Regulation

Potential applications			Storm Water regulations		
				Infiltration	No Infiltration
Residential Subdivision:	Yes		Water Quality Benefit	Yes	Yes
Commercial:	Yes		Water Quantity Benefit	Yes	Yes
Ultra Urban:	Yes		Volume Reduction	Yes	Yes
Industrial:	Yes		Attenuation Benefit	Yes	Yes
Retrofit:	Yes		Level of Benefit dependent on design criteria		
Highway Road:	Yes				

PRE-TREATMENT IN INDIANAPOLIS CULTURAL TRAIL BIORETENTION (ALABAMA STREET)

Acceptable forms of pre-treatment

- Energy dissipation to prevent erosion and scour of BMP.
- Pretreatment pollutant removal areas for concentrated collection of trash, debris, sediment, and other suspended and dissolved pollutants, i.e. forebay.
- Grass Filter Strips

Bioretention in the Urban Landscape

Bioretention systems are shallow, vegetated depressions used to promote absorption and infiltration of Storm Water runoff. This management practice is very effective at removing pollutants and reducing runoff volume. Storm Water flows into the bioretention area, ponds on the surface, infiltrates into the soil bed, and is used by plants and trees in the system.

OVERFLOW PIPE

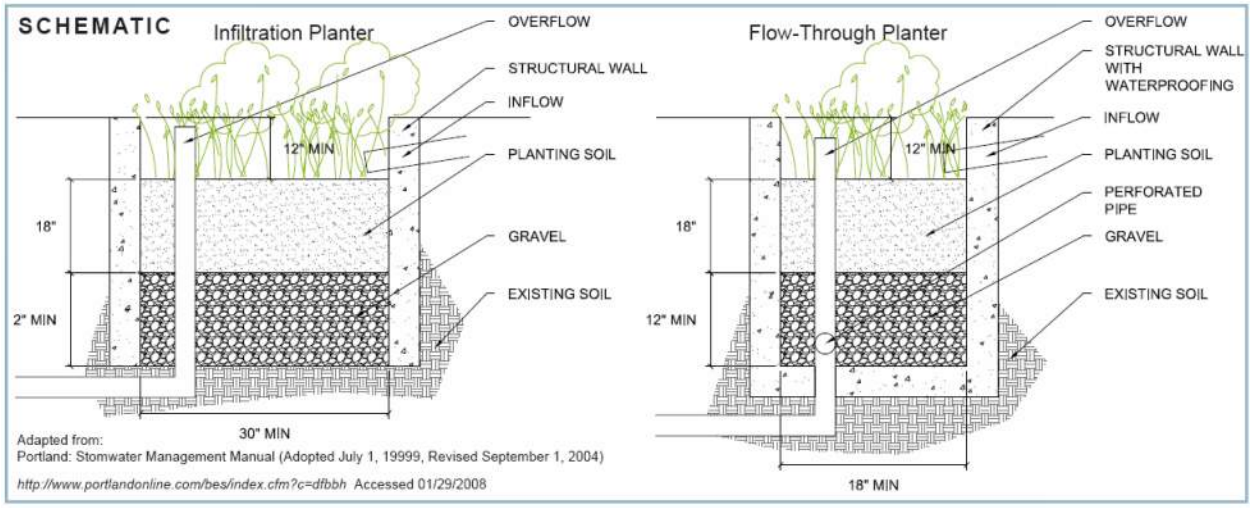
Bioretention areas are suitable for many types and sizes of development, including single-family residential, high-density commercial, and ultra urban re-development projects. Bioinfiltration/bioretention areas are generally relatively small landscaped areas that can be integrated throughout a site to manage all or part of the site's Storm Water runoff. Flexible and easy to incorporate in landscaped areas, bioretention facilities are ideal for placement in roadway median strips and parking lot islands. They can also provide water quality treatment from pervious areas, such as golf courses, filter stripswales and other large lawn areas.

In highly urbanized watersheds, bioinfiltration/bioretention is often one of the few retrofit options that can be cost effectively employed by modifying existing landscaped areas, converting islands or under-used parking areas, or integrating into the resurfacing of a parking lot. Applications of bioinfiltration/bioretention systems in urban environments include planter boxes, residential, commercial and/or industrial on site landscaping, parking lots, and roadways, which can capture both site and roof runoff. The applications of bioinfiltration/bioretention systems are not limited to this list; however, examples for each of these alternatives are provided below.

Bioretention systems and especially rain gardens may be mistaken as areas not being maintained. The City of Indianapolis maintains a voluntary registry of rain gardens in order to clearly distinguish a constructed rain garden from unmaintained ground. All owners of rain gardens should register their rain gardens with the City.

Planter Boxes

A flow-through the planter box is designed with an impervious bottom or is placed on an impervious surface. Pollutant reduction is achieved as the water filters through the soil. Flow control is obtained by storing the water in a reservoir above the soil and detaining it as it flows through the soil. This planter can be used adjacent to a building if the box is properly lined.



Residential On-lot

Landscaped garden areas (rain gardens) can be designed with bioretention systems to create decorative features, habitat, and Storm Water treatment at a residential site. The design can be as simple as incorporating a planting bed into the lowest point on a site. It is recommended that downspouts be directed into these systems after appropriate pre-treatment.

BIORETENTION INTEGRATED INTO URBAN LANDSCAPE (ALABAMA STREET, INDIANAPOLIS)

Tree Wells

Bioretention principles can be incorporated into a tree well design to create mini- treatment areas throughout a site. Care should be taken to ensure that the Engineered Soil Mix, in-situ soils and ponding area depth is appropriate to the tree size and species.

ALTERNATIVE "STREAM BED" URBAN BIORETENTION

Parking Lots

Parking lots are an ideal location for bioretention systems. Bioretention can be incorporated as an island, median, or along the perimeter of the parking area. Bioretention areas can enhance the aesthetics of a parking lot while managing Storm Water from the site. Bioretention is an excellent discharge location for parking lot pervious pavement sub-drain seep or direct discharges. Whether by curb cuts, sheet flow or sub-drains, runoff flowing into bioretention must not result in erosive velocities.

Roads and Highways

Linear bioretention basins can be constructed alongside roads or highways, in roadway medians, or in bump-outs that double as traffic calming devices. The system will manage runoff from the street and help to control automotive pollutants. The systems can also help to control roadway flooding.

Commercial/Industrial/Institutional

At commercial, industrial, and institutional sites, areas for Storm Water management and green space are often limited. At these sites, bioretention systems serve the multiple purposes of Storm Water management and landscaping. Bioretention areas can be used to manage runoff from impervious site areas such as parking lots, sidewalks, and rooftops.

NATIVE/ORNAMENTAL MIX PARKING ISLAND LANDSCAPING

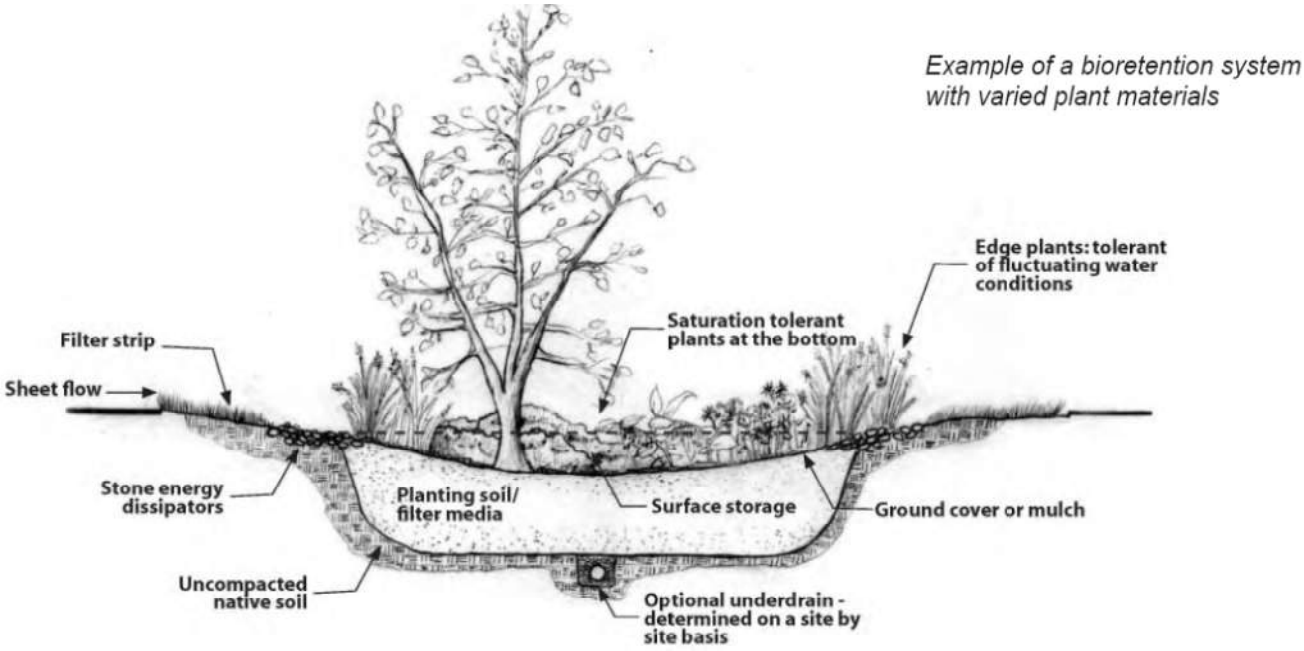
Rain Garden and Native Planting Programs

To promote rain gardens and native planting areas, the City of Indianapolis has established a Rain Garden Resource Center outlining supplies, customized planting plans, maintenance guidelines, permitting guidance, and more. The resource center is intended to be used by residents, businesses, developers, and institutions. Rain gardens and native planting areas can vary in size from a small rain garden in the corner of a residential lot to a large bioretention area receiving runoff from a commercial strip mall. Permitting requirements are most likely an issue only for larger projects, especially those that tie into City drainage, but the owners of all rain garden and native planting projects must check the permitting guidance. Information is available at:
www.indy.gov/eGov/City/DPW/SustainIndy/WaterLand/GreenInfra/Pages/RainGardenResources.aspx

Typical Components of a Bioinfiltration/Bioretention System

Bioretention systems can be designed to infiltrate all or some of the flow that they treat. The primary components of a bioretention system are:

- Pretreatment
- Flow entrance/inlet
- Surface storage (ponding area)
- Organic layer or mulch
- Engineered Planting Soil Mix filter media
- Vegetation (Native and Ornamental plantings)
- Sand bed or stone filter and underdrain, if required
- Stone storage for additional storage, if needed
- Positive overflow



Pretreatment

Pretreatment is required for all bioretention systems in order to protect the soil-plant system that provides treatment. Pretreatment protects and prolongs the life of the system by reducing sediment and other pollutant loads.

CURB CUT INLET – INDIANAPOLIS CULTURAL TRAIL BIORETENTION (ALABAMA STREET)

Flow Entrance / Inlet

It is recommended that runoff is conveyed to bioretention areas via sheet flow over a vegetated or gravel filter level spreader strip. This is not always possible due to site constraints or space limitations. On sites where curb removal is not an option or where flow is concentrated by the time it reaches the bioretention area, energy dissipation and equal flow distribution is required. Roof leaders that flow into bioretention areas also require flow energy dissipaters and equal distribution to prevent erosion in the bed.

Surface Storage (Ponding Area)

Surface storage provides temporary storage of Storm Water runoff before infiltration, filtration, evaporation, and uptake (evapotranspiration) can occur within the bioretention system. Ponding time provides water quality benefits by allowing larger debris and sediment to settle out of the water. Ponding design depths are directly related to the Engineered Soil Mix design criteria and are limited to a 24-inches in order to reduce hydraulic loading of underlying soils, minimize facility drainage time, and prevent standing water.

Engineered Planting Soil Mix and Filter Media

The Engineered Soil Mix provides a medium suitable for plant growth. This designed media acts as a physical filter between the surface storage and the native soil or sub-drainage system. It provides additional storage and a place for biological and chemical pollutant treatment before the water infiltrates into the native soil or sub-drainage system. Storage area is a function of both soil depth and bioretention surface area.

Native and Ornamental Vegetation

The plant material in a bioretention system provides a physical barrier for pollutant filtration and energy dissipation; removes nutrients and Storm Water pollutants through vegetative uptake; removes water through evapotranspiration; and, creates pathways for infiltration through root development and plant growth. A varied plant community is recommended to avoid susceptibility to insect and disease infestation and to ensure viability. A mixture of groundcover, grasses, shrubs, and trees is recommended to create a microclimate that can improve urban stresses as well as discourage weed growth and reduce maintenance.(Refer to Chapter 5: Storm Water Landscape Guidance) Do not use invasive species as listed by local, state and federal; agencies.

Organic layer or mulch

The organic layer or mulch provides a medium for biological growth, decomposition of organic material, adsorption, and binding of heavy metals. The mulch layer can also serve as a sponge that absorbs water during storms and retains water for plant growth during dry periods. It is recommended that double shredded hardwood mulch be utilized to minimize washout from Storm Water flows.

Stone bed or filter and Underdrain (if necessary)

An underdrain is generally a perforated pipe or protected bed of gravel that collects water at the bottom of the system and conveys it to the system outlet. Underdrains eliminate most infiltration because they

provide a preferential pathway for flow. A large diameter rock or gravel filter should surround the underdrain to facilitate flow to the underdrain. The underdrain stone bed should be surrounded by a non-woven, geotextile filter fabric to prevent clogging.

INSTALLATION OF BIORETENTION UNDERDRAIN

Stone Storage (if necessary)

A stone storage layer can be included to provide higher void space storage if needed in addition to the surface and soil storage.

Positive Overflows

A positive overflow must be provided at the maximum ponding depth. When runoff exceeds system storage capacity, the excess flow leaves the system through the positive overflow. If additional Storm Water controls are required on the site, the overflow can connect to a system that will provide further quantity control. If no additional Storm Water controls are required, the overflow can be connected to storm sewer or receiving water in compliance with local Storm Water management requirements.

Liners

In some instances, an impermeable liner should be used with a bioretention system. If the nearby or adjoining structures include a basement or floor below the top elevation of the bioretention system, a liner should be considered to reduce the possibility of water migration into the structure. Also, construction within a Wellhead Protection District may require the installation of a liner.

Design Considerations

Design of bioretention systems is somewhat flexible. The area, depth, and shape of the system can be varied to accommodate site conditions and constraints. The following design procedures are general guidelines that designers can follow.

- Determine the Water Quality and Quantity requirements on the site. See City of Indianapolis Storm Water Design and Construction Specifications Manual.
- Investigate the feasibility of infiltration in the area proposed for bioretention according to the infiltration guidelines outlined in **Attachment 1**. If infiltration is not feasible, consider an underdrained bioretention system or an alternate location for the bioretention area. If infiltration is feasible, determine the saturated vertical infiltration rate.
- A geotechnical report should be provided documenting the seasonal high groundwater table for the site/area certified by a professional geotechnical engineer or soil scientist.

Table 4.5.2: Suggested Starting Design Values for Areas and Depths

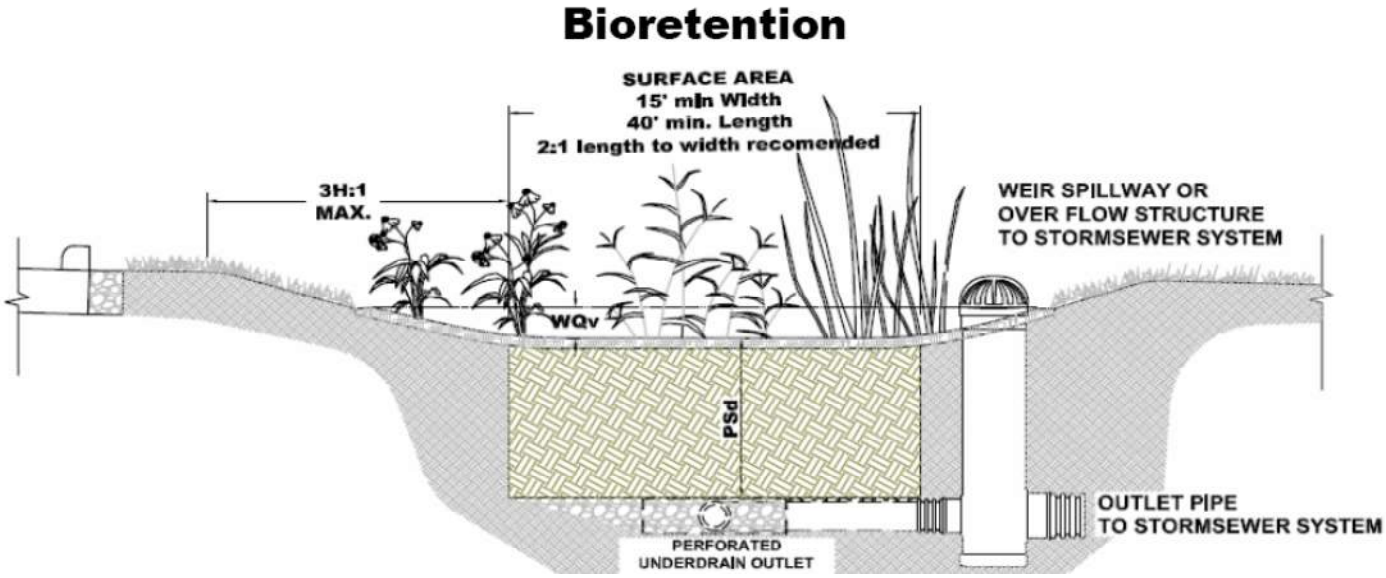
Area (surface area and infiltration area)	Largest feasible on site (*sized for expected runoff volume)
Typical Ponding Depth	6-18 inches (maximum 24 inches)
Soil Depth	2-4 feet

*Note pond depth may not exceed 2 feet

- Estimate the total storage volume and adjust area and/or depths as needed to provide required storage.
- Estimate how long the surface ponding and soil storage will take to drain based on the infiltration area and the saturated vertical infiltration rate of the native soil. The maximum drain down time for the surface storage volume is 48 hours. If storage does not drain in the time allowed, adjust

surface depth, soil depth, and/or surface area. Adjust the design until the volume, drainage time, and site constraints are met.

- Underdrain if necessary.
- Choose plants, trees, and either mulch or seeding appropriate to the site.
- Additional design information is available in the **Bioretention Design Guidelines** and **Design Example (Attachment 5)**.



Materials

Planting Soil

Refer to Chapter 5: Storm Water Landscape Guidance.

Mulch

Organic mulch shall be aged, double-shredded hardwood bark mulch or composted leaf mulch.

Plants

It is critical that plant materials are appropriate for soil, hydrologic, light, and other site conditions. Select bioretention plants that will survive within the selected zone of ponding, drain down time, sunlight, salt tolerance, and other site specific conditions. Refer to Chapter 5: Storm Water Landscape guidance for plant selection. Although plants will be subject to ponding, they may also be subject to lack of water (drought) especially in areas that get a lot of sunlight or are in otherwise highly impervious areas.

Construction Guidelines and Considerations

- Areas for bioretention shall be clearly marked before any site work begins to avoid soil disturbance and compaction during construction.
- Provide erosion and sedimentation control protection on the site such that construction runoff is directed away from the proposed bioretention location. Proposed bioretention areas may only be used as sediment traps during construction if at least two feet of soil are removed and replaced.
- Complete site elevation grading and stabilize the soil disturbed within the limits of disturbance. Do not finalize bioretention excavation and construction until the drainage area is fully stabilized.
- Excavate bioretention area to proposed invert depth and manually scarify the existing soil surfaces. Do not compact in-situ soils. Heavy equipment shall not be used within the bioretention basin. All equipment shall be kept out of the excavated area to the maximum extent possible.

- If using an underdrain and/or a gravel storage bed, place filter fabric or gravel filter, then place the rock, and set the underdrain according to the plans.
- Backfill the excavated area as soon as the subgrade preparation is complete to avoid accumulation of debris. Place bioretention soil in 12-18 inch lifts without compaction. Overfilling will be necessary to account for settlement. Presoak soil at least one day prior to final grading and landscaping to allow for settlement.
- After allowing soil to settle, complete final grading within 2 inches of the proposed design elevations, leaving space for top dressing of mulch or mulch/compost blend.
- Seed and plant vegetation as indicated on the plans and specifications.
- Place mulch and hand grade to final elevations.
- Water vegetation regularly during first year to ensure successful establishment.

Maintenance Guidelines

Properly designed and installed bioretention systems require little maintenance. Bioretention requires landscaping maintenance to ensure that the area is functioning properly. Bioretention areas initially require intense maintenance, but less maintenance is needed over time. In many cases, maintenance tasks can be completed by a landscaping contractor, who may already be hired at the site. Landscaping maintenance requirements can be less resource intensive than with traditional landscaping practices such as elevated landscaped islands in parking areas. During periods of extended drought, bioretention systems may require watering as needed. Detailed maintenance guidelines and a recommended schedule of inspection and maintenance can be found in the Example Bioretention O & M Manual.

Curb Inlet, Pre-treatment and Raised Outlet for Indianapolis Cultural Trail Bioretention (Alabama Street)

Note: Design of bioretention systems are not limited to the examples shown within this text. Successful Storm Water management plans will combine appropriate materials and designs specific to each site.

Technical Design / Engineering Requirements

The following tables summarize the requirements for engineering reports, plans and the O & M manual for bioretention, microbioretention and rain gardens.

Table 4.5.3: *Bioretention* Engineering / Drainage Report Requirements Summary

Item	Required
Storage Volume Calculations	Yes
Overflow Calculations (10-yr minimum)	Yes
Water Quality Volume Calculations (if system is part of the stormwater quality management system)	Yes
Water Quantity Volume Calculations (if system is part of the stormwater quantity management system)	Yes
Drain –Down Time (< 48 hrs, Permeability Coefficient = 0.5 in./day)	Yes
Runoff Entrance Velocity (=1.5 fps max)	Yes
Seasonal High Water Table Determination by Soil Scientist or Geotechnical Engineer within a Geotechnical Report/Investigation (water table >2 ft below underdrain or bottom of system)	Yes

Table 4.5.4: *Microbioretention* Engineering / Drainage Report Requirements Summary

Item	**Required**
Storage Volume Calculations	Yes
Overflow Calculations (10-yr minimum and non-erosive channel)	Yes
Water Quality Volume Calculations (if system is part of the stormwater quality management system)	Yes
Water Quantity Volume Calculations (if system is part of the stormwater quantity management system)	Yes
Drain –Down Time (< 48 hrs, Permeability Coefficient = 0.5 in./day)	Yes
Runoff Entrance Velocity (=1.5 fps max)	Yes
Seasonal High Water Table Determination by Soil Scientist or Geotechnical Engineer within a Geotechnical Report/Investigation (water table >2 ft below underdrain or bottom of system)	Yes

Table 4.5.5: *Bioretention* Plan Requirements

Item	Required
Profile Detail of Proposed Bioretention, Showing:	
Soil Depth (2 ft Minimum)	Yes
Maximum Ponding Depth (24 in.)	Yes
Filter Fabric	Yes
Mulch Layer (2 in. min)	Yes
Drainage Layer	Yes
Pretreatment System Including Forebay	Yes
Area Map Showing Basin Area Served by Proposed Biosystem (<5 ac)	Yes
Scaled drawing of Proposed Bioretention Showing Minimum Size > 200 sq ft, 2:1 Length to Width Ratio (Measured from Inlet to Overflow)	Yes
Filter Fabric Specifications	Yes
Soil and Mulch Specifications	Yes
Underdrain Layout, Size, Slope and Specification (6 in. minimum diameter, 8 in gravel layer)	Yes
Easement Delineation (20 ft around outside perimeter)	Yes
Center Coordinates of Bioretention System (in State Plane Coordinates) on Cover Sheet Summary Table	Yes

Table 4.5.6: *Microbioretention* Plan Requirements

Item	Required
Profile Detail of Proposed Bioretention, Showing:	
Soil Depth (2 ft Minimum)	Yes
Maximum Ponding Depth (24 in.)	Yes
Filter Fabric	Yes
Mulch Layer (2 in. min)	Yes
Drainage Layer	Yes
Impermeable Liner (where top of microretention system is above lowest floor of structures)	Yes
Pretreatment System Including Forebay	Yes
Area Map Showing Basin Area Served by Proposed Biosystem (< 20,000 sq ft)	Yes
Scaled drawing of Proposed Bioretention Showing Minimum Size > 200 sq ft, 2:1 Length to Width Ratio (Measured from Inlet to Overflow)	Yes
Filter Fabric Specifications	Yes
Soil and Mulch Specifications	Yes
Underdrain Layout, Size, Slope and Specification (6 in. minimum diameter, 8 in gravel layer)	Yes
Easement Delineation (20 ft around outside perimeter, when system is part of water quality unit)	Yes
Scaled Plan with Location of Nearest Structures, Water Wells mad Septic Systems:	
Structures (> 10ft separation)	Yes
Water Wells (>30 ft separation)	Yes
Structures (.10 ft separation)	Yes
Center Coordinates of Microbioretention System (in State Plane Coordinates) on Cover Sheet Summary Table	Yes

Table 4.5.7: *Rain Garden* Engineering / Drainage Report Requirements Summary

Item	**Required**
Storage Volume Calculations	Yes
Overflow Calculations (10-yr minimum and non-erosive channel)	Yes
Water Quality Volume Calculations (if system is part of the stormwater quality management system)	Yes
Water Quantity Volume Calculations (if system is part of the stormwater quantity management system)	Yes
Drain –Down Time (< 48 hrs, Permeability Coefficient = 0.5 in./day)	Yes
Seasonal High Water Table Determination by Soil Scientist or Geotechnical Investigation (water table >2 ft below underdrain or bottom)	Yes

Table 4.5.8: *Rain Garden* Plan Requirements

Item	Required
Profile Detail of Proposed Rain Garden Showing:	
Soil Depth (1 ft Minimum)	Yes
Maximum Ponding Depth (24 in.)	Yes
Filter Fabric	Yes
Mulch Layer (2 in. min)	Yes
Drainage Layer	Yes
Pretreatment System Such as a Forebay (for commercial, industrial and institutional facilities)	Yes
Area Map Showing Basin Area Served by Proposed Rain Garden (10,000 sq ft max or 2,000 sq ft for a single residential lot)	Yes
Soil Map	Yes
Scaled drawing of Proposed Rain Garden	Yes
Filter Fabric Specifications	Yes
Soil and Mulch Specifications	Yes
Underdrain Layout, Size, Slope and Specification (6 in. minimum diameter, 8 in gravel layer)	Yes
Center Coordinates of Rain Garden (in State Plane Coordinates) on Cover Sheet Summary Table	Yes

Table 4.5.9: *Bioretention, Microbioretention and Rain Gardens* O & M Manual Requirements

Item	Required
Tabular Inspection Schedule	Yes
Site Diagram with Green Roof Area	Yes
Inspection Checklist	Yes
Narrative description of Inspection Procedure including:	Yes
Startup Maintenance	Yes
Fertilizer Guidance	Yes
Plant Coverage Minimum Requirement (90%)	Yes
Emergency Overflow System Inspection	Yes
Erosion Inspection	Yes
Weeding	Yes
Replacing Mulch Layer Annually (when adjacent to parking lots and other hotspots) and maintaining 2 inch depth	Yes
Drain-Down Time Observation (<48 hrs)	Yes
Maintenance Guidelines (table 4.5.3)	Yes

Green Infrastructure Checklist

Bioretention:

Site requirements for use:

- Seasonal high groundwater table depth to top of subgrade must be 2' or greater. (This is to prevent high water table from reducing infiltration effectiveness.)
- If buildings adjacent to rain garden have basements make sure that the rain garden is a minimum of 10' from the building/basement. Also, depending on soil type, a waterproof membrane may be needed on the side adjacent to the building. This should be evaluated on a case by case basis.
- If adjacent buildings don't have basements, the rain garden should be located a minimum of 5' from the building.
- Note any buildings offsite near the proposed rain garden & verify city complaints/maintenance records regarding sewer backups, basement flooding, etc. for the area. If a seasonal high groundwater table exists, extensive use of infiltration methods where none previously existed could aggravate an existing problem, especially if there are basements.

Design Considerations:

- Slope of rain garden bottom can be flat to allow uniform infiltration over the entire bottom area.
- Use of an underdrain is required for areas with Hydrologic Group C & D soils. Underdrain should have positive outlet to open area, level spreader or inlet structure.
- Use of amended soils to be evaluated on a case by case basis as needed for achieving desired infiltration rate. Depth of amended soil shall be determined by type of vegetation used. 18" for plants/shrubs, deeper section when trees are used.

Construction Considerations:

- Erosion control is a must - any sediment laden water shall not be allowed to flow into the rain garden. Use of a sediment forebay/basin during construction is recommended for easier removal of sediment.
- Roof leaders and other impervious areas draining to the newly constructed rain garden should be adequately protected so as to prevent erosion. Operations & Maintenance Manual shall provide for an item to monitor erosion and replace mulch/gravel as needed. Once plants are established this should not be an issue.

4.5.1. Bioretention Example O & M Manual

Rain Garden O & M Manual

Owner Name
Address of Property
Owner Contact Name and Phone Number

BMP Narrative:
Rain Gardens shall be in accordance with the following inspection and maintenance criteria:

Inspection:
Inspection of the rain garden is required after each major rain (more than 1" of rainfall) or at least 4 times per year during the growing season (March - November).
During inspection the following should be noted on the inspection form attached:

- Presence of any trash, debris and soil accumulation
    - Ensure that the depth is maintained as shown on the plans.
- Presence of weeds
- Depth of mulch material present
- Condition of plants (note any plants that appear to be dead or dying)
- Condition of rain garden overflow structure. (Most rain gardens do not have overflow structures; however, they are used in this project to ensure Storm Water has a viable outlet.)
- Visible indication of rain garden clogging or overtopping.

Maintenance:
Maintenance of the rain garden is required when inspection reveals the following are present:

- Trash, debris and soil accumulation
    - Remove all trash and debris and dispose in accordance with city regulations
    - Remove soil accumulation and use on-site in other areas or dispose in accordance with city regulations.
    - Ensure depth of rain garden is maintained to the design depth shown on the plans.
- Weeds
    - Remove weeds regularly during the establishment period (the first couple of years). Hand weed to ensure that the soil in the rain garden does not get compacted and to minimize disturbance to plants and mulch.
    - Remove invasive weeds (Canada Thistle, Garlic Mustard and any tree seedlings) immediately to discourage their establishment.
    - Weed after watering or after a rain event for minimal disturbance and ease of removal.
- Mulch depth less than 3 inches
    - Maintain a mulch depth of 2 to 4 inches. Use hardwood mulch material. Mulch should be reapplied annually to maintain desired depth.
- Water needed (Plants appear to be dead or dying)
    - Watering is required to maintain plants during the establishment period to ensure healthy growth. Once established, plants should only require water during drought conditions.
- Overflow structure in need of cleaning (ex: grate covered with grass/leaves)
    - Keep inlet grate clear of obstructions to maintain storm outlet.

    - If damage to the inlet structure exists, repair immediately in accordance with the City of Indianapolis Drainage Standards.
- Indication that rain garden has insufficient capacity (debris on pavement surrounding the rain garden, etc.). Rain garden maximum ponding time is 48 hours. If evidence that rain garden does not drain down within the required 48 hour period, soil maintenance will be required to restore the soil porosity to the required level to obtain the drain down time.
- The amended soils must be sandy loam, loamy sand or loam mixture with clay content rating from 10 to 25 percent. The soil must have an infiltration rate of **at least 0.5 inches per hour** and a pH between 5.5 and 6.5. In addition, the planting soil should have a 1.5 to 3 percent organic content and a maximum 500-ppm concentration of soluble salts. The mulch layer must consist of 3-4 inches of commercially available fine shredded hardwood mulch or shredded hardwood chips.

Address of property

Inspector:
Date:
Time:
Weather: Rainfall over previous 2-3 days?
Rain Garden Location: Rain Garden 1 (At entrance from Fletcher Avenue)

Mark items in the table below using the following key:

- **X** Needs immediate attention
- **–** Not Applicable
- ✓ Okay
- **?** Clarification Required

Rain Garden Components:

Items Inspected	Checked		Maintenance Needed		Inspection Frequency
DEBRIS CLEANOUT	Y	N	Y	N	**M**
1. Rain gardens and contributing areas clean of debris.					
2. No dumping of yard wastes into rain garden.					
3. Litter (trash, debris, etc.) have been removed.					
VEGETATION					**M**
4. No evidence of erosion.					
5. Is plant composition still according to approved plans.					
6. No placement of inappropriate plants.					
DEWATERING AND SEDIMENTATION					
7. Rain garden dewaters between storms.					
8. No evidence of standing water.					
9. No evidence of surface clogging.					
10. Sediments should not be greater than 20% of swale design depth.					
OUTLETS/OVERFLOW SPILLWAY					**A, AMS**
11. Good condition, no need for repair.					
12. No evidence of erosion.					
13. No evidence of any blockages.					
INTEGRITY OF BIOFILTER					**A**
14. Rain garden has not been blocked or filled inappropriately.					
15. Mulch layer is still in place (depth of at least 2”).					
16. Noxious plants or weeds removed.					

Inspection Frequency Key **A= Annual, M= Monthly, AMS= After Major Storm**

COMMENTS:

OVERALL CONDITION OF FACILITY:

In accordance with approved design plans? Y / N In accordance with As Built plans? Y / N
Dimension on as built:
Field Verified Dimension:
Maintenance required as detailed above?Y / N Compliance with other consent conditions? Y / N

Comments: _____
_____

Dates by which maintenance must be completed: _____ / ___ / ____

Dates by which outstanding information as per consent conditions is required by: _____ / ___ / _____

Inspector's signature: _____

Owner/Engineer/Agent's signature: _____

Owner/Engineer/Agent's name printed: _____

4.5.2. Bioretention Designer/Reviewer Checklist

Item	Yes	No	N/A	Notes
Appropriate areas of the site evaluated?				
Infiltration rates measured?				
Were the bioretention design guidelines followed?				
Soil permeability acceptable?				
If not, appropriate underdrain provided?				
Natural, uncompacted soils?				
Level infiltration area (bed bottom)?				
Excavation in bioretention areas minimized?				
Hotspots/pretreatment considered?				
Ponding depth limited to 24 inches?				
Drawdown time less than 48 hours?				
Positive overflow from system?				
Erosion and Sedimentation control?				
Feasible construction process and sequence?				
Entering flow velocities non-erosive or erosion control devices?				
Acceptable planting soil specified?				
Was appropriate vegetation selected per the City of Indianapolis's Storm Water Landscape Guidance (Section 5) and Table 5.3.1?				
Maintenance accounted for and plan provided?				
Review of treatment volume?				
Review of calculations?				

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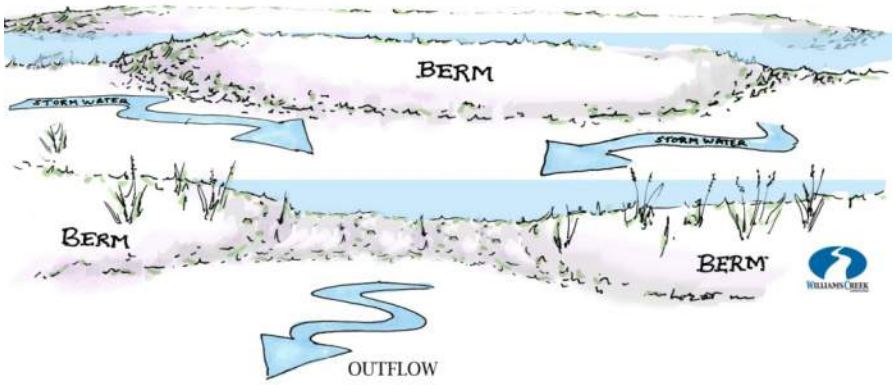
4.6. Low Impact and Retentive Grading

Low Impact Grading techniques focus on utilizing existing topography during Site layout to minimize cost. Proposing structures, roads, and other impervious surfaces along existing high ground will allow for Storm Water to drain onto adjacent Storm Water utilities with a minimum of earthwork required. In doing so, low impact grading can promote the use of existing drainage patterns on-site, minimizing the impact to downstream receiving bodies. The advantages associated with low impact grading are maximized when the existing topography is exceedingly flat, and slope and cover requirements of conventional pipe networks are at a premium. If Storm Water is kept out of traditional piping infrastructure and conveyed via swale or pond, water quality benefits will be maximized while earthwork and infrastructure costs are minimized. Storage observed en route to primary detention will decrease primary detention requirements further separating Low Impact Grading from traditional development on an economic scale.

Retentive grading techniques, alternatively, can be utilized on Sites in which the vertical fall from Development to the Storm Water outlet is high. If topographic variation is plentiful on site, retentive grading can be an effective method of slowing velocities in open channels, preventing scour, encouraging infiltration, and increasing site retention in route to primary Storm Water detention facilities. The use of retentive grading can therefore decrease the potential size of primary facilities. If retentive grading is utilized on adequately infiltrating soils, the volume of Storm Water impounded upstream of the berm may be removed from the Storm Water treatment system, and support ground water recharge. If adequately infiltrating soils are not present on the Site, underdrains placed below amended soils can help to delay and spread out the inflow hydrograph to primary detention facilities, thereby decreasing the required storage capacity of primary facilities. The filtering of Storm Water to underdrains will facilitate removal of Total Suspended Solids (TSS), when properly designed. The use of organic soil amendments can facilitate uptake of excess nutrients and provide a medium for the sorption of fecal coliforms. Berms and retentive grading systems may function alone in grassy areas or may be incorporated into the design of other Storm Water control facilities such as bioretention and constructed wetlands. When adequate freeboard exists to intermittently stage Storm Water en route, the cost of conventional Storm Water facilities may be decreased.



Low Impact and Retentive grading key elements:

- High quality topsoil in outer layer of berm that provides growing medium for plants (minimum 4 inches).
- Inner layer of berm constructed of a stable fill material.
- Established vegetation to prevent erosion and improve appearance.
- An overflow weir or runoff bypass mechanism.
- Soil amendments and underdrain placement at designer discretion.

Table 4.6.1: Low Impact and Retentive Grading Potential Application and Storm Water Regulation

Potential applications			Storm Water regulations		
				Infiltration	No Infiltration
Residential Subdivision:	Yes		Water Quality Benefit	Yes	Yes
Commercial:	Yes		Volume Reduction	Yes	No
Ultra Urban:	Limited		Attenuation Benefit	Yes	Yes
Industrial:	Yes				
Retrofit:	Yes				
Highway Road:	Yes				

Acceptable forms of pre-treatment

- Sediment forebays
- Filter strips
- Vegetated swales
- Bioretention gardens
- Wetlands
- General Disconnection of impervious areas from detention facilities

Low Impact and Retentive Grading Techniques in the Urban Landscape

Utilizing existing topography minimizes the amount of grading that needs to be conducted. Berms and retentive grading can provide an efficient method of reusing soil on site to manage Storm Water, by moving structural soil small distances and creating storage. In addition, appropriate soils upstream of a berm may be excavated to provide structural fill, and subsequently provide a location to deposit top soil removed from other parts of the Site. Addition of topsoil to berm excavations can help to support a healthy vegetative system and increased infiltration potential.

Pretreatment for other Facilities

A berm and small depression can act as a sediment forebay before Storm Water enters a bioretention basin, subsurface infiltration facility, or other facility.

Retention and Increased Capacity for other Facilities

A berm placed on the down slope side of a bioretention basin or other facility built on a mild slope can help retain Storm Water in that facility and increase its capacity without additional excavation.

Retention and Infiltration in a Shallow Depression

A shallow depression can be created behind a berm to provide an infiltration area without the need for a more complex Storm Water facility.

Flow Diversion

A berm can be placed across a slope to divert low or high flow water to a nearby channel or facility.

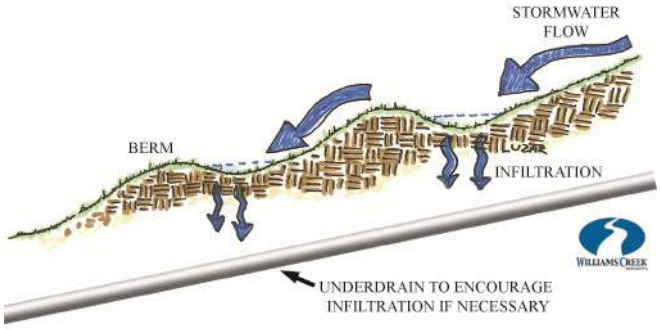
Berms in Series

A series of small berms and depressions can be placed along a slope within any surface- based conveyance system, to provide infiltration and detention while stabilizing the slope.

Components of Low Impact and Retentive Grading Techniques

Low impact techniques and retentive grading systems may be designed to convey and infiltrate all of the Storm Water they receive in small storms. These systems often include the following components:

- Topsoil
- Fill
- Vegetation
- Weir or Bypass Mechanism



RETENTIVE GRADING
CONVEYANCE, STORAGE AND TREATMENT

Topsoil

The outer portion of the berm consists of high quality topsoil to provide a growing medium for plants. A topsoil containing 30% organic material by weight can be expected to support plant growth, aid in regulation of soil nutrients, and provide a medium for adsorption of pathogens. A berm may consist entirely of high quality topsoil. To reduce cost, only the top 4 to 8 inches needs to consist of high quality topsoil, with well-drained soil, or an underdrain system making up the remainder of the berm.

Fill

A berm may consist entirely of high quality topsoil. However, cost may be reduced by constructing the inner portion of the berm of a stable fill material. In many cases, soil may be reused from elsewhere on the site.

Vegetation

Vegetation stabilizes and prevents erosion of the soil layer. Native trees and grasses are encouraged for aesthetic reasons and because of their deeper root systems which preserve long-term infiltration potentials, but turf is acceptable.

Weir or Bypass Mechanism

The berm may not be able to retain all flow during large events. An overflow weir may be designed to allow flow to overtop the berm without causing erosion. In other cases, the contours of the site may allow excess flow to bypass around the end of the berm.

Recommended Design Procedure

- Water quality–and quantity requirements must be designed within parameters required by the Storm Water Design and Construction Specifications Manual.
- Create a Conceptual Site Plan for the entire site, and determine what portion of the sizing requirements berms and retentive grading can help meet. Determine the general location of these features and the role they will play on the site. These techniques can be applied anywhere in

advance of Site discharge so long as the Storm Water is kept on the surface of the Site and not discharged to a pie.

- Create a conceptual design for the berm (or berms), including height of berm and depth of depression.

Table 4.6.2: Starting Design Values for Berm Areas and Depths	
Area (surface area and infiltration area)	Largest feasible on site (Minimum of 1 square foot of infiltration area for every 5 square feet of contributing DCIA recommended.)
Average Ponding Depth	6 -12 inches
Berm Height	6 - 24 inches

- For a berm-depression system intended to promote infiltration, investigate the feasibility of infiltration in the proposed location. The NRCS soil surveys can provide guidance as to where adequately infiltrating soils are likely to be found. However, Infiltration testing should be performed within 25 feet of the infiltration footprint. In addition infiltration characteristics should be based upon the post-construction condition of the soil. Refer to **Attachment 1** for **Guidelines for Infiltration Testing**.

- Estimate runoff reaching the system during the design storm and the maximum water level reached at the berm.

- Using infiltration area and the saturated vertical infiltration rate of the native soil, estimate how long the surface ponding will take to drain. If storage does not drain within the expected time interval between design storms, credit for volume reductions may not be allowed, due to inability to accommodate back to back storm events. The designer may adjust the design until the volume and drainage time constraints are met. A geotechnical report / analysis is required when infiltration will be utilized.

- Design an overflow or bypass mechanism for large storms.

- Consider maintenance activities when choosing berm materials and shape. For example, providing more storage than taken credit for in quantity calculations will allow for long-term sediment accrual without maintenance requirements. If native plantings are designed to develop over time into a diverse ecosystem within the depressional area, the aesthetic and ecological value of the systems will be enhanced.

- If a berm is to be mowed, the slope should not exceed a 4:1 ratio (horizontal to vertical) in order to avoid “scalping” by mower blades. If trees are to be planted on berms, the slope should not exceed a 5:1 to 7:1 ratio. Other herbaceous plants, which do not require mowing, can tolerate slopes of 3:1, though this may promote increased runoff rate and erosive conditions. If underdrains are installed to simulate the water quality and flowrate benefits of infiltration, woody vegetation is not recommended per the long term health of the underdrain system. Berm side slopes should never exceed a 2:1 ratio.

- To minimize cost, check the volume of cut and fill material. Berm height and depression depth may be adjusted to more closely balance the two.

Materials

Soil

- Topsoil stripped and stockpiled on the site should be used for fine grading. Topsoil is defined as the top layer of earth on the site, which produces heavy growths of crops, grass or other vegetation. Top soil is typically high in organic content making it unsuitable for structural fill but advantageous for promoting infiltration, nutrient transformation, and fecal coliform sorbtion.

- Soils excavated from on-site may be used for berm construction provided they are deemed satisfactory as per the above recommendations or by a soil scientist.

Vegetation

- It is critical that plant materials are appropriate for soil, hydrologic, light, and other site conditions. Native trees and grasses are strongly recommended but turf grass is acceptable. Select plants from Chapter 5: Storm Water Landscape Guidance. Take ponding depth, drain down time, sunlight, and other conditions into consideration when selecting plants from this list. Although plants will be subject to ponding, they may also be subject to drought.

- Trees and shrubs shall be freshly dug and planted in accordance with standard nursery practice.

- Perennials, grass-like plants, and groundcover plants shall be healthy, well-rooted specimens.

- Plantings shall be designed to minimize the need for mowing, pruning, and irrigation.

- A native grass/wildflower seed mix can be used as an alternative to groundcover planting. Seed mix shall be free of weed seeds.

Construction Guidelines

- Clearly marking areas for infiltration berms before any site work begins can discourage soil disturbance and compaction during construction and preserve the existing infiltration characteristics of the underlying soil.

- Provide erosion and sedimentation control protection on the site such that construction runoff is directly away from the proposed infiltration berm location. Alternatively, ensure that any sediment accrual associated with construction activities is removed to design grade before the cessation of construction activities.

- Complete site elevation grading and stabilize the soil disturbed within the limit of disturbance. Do not finalize berm excavation and construction until the drainage area is fully stabilized.

- Manually scarify the existing soil surfaces of the proposed infiltration berm locations. Do not compact in-situ soils. Heavy equipment shall not be used within the berm area.

- Backfill the excavated area as soon as the subgrade preparation is complete to avoid accumulation of debris. Place berm soil in 8 inch lifts and compact after each lift is added according to design specification. Grade berm area as fill is added.

- Protect the surface ponding area at the base of the berm from compaction. If compaction occurs scarify soil to a depth of at least 8 inches.

- After allowing for settlement, complete final grading within 2 inches of proposed design elevations. The crest and base of the berm should be level along the contour.

- Seed and plant vegetation as indicated on the plans and specifications.

- Place mulch to prevent erosion and protect establishing vegetation and manually grade to final elevations.

- Water vegetation at the end of each day for two weeks after planting is completed.

Maintenance Guidelines

Berms have low to moderate maintenance requirements, depending on the design.

Table 4.6.3: Berm & Grading Maintenance Guidelines

	Activity	Schedule
	Remove trash and debris Remove invasive plants. If desired, mow grass to maintain 2 -4 inch height.	As needed
	Inspect soil for erosion and repair eroded areas.	Monthly
	Maintain records of all inspections and maintenance activity concurrent with post-construction requirements listed in *City of Indianapolis Storm Water Design and Construction Specifications Manual.*	Ongoing

Note:

Design of berms and grading techniques are not limited to the examples shown within this text. Successful Storm Water management plans will combine appropriate materials and designs specific to each site. Berms may be used within larger basins (e.g., wetlands, wet ponds) to lengthen flow paths; these applications are discussed in-various LID literature.

4.6.1. Low Impact and Retentive Grading Designer/Reviewer Checklist

Item	Yes	No	N/A	Notes
Appropriate overflow or bypass provided?				
Berm side slopes less than 2:1?				
Berm Height limited to 24 inches?				
Appropriate slope for vegetation type and mowing requirements?				
Feasible construction process and sequence?				
Acceptable planting soil specified?				
Maintenance accounted for and plan provided?				

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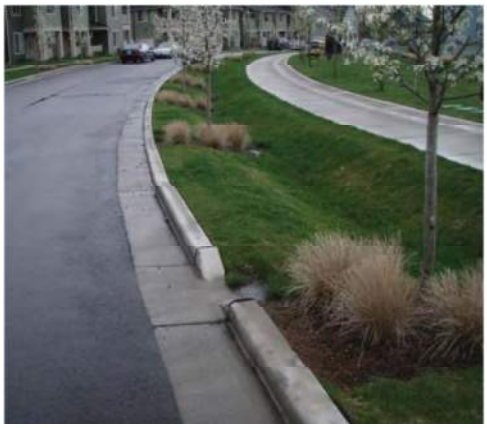
4.7. Swales



A swale is a vegetated open channel, planted with a combination of grasses and other herbaceous plants, shrubs, or trees. A traditional swale reduces peak flow at the discharge point by increasing travel time and friction along the flow path. Swales can provide some infiltration and water quality treatment; these functions can be enhanced by incorporating retentive grading, or check dams periodically along the length of the swale. In cohesive soil types, installation of a filtering substrate (for example, a mixture of 1/3 each soil, sand and organic matter) and a perforated underdrain enhance simulated infiltration capacity of swales in order to provide additional water quality treatment. In this manner, the perennial outlet is the underdrain with the retentive grading or check dams providing high flow relief. Therefore, the volume of Storm Water forced to infiltrate to the underdrain is temporarily providing storage en route to the primary detention facility. This will decrease the required size of primary detention facilities versus conventional pipe conveyance. The Designer should be encouraged to incorporate swales into the landscape and hardscape to the extent possible in order to increase aesthetic value, decrease construction cost, and provide attenuation characteristics throughout the Storm Water system. Swales planted with turf grass provide some of these functions but turf grass is not as effective as deeper-rooted vegetation at decreasing peaks, encouraging infiltration, and decreasing erosion. A swale can be more aesthetically pleasing than a rock-lined drainage system and is generally less expensive to construct.

Key elements:

- Open channel design that balances storage, treatment, and infiltration with peak flow conveyance needs
- Check dams or lateral, permeable berms to increase storage, dissipate energy, and control erosion
- Native vegetation to increase frictional resistance and stabilize soil
- Designed to fit into many types of landscapes in an aesthetically pleasing manner
- Pretreatment, such as a forebay or sediment accumulating feature
- Sediment depth marker

Table 4.7.1: Swales Potential Application and Storm Water Regulation

Potential applications			Storm Water regulations		
				Infiltration	No Infiltration
Residential Subdivision:	Yes		Water Quality Benefit	Yes	Yes
Commercial:	Yes		Volume Reduction	Yes	No
Ultra Urban:	Limited		Attenuation Benefit	Yes	Yes
Industrial:	Yes				
Retrofit:	Yes				
Highway Road:	Yes				

Acceptable forms of pre-treatment

Filter strips
Sediment Forebay

Swales in the Urban Landscape

Swales are landscaped channels that convey Storm Water and reduce peak flows by increasing travel time and flow resistance. Depending on design and underlying soil permeability, they can effectively reduce runoff volume and improve water quality. Check dams increase these functions by creating ponding areas where settling and infiltration can occur. As the number of check dams increases, a swale may resemble a series of bioretention basins while still being designed to convey peak flows. The first ponding area may be designed as a sediment forebay and function as a pretreatment practice for the remainder of the swale or other Storm Water management facilities.

Swales are applicable in many urban settings such as parking, commercial and light industrial facilities, roads and highways, and residential developments. For instance, a swale is a practical replacement for roadway median strips and parking lot curb and gutter. Swales can be an effective means of decentralizing Storm Water management so that primary detention facilities become less necessary.

SWALE IN EASEMENT OF SUBDIVISION

Commercial, Light Industrial, and Institutional Sites

These facilities often have landscaped or grassed areas that can also function as drainage pathways and infiltration areas.

Roads and Highways

Swales can be installed in some median strips and shoulders. In some cases, these systems may replace costly curb and gutter systems.

Residential Development

With approved property agreements, swales can be constructed parallel to the sidewalks and streets. Alternatively they can collect Storm Water from multiple properties and convey it to a shared facility.

Components of a Swale

Swale systems often include the following components:

- Inlet Control
- Pretreatment
- Excavated Channel
- Permeable Soil
- Outlet Control
- Check dams or lateral, permeable berms
- Stone (Optional)
- Underdrain (Limited Application)
- Vegetation

Inlet Control

Runoff can enter the swale through a curb opening, pipe, weir, or other design. Runoff may flow off a curbless parking lot or road and down a swale slope in a diffuse manner.

Pretreatment

Pretreatment can extend the life of the design if the swales are designed to accrue sediment. Vegetated or stone filter strips are options for pretreatment. A sediment forebay may be constructed at the swale inlet, or the first swale segment and a check dam may be designed as a sediment forebay and the primary maintenance point.

Excavated Channel

The channel itself provides the storage volume and conveyance capacity of the swale. Swale design should balance the infiltration and treatment requirements of small storms with needs for conveyance during large storms.

RIVER ROCK SWALE

Soil and Stone

The soil provides a growing medium for plants and allows for infiltration. Growing medium may consist of amended native soils or soil mixtures specified for infiltration. A crushed stone layer may be added beneath the soil to increase storage and promote infiltration. Stone will perform this function most effectively when placed in ponded areas.

Check Dams

It is recommended that swale designs include check dams or lateral, permeable berms. Ponding behind check dams provides storage, increases infiltration, increases travel time, reduces peaks, and helps prevent erosion by dissipating energy. Lateral, permeable berms provide a similar function, providing longitudinal filtration in addition to the functions described above.

Underdrain

In some cases, an underdrain and piping system may be provided to prevent prolonged ponding of Storm Water or to collect and convey water to another facility such as an infiltration trench. Underdrained systems may be appropriate in locations where conditions are not ideal for infiltration. In general underdrains should be installed unless the underlying soil is permeable and the saturated infiltration rate has been certified by a registered geologist, soil scientist, or engineer as well as the seasonal high water table.

Outlet Control

A swale may have an outlet control to convey water to a sewer or receiving water.

Recommended Design Procedures

Water Quality Swales must also meet the design requirements in Section 702.05 of the Indianapolis Storm Water Design and Construction Specifications Manual.

- Determine the desired Water Quality and Quantity requirements to be met by the swale on the site. The designer may choose to provide all necessary storage within the swales, or just decrease the demands at the most downstream detention facility.

- Create a Conceptual Site Plan for the entire site, and determine what portion of the requirements the vegetated swale will meet. Consider the site's natural topography in siting the swale; if possible, locate the swale along contours and natural drainage pathways.

- Investigate the feasibility of infiltration according to conditions in the area proposed for the vegetated swale. If infiltration is feasible (according to **Attachment 1, Guidelines for Infiltration Testing**), determine the saturated vertical infiltration rate. Infiltration to groundwater will remove Storm Water volume. Infiltration must be verified through field investigation by a geotechnical engineer or certified soil scientist. The seasonal high water table must also be included in the investigation and documented.

- Create a conceptual design for the vegetated swale.

Table 4.7.2: Suggested Swale Starting Design Values	
Bottom Width	2-8 Feet
Side Slopes	3-4 horizontal to one vertical recommended; 2:1 maximum*
Check Dams	Evenly spaced, 6-12 inches high**

*Swales may be trapezoidal or parabolic in shape. Recommended widths and slopes in this table may be used as a general guide for parabolic channels
**Check dams are recommended for most applications to improve infiltration and water quality. They are strongly recommended for swales in which flow in combination with soil, slope, and vegetation may result in erosive conditions.

- Consider an underdrain under any of the following conditions:
    - in areas with separate storm sewers or direct discharge to receiving waters where infiltration is infeasible and the vegetated swale is needed only to provide water quality treatment;
    - in areas with combined sewers where sufficient detention or travel time can be designed into the system to meet release rate requirements; or
    - in combination with other storm infrastructure where the system as a whole meets storage and release criteria.
- Estimate the portion of Water Quality and Water Quantity requirements met by the design.
- Using infiltration area and the saturated vertical infiltration rate of the native soil, estimate how long storage behind check dams will take to drain. The maximum drain time for the entire storage volume is 48 hours, but the Designer may choose a shorter time based on site conditions and Owner preference but no shorter than 24 hours. If storage does not drain in the time allowed, adjust channel shape, number of check dams, check dam height, or optional underdrain design. Adjust the design so that performance and drainage time constraints are met concurrently.
- Check the capacity of the swale system to perform during the 100 year regulatory event defined in the Storm Water Design and Construction Specifications Manual. An average ponding depth of 12 inches or less, and a maximum ponding depth of 24 inches is required. If higher stages are anticipated, vegetation should be selected per expected hydrologic conditions. Flow over check dams should be estimated using a weir equation, while underdrain conveyance should be modeled as a series outlet representing (1) infiltration rate over horizontal wetted area to (2) orifice flow at the underdrain daylight. Ultimately, the level of service provided on the site during large events is a joint decision of the Engineer and Owner based on safety, appearance, and potential property damage.
- Choose soil mix and swale vegetation. A minimum of 6 inches of prepared soil is recommended for the channel bottom and slopes. A detail should be included on the plan sheets including the proposed soil mixture.
- Check resistance of the swale to erosion. For long term functionality, it is recommended that the swale convey the 2-year, 24-hour design storm without erosion. For water quality purposes, channel velocities during a water quality event should not exceed resuspension velocities (2.5 ft/sec). Adjusting soil mix, vegetation, and temporary or permanent stabilization measures as needed.
- Design inlet controls, outlet controls, and pretreatment if desired.
- Check that the design meets all requirements concurrently, and adjust design as needed.
- Complete construction plans and specifications.

- Additional guidelines are summarized in the **Swale Design Guidelines (Attachment 6)**.

Materials

All material specifications should appear on the plans.

Soil

- Swale soil shall have a sandy loam, loamy sand, or loam texture per USDA textural triangle. The soil shall have a high permeability (fc>0.5in/hr) and a seasonal high water table greater than 2 feet flow the bottom of the swale.

Vegetation

- It is critical that plant materials are appropriate for soil, hydrologic, light, and other site conditions. Select plants from the list of native species provided in Chapter 5: Storm Water Landscape Guidance. Consider ponding depth, drain time, sunlight, salt tolerance, and other conditions when selecting plants from this list. Turf grass is generally not recommended but may be acceptable provided the designer can show it meets all requirements.

Check Dams

- Check dams can be constructed from natural wood, concrete, stone, boulders, earth, or other materials. The Designer should coordinate with the Department of Metropolitan Development regarding the use of non-conventional materials in the Storm Water infrastructure.

- If a stone check-dam is designed to be overtopped, appropriate selection of aggregate will ensure stability during flooding events. In general, one stone size for a dam is recommended for ease of construction. However, two or more stone sizes may be used, provided a larger stone (e.g. R-4) is placed on the downstream side, since flows are concentrated at the exit channel of the weir. Several feet of smaller stone (e.g. AASHTO #57) can then be placed on the upstream side. Smaller stone may also be more appropriate at the base of the dam for constructability purposes.

Storage Stone

- Stone used to provide additional storage shall be uniformly-graded, crushed, washed stone meeting the specifications of AASHTO No. 3 or AASHTO No. 5.

- Stone shall be separated from soil medium by a non-woven geotextile or a pea gravel filter.

Non-Woven Geotextile

- Geotextile shall consist of needled non-woven polypropylene fibers and meet the following properties:
  - Grab Tensile Strength (ASTM-D4632) ≥ 120 lbs
  - Mullen Burst Strength (ASTM-D3786) ≥ 225 psi
  - Flow Rate (ASTM-D4491) ≥ 95 gal/min/ft2
  - UV Resistance after 500 hrs (ASTM-D4355) ≥ 70%
  - Heat-set or heat-calendared fabrics are not permitted

Pipe

- Pipe used for an underdrain shall be continuously perforated and have a smooth interior with a minimum inside diameter of 6-inches. High-density polyethylene (HDPE) pipe shall meet the specifications of AASHTO M252, Type S or AASHTO M294, Type S.

Construction Guidelines

- Begin vegetated swale construction only when the up gradient site has been sufficiently stabilized and temporary erosion and sediment control measures are in place. Vegetated swales should be constructed and stabilized very early in the construction schedule, preferably before mass earthwork and paving increase the rate and volume of runoff. If the swales are constructed to assist with temporary drainage during construction, the facilities should be graded to final design grade and stabilized at the cessation of mass earthwork.

- Rough grade the vegetated swale. Equipment shall avoid excessive compaction and/or land disturbance. Excavating equipment should operate from the side of the swale and never on the bottom. If excavation leads to substantial compaction of the subgrade (where an infiltration trench is not proposed), 18 inches shall be removed and replaced with a blend of topsoil and sand to promote infiltration and biological growth. At the very least, topsoil shall be rototilled into the subgrade in order to penetrate the compacted zone and promote aeration and the formation of macropores. Following this, the area should be disked prior to final grading of topsoil.

- Construct check dams, if specified.

- Fine grade the vegetated swale. Accurate grading is crucial for swales. Even the smallest nonconformities may compromise flow conditions and may lead to ponding in undesirable locations. The accidental creation of a preferential flow path in the swale will encourage scour rather than the desired smooth laminar flow across the cross-section.

- Seed and vegetate according to final planting list. Initial seeding with an annual turf grass is recommended to provide temporary stabilization. Plant the swale at a time of the year when successful establishment without irrigation is most likely. However, temporary irrigation may be needed in periods of little rain or drought. Vegetation should be established as soon as possible to prevent erosion and scour.

- Concurrent with the previous step, stabilize freshly seeded swales with appropriate temporary or permanent soil stabilization methods, such as erosion control matting or blankets. If runoff velocities are high, consider sodding the swale or diverting runoff until vegetation is fully established.

- Once the swale is sufficiently stabilized, remove temporary erosion and sediment controls. It is very important that the swale be stabilized before receiving Storm Water flow.

Maintenance Guidelines

The following schedule of inspection and maintenance activities must be included in the O&M Manual:

Table 4.7.3: Swale Maintenance Guidelines	
Activity	Schedule
Remulch void areas. Treat or replace diseased trees and shrubs. Keep overflow free and clear of obstructions.	As needed
Inspect soil and repair eroded areas. Remove litter and debris. Clear leaves and debris from overflow.	Monthly
Inspect trees and shrubs to evaluate health.	Biannually
Add additional mulch. Inspect for sediment buildup, erosion, vegetative conditions, etc.	Annually
Maintain records of all inspections and maintenance activity.	Ongoing
Mowing of vegetated swales is design dependent	Ongoing

Note:

Design of swales are not limited to the examples shown within this text. Successful Storm Water management plans will combine appropriate materials and designs specific to each site.

4.7.1. Swale Designer/Reviewer Checklist

Item	Yes	No	N/A	Notes
Can the swale safely (with freeboard) convey the 10-year event?				
Are bottom slopes between one percent and six percent?				
Are check dams provided for slopes > 3%?				
Are check dams adequately keyed into swale bottom and sides?				
Are two-year 24hr storms non-erosive?				
Will the swale completely drain in 48 hours?				
Are side slopes between 3:1 and 5:1 H:V?				
Are swale soils loam, loamy sand or sandy loam?				
Vegetation and Mannings coefficient selected?				
Was appropriate vegetation selected per the City of Indianapolis's Storm Water Landscape Guidance (Section 5) and Table 5.3.1?				
Non-erosive inflow condition(s)?				
Erosion control provided during construction?				
Maintenance accounted for and plan provided?				

Other O & M Manual Requirements

See Section 702.05 of the Storm Water Design and Construction Specifications Manual.

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4.8. Subsurface Infiltration

Subsurface infiltration systems are designed to provide temporary below grade storage infiltration of Storm Water as it infiltrates into the ground. Dry wells, infiltration trenches and beds are a few examples of these types of systems. Infiltration is a preferred method for Storm Water management where appropriate site conditions and soils exist. The use of infiltration methods helps to minimize the Storm Water loading on existing storm sewer systems and can reduce the amount of overflows for combined sewer systems. By infiltrating Storm Water on-site, downstream impacts resulting from Storm Water flows are reduced or in some cases eliminated.

Note: some subsurface infiltration systems could be classified as Class V injection wells and may require additional permitting by both EPA and IDEM.

SUBSURFACE INFILTRATION COLLECTING DRAINAGE FROM AN IMPERVIOUS AREA

Key elements:

- Infiltration testing, outlined in **Attachment 1**, is required for this Storm Water management practice. *A factor of safety of two (2) or three (3) should be applied to the infiltration rate determine from the geotechnical report to account for future reductions in the infiltration rate due to sediment.*
- Reduce volume of runoff from a drainage area by promoting infiltration through uncompacted subgrade.
- Can be sited beneath lawns, parking areas, and recreational areas.
- Maintain minimum distance from building foundation (typically 10 feet down-gradient minimum). In addition, the top elevation of ponding in the subsurface system should be below the lowest floor of the nearby buildings.
- Storage is provided within voids of open-graded aggregate or other approved material. • System must be designed to drain down in less than 72 hours.
- Greater than 2 feet from any limiting zone such as groundwater or bedrock.
- Pre-treatment is required.
- Positive overflow required for large storms.
- Areas of soil contamination or areas of unstable soils should be avoided.

Table 4.8.1: Subsurface Infiltration Potential Application and Storm Water Regulation

Potential applications			Storm Water regulations		
				Infiltration	No Infiltration
Residential Subdivision:	Yes		Water Quality Benefit	Yes	Yes
Commercial:	Yes		Volume Reduction	Yes	No
Ultra Urban:	Yes		Attenuation Benefit	Yes	Yes
Industrial:	Yes				
Retrofit:	Yes				
Highway Road:	Yes				

Acceptable forms of pre-treatment

- Filter
- Bioretention

- Filter Strips
- Appropriate prefabricated and proprietary design
- Sumped inlets with traps
- Some systems, e.g. StormTech may require the use of an SQU or other pretreatment prior to runoff entering the system.

Subsurface Infiltration in the Urban Landscape

Subsurface infiltration systems are typically stone-filled beds or trenches beneath landscaped or paved surfaces. Storm Water flows into the subsurface infiltration system, collects within the aggregate void space, and slowly infiltrates into surrounding soils. Subsurface infiltration is a versatile management practice suitable for many different types of land uses. Both high-density development and individual residences can implement subsurface infiltration systems for Storm Water control. Their flexibility also makes them an option for a Storm Water retrofit. Several example uses for subsurface infiltration are provided below.

SUBSURFACE INFILTRATION INSTALLED AT A SCHOOL ATHLETIC FIELD

Parking Lots and Roadways

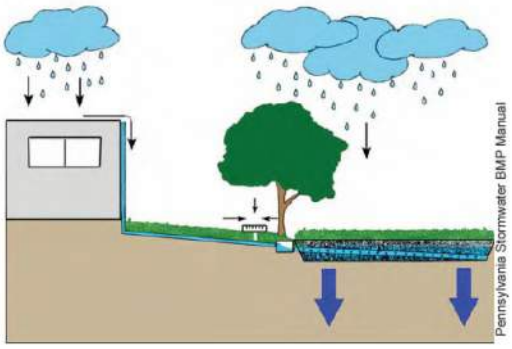
Storm Water inlets in parking lots or streets can be directly connected to subsurface infiltration systems. Sumped or trapped inlets prevent sediment and debris from migrating into the infiltration bed. The inlets can be connected to subsurface infiltration systems located underneath landscaped areas, recreation areas, or under the impervious surfaces themselves.

Lawns and Recreational Areas

Open green spaces can collect, store, and infiltrate runoff from impervious surfaces.

Direct Connection of Rooftops

Downspouts can be connected to subsurface infiltration beds at both residential and commercial sites. Small subsurface infiltration areas that manage roof runoff from residential roofs or that are distributed around a larger building to manage runoff from smaller sections of roof are often called dry wells. Although roofs do not often generate high sediment loads, sumped cleanouts must be located between the roof and the infiltration area. The roof leader connects to perforated piping when it reaches the subsurface infiltration area.

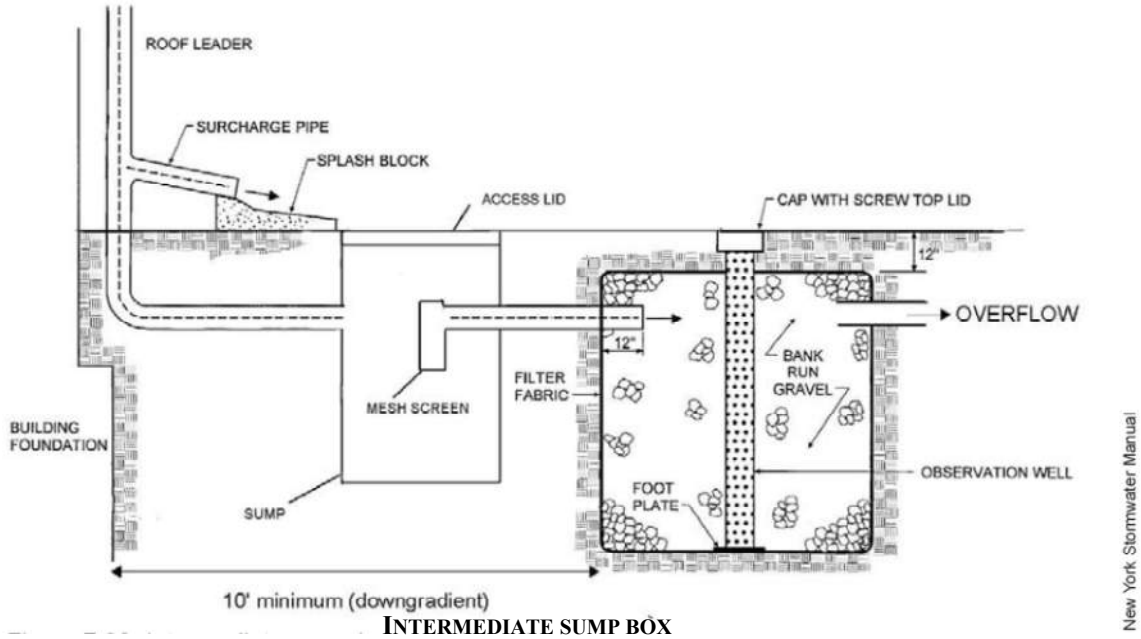


DIRECT CONNECTION OF A ROOF INTO A SUBSURFACE INFILTRATION BED

Components of a Subsurface Infiltration System

There are many variations of subsurface infiltration systems, but they are often comprised of these components:

- Inflow/Pretreatment
- Storage
- Observation well
- Infiltration/Outflow



INTERMEDIATE SUMP BOX AND DRY WELL

Inflow/Pretreatment

Subsurface infiltration systems are capable of intercepting Storm Water inflow from many sources, including rooftops, parking lots, roads, sidewalks, and driveways. It is important to prevent coarse sediments and debris from entering subsurface infiltration systems, because they could contribute to clogging and failure of the system. The following are acceptable forms of pretreatment.

PREFABRICATED STORAGE

- Roof leader sump, or an intermediate sump box
- Roof gutter guard (may require additional sump unit depending on structure design).
- Filter Strips, (See Section 4.4 Filter Strip Fact Sheet and the Storm Water Design and Construction Specifications Manual).
- Vegetated Swales, (See Section 4.7 Swales Fact Sheet and the Storm Water Design and Construction Specifications Manual).
- Stormwater Quality Treatment Unit (SQU)

Storage

The storage component of a subsurface infiltration area is typically provided by a stone filled, level-bottomed bed or trench. The void spaces between the stones stores Storm Water until it can percolate into surrounding soils. Alternative subsurface storage products may also be used to provide temporary storage. These include a variety of proprietary, interlocking plastic units with much greater storage capacity than stone fill (up to 96% void space). Perforated pipe in a stone bed can also increase the effective void space of the system. The higher void ratio of underground storage units requires a smaller footprint and can allow more flexibility in an urban environment, but proper analysis should be completed to ensure that the in-situ soils will adequately drain with the additional loading and that loading ratio and effective head maximums are not exceeded.

Observation Well

An observation well should be located at the center of the trench to monitor water drainage from the system. In a subsurface infiltration system, the water level is the primary means of measuring infiltration rates and drain-down times. A lockable above ground cap is recommended. Adequate inspection and maintenance access to the observation well should be provided. Observation wells not only provide necessary access to the system, but they also provide a means through which pumping of stored runoff can be accomplished in a failed system.

Infiltration/Outflow

Outflow occurs via infiltration through subsurface soil surrounding the infiltration storage area. A bypass system should be implemented for all infiltration systems to convey high flows around the system to downstream drainage systems. Depending on the level of Storm Water management required at the site, overflows can connect to an approved discharge point or other Storm Water management practices.

Recommended Design Procedure

- Determine actual site soil conditions using a registered geologist, soil scientist or engineer.

- Determine the Water Quality and Quantity requirements on the site. (See City of Indianapolis Storm Water Design and Construction Specifications Manual.)

- Must be greater than 10 feet down-gradient and 100 feet up-gradient. In addition, the top elevation of ponding in the subsurface system should be below the lowest floor of the nearby buildings.

- Create a Conceptual Site Plan for the entire site and determine what portion of the sizing requirements subsurface infiltration will meet. (See City of Indianapolis Storm Water Design and Construction Specifications Manual.)

- Investigate the feasibility of infiltration in the area proposed for a subsurface infiltration system. Investigate the feasibility of infiltration in the area proposed for subsurface infiltration according to **Attachment 1** (hotspot investigation, infiltration test, and geotechnical analysis). Infiltration testing must be within 25 feet of the infiltration footprint.

- Create a conceptual design for the subsurface infiltration system.

Table 4.8.2: Starting Design Values for Subsurface Infiltration Areas and Depths	
Area (surface area and infiltration area)	Largest feasible in moderately sloped areas of the site (Minimum of 1 square foot of infiltration area for every 5 square feet of contributing DCIA.)
Maximum Storage Depth	2 feet of effective head. (2 cubic feet of storage volume per square foot of infiltration area.)
Minimum distance above limiting zone	2 feet
Minimum/Maximum drain down time	24/72 hours

- Estimate the total storage volume and adjust area and/or depths as needed to provide required storage. Open-graded aggregate sub-base may be assumed to have 40% void space for storage.

- Using infiltration area and the saturated vertical infiltration rate of the native soil, estimate how long the surface ponding and soil storage will take to drain. The maximum drain down time for the entire storage volume is 72 hours, but the Engineer may choose a shorter time based on site conditions and Owner preference. If storage does not drain in the time allowed, adjust the depth and/or surface area. Adjust the design until the volume and drainage time constraints are met.

- Design a positive overflow or bypass system for larger design storms. All systems must design overflow structures and pipes to convey at least the 10-year storm.

- Include acceptable form(s) of pretreatment into design.

- Observation well to be designed with a minimum 4 inch diameter perforated plastic pipe, and placed at the invert of infiltration bed with a lockable above-ground cap.

- Complete construction plans and specifications.

Materials

All material specifications should appear on the plans.

Storage Stone

- Stone used for subsurface storage shall be uniformly-graded, crushed, washed stone meeting the specifications of the City of Indianapolis.

- Stone shall be separated from soil by a non-woven geotextile filter fabric or a pea gravel filter.

Non-Woven Geotextile

- Geotextile shall consist of needled non-woven polypropylene fibers and meet the following properties:

  - Grab Tensile Strength (ASTM-D4632) ≥ 120 lbs
  - Mullen Burst Strength (ASTM-D3786) ≥ 225 psi
  - Flow Rate (ASTM-D4491) ≥ 95 gal/min/ft2
  - UV Resistance after 500 hrs (ASTM-D4355) ≥ 70%
  - Heat-set or heat-calendared fabrics are not permitted

Pipe

- Pipe used within the subsurface system shall be continuously perforated and have a smooth interior with a minimum inside diameter of 6-inches. High-density polyethylene (HDPE) pipe shall meet the specifications of AASHTO M252, Type S or AASHTO M294, Type S.

- Any pipe materials outside the Storm Water management practice are to meet City Plumbing Code Standards.

INSTALLATION OF A SUBSURFACE INFILTRATION TRENCH

Construction Guidelines

- Areas for proposed subsurface infiltration systems shall be clearly marked before any site work begins to avoid soil disturbance and compaction during construction. If areas are compacted during construction additional infiltration testing may be required.

- Provide erosion and sedimentation control protection on the site such that construction runoff is directed away from the proposed subsurface infiltration system.

- If the infiltration area is being used as a sediment basin during construction the bottom elevation of the sediment basin must be a minimum of 2 feet above the infiltration bed invert elevation.

- Complete site elevation grading and stabilize the soil disturbed within the limit of disturbance. Do not finalize the subsurface infiltration system's excavation and construction until the drainage area is fully stabilized.

- Excavate subsurface infiltration area to proposed invert depth and manually grade and scarify the existing soil surface. The bottom of the infiltration bed shall be at a level grade.

- Existing subgrade shall NOT be compacted or subject to excessive construction equipment prior to placement of geotextile and stone bed. If it is essential that equipment be used in the excavated area, all equipment must be approved by the Engineer. Use of equipment with narrow tracks or tires, rubber tires with large lugs, or high pressure tires will cause excessive compaction and shall not be used. Should the subgrade be compacted during construction additional testing of soil infiltration rates and system redesign may be required.

- Place geotextile and recharge bed aggregate immediately after approval of subgrade preparation to prevent accumulation of debris or sediment. Prevent runoff and sediment from entering the storage bed during the placement of the geotextile and aggregate bed.
- Place geotextile in accordance with manufacturer's standards and recommendations. Adjacent strips of filter fabric shall overlap a minimum of 16 inches. Fabric shall be secured at least 4 feet outside of bed.

- Install aggregate course in lifts of 6-8 inches. Lightly compact each layer with equipment, keeping equipment movement over storage bed subgrades to a minimum. Install aggregate to grades indicated on the drawings.

- Complete surface grading above subsurface infiltration system, using suitable equipment to avoid excess compaction.

Maintenance Guidelines

As with all infiltration practices, subsurface infiltration systems require regular and effective maintenance to ensure prolonged functioning. The following table describes minimum maintenance requirements for subsurface infiltration systems that must be included in the O&M Manual.

Table 4.8.3: Subsurface Infiltration Maintenance Guidelines

Activity	Schedule
• Regularly clean out gutters and catch basins to reduce sediment load to infiltration system. Clean intermediate sump boxes, replace filters, and otherwise clean pretreatment areas in directly connected systems.	As needed
• Inspect and clean as needed all components of and connections to subsurface infiltration systems. • Evaluate the drain-down time of the subsurface infiltration system to ensure the drain-down time of 24- 72 hours.	Biannually
Maintain records of all inspections and maintenance activity.	Ongoing

Note:
Design of subsurface infiltration systems are not limited to the examples shown within this text. Successful Storm Water management plans will combine appropriate materials and designs specific to each site.

4.8.1. Subsurface Infiltration Trench Designer/Reviewer Checklist

Item	Yes	No	N/A	Notes
Infiltration rates measured?				
Soil permeability acceptable?				
If not, appropriate underdrain provided?				
Adequate separations from wells, structures, etc.?				
Natural, uncompacted soils?				
Level infiltration area (e.g., trench bottom, bed bottom)?				
Excavation in infiltration area minimized?				
Hotspots/pretreatment considered?				
Storage depth limited to two feet?				
Drawdown time less than 72 hours?				
Positive overflow from system?				
Erosion and sedimentation control?				
Feasible construction process and sequence?				
Geotextile specified?				
Pretreatment provided?				
Clean, washed, open-graded aggregate specified?				
Stable inflows provided (infiltration basin)?				
Appropriate perforated pipe, if applicable?				
Appropriate plants selected, if applicable?				
Observation well/clean out provided, if applicable?				
Maintenance accounted for and plan provided?				

4.9. Inlet and Outlet Controls

Inlet &Outlet Controls are the structures or landscape features that manage the flow into and out of a Storm Water management facility. Flow splitters, level spreaders, curb openings, energy dissipaters, traditional inlets, and curbless design are all examples and elements of inlet controls. Outlet controls regulate the release of Storm Water from a management facility. Examples of outlet controls include risers and orifices, underdrains, permeable weirs, positive overflows, sub-thermocline basin release, and impervious liners. Outlet control structures limit flow quantity and velocity to meet release rate requirements, reduce discharge flow energy and bypass flows in excess of designed Storm Water quality volume to prevent re-suspension of sediment, hydraulic overload, or erosion of management practices.

Key elements:

Inlet and Outlet controls must be designed within parameters required by the Indianapolis's Storm Water Design and Construction Specifications Manual.

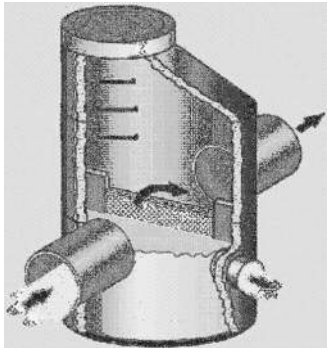
Inlet Controls:

- Flow splitters divert the design water quality volume portion of the storm hydrograph to a management facility or series of facilities, while allowing the flow of larger storms to bypass the facility.
- Curbless roads, streets, and parking lots allow Storm Water to sheet flow into a BMP.
- Curb openings allow water to flow through a curb that would otherwise block the flow.
- Level spreaders spread out concentrated flow and release it as low velocity, non-erosive diffuse flow.
- Energy dissipaters slow down and spread flow from culverts and steeper slopes.

Outlet Controls:

- Risers and orifices release ponded water at a reduced rate and reduced energy.
- Positive overflows allow Storm Water to safely flow out of a BMP.
- Underdrains collect water that has filtered through a porous medium and convey it to an outlet.
- Impervious liners prevent water from infiltrating the soil where infiltration is not desirable, such as in designated "hotspot" land uses and/or wellfield protection areas.
- Permeable weirs allow water to flow slowly through smaller openings and more quickly over the top of the weir.
- Level Spreaders spread out concentrated flow and release it as low velocity, non erosive diffuse flow.
- Energy dissipaters slow down and spread flow from culverts and steeper slopes.
- Sub-thermocline basin outlet provides direct discharge from the
- lower area of the water quality and/or quantity storage basin, reducing thermal impacts from heat island land use conditions.

Flow Splitter



Flow splitting devices are used to direct a designed water quality storm event into a Storm Water management facility, while bypassing excess flows from larger events around the facility into a bypass pipe or channel. The bypass typically connects to another Storm Water management facility or to the receiving drainage system, depending on the design and management requirements. This type of inlet control can also serve as the positive overflow for the BMP. Flow splitters can be constructed by installing diversion weirs in Storm Water control structures such as inlets and manholes. On a larger scale, they can be constructed using concrete baffles in manholes. Depending on design intent, the flow splitter can also

function as a pretreatment facility for other BMP's. Pretreatment facilities can provide a greater level of protection for the BMP as well as decreasing short and long term maintenance. An alternative to a diversion weir could be offsetting the outlet pipes to allow flow to the BMP prior to outlet to the structure/bypass.

Design Criteria

There are two basic components involved in the design of flow splitters: the elevation of the bypass structure, which is based on the designed maximum ponding elevation in the BMP, and capacity of the inlet and outlet control structures of the BMP, which control the maximum flow the BMP can receive and discharge.

Bypass Elevation:

The elevation of the bypass baffle or weir dictates the maximum elevation of the water in the BMP or the maximum rate of flow that enters the BMP. The bypass elevation can be selected by setting it equal to the design storage elevation in the BMP or the height of the peak flow rate. Flow will only start to bypass the BMP once it exceeds the design elevation of the bypass structure. The water level in the BMP may exceed the design level for large infrequent storms that utilize the bypass, so the BMP should provide adequate freeboard to prevent overflow.

Pipe Capacity:

The capacity of the influent and effluent pipes can also limit flow into and out of the BMP. Controlling flows in this fashion can help to minimize erosion and scour in the BMP and at the outlet structure. However, minimum pipe diameters required by the design manual should be noted and other structures such as orifices used as appropriate. Adequate bypass capacity should be provided for conveyance of storm flow in excess of BMP design.

CURBLESS INLET TO BIORETENTION – INDIANAPOLIS, IN

Curbless Design

Curbless designs allow Storm Water to flow directly from the impervious source to the BMP. This type of design discourages concentration of flow and reduces the energy of Storm Water entering a management facility. Curbless designs are often used with parking bioretention islands or roadside swales.

Curb Openings

Curb openings provide an alternative inlet control when a curbless design is not possible. Bioretention and landscaped islands in curbed parking lots or roadways often use curb openings as inlet controls. If flow is to be introduced through curb openings, the pavement edge should be slightly higher than the elevation of the vegetated areas. Curb openings should be at least 12 -18 inches wide to prevent clogging (CA Storm Water Manual). Inlet design of the curb openings need to address energy reduction, erosion protection and flow dispersion.

CURB CUT INLET – BURNSVILLE, MN

CURB CUT OUTLET TO FILTER STRIP – RICHMOND VILLAGE SHOPS, RICHMOND, IN

Level Spreaders

Level spreaders are controls that are designed to uniformly distribute concentrated flow into a BMP. There are many types of level spreaders that can be selected based on the peak rate of inflow, the duration of use, and the site conditions. Level spreaders help reduce concentrated flow, thereby reducing energy, erosion and increasing the design life of many Storm Water facilities. All level spreader designs follow the same principles:

- Concentrated flow enters the spreader via pipes, swales, or curb openings.
- The flow is slowed and energy is dissipated.
- The flow is distributed throughout a long linear shallow trench, behind a low berm, through a channel drain or through a perforated pipe.
- Water then flows over the berm or edge of trench/channel drain uniformly along the entire length.

SEQUENTIAL INFILTRATING LEVEL SPREADERS AND FILTER STRIPS – COFFEE CREEK, CHESTERTON, IN

The following considerations are important when designing and constructing level spreaders:

STABILIZED UPSTREAM AND DOWNSTREAM OF LEVEL SPREADER

- It is critical that the edge over which flow is distributed is level. If there are small variations in height on the downstream lip small rivulets will form. Experience suggests that design variations on the downstream side of the discharge can stop water from re-concentrating and potentially causing erosion downstream of the level spreader. Typically the design includes porous media such as a gravel seam around the discharge area on the downstream side.

- The downslope side of the level spreader should be clear of debris. After construction, debris such as soil, wood, and other organic matter might accumulate immediately upstream and/or downstream of the level spreader. This effectively blocks the level spreader's capability to discharge a diffused flow, forcing it to reconcentrate.

- The downstream side of the level spreader should be fully stabilized before the level spreader is activated. If a level spreader is installed above a disturbed area without sufficient established vegetative cover or other adequate ground cover such as construction matting (straw-coconut blanket), erosion rills will quickly form. Even sheet flow can cause significant downstream erosion on disturbed areas.

- Do not construct level spreaders in newly deposited fill without adequate compaction. Undisturbed and/or compacted earth is much more resistant to erosion than fill. Erosion is even likely to occur over a well-established young stand of grass planted on fill.

- Typical level spreaders are not generally designed for large diameter sediment removal facilities and may require pretreatment of flow prior to entering BMP. Significant sediment and debris deposition in the spreader can render it ineffective.

Types of Level Spreaders

Rock lined or vegetated Channel

Rock-lined and vegetated channels function as level spreaders when the lower (downslope) lip of the channel is level. The channel works best when it is placed along an elevation contour. Channel depths and widths vary greatly upon design need. The depth of the channel depends on the flow and pretreatment design considerations. Smaller rock-lined or vegetated channels do not typically serve as detention devices.

Concrete Troughs and Half Pipes

Concrete troughs 4-12 inches deep can be used as level spreaders. Half sections of pipe can also be used for the same function. The depths of the trough or pipe will depend on the flow. Concrete troughs are a more expensive level spreader alternative; however, they are easy to maintain and have a longer design life. If sediment or debris accumulates in the trough or pipe, it can be easily removed. Concrete level spreaders have design lives of up to 20 years while other level spreader designs may be able to effectively function for a period of 5-20 years. Accordingly, long term maintenance and replacement costs should be lower if installed properly.

Treated and Untreated Lumber

Treated and untreated lumber is not allowed as a level spreading device due to issues with deformation and decomposition.

Composite or plastic lumber

Composite and/or plastic lumber can be beneficial components of a level spreader design.

Level Spreader System Configuration

A typical level spreader system consists of pre-treatment (e.g., a forebay), principal treatment (e.g., a level spreader with grassed buffer), and emergency treatment (e.g., a reinforced grassy swale downslope of spreader). A stilling area such as a forebay is particularly useful upstream of a level spreader, because low energy should be dissipated before the flow enters a level spreader. The forebay will periodically fill with sediment, which must be removed.

Energy Dissipaters

Energy dissipaters are typically engineered devices such as rip-rap aprons or concrete baffles designed to reduce the velocity, energy, and turbulence of the flow. Where applicable, more aesthetically available landscape boulders can also be used. These structures can be employed when highly erosive velocities are encountered at the end of culverts or at the bottom of steep slopes where aesthetics are not a concern. A standard reference for design of these structures is U.S. Army Corps of Engineers, Hydraulic Engineering Center Circular 14 (HEC-14).

Riprap Aprons

Riprap aprons are commonly used for energy dissipation, due to their relatively low cost and ease of installation. A flat riprap apron can be used to prevent erosion at the transition from a pipe or box culvert outlet to a natural channel. Riprap aprons will provide adequate protection if there is sufficient length and

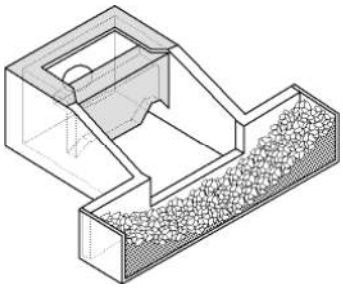
flare to dissipate energy by expanding the flow. City of Indianapolis Transportation and/or Indiana Department of Transportation (INDOT) typical riprap design standards provide a sound approach for riprap apron design.

Riprap Basins

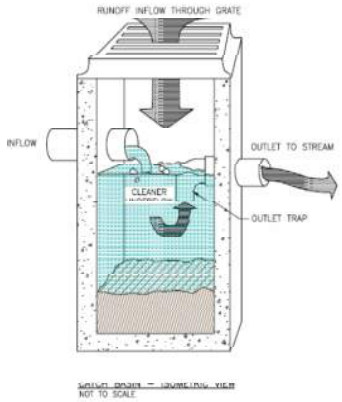
A riprap outlet basin is a pre-shaped scour hole lined with riprap that functions as an energy dissipater. It is recommended that temporary or if necessary permanent upstream sediment pretreatment controls are required to protect the riprap basin.

Baffled Outlets

A baffled outlet is a boxlike structure with a vertical hanging baffle and an end sill. Energy is dissipated primarily through the impact of the water striking the baffle and through the resulting turbulence.



ISOMETRIC VIEW OF BAFFLED OUTLET



Inlets and Catch Basins

Traditional inlets and catch basins, although not recommended, may be used as an inflow device for Storm Water facilities where curb and gutter design is desired or required. The disadvantage of traditional inlets is that the inverts of the outlet pipes are relatively deep, and excavation of Storm Water facilities may need to be deeper than with curb openings or a curbless design. A standard reference for designing traditional drainage systems is U.S. Army Corps of Engineers, Hydraulic Engineering Center Circular 22 (HEC-22). Any inlet or catch basin that connects to a BMP must have at least a one (1) foot sump.

Maintenance Concerns for Inlet Controls

The following maintenance items must be included in the O & M Manual.

Table 4.9.1: Inlet Maintenance Guidelines

Activity	Schedule
Inlet control devices should be inspected after several storms to ensure that they are functioning properly and that there are no erosion or debris problems developing. Source of sediment contamination should be identified and controlled when native soil is exposed or erosion channels are present.	As needed from monthly (minimum) inspection
Inspected for sediment and debris buildup. Sediment buildup exceeding 2 inches in depth or that begins to constrict the flow path should be removed. Clean out leaves, trash, debris, etc.	As needed from monthly (minimum) inspection
Maintain records of all inspections and maintenance activity. Include estimate of sediment and/or debris removed Indicate sediment and/or debris disposal methods	Ongoing, with documentation of each monthly inspection report

Outlet Controls

Risers and Orifices

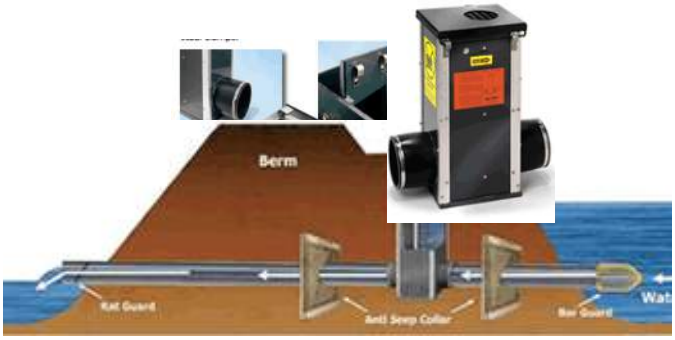
An orifice is a circular or rectangular opening of a prescribed shape and size that allows a controlled rate of outflow when the orifice is submerged. When it is not submerged, the opening acts as a weir. The flow rate depends on the height of the water above the opening and the size and edge treatment of the orifice. A riser is a vertical structure with one or more orifices that provide the controlled release in combination.

Control structures may consist of several orifices and weirs at different elevations to meet Storm Water management requirements. Multiple orifices may be necessary to meet the water quality volume and/or flood protection performance requirements for a detention system. Orifices may be located at the same elevation if necessary to meet performance requirements. Small orifices are sometimes needed when a Storm Water management system must meet low flow rate requirements.

CURB CUT INLET AND OVERFLOW OUTLET, BIORETENTION, INDIANAPOLIS, IN

Protection from Clogging

Protection from clogging is required for any orifice size. Small orifices used for slow release applications can be susceptible to clogging, which prevents the structural control from performing its function and potentially causing adverse impacts. Design measures, e.g. trash racks or screens, can be taken to prevent clogging. These measures are most effective when used in combination with periodic inspection and maintenance. The use of sumped inlets should include a hood on the outlet pipe.



BIORETENTION POSITIVE OVERFLOW OUTLET – DILLON PARK, HAMILTON COUNTY, IN

Positive Overflows

A positive overflow permits Storm Water to flow out of the BMP when the water level reaches a maximum design elevation in a subsurface feature or a maximum ponding depth in a surface feature. Flow through the positive overflow can either connect to another BMP or an approved point of discharge. A multi-stage outlet control may include a number of orifices for controlled flow and a positive overflow to quickly pass flow during extreme events. Overflow structures should be sized to safely convey larger storms from the BMP. If flow reaches the BMP via a flow splitter, this structure can provide the positive overflow.

Underdrains

Underdrains are conduits, such as perforated pipes, horizontal gravel seams, and/or gravel filled trenches that intercept, collect, and convey Storm Water that has percolated through soil, and engineered media, a suitable aggregate, and/or geotextile. Perforated underdrains are an outlet control when the collected water contributes to storm discharges as regulated under the Indianapolis's Storm Water Design and Construction Specifications Manual. Underdrains may be used in combination with other techniques such as bioretention to regulate outflow. Design of underdrains should consider the following criteria based on site specific conditions and the Indianapolis's Storm Water Design and Construction Specifications Manual:

- A permeable filter fabric is placed between the gravel layer and surrounding soil to prevent sediment contamination.

- Clean out access must be provided for all underdrain systems. Clean outs shall be placed, at a minimum, at each underdrain turn fitting.

Impervious Liners

Impervious liners are considered an outlet control because they prevent water from infiltrating and thus crossing a system boundary. Impervious liners may be selected from the following four types: compacted till liners, clay liners, geomembrane liners, and concrete liners. Underdrains can be used in conjunction with impervious liner design as long as the underdrain outlet does not conflict with the impervious liner function.

Permeable Weirs

Permeable weirs are typically constructed from composite or plastic lumber stacked with spaces between each timber to provide long, narrow openings that slowly pass Storm Water. They have the appearance of a wooden fence. Under low flow conditions, water ponds behind the permeable weir and slowly seeps through the openings between the timbers, functioning like a dry extended storage pond. Under high flow conditions, water flows both over and through the weir.

Permeable weirs are generally used in wetland areas, constructed water quality treatment ponds, water quality swales, and/or pretreatment forebays. They promote sedimentation by slowing flow velocities as water ponds behind the weir. They also provide a means of spreading runoff as it is discharged, helping to decrease concentrated flow and reduce velocities as the water travels downstream.

Maintenance Concerns for Outlet Controls

Table 4.9.2: Outlet Maintenance Guidelines		
	Activity	Schedule
	Outlet control devices should be inspected after several storms to ensure that they are functioning properly and that there are no erosion or debris problems developing. Source of sediment contamination should be identified and controlled when native soil is exposed or erosion channels are present.	As needed from monthly (minimum) inspection
	Inspected for sediment and debris buildup. Sediment buildup exceeding 2 inches in depth or that begins to constrict the flow path should be removed. Clean out leaves, trash, debris, etc.	As needed from monthly (minimum) inspection
	Maintain records of all inspections and maintenance activity. • Include estimate of sediment and/or debris removed • Indicate sediment and/or debris disposal methods	Ongoing, with documentation of each monthly inspection report

Note:
Design of inlet and outlet controls are not limited to the examples shown within this text. Successful Storm Water management plans will combine appropriate materials and designs specific to each site.

4.9.1. Inlet and Outlet Controls Designer/Reviewer Checklist

Type of inlet control proposed_____

Type of outlet control proposed _____

Item	Yes	No	N/A	Notes
Rate of inflow/outflow calculated?				
Properly sized for drainage area, flow, pollutant capture?				
Adequate freeboard to prevent overflow?				
Proper bypass elevation?				
Manufacturer's recommendations followed?				
Details provided for device and connections?				
Erosion control provided, if necessary?				
Easy access/visibility for maintenance?				
Orifice protected from clogging?				
Avoidance of Storm Water concentration as much as practical?				
Slope considered and appropriate?				
Receiving vegetation considered?				
Located in undisturbed virgin soil?				
If not, will soil be properly compacted and stabilized?				
Acceptable minimum flow path length below BMP?				
Appropriate vegetation selected for stabilization?				
Feasible construction process and sequence?				
Erosion and sedimentation control provided to protect spreader?				
Maintenance accounted for and plan provided?				
If used during construction, are accumulated soils removed?				

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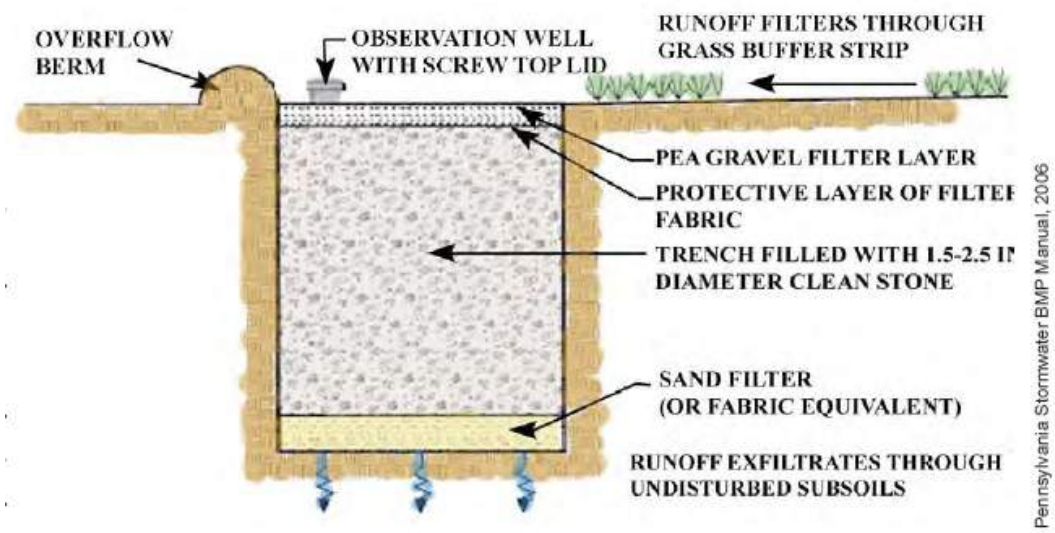
4.10. Filters

Filters are structures or excavated areas containing a layer of sand, compost, organic material, or other filter media. They reduce pollutant levels in Storm Water runoff by filtering sediments, metals, hydrocarbons, and other pollutants. Filtered Storm Water may be infiltrated or released to a sewer or receiving water. Depending on design, the filter media may provide significant detention time or may be combined with an outlet control. Filters are best used in high density urban areas where there is little opportunity of clogging from drainage areas with high pervious cover or high sediment yield sites.

There are three primary types of filters: surface, perimeter and underground filters.

- Surface filters can be an excavated trench or concrete structure.
- Perimeter filters are typically enclosed vaults located along the edge of parking areas.
- Underground filters are primarily used for areas where available space is extremely limited.

When properly designed, constructed and maintained, filters have the ability to remove 80% of the total suspended solids load in urban runoff.



FILTER WITH INFILTRATION

Key elements:

- Acceptable technique on sites where vegetated systems are impractical.
- Surface ponding that drains down in no more than 48 hours.
- Filter medium (typically sand, peat, or a mixture) removes pollutants and provides some travel time. The filter medium shall have a high permeability (fc>0.5in/hr).
- Typically two or more chambers are used in a filter system. The first is the sedimentation chamber or forebay which removes floatables and heavy sediments. The second is the filtration chamber which removes pollutants from the runoff by filtering through the sand bed or other filter media.

- Underdrain allowed on sites where infiltration is infeasible, in Wellfield Protection Areas or where a filter is used in combination with other practices.

- Flow splitter or positive overflow bypasses large storms. Typically an 'off-line' Storm Water quality system. To control flow rate, filters are usually combined with another structural control.

- Maintenance required to maintain capacity of system.

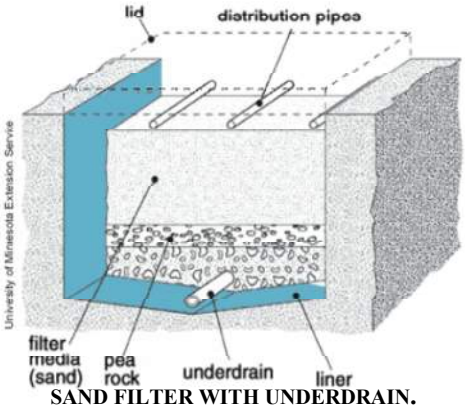
- Observation well is required for visual inspection.

Table 4.10.1: Filters Potential Application and Storm Water Regulation

Potential applications			Storm Water regulations		
				Infiltration	No Infiltration
Residential Subdivision:	Limited		Water Quality Benefit	Yes	Yes
Commercial:	Yes		Volume Reduction	Yes	No
Ultra Urban:	Yes		Attenuation Benefit	Yes	Yes
Industrial:	Yes				
Retrofit:	Yes				
Highway Road:	Yes				

Acceptable forms of pre-treatment

- Filter strips
- Appropriate prefabricated and proprietary designs
- Swales
- Sediment forebays
- Bioretention
- Planter boxes



SAND FILTER WITH UNDERDRAIN.

Storm Water Filters in the Urban Landscape

Storm Water filters are suitable for sites without sufficient surface area available for vegetated bioretention basins. Filters are designed to either infiltrate or to treat and convey runoff to a disposal point. The two biggest differences between a filter and a bioretention basin, as defined in this Manual, are surface vegetation and the use of underground containment structures. Vegetated basins often include a filtering layer that may be designed according to the guidelines in this section. Filters are recommended as a viable Storm Water Quality Practices for use in:

- Parking lots
- Roadways and Highways
- Light Industrial sites
- Transportation facilities
- Fast food and shopping areas
- Waste Transfer Stations
- Urban Streetscapes

STORM WATER FILTER

Filters may be visible from the surface or completely subsurface as shown in the two figures below. They may be designed as a single large chamber or filter bed (often with a

small chamber or forebay for pretreatment) or as a long, narrow underground structure at the perimeter of a parking lot. Larger underground filter structures are used where space is limited and contributing areas are of high density.

Components of a Storm Water Filter System

Storm Water filters can be designed to infiltrate all or some of the flow. Components of Storm Water filter system shall include:

- Excavation or container
- Pretreatment
- Flow entrance/inlet
- Surface storage (ponding area)
- Filter media
- Underdrain, if required
- Positive overflow

VEGETATED FILTER

Excavation or Container

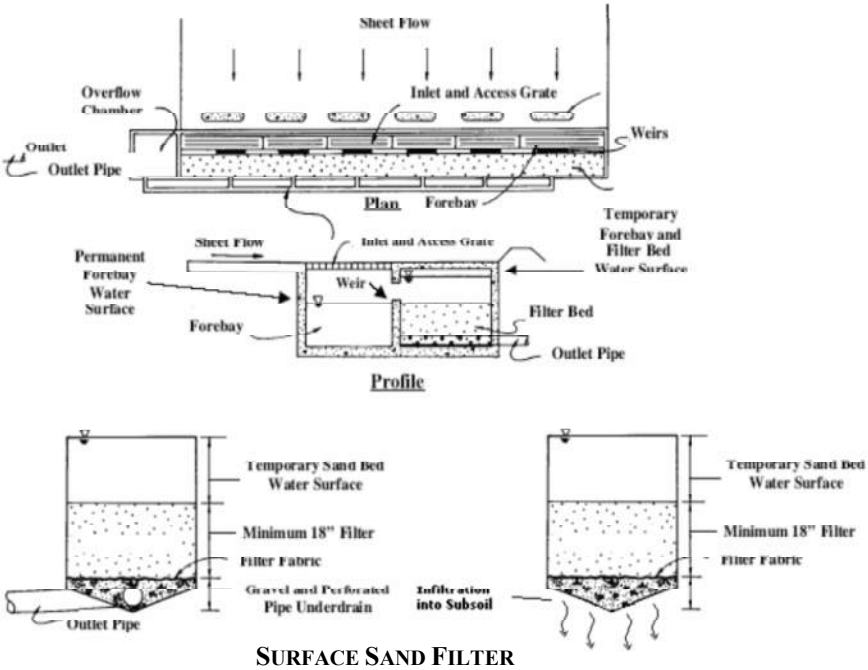
The filer media may be contained in a simple trench lined with a geotextile, or it may be contained in a more structural facility such as concrete. In either case, the container may be designed either to allow infiltration or to collect flow in an underdrain system.

Pretreatment

A chamber or forebay may be installed for pretreatment, including the removal of coarse particles and trash.

Flow Entrance/Inlet

Flow may be introduced to a filter through any of the controls discussed in the Inlet and Outlet Controls Fact Sheet (Chapter4.9). If Storm Water does not enter as sheet flow, a flow spreader is required.



SURFACE SAND FILTER

Surface Storage (ponding area)
The filter allows water to pond during intense storms as water flows slowly through the filter media.

Filter Media
Storm Water flows onto filter media where sediments and other pollutants are separated from the Storm Water. Filter materials such as sand, peat, granular activated carbon (GAC), leaf compost, pea gravel and others are used for water quality treatment. Coarser materials allow faster transmission, but finer media filters particles of a smaller size. Sand has been found to be a good balance between these two criteria (Urbonas, 1999), but different types of media remove different pollutants. While sand is a reliable material to remove TSS, (Debusk and Langston, 1997) peat removes slightly more TP, Cu, Cd, and Ni than sand. Depending on the characteristics of the Storm Water runoff, a combination of these filter materials will provide the best quality results. In addition to determining the degree of filtration, media particle size determines travel time in the filter and plays a role in meeting release rate requirements.

Underdrain (if required)
Infiltration is required where feasible unless the filter is combined with another facility that provides infiltration. Filters that do not infiltrate collect water through an underdrain system. Systems that utilize infiltration must have a soil investigation performed by a geotechnical engineer or soil scientist. The investigation must include documentation of the seasonal high water table and infiltration rate.

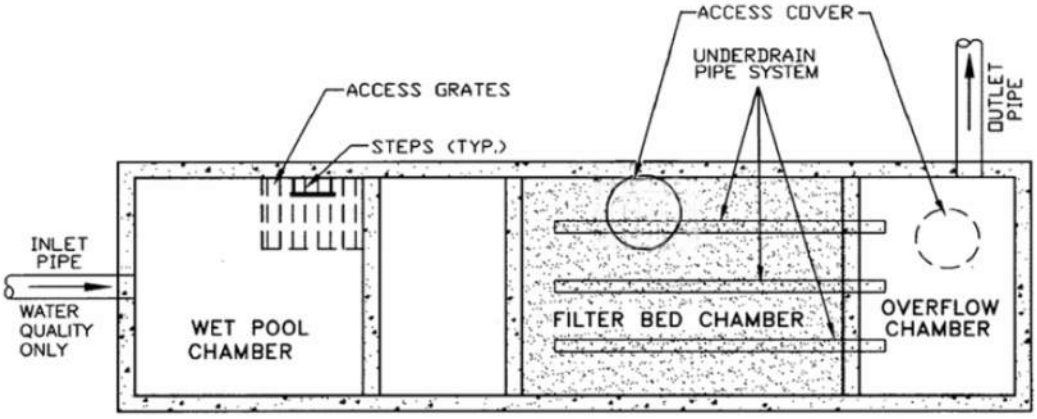
Positive Overflow
Filters must be designed to allow overflow or bypass of larger storm volumes. Flow splitters, diversion chambers, or proprietary devices can be used to divert a portion of flow to a filter in an off-line design. A design that is considered on-line allows water to flow across the surface of the filter before being discharged over a weir or other control.

Recommended Design Procedures
- Determine the Water Quality and Quantity requirements for the site. See the City of Indianapolis Storm Water Design and Construction Specifications Manual.

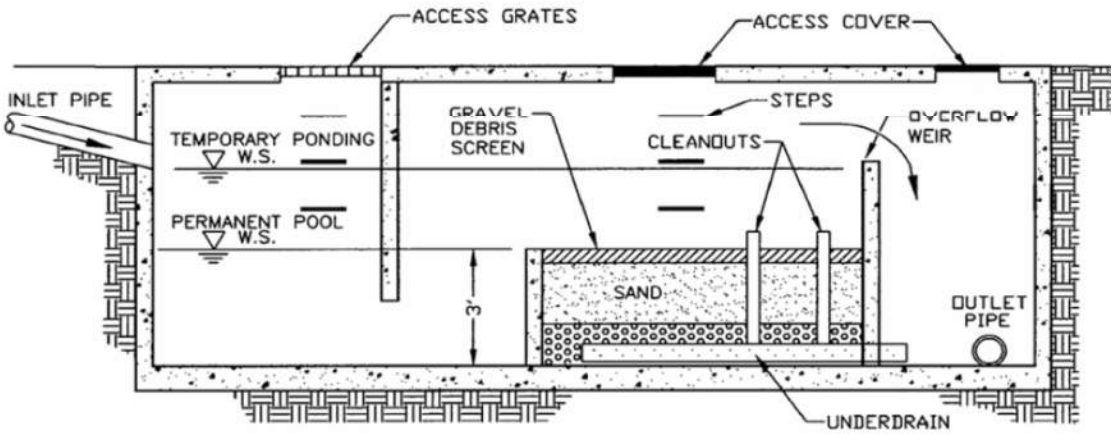
- Create a Conceptual Site Plan for the entire site and determine what portion of the Storm Water control requirements the filters will meet. See the City of Indianapolis Storm Water Design and Construction Specifications Manual.

- Investigate the feasibility of infiltration in the area proposed for the Storm Water filter. If infiltration is feasible, determine the saturated vertical infiltration rate. Design proceeds differently depending on the feasibility of infiltration. Refer to **Attachment 1, Guidelines for Infiltration Testing**.

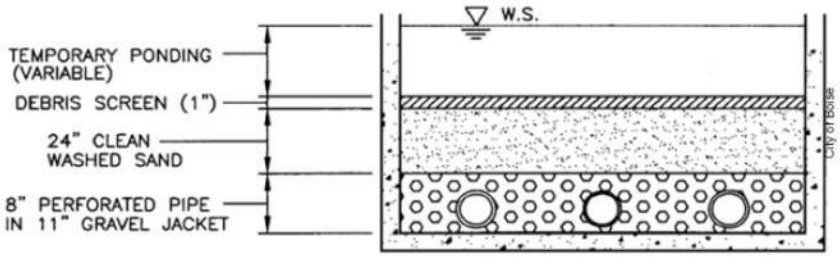
- Create a conceptual design for the Storm Water filter.



PLAN VIEW



PROFILE



• The filter area may be estimated initially using Darcy's Law, assuming the soil media is saturated.
Af = (V x d) / [k x t (h + d)]
Af = Surface area of filter bed (square feet)
V = Volume to be managed, i.e. water quality volume (cubic feet)
d = Depth of filter media (feet)
t = Filter bed drain time (days)
h = Head (average in feet)
k = Saturated hydraulic conductivity of filter media (feet/day)
k Design values: sand = 3.5 feet/day; peat = 2.5 feet/day; leaf compost = 8.7 feet/day

- For filters designed for infiltration, estimate the total storage volume and adjust area and/or depths as needed to provide required storage.

Table 4.10.2: Suggested Starting Design Values for Ponding and Media Depths	
Average Ponding Depth	3-6 inches
Filter Media Depth	18 - 30 inches

- Using Storm Water filter area and the saturated vertical infiltration rate of the filter media, estimate the drainage time for ponded surface water. The saturated vertical infiltration rate may be based on the estimated saturated hydraulic conductivity of the proposed filter materials. The maximum drain down time for the entire storage volume is 72 hours, but a surface drain down time of 24-48 hours is recommended. If storage does not drain in the time allowed, adjust pretreatment depth, filter media depth, and surface area. Adjust the design until the volume and drainage time constraints are met.
- Design underdrains to minimize the chances of clogging. Pea gravel filters can be used for this purpose. Pea gravel filters should include at least 3 inches of gravel under the pipe and 6 inches above the pipe.
    - Consider an underdrain only under one of the following conditions:
        - in areas with separate storm sewers or direct discharge to receiving waters where infiltration is infeasible and the filter system is needed only to provide water quality treatment;
        - in areas located within a Wellfield Protection District;
        - in areas with combined sewers where sufficient detention or travel time can be designed into the system to meet release rate requirements; or
        - in combination with other BMPs where the system as a whole meets storage and release criteria.
- Design any structural components required.
- Complete construction plans and specifications.

Materials

All material specification should be included on the plans.

Stone Storage (if used)

- Stone used to provide additional storage shall be uniformly-graded, crushed, washed stone meeting the specifications of AASHTO No. 3 or AASHTO No. 5.

- Stone shall be separated from filter medium by a non-woven filter fabric or a pea gravel filter.

Filter Media

- Peat shall have ash content <15%, pH range 3.3-5.2, loose bulk density range 0.12-0.14 g/cc.

- Sand shall be clean, medium to fine sand, and have organic material meeting specifications of AASHTO M-6 (0.02” - 0.04”) or ASTM-C-33.

- Prefabricated filter media shall meet filter design and water quality specifications.

Piping

- Pipe shall have continuous perforations, smooth interior, and minimum diameter of 6 inches. High density polyethylene (HDPE) pipe shall meet specifications of AASHTO M252, Type S or AASHTO M294, Type S.

Construction Guidelines

- Areas for Storm Water filters shall be clearly marked before any site work begins to avoid soil disturbance and compaction during construction.

- Permanent filters should not be installed until site is stabilized. Excessive sediment generated during construction can clog filter and prevent its function prior to post-construction benefits.

- Structures such as inlet boxes, reinforced concrete boxes, inlet controls, and outlet structures should be constructed in accordance with manufacturer's guidelines or Engineer's guidance.

- Excavated filters or structural filters that infiltrate should be excavated in such a manner as to avoid compaction of the sub-base. Structures should be set on a layer of clean, lightly compacted gravel specified as AASHTO No. 57.

- A layer of permeable non-woven geotextile should underlie infiltration filters.

- Place underlying gravel/stone in minimum 6 inch lifts and lightly compact. Place underdrain pipes in gravel during placement (if applicable).

- Wrap and secure non-woven geotextile to prevent gravel/stone from clogging with sediments.

Maintenance Guidelines

For filters located entirely underground, unobstructed access for must be provided over the entire sand filter, including inlet and outlet pipe structures, by either doors or removable panels. Ladder access is required for vault heights greater than 4 feet. The O & M Manual should also note when entrance into the filter is considered as an OSHA confined space.

The following table provides items that must be included in the O & M Manual.

Table 4.10.3: Filter Maintenance Guidelines

Activity	Schedule
Rake filter media surface for the removal of trash and debris from control openings. Repair of leaks from the sedimentation chamber or deterioration of structural components.	As needed
Inspect filter for standing water (filter drainage is not optimal) and discoloration (organics or debris have clogged filter surface).	Quarterly
Removal of the top few inches of filter media and cultivation of the surface when filter bed is clogged. Clean out accumulated sediment from filter bed chamber. Clean out accumulated sediment from sedimentation chamber.	Annually
Maintain records of all inspections and maintenance activity.	Ongoing

In areas where the potential exists for the discharge and accumulation of toxic pollutants (such as metals), filter media removed from filters must be handled and disposed of in accordance with all State and Federal Regulations.

Winter concerns

Indiana's low temperature dips below freezing for about four months out of every year, and surface filtration may not take place as well in the winter. Peat and compost may hold water, freeze, and become impervious on the surface. Design options that allow direct sub-surface discharge into the filter media during cold weather may help overcome this condition.

Siting constraints:

For a surface filter that infiltrates into the existing soil, the minimum distance between the bottom of the filter and the elevation of the seasonally high water table is 2 feet.

To protect the aquifer, infiltration shall not be used on hotspot sites or within well field protection areas.

Note:

Design of Storm Water filters are not limited to the examples shown within this text. Successful Storm Water management plans will combine appropriate materials and designs specific to each site.

4.10.1. Filter Designer/Reviewer Checklist

Item	Yes	No	N/A	Notes
Adequate depth of filter media?				
Acceptable drawdown time (72 hour max.)?				
Pretreatment provided?				
Adequate hydraulic head available for filter to operate?				
Flow bypass and/or overflow provided?				
Permeability of filter media acceptable?				
Hotspots/pretreatment considered?				
Underdrain provided for non infiltration systems?				
Appropriate placement of nonwoven filter fabric?				
Gravel layer provided beneath filter media?				
Non-erosive inflow condition?				
Adequate surface area provided?				
Construction timing places installation after site stabilization?				
Erosion control provided during construction?				
Cleanouts included?				
Maintenance accounted for and plan provided?				

Other O & M Manual Requirements

See Section 702.04 (Figure 702-17) for other O&M Manual requirements.

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4.11. Subsurface Vaults

Subsurface Vaults are specialized underground structures designed similarly as above ground detention or retention basins. These underground basins can be utilized for groundwater recharge by allowing infiltration. They are usually constructed of either concrete or plastic and must account for the potential loading from the expected bearing weight from the intended land use above them. Subsurface vaults are used commonly for Storm Water storage for small parcels where it is infeasible to have adequate surface storage via an open basin. It is also very common to design such facilities for various vehicle loadings as parking lots or for recreational surfaces, such as tennis and basketball courts. Water quality structures are required to treat Storm Water runoff and remove debris before filling a subsurface vault. Subsurface vaults are typically dry systems, primarily used for Storm Water quantity control. Less common are wet water quality systems designed to maintain a permanent pool to dissipate energy and settle particulate Storm Water pollutants. The City of Indianapolis does not allow for subsurface quantity control vaults to act as water quality control treatment facilities, therefore wet systems are typically not utilized locally.

Key elements:

- Effective for urban areas with high valued land and limited space.
- Equally effective in areas of combined sewer and separate storm sewers areas.
- Provides peak rate control.
- Pretreatment water quality facilities are required before Storm Water can discharge into subsurface vaults.
- Weight bearing loading capabilities for anticipated land use above vault.
- Maintenance required periodically to remove sediment and debris.

STORMTRAP® SUBSURFACE VAULT WITH INFILTRATION, GARY, IN

Table 4.11.1: Subsurface Vaults Potential Application and Storm Water Regulation

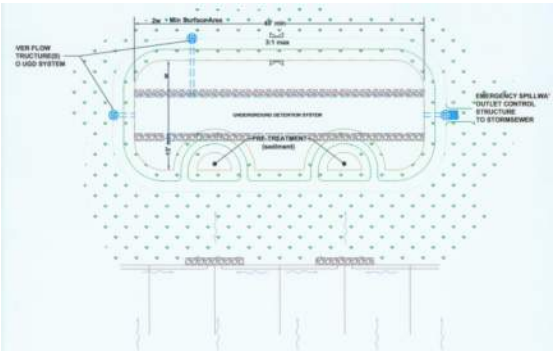
Potential applications			Storm Water regulations		
				Infiltration	No Infiltration
Residential Subdivision:	Yes		Water Quality Benefit	Yes	No
Commercial:	Yes		Volume Reduction	Yes	Yes
Ultra Urban:	Yes		Attenuation Benefit	Yes	Yes
Industrial:	Yes				
Retrofit:	Yes				
Highway Road:	Yes				

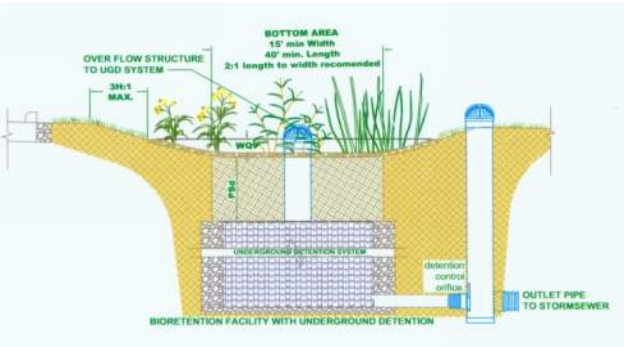
Acceptable forms of pre-treatment

- Sediment chamber or wet subsurface vault
- Sediment forebay (rain gardens, bioretention, open basin, etc.)
- Appropriate prefabricated mechanical and propriety designs. Some systems, e.g. StormTech may require the use of an SQU or other pretreatment prior to the system.

Subsurface Vaults in the Urban Landscape

Subsurface vault systems are suitable for projects where space is limited and other Storm Water management systems are not feasible. Subsurface vaults may be used for commercial, industrial, or roadway projects. The presence of a subsurface vault in most cases does not alter the intended land use at the surface. The subsurface vault must meet structural requirements for overburden support and land use loading to be applicable in urban settings. Some applications of subsurface vaults are provided; however, examples are not limited to this list.





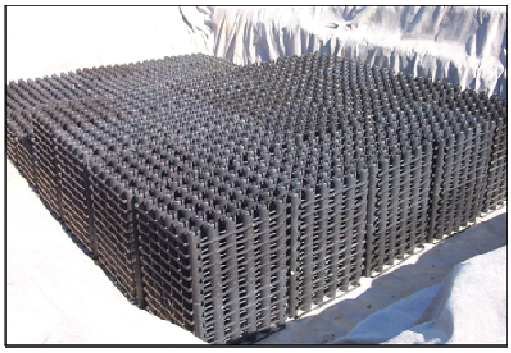
BIORETENTION USED FOR PRETREATMENT, WATER QUALITY VOLUME AND INLET CONTROL PRIOR TO INFILTRATIVE SUBSURFACE VAULT DETENTION - ZIONSVILLE, IN

Components of a Subsurface Vault

Subsurface vault systems contain a combination of the following components:

Pretreatment

Pretreatment can include a forebay/grit chamber, subsurface wet vault, or water quality treatment structure (SQU). Pretreatment is required to also include features to trap floatables and where land use dictates an oil/water separator. Baffles or walls within the subsurface vault separate the entire volume into multiple chambers. Storage volume present in a pretreatment structure may be considered part of the total design storage volume required.



INVISIBLE STRUCTURES® INFILTRATION FEATURE – PORTER COUNTY JAIL, VALPARAISO, IN

Inlet Control

The inlet control of a subsurface vault should be connected to the Storm Water water quality pretreatment facilities. The subsurface vault should be sized according to the area entering into the system. Parking lots, roadways, and large rooftop areas are typically the drainage areas contributing to the subsurface vault system. The inlet control may include a flow splitter to regulate the rate and volume of water entering the vault.

Storage Structure

Storage often provided by a concrete structure, a large pipe, or a group of pipes.

Infiltration Feature

Infiltration is typically not a major function of a subsurface vault; however, some designs may allow it. The designer must consider soil conditions and maximize the ratio of infiltration area to drainage area. Guidelines for infiltration practices are outlined in **Attachment 1**. Infiltration must be verified through field investigation by a geotechnical engineer or certified soil scientist. The seasonal high water table and infiltration rate must also be included in the investigation and documented.

Permanent Pool

A permanent pool of water may be incorporated to dissipate energy. When a permanent pool is incorporated in a design, the design may be referred to as a "wet vault". This design provides a benefit similar to that of a surface wet pond. Wet subsurface vaults cannot be used for water quality treatment and the permanent pool area cannot be utilized for Storm Water quantity control.

CONTECH® SUBSURFACE VAULT, FEDERAL EXPRESS ® FACILITY – INDIANAPOLIS AIRPORT

Slow Release Structure

The slow release structure regulates the rate of outflow for storms up to the design capacity. The storage volume and slow release together allow a subsurface vault to meet channel protection and peak release rate criteria.

Overflow Structure

An overflow structure allows storms in excess of the design storm to pass through the structure without being detained. An overflow structure at the outlet, a flow splitter at the inlet, or a combination may be used to safely convey large storms.

Access Feature

This feature is used for maintenance and inspection purposes and most commonly consists of a panel or manhole entry port leading to the storage area.

Recommended Design Procedure

- Determine the water quality/recharge, stream bank protection, and peak rate control requirements for the site.
- Create a Conceptual Site Plan for the entire site, and determine what portion of the sizing requirements the subsurface vault will meet.
- Create a conceptual design for the subsurface vault, including enough volume to meet storage requirements.
- Estimate the total storage volume and adjust facility sizing as needed to provide required storage. Any permanent pool areas should not be included in the storage volume estimation.
- Choose and design pretreatment as appropriate. The pretreatment volume is part of the total volume. An oil/water separator should be considered to treat incoming flow from industrial sites or parking lots.
- Decide whether to design for infiltration. The procedure followed and requirements are similar to that for bioretention or infiltration basin design.
- Design the release structure to comply with site release rate requirements.

- Design a positive overflow or bypass system for large storms. The outlet structure and design head should provide adequate flow to avoid overtopping the vault.

- Design adequate maintenance access for each vault to connect to ground level.

- Complete construction plans and specifications. At a minimum, plans should include plan view, cross sections, and inlet and outlet details.

CONTECH® SUBSURFACE VAULT – KMART, BLOOMINGTON, IN

STORMTRAP® SUBSURFACE VAULT - MUNICIPAL BUILDING, LEBANON, IN

Maintenance Guidelines

The systems must be designed so that the vault can have easy access for inspection and maintenance. Subsurface vaults can be considered confined spaces. All maintenance procedures must comply with all local, state and federal requirements.

Table 4.11.2: Subsurface Vaults Maintenance Guidelines

Activity	Schedule
Removal of sediment and debris from subsurface vault chamber(s) when the sediment zone is full. Sediments should be tested for toxicants in compliance with current disposal requirements if land uses in the catchments include commercial or industrial zones, or if indications of pollution are noticed.	As needed
Inspection of subsurface vault and control structures. Floating debris and accumulated petroleum products should be removed.	Quarterly
Maintain records of all inspections and maintenance activity	Ongoing

Note:

The designs of subsurface vaults are not limited to the examples shown within this text. Successful Storm Water management plans will combine appropriate materials and Storm Water quantity and quality designs specific to each site.

4.11.1. Subsurface Vault Designer/Reviewer Checklist

Item	Yes	No	N/A	Notes
Level infiltration area (e.g., trench bottom, bed bottom)?				
Excavation in infiltration area minimized?				
Hotspots/pretreatment considered?				
Feasible construction process and sequence?				
Geotextile specified?				
Pretreatment provided?				
Slow release structure used?				
Appropriate pipe, if applicable?				
Storage requirements met?				
Observation well/clean out provided, if applicable?				
Maintenance accounted for and plan provided?				

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4.12. Detention Basins

Detention Basins can be a cost effective method to provide temporary storage, conveyance, and treatment of runoff when used within the context of Low Impact Development (LID) strategies. Long, linear, interconnected basins can provide the designer with an economically attractive method to provide source control of Storm Water as well as convey water without the slope and cover requirements of conventional storm sewer design. This allows for the drainage of the proposed development to more closely mimic existing conditions, minimizing earth work and the ecological impact to downstream receiving bodies. Further, the associated open vegetated aesthetics can provide for passive recreation, quality of life, and increase property values.

LONG, LINEAR, INTERCONNECTED BASIN

Detention basins provide storage on the surface or subsurface either by impoundment within a natural depression, or in an excavated area. Traditional detention basins function primarily to provide water quantity control. The designer should note that detention basins can also be configured to provide water quality treatment. These designs should incorporate methods that remove target pollutants. More information on incorporating methods and designs for water quality must be designed within parameters required by the Storm Water Design and Construction Specifications Manual.

Key elements:

- Most basins are designed to provide channel protection and flood control only.
- Pretreatment, such as rain gardens or wetland entrainment facilities can help decrease maintenance.
- Over-excavation in anticipation of sediment accrual can prolong the design life of the basin.
- Vegetation stabilizes the soil in the basin.
- Outlet structure design is critical and determines how the basin meets Storm Water control requirements.

Table 4.12.1: Detention Basins Potential Application and Storm Water Regulation

Potential applications			Storm Water regulations		
				Infiltration	No Infiltration
Residential Subdivision:	Yes		Water Quality Benefit	Yes	Yes
Commercial:	Yes		Volume Reduction	Yes	No
Ultra Urban:	Limited		Attenuation Benefit	Yes	Yes
Industrial:	Yes				
Retrofit:	Yes				
Highway Road:	Yes				

Acceptable forms of pre-treatment

- Sediment forebays
- Filter strips
- Vegetated swales
- Bioretention gardens
- Wetlands
- General Disconnection of impervious areas from detention facilities

Detention Basins in the Urban Landscape

Detention basins are suitable for large developments and high-density commercial projects. They can often be designed for use between storm events, creating an open space available for recreational purposes.

Components of a Detention Basin

Detention basins are typically comprised of the following components:

- Pretreatment
- Vegetation
- Micropool
- Outflow structure

SEDIMENT FOREBAY

Sediment Forebay (Pretreatment)

Supplementing a dry pond design with a sediment forebay is required to increase the treatment efficiency. The sediment forebay improves pollutant reduction by trapping larger particles near the inlet of the pond. The forebay should include a permanent pool to minimize the potential for scour and re-suspension. Sediment forebays should be designed with ease of maintenance. Forebays must be accessible to heavy machinery. Those constructed with a bottom made of concrete or other solid material make sediment removal easier and more accessible by heavy machinery.

Keeping Storm Water out of a pipe and within a minimally sloped, vegetated landscape in advance of a detention basin can be considered another source control to provide pre-treatment. If no pretreatment is proposed, then the entire Detention Basin can be viewed as the forebay. The design volume of the Basin should reflect a summation of volume necessary for attenuation requirements as well as the accumulation of sediment over a prescribed design life such as 50 or 100 years. Sediment accrual rates based upon land use and / or soil type are available and should be referenced in the design.

Vegetation

Surface vegetation in the basin provides erosion control, sediment entrapment, aesthetic value, and acts as a water fowl (Canadian Geese) deterrent. The images below demonstrate a traditional detention pond planted with turf grass, which does not provide the above items, and a detention pond edge planted with native forbes and grasses. Side slopes, berms, and basin surface should be planted with species concurrent with expected hydrologic conditions. Appropriate species can be found in Chapter 5: Storm Water Landscape Guidance.

WET AND/OR DRY POND EDGE OPTIONS- CONVENTIONAL TURF EDGE

WET AND/OR DRY POND EDGE OPTIONS- NATIVE FORB AND GRASS EDGE

Micropool at the Outlet (Optional)

Applying a micropool design to a detention basin can increase water quality performance. The micropool is typically shallow and permanently inundated. Its function is to reduce re-suspension and to guard against vegetation encroachments toward the outlet. The micropool can be planted with wetland vegetation species but should be deep enough at the outlet pipe to discourage vegetative encroachments that could encourage clogging over the design life. Refer to Chapter 5: Storm Water Landscape Guidance.

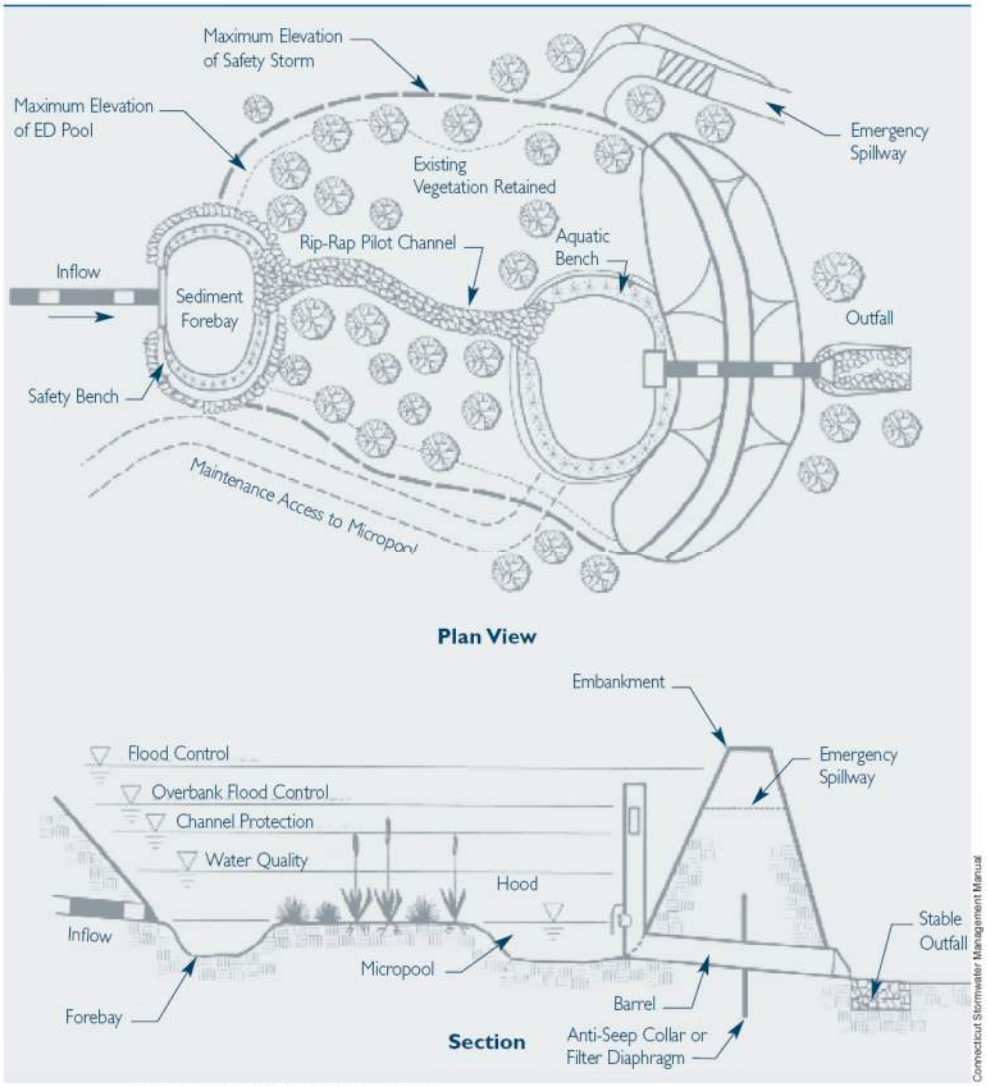
Pennsylvania Stormwater BMP Manual

Athletic field to be used as a detention basin

Outflow Structure

The outlet structure determines the performance of the basin. By installing a multi-stage outlet, the basin can be designed to meet both Water Quality and Flood Control requirements.

A gate valve or orifice plate may be used to regulate the drawdown time. In general, the outflow structure should have an acceptable means of preventing clogging, i.e. trash rack or screen, at the entrance to the structure over the design life to minimize maintenance requirements. The design must be designed within parameters required by the Storm Water Design and Construction Specifications Manual.



Extended detention basin schematic

Recommended Design Procedure

- Determine the Storm Water management requirements for the site within parameters required by the Storm Water Design and Construction Specifications Manual.

- Create a Conceptual Site Plan for the entire site and determine what portion of the control requirements the detention basin will meet.

- Consider a dry extended detention basin to provide water quality treatment if infiltration is infeasible on the site. Organic soil amendments may be utilized above proposed underdrain systems in order to simulate infiltration to remove dissolved metals and *E. coli*.

- Detention basins should be considered in existing low areas so that the facility can be constructed with low impact and minimal earth work.
- Extended detention basins should not be considered within USACE or IDNR jurisdictional waters, unless the applicable permit is first obtained.

- Create a conceptual design for the basin. Estimate required basin size according to design parameters as well as approved calculation method required by the Storm Water Design and Construction Specifications Manual.

Table 4.12.2: Starting Design Parameters for Detention Basins	
Detention time for water quality volume	Designer should reference the Storm Water Design and Construction Specifications Manual.
Water depth	Designer should reference the Storm Water Design and Construction Specifications Manual.
Width	depends on design
Shape	Design basin to maximize length of Storm Water flow pathways, and to minimize short-circuiting from inlet to outlet

- Design an outlet structure (or multiple structures) that provides the level of control required. (A multistage outlet structure will generally reduce the necessary size of the facility)

- Energy dissipaters are to be placed at the end of the primary inlets to discourage erosion.

- If the basin discharges to a channel with dry weather flow care shall be taken to minimize tree clearing along the downstream channel, and to reestablish a forested riparian zone between the outlet and natural channel.

- The hydraulic design of all outlet structures must consider any tailwater effects of downstream waterways within parameters required by the Storm Water Design and Construction Specifications Manual.

- The primary and low flow outlet shall be protected from clogging by an acceptable means.

- On sites that have the potential for accidental spills, the outflow structure should be fitted with a valve so that discharge from the basin can be halted. This same valve also can be used to regulate the rate of discharge from the basin.

- Emergency overflow design should agree with design criteria within parameters required by the Storm Water Design and Construction Specifications Manual.

- Determine the final contours of the basin.

Table 4.12.3: Contour Design Parameters for Detention Basins	
Lowest basin elevation	2 feet above seasonal high water table (Minimum) if infiltration is accounted for in hydraulic calculations.
Basin shape	Irregularly shaped to lengthen effective flow path and provide natural appearance
Low flow channels	may be used to discourage severe ponding due to native soils if necessary Always vegetate with a maximum slope of 3% to encourage sedimentation Consider other BMPs such as wet ponds, constructed wetlands or bioretention
Vegetated embankments	Less than or equal to 3 feet in height (Recommended) 20 feet in height (Maximum)* Maximum slope 3:1 (Horizontal to vertical)
Basin freeboard	Minimum 1 foot above the 100-yr design storm
* 20 feet or higher or that which will impound more that 100 acre-feet of runoff or drain more than 1 square mile will be regulated as dams by IDNR. Consult - IC 14-27-7.5 for further detail.	

- Design an inlet control so that inflow energies can be dissipated. If specified, the sediment forebay volume may be considered to meet a portion of the water quality volume if non-turbulent conditions are expected to dominate during inflows.

Table 4.12.4: Inlet Control and Sediment Forebay	
Forebay length	10 percent of projected flow path (Minimum)
Storage	Designed to trap sediment over a period of 2 to 10 years

- Verify that the basin meets all control requirements concurrently as designed.

- Choose appropriate vegetation using the guidelines in Chapter 5: Storm Water Landscape Guidance. Fertilizers containing phosphorus shall not be used. The use of pesticides is discouraged.

- Complete construction plans and specifications.

Materials

Basin Soil

- A minimum of 6 inches of planting soil is recommended. Soil shall be a high-quality topsoil with a loam or sandy loam texture. The use of 30% organic content by volume is recommended for dry basins that discharge to waterways listed on the IDEM 303(d) for dissolved metals or fecal coliforms.

- Clay cores may be necessary in basins designed to withstand excessive pressures and seepage forces.

Plants

- It is critical that plant materials are appropriate for soil, hydrologic, light, and other site conditions. Select plants from Chapter 5: Storm Water Landscape Guidance.

- Trees and shrubs shall be freshly dug and grown in accordance with good nursery practice.

- Perennials, grass-like plants, and groundcover plants shall be healthy, well-rooted specimens.

- Plantings shall be designed to minimize the need for mowing, pruning, and irrigation.

Construction Guidelines

- Install all temporary erosion and sedimentation controls. The area immediately adjacent to the basin must be stabilized in accordance with IDEM Rule 5 during construction activities and Rule 13 at the cessation of construction activities.

- Prepare site for excavation and/or embankment construction.

- All existing vegetation should be left in place if feasible, and shall only be removed if necessary for construction.

- Care should be taken to prevent compaction of the basin bottom.

- If excavation is required, clear the area to be excavated of all vegetation.

- Excavate bottom of basin to desired elevation (if necessary).

- Install surrounding embankments and inlet and outlet control structures.

- Grade subsoil in bottom of basin, taking care to prevent compaction. Compact surrounding embankment areas and around inlet and outlet structures.

- Apply and grade planting soil.

- Apply geotextile and other erosion-control measures.

- Seed, plant, and mulch according to Planting Plan.

Maintenance Guidelines

- Properly designed Detention Basins should require little to no maintenance throughout the design life. However, maintenance is expected for the proper operation of detention basins. Plans for detention basins should identify owners, parties responsible for maintenance, and an inspection and maintenance schedule for extended storage detention basins.

Table 4.12.5: Detention Basin Maintenance Guidelines	
Activity	Schedule
Remove trash and debris Remove invasive plants. Grassed areas may require periodic prudent fertilizing, dethatching and soil conditioning. Trees, shrubs, and other vegetative cover may require periodic maintenance such as fertilizing, pruning, and pest control. Mow/trim detention basin vegetation if desired.	As needed
Sediment should be removed from the basin at such time as the sediment accrues to an extent such that the Basin loses design attenuation capacity.	As needed
Inspect outlet control structure	Quarterly and after every storm greater than 1 inch
Inspect detention basin for potential problems including: subsidence, erosion, cracking or tree growth on the embankment; damage to the emergency spillway; sediment accumulation around the outlet; inadequacy of the inlet/outlet channel erosion control measures; changes in the condition of the pilot channel; and erosion within the basin and banks.	Annually
Maintain records of all inspections and maintenance activity.	Throughout the design life
*The frequency of sediment removal depends on the design, which should account for site conditions such as soil type, impervious percentage, and drainage area, all of which influence the sediment load on the basin.	

- In most cases, no specific limitations have been placed on disposal of sediments removed from detention basins. Studies to date indicate that pond sediments are likely to meet toxicity limits and can be safely landfilled. On-site sediment disposal is always preferable as long as the sediments are deposited away from the shoreline to prevent their re-entry into the pond and away from recreation areas where people could inhale resulting dust. Sediment disposal should be included in the Operations and Maintenance (O & M) Plan and will be evaluated on a site by site basis. Designers are encouraged to plan for long-term sediment-accumulation within detention basins, which is more economical, and environmentally preferable to dredging and disposing of sediments.

- Sediments should be tested for toxicants in compliance with current disposal requirements if land uses in the drainage area include commercial or industrial zones, or if visual or olfactory indications of pollution are noticed.

4.12.1. Detention Basin Designer/Reviewer Checklist

Item	Yes	No	N/A	Notes
Pretreatment considered?				
Forebay provided?				
Minimum depths of 10 feet for wet ponds used?				
Appropriate inlet and outlet structures?				
Outlets protected from clogging?				
Trash rack provided to prevent clogging?				
Lowest base elevation above seasonal water table?				
Feasible construction process and sequence?				
Bank vegetation requirements met?				
Appropriate plant species indicated?				
Bank slope requirements met?				
Soil requirements met?				
Storage requirements met?				
Maintenance accounted for and plan provided?				

Other O & M Manual Requirements

See Section 702.01 of the Storm Water Design and Construction Specifications Manual.

5. Storm Water Landscape Guidance

Landscaping is a critical element to improve both the function and appearance of Storm Water management practices. Integrated Storm Water landscapes can provide many benefits such as construction cost savings, reduced maintenance, aesthetic enhancement, and the improved long-term functionality. A well-designed and established landscape will also prevent post-construction soil erosion. Additionally, these approaches can help mitigate urban heat island effects, improve air quality, and reduce atmospheric carbon levels. These benefits only exist if the right tree and plant are selected for the right place and properly maintained.

Vegetated Storm Water management systems are a preferred practice. Storm Water management practices can be integrated within planned landscape areas, with minor modifications to conventional landscape design. It is essential that impervious surfaces be graded toward the vegetated areas that are used as the Storm Water management facility and that these facilities are depressed to allow for flow and/or surface ponding. Guidance for the design of inlets to vegetated Storm Water management practices can be found in Section 4.9: Inlet and Outlet Controls. Since these design approaches are still new to many construction contractors it is advisable to clearly show these details in cross section and plan view drawings.

This section provides landscaping and plant selection guidance for effective Storm Water management and is organized as follows: Section 5.1: Planting Guidance contains general guidance that should be considered when landscaping any Storm Water management practice. Section 5.2: Storm Water management Specific Landscaping Requirements includes specific planting and site preparation information for selected design. Section 5.3: Native and Recommended Non-invasive Plant lists appropriate plants for use in Storm Water management practices in the Midwest. Table 5.3.2 provides a comprehensive list of plants that was reviewed and revised by two local native plant nurseries. Key information useful for the selection of plant material for Storm Water landscaping is presented, including National Wetland Indicator Status, preferred hydrologic zones, and aesthetic considerations.

5.1. Planting Recommendations / Guidelines

General guidance for all Storm Water management plantings:

Planting selection and arrangement

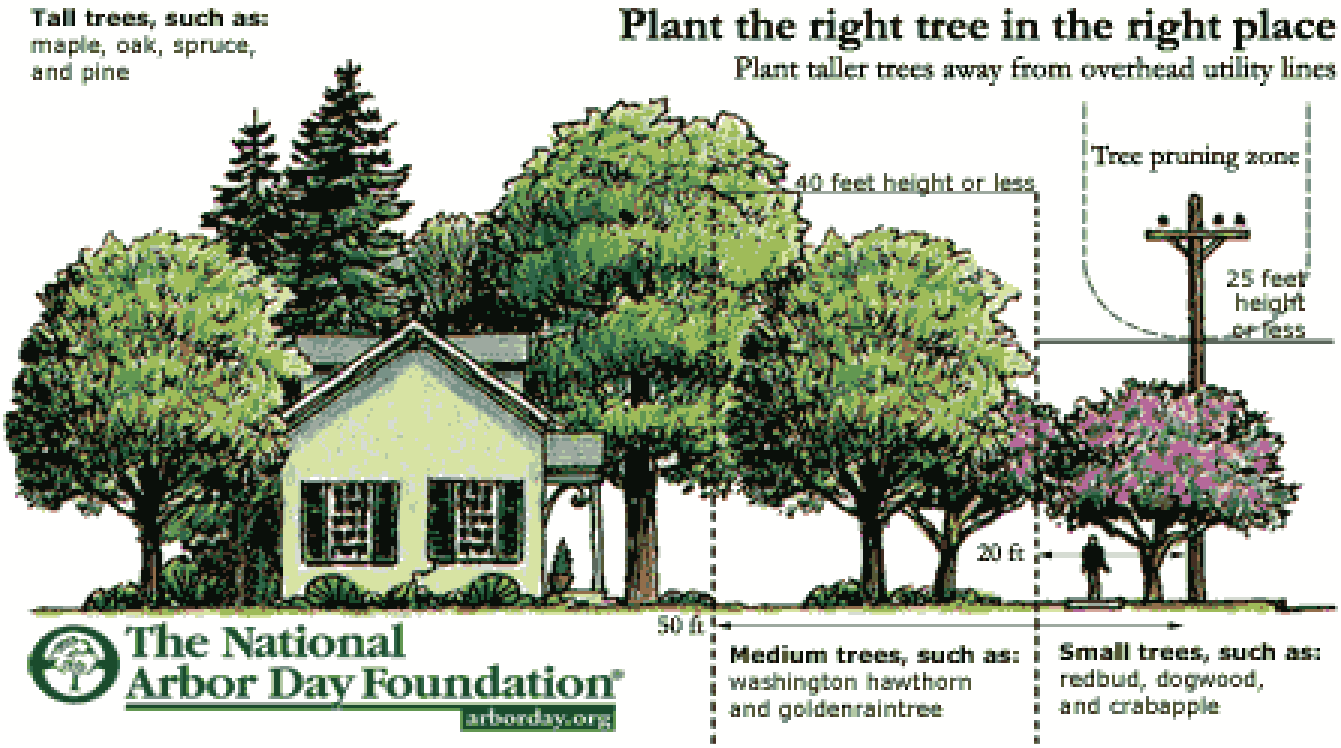
- Existing native and non-invasive vegetation should be preserved where possible.
- Noxious weeds and invasive species shall not be specified or used.
- Selection and placement of trees is important for the long
- Plant stream and water buffers with trees, shrubs, ornamental grasses, and herbaceous materials where possible, to stabilize banks and provide shade. This will help to reduce thermal warming, reduce erosion, increase roughness and protect habitat.
- Avoid plantings that will require routine or intensive chemical applications (i.e. turf area). Use low maintenance ground cover as an alternative to turf.

- Stressors (e.g. wind, exposure, exposure to deicing salt, insects, drought and inundation tolerance, and disease), micro-climates, and sunlight conditions should also be considered when laying out the planting plan.

- Aesthetics and visual characteristics should be a prime consideration. Plant form, texture, color, bloom time and fragrance are important to the overall feel of the site. Plants can be used to enhance and frame desirable views or screen undesirable views. Care should be taken to not block views at entrances, exits, or along difficult road curves.

- Trees and shrubs should be placed in a manner that restricts pedestrian access to steep pools or slopes without blocking maintenance access.

- Existing and proposed utilities must be identified and considered. Large trees next to utility lines must be avoided. Refer to Right Tree Right Place, provided by the National Arbor Day Foundation for more information.



Maintenance Considerations

- The designer should carefully consider the long-term vegetation management strategy for the Storm Water management practice, keeping in mind the maintenance legacy for future owners. <u>The Storm Water management maintenance agreement must include requirements to ensure vegetation cover in perpetuity</u>.

- Provide signage to help educate the public about Storm Water management practices and to designate limits of mowing (wildflower areas, meadows, etc.)

Embankments, spillways, dams, and orifices

- Planting of trees, shrubs, and/or any type of woody vegetation is not allowed on structural embankments.

- All emergency spillways should be stabilized with plant material that can withstand strong flows. Root material should be fibrous and substantial but lack a taproot.

- Trees or shrubs known to have long taproots should not be planted within the vicinity of an earthen dam or subsurface drainage facilities.

- Plant trees and shrubs at least 25 feet away from a principal spillway structures.

- Plant trees and shrubs at least 15 feet away from the toe of slope of a dam.

Soils

Storm Water management practice soils should provide adequate infiltration rates and be suitable for healthy tree and vegetation growth. Soil analysis should be conducted within the Storm Water management area to determine appropriate levels and types of soil amendments.

If topsoil exists on site and is stockpiled for re-use, appropriate erosion control measures as required by the Indiana Department of Environmental Management (IDEM) shall be used.

Site Selection, Preparation and Grading

When selecting a location for the Storm Water management practice, take into consideration the physical variables of the site and the effects they will have on the design. Some variables to consider include amount of sunlight received and solar orientation, wind speed and direction, temperature gain and surface characteristics. For example: sites facing northeast receive morning sun and tend to be cooler and wetter than those facing southwest; runoff from asphalt will be hotter than that from concrete; etc. Combinations of these variables create different micro-climates and should be taken into account when placing the Storm Water management practice and selecting plants.

Unwanted vegetation in the Storm Water management practice area shall be removed during site preparation with equipment appropriate for the type of material encountered and site conditions. It is recommended that the maximum amount of pre-existing native vegetation be retained and protected.

No material storage or heavy equipment is allowed within the Storm Water management practice design area after site cleaning and grading has been completed, except to excavate and grade as needed to build the system. No compaction of infiltration areas should occur during this excavation.

After the Storm Water management practice area is cleared and graded, any necessary soil amendments should be added and tilled into the existing soil to the depth specified for each Storm Water management practice. <u>No tilling shall occur within the drip line of existing trees</u>. After tilling is complete, no other construction traffic shall be allowed in the area, except for planting and related work. Where topsoil is needed, (for example swales and dry detention basins) it should be spread to a depth of 4-8 inches and lightly compacted to minimum thickness of 4 inches. This provides organic matter and important

nutrients for the plant material. The use of topsoil allows vegetation to become established faster and roots to penetrate deeper. This ensures quicker and more complete stabilization, making it less likely that the plants will wash out during a heavy storm.

Mulch

The mulch layer helps maintain soil moisture and avoid surface sealing which reduces permeability. Mulch helps prevent erosion, and provides a micro-environment suitable for soil biota at the much/soil interface. It also serves as a pretreatment layer, trapping the finer sediments which remain suspended after the primary pretreatment. Mulch shall not be mounded around the base of trees; this can cause the trunks to rot. Approved mulching materials include organic materials such as compost, bark mulch, leaves, as well as small river gravel, pumice, or other inert materials. Grass clippings should not be used as mulch. For ground cover plantings, the much shall be applied to cover all soil between plants. Care should be exercised to use the appropriate amount of mulch - any more than 3-4 inches can negatively impact growing conditions and cause excessive nutrients to leach into the Storm Water management area. Mulch shall be weed-free. Manure mulching and high-fertilizer hydroseeding are prohibited in a Storm Water management practice area during and after construction.

Irrigation

Newly installed plant material requires water in order to recover from the shock of being transplanted. Be sure that some source of water is provided during establishment of the Storm Water management practice, especially during dry periods. This will reduce plant loss and provide the new plant materials with a chance to establish root growth.

Permanent irrigation systems are allowed, but designers are encouraged to minimize the need for permanent irrigation. Innovative methods for watering vegetation are encouraged, such as the use of cisterns.

Storm Water Management Practice Screening

Storm Water management practice elements such as chain link fences, concrete bulkheads, outfalls, rip-rap, gabions, large steel grates, steep side slopes, manhole covers/vault lids, berm embankments planted only with grasses, exposed pipe, banks, retaining walls greater than 2 feet high, and access roads are generally not aesthetically pleasing. When these elements face public right-of-way or other private property, it is recommended that they be screened with plant materials. Designers are strongly encouraged to integrate aesthetically pleasing landscape design with Storm Water management practices.

Pollution Prevention

Storm Water pollution prevention practices related to landscaping can be categorized into two broad categories: Toxic Substances Use Reduction and Pollutant Source Reduction.

Toxic Substance Use Reduction

Projects shall be designed to minimize the need for toxic or potentially polluting materials such as herbicides, pesticides, fertilizers, or petroleum based fuels within the Storm Water management area before, during, and after construction. Use of these materials creates the risk of spills, misuse, and future draining or leaching of pollutants into facilities or the surrounding area.

Pollutant Source Reduction

Materials that could leach pollutants or pose a hazard to people and wildlife shall not be used as components of a Storm Water management practice. Some examples of these materials are

chemically treated railroad ties and lumber and galvanized metals. Many alternatives to these materials are available.

Storm Water Management Area Establishment and Maintenance

Establishment procedures should include: control of invasive weeds, prevention of damage from animals and vandals, use of erosion control mats and fabrics in channels, temporary diversion of flows from seeded areas until stabilized, mulching, re-staking, watering, and mesh or tube protection replacement, to the extent needed to ensure plant survival. To ensure landscape plant survival and overall Storm Water facility functional success, the design and construction documents must include elements that help achieve these results. Construction specifications and details need to include staking, irrigation schedule, soil amendments, and plant protection.

Table 5.1.1: Planting Specifications

Specification Element	Elements
Sequence of Construction	Describe site preparation activities, soil amendments, etc.; address erosion and sediment control procedures; specify step-by-step procedure for plant installation through site clean-up.
Contractor's Responsibilities	Specify the contractors responsibilities, such as watering, care of plant material during transport, timeliness of installation, repairs due to vandalism, etc.
Planting Schedule and Specifications	Specify the materials to be installed, the type of materials (e.g., B&B bare root, containerized); time of year of installations, sequence of installation of types of plants; fertilization, stabilization seeding, if required; watering and general care.
Maintenance	Specify inspection periods; mulching frequency (annual mulching is most common); removal and replacement of dead and diseased vegetation; treatment of diseased trees; watering amount and schedule after initial installation (once per day for 14 days is common); repair and replacement of staking and wires.
Warranty	All plants shall contain a 2 year warranty. Specifications should contain the warranty period, the required survival rate, and expected condition of plant species at the end of the warranty period.

5.2. Facility Specific Landscaping Guidance

The planting recommendations shown under this section are based on research, local experience and/or standard landscape industry methods for design and construction. It is critical that selected plant materials are appropriate for soil, hydrologic, and other site conditions. Storm Water Management plans should use appropriate native and recommended non-invasive species from the Recommended Plant Lists in Table 5.3.1. The design for planting shall minimize the need for herbicides, fertilizers, pesticides, or soil amendments at any time before, during, and after construction and on a long-term basis. Plantings should be designed to minimize the need for mowing, pruning, and irrigation. Grass or wildflower seed shall be applied at the rates specified by the suppliers. If plant establishment cannot be achieved with seeding by the time of substantial completion of the Storm Water management practice portion of the project, the contractor shall plant the area with wildflower sod, plugs, container plants, or some other means to complete the specified plantings and protect against erosion.

Green Roof Landscaping Requirements

Plantings used on green roofs shall be self-sustaining, with little to no need for fertilizers or pesticides. Shrubs, herbs, succulents, and/or grasses shall be used to cover most of the green roof. See **Chapter 4.1**: Green Roofs for more specific information on green roof recommendations.

Planter Box Landscaping Requirements

The following quantities per 100 square feet of planter box area are suggested:

- 4 - Large shrubs/small trees 3-gallon containers or equivalent.
- 6 - Shrubs/large grass-like plants 1-gallon containers or equivalent.
- Ground cover plants: 1 per 12 inches on center, triangular spacing. Minimum container: 4-inch pot. Spacing may vary according to plant type.

Note: Container planting requires that plants be supplied with nutrients that they would otherwise receive from being part of an ecosystem. Since they are cut off from these processes they must be cared for accordingly.

Infiltration and Filter System Recommendations

Infiltration and filter systems either take advantage of existing permeable soils or create a permeable medium such as sand for water quality and groundwater recharge. The most common systems include infiltration trenches, infiltration basins, sand filters, and organic filters. When properly planted, vegetation will thrive and enhance the functioning of these systems. For example, pre-treatment buffers will trap sediment that is often bound with phosphorous and metals. Vegetation planted in the Storm Water Management Practice will aid in nutrient uptake and water storage. Additionally, plant roots will create macropores for Storm Water to permeate soil for groundwater recharge. Finally, successful plantings provide aesthetic value and wildlife habitat, making these facilities more desirable to the public.

Design Constraints:
Along with the guidelines listed at the start of this section, the following should be adhered to:

- Determine areas that will be saturated with water and water table depth so that appropriate plants may be selected (hydrology will be similar to bioretention facilities, see Figure 5.2.1 and associated tables for planting material guidance).
- Plants shall be located so that access is possible for structure maintenance.

Vegetated Swale Landscaping Requirements

The following quantities per 200 square feet of swale area are suggested:

- 1 Evergreen or Deciduous tree:
    - Evergreen trees: Minimum height: 6 feet.
    - Deciduous trees: Minimum caliper: 1 ½ inches at 6 inches above base.
    - Multi-sterm trees: Minimum root ball diameter: 20 inches and 6' tall
- Grass: Seed or sod is required to completely cover the swale bottom and side slopes.
- (Shrubs are optional)

Vegetation or ground cover within the swale should be suitable for expected velocities. For the swale flow path, approved native grass mixes are preferable. The applicant shall have plants established at the time of Storm Water management plan completion (at least 3 months after seeding). No runoff should be

allowed to flow in the swale until grass is established or soil is otherwise stablized. Native wildflowers, grasses, and ground covers are preferred to turf and lawn areas. These type of landscape can be designed to require mowing only once or twice annually.

Vegetated Infiltration Basin and Dry Detention Pond Landscaping Requirements

Vegetation increases evapotranspiration, helps improve infiltration functions, protects from rain and wind erosion and enhances aesthetic conditions. The following quantities per 300 square feet of basin area are suggested.

- 1 Evergreen or Deciduous tree:
  - Evergreen trees: Minimum height: 6 feet.
  - Deciduous trees: Minimum caliper: 1 ½ inches at 6 inches above base.
  - Multi-sterm trees: Minimum root ball diameter: 20 inches and 6' tall
- 4 Large shrubs/small trees 3-gallon containers or equivalent
- 6 Shrubs/large grass-like plants 1-gallon containers or equivalent
- Ground cover plants: 1 per 12 inches on center, triangular spacing, for the ground cover planting area only, unless seed or sod is specified. Minimum container: 4-inch pot. At least 50 percent of the Storm Water management area shall be planted with grasses or grass-like plants.

Native wildflowers, grasses, and ground covers are preferred to turf and lawn areas. These type of landscape can be designed to require mowing only once or twice annually.

Appropriate plants should be selected based on ponding depth and drain-down time in the basin. Infiltration systems will be dry much of the time and should be vegetated with drought tolerant species especially if they will not be irrigated.

Bioretention Landscaping Requirements

Planting Soil Bed Characteristics

The characteristics of the soil for the bioretention system are perhaps as important as the facility location, size, and treatment volume. The soil must be permeable enough to allow runoff to filter through the media, while having characteristics suitable to promote and sustain a robust vegetative cover crop. In addition, much of the nutrient pollutant uptake (nitrogen and phosphorus) is accomplished through adsorption and microbial activity within the soil profile. Therefore, the soils must balance soil chemistry and physical properties to support biotic communities above and below ground. Planting soil should meet the following specifications, which are also outlined in the typical detail in **Attachment 1**:

1. The intent of the amended soil specification is to allow for proper operation of the Storm Water system; provide for adequate infiltration; and foster the healthy growth of the vegetated Storm Water system. The soil specification is for any vegetated Storm Water system (e.g. Rain garden, bioretention, swale, etc.).

2. Amended soil shall be a well-blended homogeneous mixture of 15 to 30% compost, 20-30% top soil or amended topsoil, and the remainder coarse, washed sand. Compost, top soil or amended topsoil and sand are further specified in items 3-5.

3. Compost shall be organic leaf compost, aged leaf mulch, or other compost mature with regard to its suitability for serving as a soil amendment. The compost shall have a moisture content that has no visible free water or dust produced when handling the material. Compost shall meet the following:

	Min.	Max.
Percent passing 1” sieve:	99%	100%
Percent passing 5/8” sieve:	90%	100%
Percent passing ¼” sieve:	40%	90%

4. The topsoil texture must be silt loam, sand, sandy loam, loamy sand, or loam. The topsoil shall not contribute clay content such that the amended soil mixture is >5% clay. If the topsoil does not meet these characteristics, then it shall be adjusted by the addition of an acceptable planting soil.

5. Sand shall be USDA coarse sand (0.02-0.04”) conforming to ASTM C33 (fine aggregate concrete sand) and shall be clean construction sand, free of deleterious materials. <5% fines.

6. The amended soil shall be a uniform mix, free of stones, stumps, roots, or similar objects larger than one inch in diameter. The amended soil shall be less than 5% clay. The amended soil shall be free of brush or seeds from noxious weeds.

7. The amended soil shall have a pH range of 5.5 to 6.5; an infiltration rate of no less than 0.5 inches per hour; 4 to 8% organic matter; and a maximum of 500 ppm concentration of soluble salts. Soil tests for these parameters shall be performed for every 500 cubic yards of planting soil, with the exception of pH and organic content tests, which are required only once per vegetated Storm Water system area.

8. Soil compaction in the area of the vegetated Storm Water system shall be minimized by limiting construction traffic and utilizing tracked vehicles. Amended soil shall be placed in lifts of 12-18 inches, loosely compacted (tamped lightly with a dozer or backhoe bucket) after placement in the vegetated Storm Water system area.

Planting Plan Guidance

- Trees and shrubs shall be freshly dug and grown in accordance with good nursery practice.
- Perennials, grass-like plants, and ground-cover plants shall be healthy, well-rooted specimens.
- Plantings shall be designed to minimize the need for mowing, pruning, and irrigation.

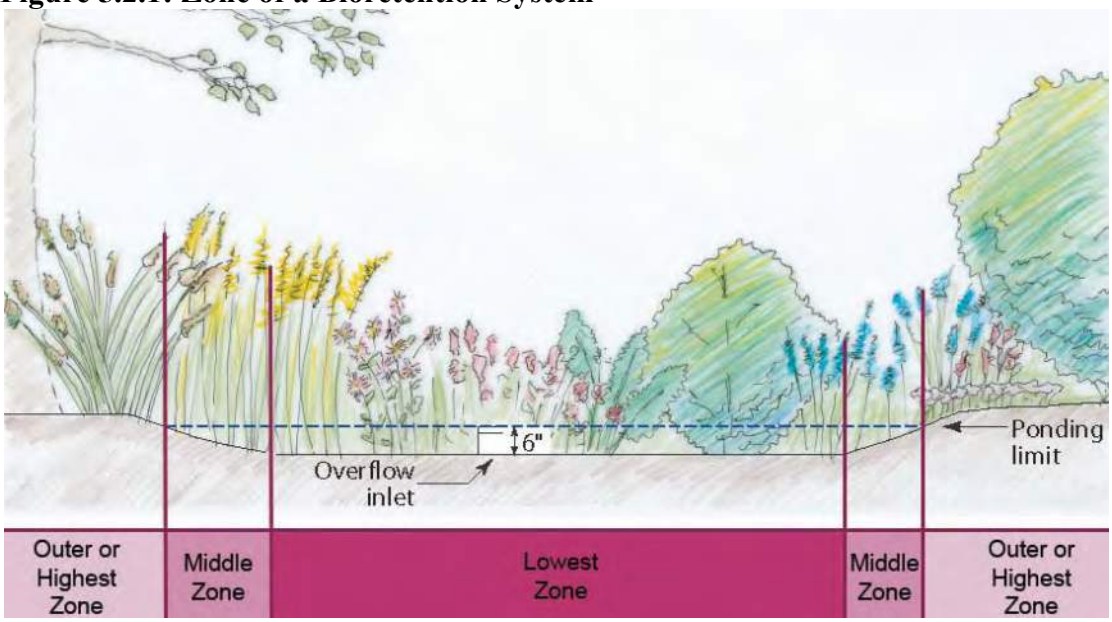
The following quantities per 100 square feet of bioretention area are suggested:

- 1 large tree per 100 square feet of bioretention area
- 2-4 small trees or shrubs per 100 square feet of bioretention area
- 6 ferns or grass-like plants per 100 square feet of bioretention area (1-gallon containers)
- Groundcover plantings and wildflower plugs on 12 inch centers with triangular spacing.
- A native grass/wildflower seed mix can be used as an alternative to groundcover planting. Seed mix shall be free of weed seeds.

Plant material selection should be based on the goal of simulating a terrestrial forested community of native species. Bioretention simulates an ecosystem consisting of an upland-oriented community dominated by trees, but having a distinct community, or sub-canopy, of understory trees, shrubs and herbaceous materials. The intent is to establish a diverse, dense plant cover to treat Storm Water runoff and withstand urban stresses from insect and disease infestations, drought, temperature, wind, and exposure.

The proper selection and installation of plant materials is key to a successful system. There are essentially three zones within a bioretention system (Figure 5.2.1). The lowest elevation supports plant species adapted to standing and fluctuating water levels. The middle elevation supports a slightly drier group of plants, but still tolerates fluctuating water levels. The outer edge is the highest elevation and generally supports plants adapted to dryer conditions. However, plants in all the zones should be drought tolerant. Plants should also have high salt tolerance if bioretention area receives runoff from ground level impervious surfaces.

Figure 5.2.1: Zone of a Bioretention System



Lowest Zone (Hydrologic zones 2-4):
Plant species adapted to standing and fluctuating water levels. Frequently used native plants include*:

Table 5.2.1: Lowest Zone (Hydrologic zones 2-4) Suggested Plants

asters (Aster spp.)	winterberry (llex verticillata)
goldenrods (Solidago spp.)	arrowwood (Viburnum dentatum)
bergamot (Monarda fistulosa)	sweet pepperbush (Clethra alnifolia)
blue-flag iris (Iris versicolor)	bayberry (Myrica pensylvanica)
sedges (Carex spp.)	buttonbush (Cephalanthus occidentalis)
ironweed (Vernonia spp)	white oak (Quercus bicolor)
blue vervain (Verbena hastate)	elderberry (Sambucus Canadensis)
joe-pye weed (Eupatorium spp.)	bald cypress (Taxodium distichum)
swamp milkweed (Asclepias incarnata)	river birch (Betula nigra)
switchgrass (Panicum virgatum)	sweetgum (Liquidambar styraciflua)
shrub dogwoods (Cornus spp.)	northern white cedar (Juniperus virginiana)
swamp rose (Rosa palustris)	red maple (Acer rubrum)

* Refer to the plant list for a complete listing

Middle Zone (Hydrologic zones 4-5):
This zone is slightly drier than the lowest zone, but plants should still tolerate fluctuating water levels. Some commonly planted native species include*:

Table 5.2.2: Middle Zone (Hydrologic zones 4-5)

black snakeroot (Cimicifuga racemosa)	spicebush (Lindera benzoin)
switchgrass (Panicum virgatum)	hackberry (Celtis occidentalis)
spotted joe-pye weed (Eupatorium maculatum)	willow oak (Quercus phellos)
cutleaf coneflower (Rudbeckia lacinata)	winterberry (llex verticillata)
frosted hawthorn (Crataegus pruinosa)	slippery elm (Ulmus rubra)
ostrich fern (matteuccia struthiopteris)	blackhaw viburnum (Viburnum prunifolium)
sensitive fern (onoclea sensibilis)	Nannyberry (Viburnum)
ironwood (Carpinus caroliniana)	witch-hazel (Hamamelis virgniana)
obedient plant (Physostegia virginiana)	steeplebush (Spiraea tomentosa)

*Refer to the plant list for a complete listing

Outer Zone (Hydrologic zones 5-6):
Generally supports plants adapted to drier conditions. Examples of commonly planted native species include*:

Table 5.2.3: Outer Zone (Hydrologic zones 5-6)

many grasses & wildflowers	juniper (Juniperus communis)
basswood (Tilia americana)	sweet-fern (Comptonia peregrina)
white oak (Quercus alba)	eastern red cedar (Juniperus virginiana)
scarlet oak (Quercus coccinea)	smooth serviceberry (Amelanchier laevis)
black oak (Quercus velutina)	american holly (llex opaca)
american beech (Fagus grandifolia)	sassafras (Sassafras albidum)
burr oak (Quercus macrocarpa)**	shummard oak (Quercus shumardii)**
mapleleaf viburnum (viburnum acerifolium)	wild hydrangea (Hydrangea arborescens)
black chokecherry (Aronia melanocarpa)	white pine (Pinus strobus)

*Refer to the plant list for a complete listing
**Can be used in both the middle zone and outer zone-most adaptable oaks to constructed sites and variable hydrology.
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Filter Strip Landscaping Requirements

It is critical that plant materials are appropriate for soil, hydrologic, light, and other site conditions. Select vegetation from the list of native species found in this section (Table 5.3.1). Take soil infiltration capacities, sunlight, pollution tolerances, root structure, and other considerations into account when selecting plants from this list.

Filter strips should be planted with meadow grasses, shrubs, and native vegetation (including trees) from the list provided in Section 5.3: Native and Recommended Non-invasive Plants.

For the filter strip, approved native grass mixes are preferable. Seed shall be applied at the rates specified by the supplier. The applicant shall have plants established at the time of Storm Water management area completion (at least 3 months after seeding). No runoff shall be allowed to flow across the filter strip until the vegetation is established. Trees and shrubs may be allowed in the flow path if the filter strip exceeds the minimum length and widths specified.

Filter strips often make a convenient area for snow storage. Therefore, filter strip vegetation should be salt-tolerant, and the maintenance schedule should involve removal of sand build-up at the toes of the slope. If the filter strip cannot provide pretreatment in the winter due to snow storage or vegetation choice, other pretreatment should be provided.

Vegetation cover should be maintained at 85 percent. If vegetation is damaged, the damaged areas should be reestablished in accordance with the original specifications. In all design cases where vegetation is to be established, the planting regime should be as dense as the soil conditions can sustain. This is especially true at the top portions of the filter strip where the highest sheet flow velocities are found. Soils that can sustain higher quantities and qualities of vegetation may need to be added to insure thick vegetative densities needed for sustainable filter strip performance. All vegetation deficiencies should be addressed without the use of fertilizers and pesticides if possible.

5.3. Native and Recommended Non-invasive Plants

Native plant species are recommended over exotic foreign species because they are well adapted to local climate conditions. This will result in less replacement and maintenance, while supporting the local ecology.

<u>The list is intended as a guide for general planting purposes and planning considerations. Knowledgeable landscape designers and nursery suppliers may provide additional information for considering specific conditions for successful plant establishment and accounting for the variable nature of Storm Water hydrology. Because individual plants often have unique growing requirements difficult to convey in a general listing, it will be necessary to research specific information on the plant species proposed in order to ensure successful plant establishment.</u>

Chapter 701 of the municipal code of the City of Indianapolis references the most up to date prohibited species list. Table 5.3.1 lists native and recommended plants and is organized by Type and Latin name. Additional information given for each species includes: Common name, National Wetland Indicator Status, hydrologic zone, inundation tolerance, drought tolerance, salt tolerance, mature canopy spread, mature height, light requirements, nativity, commercial availability, and notes to provide guidance for application and selection. For example, some trees are well suited to landscaped areas that will receive Storm Water runoff, while others may not tolerate the additional moisture.

Hydrologic Zones

For planting within a Storm Water management area, it is necessary to determine what hydrologic zones will be created. Hydrologic zones describe the degree to which an area is inundated by water (see Figure 5.2.1 for an example of hydrologic zones in a bioretention basin). Plants have differing tolerances to inundations and as an aid to landscape designers, these tolerance levels have been divided into six zones and corresponding plant species have been identified. In Table 5.3.1 each plant species has a corresponding hydrologic zone provided to indicate the most suitable planting location for successful establishment. While the most common zones for planting are listed in parenthesis, the listing of additional zones indicates that a plant may survive over a broad range of hydrologic conditions. Just as plants may, on occasion, be found outside of their hardiness zone, they may also be found outside of their hydrologic zone. Additionally, hydrologic conditions in a Storm Water management facility may fluctuate in unpredictable ways; thus the use of plants capable of tolerating wide varieties of hydrologic conditions greatly increases a successful planting. Conversely, plants suited for specific hydrologic conditions may perish when hydrologic conditions fluctuate, thus exposing the soil and increasing the chance for erosion.

Wetland Indicator Status

The Wetland Indicator Status (from Region 1, Reed, 1988) has been included to show "the estimated probability of a species occurring in wetlands versus non-wetlands: (Reed, 1988). Reed defines the indicator categories as follows:

- Obligate wetland (OBL): Plants, which nearly always (more than 99% of the time) occur in wetlands under natural conditions.
- Facultative Wetland (FACW): Plants, which usually occur in wetlands (from 67 to 99% of the time), but occasionally found in non wetlands.
- Facultative (FAC): Plants, which are equally likely to occur in wetlands and non wetlands and are found in wetlands form 34 to 66% of the time.
- Facultative Upland (FACU): Plants, which usually occur in non wetlands (from 67 to 99% of the time), but occasionally found in wetlands.
- Upland (UPL): Plants, which almost always (more than 99% of the time) under natural conditions occur in non wetlands.
- A given indicator status shown with a "+" or a "-" means that the species is more (+) or less (-) often found in wetlands than other plants with the same indicator status without the "+" or "-" designation.

Inundation Tolerance

Since the Wetland Indicator Status alone does not provide an indication of the depth or duration of flooding that a plant will tolerate, the "Inundation tolerance" column is designed to provide further guidance. If a plant is capable of withstanding permanent saturation, the depth of this saturation is listed (for example, "saturated" indicates the soil can be moist at all times, "sat, 0-6" indicates that the species can survive in constantly moist soil conditions with up to 6" of standing water). Conversely, a plant may only tolerate seasonal inundation - such as after a storm event - or may tolerate inundation - such as after a storm event - or may not tolerate inundation at all. This type of plant would be well suited for a Storm Water management area that is expected to drain quickly or in the drier zones of the Storm Water management practice.

Drought Tolerance (N=none; L=low; M=medium; H=high)

The drought tolerance column is meant to provide a way for Storm Water management plan designers to select appropriate native plants that can survive in hot summer conditions, with a minimum of irrigation. Drought tolerance is defined as the relative tolerance of the plant to drought conditions compared to other plants in the same region (USDA, 2005).

Salt Tolerance (N=none; L=low; M=medium; H=high; U=Unknown)

This column ranks the relative tolerance of a species to salt content in the soil. If U (unknown) is displayed, no research was found for that particular species.

Height Range

This column provides the approximate mature height of plant species in optimal growing conditions. This height may be reduced dramatically in the urban environment where light, space, and other factors may not be as readily available as in a forest or field setting. However, by providing as much space as possible for a plant to grow and by choosing appropriate species for a planting area, improved - if not optimal - growing conditions can be achieved. For example, a tree planted in a sidewalk pit measuring 4 feet x 4 feet may only reach half its mature height, while a tree planted in a 4 foot wide "trough" style planting bed will grow taller and live longer, because it will have greater access to air and water.

Light Requirement

The light requirements for each species are listed as ranges between full shade and full sun. At the bottom of the range - full shade - plants thrive in conditions where they receive filtered, or dappled, light for the entire day (such as under an oak tree). In the middle of the range are plants that grow best in part shade, where they are in full shade for 2-3 hours during midday. Plants that require full sun should be sited so that they receive 5 or more hours of direct sun during the growing season. Some plants requiring full sun may still do well in a part shade environment, depending on the quality and duration of the light the plants receive when they are not in the shade.

Container-grown plants include trees, shrubs, wildflowers, ferns, grasses, and sedges. This is an excellent alternative to the far more expensive balled-and-burlapped (B&B) form of trees and shrubs, although the size of the tree is almost always smaller. Nurseries often provide a few container sizes for each species.

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Table 5.3.1: Recommended Plant List (the excel spreadsheet is available online to download for easier use)

Latin Name	Common Name	National Wetland Indicator	Hydrologic Zone	Indundation Tolerance	Community	Drought Tolerance (N=None; L=Low, M=Medium, H=High)	Salt Tolerance (N=None, L=Low, M=Medium,H=High, U=Unkown)	Deer Tolerance, discourages deer predation. Seldom damaged (S), Rarely Damaged (R) Occasionally Damaged (O)	Sun	Height range variable depending on soil conditions, hydrology, light	Flower Season	Color	Notes
Forbs (Wildflowers)													
Acorus calamus	Sweet Flag	OBL	3, 4	SAT, 0-6"	sedge meadow, shallow water emergent	L	M	R	sun	2-3 ft	May-June	Green	occurs in shallow water of ponds, tolerated moving water, installation of plugs 0-2".
Actinomeris alternifolia	Wingstem	FACW			wet mesic woods			R	psun-shade	4-7 ft	July-Sept	Yellow	Easy to establish from seed.
Alisma subcordatum	Water Plantain	OBL	2	SAT, 0-1'	sedge meadow, shallow water emergent	N	N	R	sun	1-2 ft	June-Sept	White	emergent aquatic, slow moving water, installation depth 0-1", will spread, great for parasitic wasp .
Allium cernuum	Nodding Wild Onion	UPL			mesic prairie , dry woods, mesic savanna			R	sun-psun	1-2 ft	July-Aug	Pink	Beautiful pinlish white flowers for wide range of habits.
Angelica atropurpurea	Angelica	OBL			sedge meadow, wet wood edge,			R	sun-psun	5-8 ft	June	White	Stricking large round multi-compound umbels of white flowers, "large white balls".Plant juices can cause dermatitis to sl
Aquilegia canadensis	Columbine	UPL			dry woods, open prairie		L	O	psun-shade	2-3 ft	May-June	Salmon/yellow	Very popular species, good humming bird attractant.
Asclepias incarnata	Marsh Milkweed	OBL	2 (3, 4)	SAT, 0-6"	sedge meadow, wet prairie	N	N	S	sun	3-4 ft	July-Aug	Pink	pink-rose purple flowers in several umbels
Asclepias tuberosa	Butterflyweed	UPL	5, 6	NO	dry prairie	H	L	S	sun	1-2 ft	June-July	Orange	bright orange flowers in umbels
Aster azureus	Sky-Blue Aster	UPL			dry prairie, mesic prairie, mesic savanna		L	O	sun-psun	1-2 ft	Sept	Blue	Easy to establish from seed.
Aster cordifolius	Heart-Leaved Blue Wood Aster	UPL	5, 6	NO	mesic woods	M	L	O	psun-shade	1-3 ft	Sept-Oct	Blue	blue-violet to rose disk and ray flowers, very easy to eastablish in wide range woodland soils.
Aster ericoides	Heath Aster	FACU-			dry prairie, mesic prairie		M	O	sun	1-2 ft	Sept-Oct	White	Minute white rays, yellow center.
Aster firmus	Shining Aster	OBL			sedge meadow, wet prairie			O	sun	3-4 ft	Sept-Oct	Lavender	Easy to establish from seed.
Aster laevis	Smooth Aster	UPL			mesic prairie, dry savanna		L	O	sun-psun	3-5 ft	Sept-Oct	Blue	Easy to establish from seed.
Aster lateriflorus	Side-Flowering Aster	FACW-			mesic woods, wet-mesic woods			O	shade	1-3 ft	Sept-Oct	White	Easy to establish from seed.
Aster novae-angliae	New England Aster	FACW+	(3, 4) 5	L	sedge meadow, wet prairie, wet-mesic prairie, m	N		O	sun	3-5 ft	Sept-Oct	Purple	violet to blue rays with yellow disks
Aster puniceus	Swamp Aster	OBL		SEASONAL	sedge meadow		M	O	sun-psun	3-6 ft	Sept-Oct	Lavender	Easy to establish from seed.
Aster sericeus	Silky Aster	UPL			dry prairie			O	sun	1 ft	Sept-Oct	Purple	Delicate whispy stems, flowers and plants, excellent sandy soil species
Aster shortii	Short's Aster	UPL			mesic woods			O	shade	2-3 ft	Sept-Oct	Purple	Easy to establish from seed.
Aster simplex	Panicled Aster	OBL		SEASONAL	sedge meadow, wet mesic prairie, wet mesic woods			O	sun-psun	3-5 ft	Sept-Oct	White	Easy to establish from seed.
Aster umbellatus	Flat-Topped Aster	FACW			sedge meadow, wet prairie			O	sun	3-5 ft	Sept-Oct	White	Easy to establish from seed.
Baptisia australis	Blue False Indigo	UPL	4, 5, 6	SEASONAL	wet-mesic prairie	L	M	R	sun-psun	2-4 ft	May-June	Blue	showy blue flowers; shrub-like; nitrogen fixer; adaptable
Baptisia leucantha	White False Indigo	UPL			mesic prairie, dry prairie		M	R	sun-psun	3-4 ft	June-July	White	Stricking white flowers, interesting persitant black seed pods
Blephilia hirsuta	Hairy Wood Mint	FACU-			mesic woods			R	shade	1-3 ft	July-Aug	White	Beautiful flower heads, persitant seed structure.
Boltonia latisquama	False Aster	OBL			sedge meadow		L	no listing or possible food preference.	sun	3-6 ft	Aug-Sept	White	Easy to establish.
Caltha palustris	Marsh Marigold	OBL			sedge meadow, wet woodlands	L		no listing or possible food preference.	psun-shade	1-2 ft	April	Yellow	Best success if consistant water levels or constant dampness.
Cassia hebecarpa	Wild Senna	FACW			sedge meadow, wet prairie			no listing or possible food preference.	sun-psun	3-5 ft	July-Aug	Yellow/Black	Easy to establish from seed, good legume.
Chelone glabra	White Turtlehead	OBL	3, 4, 6	SEASONAL	sedge meadow	L	N	O	partial shade	2-4 ft	Aug-Sept	White	snapdragon-type white flowers
Chelone obliqua	Pink Turtlehead	OBL			sedge meadow			O	partial shade	2-4 ft	Aug-Sept	Pink	snapdragon-type pink flowers
Coreopsis palmata	Plains Coreopsis	UPL			dry prairie			R	sun	1-2 ft	July-Aug	Yellow	Spreads from emergent roots all directions
Coreopsis tripteris	Tall Coreopsis	UPL			mesic prairie			R	sun	6-8 ft	Aug-Sept	Yellow	Spreads from emergent roots all directions
Decodon verticillatus	Swamp Loosestrife	OBL		SEASONAL	emergent			R	sun	3-4 ft	July-Aug	Pink	Excellent shore line protector.
Desmodium illinoiense	Illinois Tick Trefoil	UPL			mesic prairie			no listing or possible food preference.	sun	3-5 ft	July-Sept	Pink	Easy to establish from seed, good legume.
Echinacea pallida	Pale Purple Coneflower	UPL			mesic prairie			S	sun	4-6 ft	May-June	Pink	Easy to establish from seed.
Echinacea purpurea	Purple Coneflower	UPL			mesic prairie, mesic savanna, dry woods		M	S	sun-psun	3-4 ft	June-Aug	Pink	Easy to establish from seed.
Eryngium yuccifolium	Rattlesnake Master	FAC+			mesic prairie, dry prairie			O	sun	3-4 ft	July-Sept	White	Unusual leafs, flowers and seed heads, a must for applicable habits.
Eupatorium coelestinum	Blue Mist Flower	FAC	4, 5, 6	SEASONAL	wet mesic woods	M	N	S	psun	1-2 ft	Sept-Oct	Blue	groundcover; blue flowers on neat foliage; spreads easily
Eupatorium fistulosum	Hollow Joe-Pye Weed	FACW	(3, 4) 5	SEASONAL	sedge meadow	L	N	S	sun	7-10 ft	Aug -Sept	Pink	many white flowers in large, branching clusterts
Eupatorium maculatum	Spotted Joe-Pye Weed	FACW	(3, 4) 5	SEASONAL	sedge meadow	L	N	S	sun	4-6 ft	Aug - Sept	Pink	light purple flowers; attracts butterflies (swallow tails)
Eupatorium perfoliatum	Boneset	FACW+	(2, 3) 4	SEASONAL	sedge meadow, wet prairie	L	M	S	sun	3-5 ft	Aug-Sept	White	clusters of grayish-white flowers
Eupatorium purpureum	Sweet Joe-Pye Weed	FAC	3 (4, 5)	SEASONAL	mesic woods	L	U	S	psun-shade	4-6 ft	July-Aug	Pink	vanilla scented flowers
Eupatorium rugosum	White Snakeroot	UPL	5, 6	NO	mesic woods	M	M	S	psun-shade	2-4 ft	Sept	White	white flowers in large clusters
Filipendula rubra	Queen of the Prairie	FACW	4, 5, 6	SEASONAL	sedge meadow	N	U	no listing or possible food preference.	sun	4-7 ft	June-July	Pink	prefers well-drained moist soils; foamy clusters of blooms
Gentiana andrewsii	Bottle Gentian	FACW			sedge meadow, wet prairie, wet-mesic prairie			no listing or possible food preference.	sun	1-2 ft	Sept-Oct	Blue	Unique purpulish blue flowers, when conditions are optimal excellent spread potential.
Geranium maculatum	Wild Geranium	FACU	5, 6	NO	mesic woods	M	U	no listing or possible food preference.	shade	1-2 ft	Apr-May	Pink	groundcover; rose-purple flowers in small clusters
Helenium autumnale	Autumn Sneezeweed	FACW+	3, 4, 5	SEASONAL	sedge meadow, wet prairie	L	M	S	sun-psun	3-5 ft	Sept-Oct	Yellow	showy yellow daisy-like flowers; moist meadows; stream banks
Helianthus grossesseratus	Sawtooth Sunflower	FACW-			wet mesic prairie, mesic prairie			no listing or possible food preference.	sun	5-10 ft	Aug-Sept	Yellow	Does utilize illiliopathy (chemical that inhibits other copeting species)
Helianthus mollis	Downy Sunflower	UPL			mesic prairie , dry prairie			no listing or possible food preference.	sun	2-4 ft	Aug-Sept	Yellow	Does utilize illiliopathy (chemical that inhibits other copeting species)
Helianthus occidentalis	Western Sunflower	UPL			mesic prairie , dry prairie			no listing or possible food preference.	sun	2-3 ft	Aug-Sept	Yellow	Does utilize illiliopathy (chemical that inhibits other copeting species)
Helianthus rigidus	Showy Sunflower	UPL			mesic prairie , dry prairie			no listing or possible food preference.	sun	3-5 ft	Aug-Sept	Yellow	Does utilize illiliopathy (chemical that inhibits other copeting species)
Heliopsis helianthoides	False Sunflower	UPL	3, 4, 5, 6	SEASONAL	mesic prairie , mesic woods , mesic savanna	M	U	no listing or possible food preference.	sun-psun	3-5 ft	July-Sept	Yellow	pale yellow cone-shaped rays with yellow disks, has milder version of (illiliopathy)
Hibiscus palustris	Swamp Rose Mallow	OBL		SEASONAL	sedge meadow		M	no listing or possible food preference.	sun	3-6 ft	July-Sept	White-Pink	Excellent shore line protector.
Hypericum pyramidatum	Great St.John's Wort	FAC+			sedge meadow			S	sun	4-6 ft	July-Aug	Yellow	Vibrant "fluorescent" yellow flowers
Iris versicolor	Wild Iris	OBL	2 (3, 4)	SAT, 0-6"	sedge meadow, shallow water emergent	N	L	R	sun-psun	2-3 ft	May-June	Blue	blue-violet flowers, excellent shoreline prtection.
Iris virginica shrevei	Blue Flag Iris	OBL		SEASONAL	sedge meadow			R	sun-psun	2-3 ft	May-June	Blue	Excellent shore line protector.
Justicia americana	Water Willow	OBL		SEASONAL	emergent		L	no listing or possible food preference.	sun	1-2 ft	June-July	Pink	Excellent shore line protector, grows from cuttings, first to colonize new sand bar, tolerates flow.

Table 5.3.1: Recommended Plant List, continued

Latin Name	Common Name	National Wetland Indicator	Hydrologic Zone	Indundation Tolerance	Community	Drought Tolerance (N=None; L=Low, M=Medium, H=High)	Salt Tolerance (N=None, L=Low, M=Medium,H=High, U=Unkown)	Deer Tolerance, discourages deer predation. Seldom damaged (S), Rarely Damaged (R) Occasionally Damaged (O)	Sun	Height range variable depending on soil conditions, hydrology, light	Flower Season	Color	Notes
Forbs (Wildflowers)													
Lespedeza captiata	Round-Headed Bush Clover	UPL			mesic prairie, dry prairie			no listing or possible food preference.	sun	2-4 ft	Aug-Sept	Yellow	Important legume
Liatris aspera	Rough Blazing Star	UPL			mesic prairie, dry praire		L	S	sun	1-3 ft	Aug-Sept	Purple	Beautiful purple "sticks"
Liatris scariosa nieuwlandii	Savanna Blazing Star	UPL			mesic prairie, mesic savanna			S	sun-psun	2-3 ft	Aug-Sept	Purple	Beautiful purple "sticks"
Liatris spicata	Dense Blazing Star	FAC+	4, 5	SEASONAL	mesic prairie, wet mesic prairie, sedge meadow	L	L	S	sun	3-5 ft	July-Aug	Purple	easy to grow; tall spikes of lavender blooms, beautiful purple "sticks"
Lobelia cardinalis	Cardinal Flower	OBL		SEASONAL	wet woods, sedge meadow			S	sun-shade	1-3 ft	Aug-Sept	Red	Vibrant red, basal plant parts prefer shading, short lived in full sun.
Lobelia siphilitica	Great Blue Lobelia	FACW+	3, 4	SATURATED	wet woods, sedge meadow	N	U	S	sun-shade	1-3 ft	Aug-Sept	Blue	blue-white flowers
Lycopus americanus	Common Water Horehound	OBL		SEASONAL	sedge meadow			no listing or possible food preference.	sun	1-2 ft	July-Aug	White	Can grow somewhat weedy.
Mimulus ringens	Monkeyflower	OBL	3, 4	SATURATED	sedge meadow	N	U	S	sun	2-4 ft	July- Sept	Lavender	blue-violet flowers
Monarda fistulosa	Bergamot	UPL	5, 6	NO	mesic prairie	N	L	R	sun	2-4 ft	July-Aug	Lavender	pink to lavender flowers, scented leaves, anti-predation species, when deer are heavy.
Parthenium integrifolium	Wild Quinine	UPL			mesic prairie, mesic savanna			no listing or possible food preference.	sun-psun	2-3 ft	July-Aug	White	Unusual white flower clusters
Peltandra virginica	Arrow Arum	OBL	(1, 2) 3	SAT, 0-1'	shallow water emergent	N	L	no listing or possible food preference.	sun	2-3 ft	June-July	Green	Excellent shoreline protector, tolerates flow, emergent aquatic; resembles an arrowhead (see leaf veins)
Penstemon calycosus	Smooth Penstemon	FACU			wet mesic woods, mesic woods			no listing or possible food preference.	psun-shade	2-3 ft	June	Purple	Striking white tubular flowers
Penstemon digitalis	Foxglove Penstemon	FAC	5, 6	NO	wet mesic prairie,mesic prairie,	H	M	no listing or possible food preference.	sun-psun	2-3 ft	June	White	white with purple tinged tubular flowers
Penstemon hirsutus	Hairy Penstemon	UPL			mesic prairie, dry prairie, mesic savanna			no listing or possible food preference.	sun-psun	1-2 ft	May-June	Purple	Darker purple tinge then digitalis, excellent contrast when blooming side by side/mixed.
Petalostemum candidum	White Prairie Clover	UPL			mesic prairie, dry prairie			no listing or possible food preference.	sun	1-2 ft	July-Aug	White	Can't beat the persistent white flowers and vegetation.
Petalostemum purpureum	Purple Prairie Clover	UPL			mesic prairie, dry prairie		L	no listing or possible food preference.	sun	1-2 ft	July-Aug	Purple	Can't beat the persistent purple flowers and vegetation.
Physostegia virginiana	Obedient Plant	FAC+	4, 5	SEASONAL	sedge meadow, wet prairie, wet mesic prairie	L	L	S	sun	2-4 ft	Aug-Sept	Pink	tall graceful plant with pink tubular flowers; very tolerant
Polygonum coccineum	Red Smartweed	OBL			shallow water emergent, sedge meadow		M	no listing or possible food preference.	sun	2-3 ft	Aug-Sept	Pink	Can grow somewhat weedy.
Pontederia cordata	Pickerel Weed	OBL	(2, 3) 4	SATURATED	shallow water emergent	N	L	no listing or possible food preference.	sun	2-3 ft	July-Sept	Blue	Excellent shoreline component, may suffer mortality if exposed to freeze. Heart-shaped leaves with purple flowers
Potentilla arguta	Prairie Cinquefoil	FACU-			mesic prairie, dry prairie			R	sun	2-3 ft	July-Aug	Sulphur	Unusual yellow flowers, seed head very persitant and interesting.
Pycnanthemum tenuifolium	Narrow-Leaf Mountain Mint	FAC			mesic prairie, dry prairie			R	sun	1-2 ft	July-Aug	White	Great anti-predation sprecies to seed heavy when deer problems.
Pycnanthemum virginianum	Common Mountain Mint	FACW+			sedge meadow, wet prairie, mesic prairie			R	sun	1-2 ft	July-Aug	White	Great anti-predation sprecies to seed heavy when deer problems.
Ratibida pinnata	Yellow Coneflower	UPL			mesic prairie			S	sun	3-5 ft	July-Aug	Yellow	Easy to grow from seed, favored yellow prairie species
Rudbeckia fulgida speciosa	Showy Black-Eyed Susan	UPL			sedge meadow, wet mesic prairie			no listing or possible food preference.	sun	2-3 ft	Aug-Sept	Gold	Easy to grow from seed, favored yellow prairie species
Rudbeckia laciniata	Green-Headed Coneflower	FACW	4, 5	SEASONAL	wet-mesic woods	H	N	no listing or possible food preference.	psun	5-8 ft	July-Aug	Yellow	yellow flowers with drooping rays and green eyes; moist thickets; swamps
Rudbeckia subtomentosa	Sweet Black-Eyed Susan	FACU+			mesic prairie, wet mesic prairie			no listing or possible food preference.	sun	3-5 ft	Aug-Sept	Yellow	Long lived species, beautiful!
Sagittaria latifolia	Common Arrowhead	OBL	1, 2, 3	SAT, 0-2'	shallow water emergent	N	N	no listing or possible food preference.	sun	1-3 ft	July-Sept	White	emergent aquatic, tubers are edible
Saururus cernuus	Lizard's Tail	OBL	2, 3, 4	SAT, 0-1'	shallow water emergent, sedge meadow	N	U	no listing or possible food preference.	sun-shade	1-2 ft	June-July	White	emergent aquatic, fragrant white flowers, rapid root spread once established, tolerates flow.
Sedum ternatum	Wild Stonecrop	UPL	6	NO	mesic woods	M	U	no listing or possible food preference.	shade	3 in	May	White	groundcover; likes rocky banks
Senecio aureas	Golden Ragwort	FACW	4, 5	SEASONAL	sedge meadow, wet woods	L	N	no listing or possible food preference.	psun-sun	1 ft	May	Yellow	groundcover; flowers in terminal clusters with many golden "fluorescent" rays
Senecio obovatus	Round-Leaf Ragwort	FACU-			dry woods,mesic woods			no listing or possible food preference.	psun-shade	1ft	April-May	Yellow	clusters with many golden "fluorescent" rays
Silene regia	Royal Catchfly	UPL			mesic prairie			no listing or possible food preference.	sun	2-4 ft	July-Aug	Red	Vibrant red five petal flowers, likes rich soil, full sun.
Silphium integrifolium	Rosinweed	UPL			mesic prairie, wet mesic prairie			no listing or possible food preference.	sun	3-6 ft	July-Aug	Yellow	Great reate of spread, favored wild life seed source
Silphium laciniatum	Compass Plant	UPL			mesic prairie			no listing or possible food preference.	sun	5-8 ft	July-Sept	Yellow	Great reate of spread, favored wild life seed source, manificent leafs size and shape!
Silphium perfoliatum	Cup Plant	FACW-			wet mesic woods, wet mesic prairie			no listing or possible food preference.	sun-psun	5-9 ft	July-Sept	Yellow	Can grow very aggressive, use sparingly.
Silphium terebinthinaceum	Prairie Dock	UPL			wet mesic prairie, mesic prairie			no listing or possible food preference.	sun	5-10 ft	July-Sept	Yellow	Great reate of spread, favored wild life seed source, magnificent leaf size and shape, very tall.
Solidago caesia	Blue-stemmed Goldenrod	UPL			mesic woods, dry woods			no listing or possible food preference.	shade	1-2 ft	Sept-Oct	Yellow	Very easy to establish in wide range of woodland soils.
Solidago flexicaulis	Zig-Zag Goldenrod	FACU			wet mesic woods, mesic woods			S	shade	1-2 ft	Sept-Oct	Yellow	Gread rate of spread once established.
Solidago gigantea	Late Goldenrod	FACW			sedge meadow, wet mesic prairie, wet mesic woods			S	sun-shade	3-5 ft	Sept-Oct	Yellow	Can be somewhat aggressive.
Solidago graminifolia	Grass-Leaved Goldernrod	FACW-			sedge meadow.wet mesic prairie			S	sun	3-4 ft	Sept-Oct	Yellow	Very easy to establish in wide range of woodland soils.
Solidago juncea	Early Goldenrod	UPL			mesic prairie, dry prairie			S	sun	1-2 ft	July-Aug	Yellow	Very easy to establish in wide range of woodland soils.
Solidago nemoralis	Grey Goldenrod	UPL	6	NO	mesic prairie, dry prairie	M	N	S	sun	1-2 ft	Sept-Oct	Yellow	dry, sterile soils; yellow flower clusters
Solidago ohioensis	Ohio Goldenrod	OBL			sedge meadow			S	sun	2-3 ft	Sept	Yellow	Very bright yellow flowers
Solidago patula	Swamp Goldenrod	OBL		SEASONAL	sedge meadow			S	sun-psun	3-6 ft	Sept	Yellow	Excellent wet-wetland species, notable basal leafs.
Solidago riddellii	Riddell's Goldenrod	OBL			sedge meadow, wet-mesic prairie			S	sun	2-4 ft	Sept-Oct	Yellow	Very bright yellow flowers
Solidago rigida	Stiff Goldenrod	FACU-			mesic prairie, dry prairie		L	S	sun	3-5 ft	Sept-Oct	Yellow	Very easy to establish in wide range of woodland soils.
Solidago rugosa	Wrinkled Goldenrod	FAC	3, 4, 5	NO	sedge meadow	M	N	S	sun-psun	2-3 ft	Sept	Yellow	yellow flowers, also very easy to establish, spreads from root emergents all directions.
Solidago speciosa	Showy Goldenrod	UPL			mesic prairie, dry prairie, mesic savanna		L	S	sun-psun	1-3 ft	Sept-Oct	Yellow	Very easy to establish in wide range of woodland soils.
Sparganium androcladum	Branched Burreed	OBL			shallow water emergent			no listing or possible food preference.	sun	1-2 ft	June-July	Green	Excellent rate of spread, good shorline protection.
Sparganium eurycarpum	Giant Burreed	OBL	1 (2, 3)	SAT, 0-12'	shallow water emergent	N	N	no listing or possible food preference.	sun	3-6 ft	June-July	Green	emergent aquatic, excellent rate of spread, good shorline protection.
Stylophorum diphyllum	Celandine Poppy	UPL			mesic woods			no listing or possible food preference.	shade	1-2 ft	April-May	Yellow	Unusual woodland species, spreads well once established.
Verbena hastata	Blue Vervain	FACW+	3, 4	SAT	sedge meadow	N	L	no listing or possible food preference.	sun	3-5 ft	July-Sept	Blue	violet blue flowers in erect spikes
Vernonia altissima	Tall Ironweed	UPL			wet mesic prairie, mesic prairie, mesic savanna			S	sun-psun	5-10 ft	Aug-Sept	Purple	Striking purple/magenta flowers, very versitle plants
Vernonia fasciculata	Smooth Ironweed	FACW			wet mesic prairie			S	sun	3-6 ft	Aug-Sept	Purple	Striking purple/magenta flowers, very versitle plants
Veronicastrum virginicum	Culver's Root	FAC			wet mesic prairie			no listing or possible food preference.	sun-psun	3-6 ft	July-Aug	White	Impressive white candle obreas.
Zizia aurea	Golden Alexanders	FAC+			sedge meadow, wet mesic prairie, mesic prairie		L	no listing or possible food preference.	sun-psun	2-3 ft	May	Yellow	Very bright yellow flowers, spreads rapidly once established.

Table 5.3.1: Recommended Plant List, continued

Latin Name	Common Name	National Wetland Indicator	Hydrologic Zone	Indundation Tolerance	Community	Drought Tolerance (N=None; L=Low, M=Medium, H=High)	Salt Tolerance (N=None, L=Low, M=Medium,H=High, U=Unkown)	Deer Tolerance, discourages deer predation. Seldom damaged (S), Rarely Damaged (R) Occasionally Damaged (O)	Sun	Height range variable depending on soil conditions, hydrology, light	Flower Season	Color	Notes
Graminoids (Grasses, Rushes, & Sedges)												**Texture**	
Andropogon gerardii	Big Bluestem	FACW	(4, 5) 6	NO	mesic prairie, wet mesic prairie	H	M	R	sun	5-8 ft	July-Aug	Coarse	warm-season grass, used with Sorgastrum provides nice contract (reddish brown, blondish tan)
Bouteloua curtipendula	Side-Oats Grama	UPL			dry prairie		M	no listing or possible food preference.	sun	1-3 ft	July-Aug	Medium	Easy to establish, beautiful when seed heads present.
Bromus latiglumis	Tall Brome	UPL			wet-mesic woods			no listing or possible food preference.	psun-shade	3-4 ft	July-Aug	Medium	Robust species for flood planr applications
Bromus pubescens	Woodland Brome	UPL			mesic woods, dry woods			no listing or possible food preference.	psun-shade	1-3 ft	June-July	Medium	Easy to establish in wide range of woodland soils.
Calamagrostis canadensis	Blue-Joint Grass	OBL		SEASONAL	sedge meadow, wet prairie			R	sun	2-4 ft	June-July	Medium	Clump former that spreads well once established
Calamovilfa longifolia var magna	Sand Reed	UPL			sand dunes		L	R	sun	4-6 ft	July-Aug	Coarse	Excellent sandy soil full sun sprecies, tolerates foot trafic
Carex annectans var xanthocarpa	Yellow Fox Sedge	OBL		SEASONAL	sedge meadow, wet-mesic prairie			S/R	sun	2-3 ft	May-June	Fine	Sedges are excellent foundation species.
Carex bicknellii	Prairie Oval Sedge	UPL			dry prairie, mesic prairie		M	S/R	sun	1-2 ft	May	Fine	Sedges are excellent foundation species.
Carex brevior	Plains Oval Sedge	UPL			dry prairie		M	S/R	sun	1-2 ft	May-June	Medium	Sedges are excellent foundation species.
Carex bromoides	Brome Hummock Sedge	OBL			wet woods, sedge meadow			S/R	psun-shade	1-2 ft	May	Fine	Sedges are excellent foundation species.
Carex cephalophora	Short-headed Bracted Sedge	FACU			mesic woods, dry woods			S/R	psun-shade	1 ft	May	Fine	Sedges are excellent foundation species.
Carex comosa	Bristly Sedge	OBL		SEASONAL	shallow water emergent , sedge meadow			S/R	sun	1-3 ft	June-July	Coarse	Sedges are excellent foundation species, great shoreline component.
Carex crinita	Fringed Sedge	OBL		SEASONAL	sedge meadow			S/R	sun-shade	2-4 ft	May-June	Medium	Sedges are excellent foundation species.
Carex cristatella	Crested Sedge	FACW+		SEASONAL	sedge meadow		M	S/R	sun-psun	2-3 ft	May-June	Fine	Sedges are excellent foundation species.
Carex davisii	Davis Wood Sedge	FACW+			mesic woods			S/R	psun-shade	2 ft	May	Medium	Sedges are excellent foundation species.
Carex emoryi	Riverbank Tussock Sedge	UPL			sedge meadow			S/R	sun-psun	2 ft	May	Medium	Sedges are excellent foundation species.
Carex frankii	Frank's Sedge	OBL			sedge meadow, wet mesic woods			S/R	sun-shade	1-2 ft	June-July	Coarse	Sedges are excellent foundation species.
Carex gracillima	Gracefull Wood Sedge	FACU+			mesic woods			S/R	shade	1-2 ft	May	Medium	Sedges are excellent foundation species.
Carex granularis	Meadow Sedge	FACW+			sedge meadow, wet mesic woods			S/R	sun-shade	1-2 ft	May-June	Medium	Sedges are excellent foundation species.
Carex grayi	Burr Sedge	FACW		SEASONAL	wet mesic woods			S/R	psun-shade	1-2 ft	May-June	Medium	Sedges are excellent foundation species, unusual star shapped (persistant) seed head.
Carex hirtifolia	Hairy Wood Sedge	UPL			mesic woods			S/R	pshade-shade	1-2 ft	May-June	Medium	Sedges are excellent foundation species.
Carex hystericina	Porcupine Sedge	OBL		SEASONAL	sedge meadow			S/R	sun	1-2 ft	May-June	Medium	Sedges are excellent foundation species.
Carex jamesii	Grass Sedge	UPL			mesic woods			S/R	shade	6 in	April-May	Fine	Sedges are excellent foundation species.
Carex lacustris	Lake Sedge	OBL		SEASONAL	sedge meadow, shallow water emergent		L	S/R	sun-shade	2-4 ft	May	Coarse	Sedges are excellent foundation species, great shoreline component.
Carex laxiflora	Beech Wood Sedge	UPL			mesic woods			S/R	shade	1 ft	April	Coarse	Sedges are excellent foundation species.
Carex lupulina	Hop Sedge	OBL		SEASONAL	wet woods		L	S/R	psun-shade	1-2 ft	May-June	Medium	Sedges are excellent foundation species, great shoreline component.
Carex lurida	Lurid Sedge	OBL		SEASONAL	sedge meadow		L	S/R	sun-psun	1-2 ft	May-June	Medium	Sedges are excellent foundation species, great shoreline component.
Carex molesta	Field Oval Sedge	UPL			sedge meadow			S/R	sun-psun	2 ft	May-June	Medium	Sedges are excellent foundation species.
Carex muhlenbergii	Sand Bracted Sedge	UPL			dry prairie, dry savanna			S/R	sun-psun	1-2 ft	May-June	Fine	Sedges are excellent foundation species.
Carex muskingumensis	Palm Sedge	OBL		SEASONAL	wet woods, wet mesic woods			S/R	shade	1-2 ft	May-June	Fine	Sedges are excellent foundation species, common wet woods species.
Carex normalis	Spreading Oval Sedge	FAC			wet mesic woods, mesic woods			S/R	psun-shade	1-3 ft	May-June	Medium	Sedges are excellent foundation species.
Carex pellita	Wooly Sedge	OBL			sedge meadow, wet mesic prairie			S/R	sun	1-2 fet	May	Medium	Sedges are excellent foundation species.
Carex radiata	Straight-Styled Wood Sedge	FAC-			wet mesic woods, mesic woods			S/R	shade	1 ft	April-May	Fine	Sedges are excellent foundation species.
Carex scoparia	Lance-Fruited Oval Sedge	FACW		SEASONAL	sedge meadow, wet mesic prairie			S/R	sun	2-3 ft	May	Medium	Sedges are excellent foundation species.
Carex shortiana	Short's Sedge	FAC			sedge meadow, wet mesic woods			S/R	sun-psun	2-3 ft	May	Medium	Sedges are excellent foundation species.
Carex sparganioides	Burreed Sedge	FAC			mesic woods			S/R	psun-shade	1-2 ft	May	Fine	Sedges are excellent foundation species.
Carex squarrosa	Narrow-Leaved Cattail Sedge	OBL		SEASONAL	sedge meadow, wet woods			S/R	psun-shade	1-2 ft	May	Medium	Sedges are excellent foundation species.
Carex stipata	Awl-Fruited Sedge	OBL		SEASONAL	sedge meadow			S/R	sun-shade	2-3 ft	May	Medium	Sedges are excellent foundation species.
Carex stricta	Tussock Sedge	OBL		SEASONAL	sedge meadow		L	S/R	sun-psun	2 ft	May	Fine	Sedges are excellent foundation species, great shoreline component.
Carex tribuloides	Pointed Oval Sedge	FACW+		SEASONAL	sedge meadow, wet woods			S/R	sun-shade	2-3 ft	May	Medium	Sedges are excellent foundation species.
Carex trichocarpa	Hairy-Fruited Lake Sedge	OBL		SEASONAL	sedge meadow			S/R	sun-psun	2-4 ft	May	Medium	Sedges are excellent foundation species.
Carex vulpinoidea	Fox Sedge	OBL		SEASONAL	sedge meadow- wet mesic		M	S/R	sun-psun	2-3 ft	May-June	Fine	Sedges are excellent foundation species, great shoreline component.
Chasmanthium latifolium	Northern Sea Oats	FACU	4, 5	SEASONAL	mesic woods	M	N	R	psun-shade	2-3 ft	July-Aug	Medium	Groundcover/clump former; dangling "oats" seed formation very persistant!
Cinna arundinacea	Common Wood Reed	FACW		SEASONAL	wet-mesic woods			no listing or possible food preference.	shade	3-5 ft	Aug-Sept	Medium	Common wet woods species.

Table 5.3.1: Recommended Plant List, continued

Latin Name	Common Name	National Wetland Indicator	Hydrologic Zone	Indundation Tolerance	Community	Drought Tolerance (N=None; L=Low, M=Medium, H=High)	Salt Tolerance (N=None, L=Low, M=Medium,H=High, U=Unkown)	Deer Tolerance, discourages deer predation. Seldom damaged (S), Rarely Damaged (R) Occasionally Damaged (O)	Sun	Height range variable depending on soil conditions, hydrology, light	Flower Season	Color	Notes
Graminoids (Grasses, Rushes, & Sedges)												**Texture**	
Deschampsia caespitosa	Tufted Hair Grass	OBL		SEASONAL	sedge meadow		L	no listing or possible food preference.	sun	2-3 ft	May-June	Fine	Whispy flowering stalks and nice clump former
Diarrhena americana	Beak Grass	FACU			mesic woods			no listing or possible food preference.	shade	1-2 ft	Aug	Medium	Excellent woodland grass species.
Eleocharis erythropoda	Creeping Spike-Rush	OBL		SEASONAL	shallow water emergent		M	no listing or possible food preference.	sun	1-2 ft	May-July	Fine	Great rate of spread.
Elymus canadensis	Canada Wild Rye	FACU+	4, 5, 6	SEASONAL	mesic praire, dry prairie, mesic savanna	M	M	no listing or possible food preference.	sun-psun	3-4 ft	June-July	Coarse	cool season, clump-forming grass with wheat-like spikes that remain until winter
Elymus riparius	Riverbank Wild Rye	FAC-		SEASONAL	wet mesic woods, mesic woods			no listing or possible food preference.	psun-shade	3-5 ft	July-August	Coarse	Common wet edge wooded species.
Elymus villosus	Silky Wild Rye	UPL			mesic woods			no listing or possible food preference.	shade	1-2 ft	June	Medium	Common woodland species
Elymus virginicus	Virginia Wild Rye	FACW-	4, 5	SEASONAL	mesic woods, wet-mesic woods	M	N	no listing or possible food preference.	sun-shade	2-3 ft	June-July	Coarse	spreads easilty; good for erosion control; very tolerant
Eragrostis spectablis	Purple Love Grass	UPL	5, 6	NO	dry prairie	H	N	no listing or possible food preference.	sun	1 ft	July-Sept	Medium	groundcover; delicate purple flowers seem to float above the plant
Glyceria striata	Fowl Manna Grass	OBL	(2, 3) 4	SEASONAL	sedge meadow, wet woods	L	N	no listing or possible food preference.	sun-shade	2-4 ft	May-June	Medium	Common wet woods species, clump forming, rapid spread rate potential.
Hystrix patula	Bottlebrush Grass	UPL			mesic woods			S	psun-shade	3-5 ft	June-Aug	Medium	Wooded slopes component, establishes easily.
Juncus canadensis	Canada Rush	OBL		SEASONAL	sedge meadow		M	R	sun	1-2 ft	June-July	Fine	Spreads from root emergents all direction and from seed (very minute dust)
Juncus effusus	Soft Rush	FACW+	(2, 3) 4	SAT, 0-1'	shallow water emergent	M	L	R	sun-psun	2-4 ft	May-June	Medium	Great rate of spread, clump former, great component to shoreline, seed fine like dust.
Juncus torreyi	Torrey's Rush	OBL		SEASONAL	sedge meadow		M	R	sun	1-2 ft	June	Medium	Interesting seed heads, little balls on sticks.
Koeleria cristata	June Grass	UPL			dry prairie, dry savanna			R	sun-psun	1-2 ft	May-June	Fine	Short lived, but establishes easily from seed, clump forming.
Leersia oryzoides	Rice-Cut Grass	OBL		SEASONAL	sedge meadow			no listing or possible food preference.	sun-psun	2-4 ft	Aug-Sept	Medium	Can be very aggressive, leaves known to slice into skin easily, shallow menacing cuts.
Panicum virgatum	Switch Grass	FAC+			wet-mesic prairie		H	S	sun	3-5 ft	July-Aug	Medium	Very aggressive, use sparingly.
Schizachyrium scoparium	Little Bluestem	FACU	6	NO	mesic prairie, dry prairie	H	L	R	sun	2-3 ft	Aug-Sept	Medium	warm-season grass, tolerates poor, dry soils
Scirpus acutus	Hardstem Bulrush	OBL		SEASONAL	sedge meadow, shallow water emergent		M	S	sun	4-6 ft	May-June	Coarse	Excellent shoreline component, good rate of spread, introduction should be 0-3"
Scirpus atrovirens	Dark Green Bulrush	OBL		SEASONAL	sedge meadow			S	sun	3-5 ft	May-June	Coarse	Spreads and establishes easily
Scirpus cyperinus	Woolgrass	OBL		SEASONAL	sedge meadow		M	S	sun	3-5 ft	July-Aug	Medium	Spreads and establishes easily, tolerates dry downs quite well!
Scirpus fluviatilis	River Bulrush	OBL		SEASONAL	shallow water emergent			S	sun	3-7 ft	May-June	Coarse	Excellent shoreline component, good rate of spread, introduction should be 0-3"
Scirpus pendulus	Reddish Bulrush	OBL		SEASONAL	sedge meadow		M	S	sun	3-5 ft	May-June	Medium	Spreads and establishes easily, tolerates dry downs quite well!
Scirpus pungens	Three-Square Bulrush	OBL		SEASONAL	sedge meadow, shallow water emergent		M	S	sun	2-5 ft	June	Medium	Excellent shoreline component, good rate of spread, introduction should be 0-3"
Scirpus validus	Soft-Stem Bulrush	OBL		SEASONAL	sedge meadow, shallow water emergent		M	S	sun	4-8 ft	May-June	Coarse	Excellent shoreline component, good rate of spread, introduction should be 0-3"
Sorghastrum nutans	Indian Grass	UPL	6	NO	mesic prairie, dry prairie	M	M	R	sun	4-6 ft	Aug-Sept	Medium	warm-season grass
Spartina pectinata	Prairie Cordgrass	FACW+			wet mesic prairie, wet prairie, sedge meadow		H	no listing or possible food preference.	sun	4-7 ft	July-Aug	Coarse	Very versitile species, tolerates wet/dry extreemes, tends to grow in mon-typic stands.
Sporobolus heterolepis	Prairie Dropseed	FACU-			mesic prairie, dry prairie		L	no listing or possible food preference.	sun	1-3 ft	July-Sept	Fine	Excellent clump former, smells like coriander when blooming, hard to establish from seed (seed very perishable)
Woody Plants												Color	
Amorpha canescens	Leadplant	UPL			mesic prairie, dry prairie, mesic savanna				sun-psun	1-3 ft	June-July	Purple	Excellent legume, prairie shrub
Ceanothus americanus	New Jersey Tea	UPL			mesic prairie, dry prairie, mesic savanna				sun-psun	1-3 ft	June-July	White	Dificult to establish from seed (special pre-treatments neccesary)
Cephalanthus occidentalis	Buttonbush	OBL		SEASONAL	shallow water emergent, sedge meadow				sun-shade	6-10 ft	June-Aug	White	Excellent shoreline component, common wet woods shrub, grows well from cuttings.
Clematis virginiana	Virgin's Bower	FAC			sedge meadow, wet woods				sun-psun	4-8 ft	Aug-Sept	White	Excellent wet woods vine.

Table 5.3.1: Recommended Plant List, continued

*** WET LAND INDICATOR (probability of occurring in a wetland):**

OBL	Obligate wetland species	99%
FACW	Faculative wetland species	67-99%
FACW	Faculative species	34-66%
FACU	Faculative upland species	1-33%
UPL	Upland species	1%
(+)	indicates that the species occurs in the higher portion of the range	
(-)	indicates that the species occurs in the lower portion of the range	

Those species with no wetland indicator are virtually intolerant of flooding or prolonged soil saturation during the growing season.

**** HYDROLOGIC ZONES**

Zone 1: Open water - Permanent pool (12 inches - 6 feet)
This zone is best colonized by submergent plants, if at all. This deep water zone is not usually planted for several reasons: there are few species that can grow in this zone, and many are not commercially available: open water areas provide unique habitat; and deep water aquatic plants may clog the stormwater facility outlet structure. The benefits of planting in this zone include the absorption of nutrients in the water column; enhanced sediment deposition; improved oxidation; and the creation of additional habitat.

Zone 2: Shallow water terrace/Aquatic bench (6 inches - 1 foot)
This zone offers ideal conditions for a wide variety of emergent wetland plants. These areas typically fringe the ponding area and are permanently inundated.

Zone 3: BMP Fringe - Low marsh (0-6 inches regular inundation)
This zone is typically the shore line of a pond or wetland - its width determined by the design slope. This zone is usually inundated except during periods of drought and is the interface between the emergent wetland plantings and the upland plantings. Plants must be able to withstand periods of inundation as well as periods of drought and should have some capacity for slop stablization.

Zone 4: BMP Fringe - High Marsh (periodic inundation, saturated soils)
This zone extends upslope from zone 3 and may be inundated after storms. It constitutes the majority of the temporary extended detention area. Plants selected should be able to withstand periodic inundation after storms as well as significant drought during the summer.

Zone 5: Floodplain terrace (infrequent inundation, temporarily saturated soils)
Zone 5 is infrequently saturated by floodwaters that quickly recede in a day or less. Plants should be able to withstand infrequent inundation as well as drought and should offer some slope stabilization.

Zone 6: Upland (never inundated)
This zone extends above the maximum design water surface elevation. Plant selection should be based on local soil and light conditions, and on the amount of available space for plantings.

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6. Applicability and Comparison

The performance and effectiveness of a Best Management Practice (BMP) for treating and/or controlling Storm Water runoff depend on project type, site conditions, design, operation, and maintenance of the BMP. The initial selection of a BMP appropriate for the site sets the stage for effective Storm Water management. The numerous combinations of potential projects, locations, land use, and available space make this selection challenging.

Table 6.0.1 shows which BMPs are potentially suited for a site based on land use and land area. For example, a detention basin may be less suited to an ultra urban site than it is to a single family residential subdivision. Each BMP can be adapted to most land uses and other factors must be considered. The issue of available land area is specifically addressed in the last column of Table 6.0.1. Some BMPs, such as green roofs, have little to no space requirements, while others, such as detention ponds, take up a large amount of space on the site. BMPs requiring a high level of dedicated land would not be appropriate for sites where most of the land will be developed for other uses, typical in ultra urban areas.

Table 6.0.1: Green Storm Water Infrastructure Land Use and Land Area Selection Matrix

	Criteria								
	Land Use								**Land Area Req'd**
Practices	**SF Res.**	**MF Res.**	**Com.**	**Schools**	**Ultra Urban**	**Indust.**	**Retrofit**	**Road/ Roadside**	
Green Roofs	○	○	●	●	●	●	◉		○
Permeable Pavement	◉	◉	●	●	●	○	◉	◉	○
Rain Water Harvesting	●	●	●	●	◉	●	●		○
Filter Strips	●	●	●	●	◉	◉	◉	●	◉
Bioretention	●	●	●	●	●	●	●	●	◉
Low Impact/ Retentive Grading	●	●	●	●	◉	●	●	●	○
Swales	●	●	●	●	◉	●	●	●	◉
Subsurface Infiltration	●	●	●	●	●	●	●	●	●
Inlet and Outlet Control	●	●	●	●	●	●	●	●	○
Filters		◉	●	●	●	●	●	●	◉
Subsurface Vaults	○	○	●	●	●	●	○	○	◉
Detention Basin*	○	●	●	●	○	●		○	●

● - Well suitability for land use applications or high relative dedicated land area required.
◉ - Average suitability for land use applications or moderate relative dedicated land area required.
○ - Low suitability for land use or relative low dedicated land area required.
Blank – Not applicable for land use.
*Note: In retrofit cases consider enhancing an existing detention basin/pond with a native planting buffer.

Once BMP selection has been narrowed down based on land use and space requirements; the effectiveness of the BMP for volume reduction, peak discharge control, and water quality should be evaluated. Table 6.0.2 shows the effectiveness of the BMPs in meeting these Storm Water management objectives, assuming they are designed, operated, and maintained effectively. BMPs differ in their ability to store, attenuate, and treat Storm Water. When a BMP does not meet a Storm Water management objective, another BMP can be added to form a treatment train. Some BMPs can be designed with or without infiltration and this will affect its ability to meet the objectives.

Table 6.0.2: Effectiveness of BMPs in Meeting Storm Water Management Objectives

Practices	Volume	Peak Discharge	Water Quality
Green Roofs	●	●	●
Green Roof w/Infiltration	○	○	○
Permeable Pavement	●	●	○
Permeable Pavement w/Infiltration	●	●	●
Rain Water Harvesting*	●	●	●
Filter Strips	○	○	●
Filter Strips w/Infiltration	○	○	○
Bioretention	●	●	●
Low Impact/ Retentive Grading	○	●	●
Low Impact/ Retentive Grading w/Infiltration	●	●	●
Swales	○	●	●
Swales w/Infiltration	●	●	●
Subsurface Infiltration	○	●	●
Subsurface Infiltration w/Infiltration	●	●	●
Inlet and Outlet Control	○	⦿	⦿
Filters	○	●	●
Filters w/Infiltration	●	●	●
Subsurface Vaults	●	●	○
Subsurface Vaults w/Infiltration	●	●	●
Detention Basin	○	●	●
Detention Basin w/Infiltration	●	●	●

* A single cistern typically provides greater volume reduction than a single rain tank.

Key: ● High effectiveness ⦿ Medium effectiveness ○ Low effectiveness

Rankings are qualitative. "High effectiveness" means that one of the GIP's primary functions is to meet the objective. "Medium effectiveness" means that a GIP can partially meet the objective but should be used in conjunction with other BMPs. "Low effectiveness" means that the GIP's contribution to the objective is a byproduct of its other functions, and another decentralized control should be used if that objective is important.

Other criteria, such as maintenance requirements, safety concerns, potential pollutants, aesthetics, and public amenities must also be taken into consideration. Planning for Storm Water management early in the design phase can allow opportunities to enhance the property and benefit the environment. Examples based on road/roadside, parks/open space, and multiple family residential areas are given below.

Road/Roadside projects are typically designed with the primary purpose of transportation with Storm Water management taken into account late in the design process. The result is often an end of pipe BMP, such as a mechanical unit. Mechanical units do meet water quality requirements, but lack additional benefits that can be found in other BMPs. Maintaining Storm Water quality units also requires the use of specialized equipment and it can be difficult to access and inspect the unit. If the roadway is instead designed with a swale or ditch, the additional benefit of volume and flow rate reduction can be seen. If space for a swale or ditch is limited, hybrid ditches typically have a smaller footprint than conventional ditches and can be connected to the storm drain system via a subsurface pipe. Unlike a mechanical unit, Storm Water entering the swale from the roadway receives some pretreatment along the side slope. The swale or ditch itself can also be designed to encourage filtering and infiltration. This treatment reduces erosion from concentrated flow and reduces pollutants.

In the design of schools and parks as new development or redevelopment projects, there is generally open land available for the installation of BMPs. However, some opportunities for the installation of BMPs to improve Storm Water quality are often not utilized. Schools and parks provide an excellent opportunity for demonstration sites of green infrastructure BMPs including: permeable pavement, rain gardens, bioretention, vegetated swales, native plantings, and riparian or stream bank restoration. Routine maintenance is generally already being done at these sites. The use of native plants and rain gardens may reduce maintenance cost by reducing the need to mow, spray, and water non native plants or turf grass that is commonly used. Demonstration sites can be used to promote the use of native plants and rain gardens to residents who visit the schools or park areas. Schools and parks are also an excellent location to showcase permeable pavement, rain gardens and rain water harvesting. The City can promote permeable pavement sites to developers through literature and tours. Rainwater harvesting is highly visible and can be appealing to both private homeowners and developers when shown to be an easy way to conserve water and help the environment.

Multiple family residential sites are usually developed to maximize living units and parking and then ponds or mechanical units are inserted to treat the resulting Storm Water runoff. By considering Storm Water management earlier in the design process, natural features can be preserved or restored and storage can be distributed in several areas. Preserving natural features (e.g. forested areas and wetlands) at a development site often leads to an increased value to the lots that are adjacent to the natural feature. By using distributed storage (e.g. rain gardens) at a development site this enhances both the landscape and the quality of Storm Water and also could be used to educate the public about Storm Water quality and create awareness of the City's rain garden and native planting program. Adding walkways or common areas around BMPs can create valuable site amenities to promote sustainability and livability throughout the neighborhood.

6.1. Evaluation of Green Design Techniques

The integrated approach to Storm Water management requires consideration of many new concepts and practices. In addition to identifying the appropriate BMP based on land use and

Storm Water Management objectives, as described above, cost and performance comparisons between Storm Water Management options are often conducted. However, a direct comparison of the costs and performance of these new practices to conventional engineered storm drainage systems, or for that matter to each other, should be handled with caution for a number of reasons:

1. The practices apply to different areas and situations. Some, such as rain barrels, apply only to residential areas, whereas others, such as rooftop storage, would be implemented only in large commercial/industrial/ institutional buildings, and others, such as inlet restrictors, would be installed in paved areas. The level of performance (amount of water controlled) also varies widely.

2. Onsite Storm Water reduction practices offer a widely-varying range of benefits beyond Storm Water reduction, such as water quality benefits, groundwater recharge, habitat improvement, and educational values.

3. The integrated approach involves small scale, distributed practices that will have accumulated results - maybe not always more efficiently than engineered solutions, but often more effective, with improved benefits and increased participation and long term implementation.

4. The concepts of green infrastructure, sustainable development, and improved site design will require a mix of structural, nonstructural, institutional, and educational elements. Implementation of these elements will necessitate increased partnerships. The onsite practices attractive to private residents offer partnership opportunities with community and neighborhood groups, special interest groups (such as garden clubs), and municipalities. The practices that are more appropriate for institutional or commercial property owners offer the City the opportunity to partner with existing organizations that have many properties, such as school districts, banks, or developers.

5. The onsite practices offer a wonderful opportunity to educate the public about Storm Water and watershed health and protection. Residential programs lend themselves to enhancing homeowner understanding of Storm Water issues.
Practices such as rain gardens or downspout disconnects are very tangible, easily understood concepts. Practices that involve established institutions allow the City to raise awareness among large groups of people, such as service organizations or tenants of properties. Practices such as green roofs, when partnered with a school district, offer the City the chance to build an education program for school children and their parents. Establishing some sort of recognition program to residents/institutions who participate in Storm Water reduction practices provide the City with additional education/awareness opportunities through publicity and media coverage.

It is helpful to evaluate the attributes and limitations of the Storm Water reduction practices and to understand the conditions under which these practices perform best. For each practice, Table 6.1.1 summarizes the flow benefits, environmental features, implementability, function, operation and maintenance needs, and potential to promote environmental awareness.

1. All practices provide some reduction in Storm Water flow (otherwise, of course, they would not be included in the table). However, the level of hydrologic/hydraulic performance varies widely.

2. Three-fourths of the practices have the potential - depending on the design - to provide at least marginal benefits during "major" (> 1") storms.

3. All but two of the practices may be expected to provide pollutant removal and water quality benefits.

4. While many practices are believed to be acceptable to the public, a fairly intensive public education program will be needed for successful implementation.

5. Over three fourths of the practices offer opportunities for partnerships.

6. About 65% of the practices utilize vegetation; 82% increase infiltration; and
53% involve Storm Water storage.

7. Over one-half of the practices have a "good" or "very good" potential to help promote environmental responsibility and awareness.

8. A few practices - French drains, dry wells, and infiltration sumps - may have limitations that merit site specific soils investigations.

Table 6.1.2 presents the cost effectiveness of the practices. Capital costs and costs per impervious acre served are provided. Note that the amount of Storm Water reduction varies: a rain barrel may store only ¼" of runoff from a roof, while a green roof may accommodate more than 2" of rainfall. The cost effectiveness estimates do not reflect these variations in performance. The cost per impervious acre served ranges from less than $1,000 per acre to $653,400 per acre. The median cost is approximately $16,000 per impervious acre.

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Table 6.1.1: Evaluation of Storm Water Reduction BMPs
(Milwaukee Metropolitan Sewerage District (MMSD), 2005)

Stormwater Reduction Practice	Flow					Environmental		Implementability							Function			Operations and Maintenance Needs	Environmental Awareness
	Delays Runoff	Reduces Runoff Volume	Reduces Peak Flow	Increases Infiltration	Effective in Major Storms	Water Quality Protection	Ecology/ Habitat Improvement	Public Acceptance	Public Education Needed	Financial Incentive Needed	Sensitive to Proper Operation	Opportunity for Partnership	Applicability	Limitations	Plant Uptake	Infiltration	Storage		
1. Downspout Disconnection	Yes	Yes	Yes	Yes	Yes	Yes	No	Good	Yes	Yes	No	Yes	CSSA only.	Interior downspouts. House foundations. Basement flooding. Safety / ice concerns.	*	*		Low. Inspections.	Good. Residential / neighborhood.
2. Rain Barrels	Yes	Yes	Yes	Maybe	No	Maybe	No	Good	Yes	Yes	Yes	Yes	Residential.	Mosquitos. Small lots. House foundations. Winter.	*	*	*	Moderate. Must be emptied. Winter storage. Check fittings and connections.	Very good. Residential.
3. Cisterns	Yes	Yes	Yes	Maybe	Yes	Maybe	No	Fair/Poor	Yes	Yes	Yes	Yes	Residential. Commercial. Industrial.	May reuse water (potential: laundry, toilet, outdoor uses). Winter.			*	Moderate. Check fittings and connections. Disconnect / empty in winter.	Average.
4. Rain Gardens	Yes	Yes	Yes	Yes	No	Yes	Yes	Good	Yes	Maybe	Yes	Yes	Residential and light commercial/industrial.	Land availability. Unsuitable soils.	*	*		Moderate. Plant upkeep. Weed control. Occasional watering.	Very good. Residential/community.
5. Green Roofs	Yes	Yes	Yes	No	Maybe	Yes	Yes	Fair	No	Yes	Yes	Yes	Flat roofs (subject to limitations). Industrial. Commercial.	Load-bearing capacity. Moisture and root penetration resistance.	*	*	*	Moderate. Plant upkeep and maintenance of roof structure. More maintenance than a conventional roof.	Good. Institutions/commercial/industrial.
6. Rooftop Storage	Yes	Maybe	Yes	No	Yes	No	No	Good	No	No	No	Yes	Commercial, industrial, and institutional flat roofs.	Load-bearing capacity. Waterproofing. Mosquitos.			*	Low.	Good.
7. Green Parking Lots	Yes	Yes	Yes	Yes	Maybe	Maybe	Yes	Good	Yes	No	No	Yes	Commercial, industrial, institutional.	Open space. Suitable soil	*	*		Moderate. Maintain vegetation.	Good public display.
8. Stormwater Trees	Yes	Yes	Yes	Yes	Maybe	Maybe	Yes	Good	Yes	Yes	No	Yes	Most pervious areas, and in planters.	Pervious open space.	*	*		Moderate. Routine tree maintenance and watering.	Good for community group participation.
9. Porous Pavement	Yes	Yes	Yes	Yes	Yes	Yes	No	Fair	Yes	Maybe	Yes	Yes	Low traffic areas and parking lots. Sidewalks.	Winter freeze/thaw.		*		High. High maintenance and cleaning needed to prevent clogging. Monthly vacuuming and power	Good.
10. Inlet Restrictors/ Pavement Storage	Yes	No	Yes	No	Yes	No	No	Poor	Yes	No	No	No	Streets with flat grades, low traffic, and curbs and berms to impound water. Residential feeder streets.	Safety. Street access.			*	Low. Minimal.	Average. Maybe good for municipal recognition.

Table 6.1.1: Evaluation of Storm Water Reduction BMPs, continued

Stormwater Reduction Practice	Flow					Environmental		Implementability							Function			Operations and Maintenance Needs	Environmental Awareness
	Delays Runoff	Reduces Runoff Volume	Reduces Peak Flow	Increases Infiltration	Effective in Major Storms	Water Quality Protection	Ecology/ Habitat Improvement	Public Acceptance	Public Education Needed	Financial Incentive Needed	Sensitive to Proper Operation	Opportunity for Partnership	Applicability	Limitations	Plant Uptake	Infiltration	Storage		
11. Bioretention	Yes	Yes	Yes	Maybe	Maybe	Maybe	Yes	Good	No	No	No	Yes	Open land areas. Well-drained soils (or w/ under drain).	Land availability. Unsuitable soils.	*	*	*	Low. Vegetation upkeep - mowing, removal of invasive species, replanting, removal of debris, and corrosion control.	Average.
12. On-site Filtering Practices	Yes	Yes	Yes	Yes	Maybe	Yes	Maybe	Fair	Yes	Yes	Yes	Yes	Small drainage area.	No steep slopes. Risk of clogging. Standing water.	*	*		High. Inspections and cleaning to prevent clogging.	Average.
13. Pocket Wetlands	Yes	Yes	Yes	No	Yes	Yes	Yes	Fair/Poor	No	No	No	Yes	Parking lots. Small sites.	Supplemental irrigation. Site requirements. Mosquitos. Winter & salt.	*	*	*	Low. Sediment removed. Invasive species.	Good.
14. French Drains and Dry Wells	Yes	Yes	Yes	Yes	Maybe	Yes	No	Poor	Yes	No	No	Yes	Small drainage areas. Residential.	Permeable soils. Adequate depth to gw. Clean water.		*	*	Low. Annual training. Replace rock and clean out sediment.	Average.
15. Infiltration Sumps	Yes	Yes	Yes	Yes	Maybe	Yes	No	Fair	No	No	No	No	Residential areas <50% impervious. Placed in rights of way of smaller streets.	Permeable soils. Adequate depth to gw.		*		Low. Clean out sumps every 2-3 years. Every year inspection.	Average.
16. Compost Amendments	Yes	Yes	Yes	Yes	No	Yes	Maybe	Fair	Yes	Yes	No	Yes	Highly compacted soils with low organic matter and nutrients.	Temporarily disturbs vegetative cover.	*	*		Low. None.	Average.
17. Stormwater Rules and Redevelopment Policies	Yes	Yes	Yes	Maybe	Yes	Yes	Maybe	Fair	No	No	No	No	New development and redevelopment.	Prescriptive. Rigid criteria.	*	*	*	Low. None.	Average.

Table 6.1.2: Cost Effectiveness of Storm Water Reduction BMPs

(Milwaukee Metropolitan Sewerage District (MMSD), 2005)

Stormwater Reduction Practice	Capital Cost	$/Impervious Acre Served (min)	$/Impervious Acre Served (max)	Vol of Runoff/ Imp Ac [gal]	$/gal (min)	$/gal (max)	Assumptions
1. Downspout Disconnection	$50 to $250/downspout.	$4,400	$21,800	12,938	0.34	1.68	Each downspout disconnection drains 500 square feet of roof
2. Rain Barrels	$150/each rain barrel.	$13,100	--	10,345	1,27	NA	Each rainbarrel drains 500 square feet of roof and captures 0.4".
3. Cisterns	$1,000 (500 gallon) to $5,000 (6,500 gallon underground).	$43,600 $10,000		19,400 12,938	2.25 0.77	NA 1.55	500-gallon cistern drains 1,000 square feet of roof for 0.75" rain. Two 6,500 gal can capture 1". Water re-use may reduce water supply costs.
4. Rain Gardens	$5 to $10/square foot.	$21,800	$43,600	25,875	0.84	1.69	100 square foot rain garden drains 1,000 feet of roof.
5. Green Roofs	$15/square foot of roof $8/sq ft (net)	$348,480	$653,400	12,938	26.93	50.5	Complete green roof system includes watertight membrane, protective layer, insulation, drainage system, filter layer, soil, and plants.
6. Rooftop Storage	$100/drain restrictor. $5/square foot waterproofing	$4,356	$222,200	25,875	0.17	8.59	One restrictor per 1,000 square feet of roof. Waterproof entire roof.
7. Green Parking Lots	$200/tree pit. $13,000-$30,000/acre bioretention. $2/square foot turf pavers.	$10,000	$11,700	25,875	0.39	0.45	10% of parking lot area is bioretention, and 10% is turf paved.
8. Stormwater Trees	$200 - $340/tree	$27,800	$47,260	22,869	1.22	2.07	Each acre of trees receives drainage from one impervious acre. $670 per residential acre; $3,300 per commercial/industrial acre. Street trees assume 20' diam. canopy/tree (314 sq ft).
9. Porous Pavement	$2-$4/square foot	$81,700	$174,000	25,875	3.16	6.72	Lower cost is turf or gravel paver; higher cost is porous asphalt or concrete.
10. Inlet Restrictors / Pavement Storage	$400-$1,200 per restrictor	$450	$1,350	54,450	0.01	0.02	Each inlet restrictor serves 1.5 acres @ 60% impervious.
11. Bioretention	$13,000-$30,000/acre.	$6,500	$15,000	25,875	0.25	0.58	Each bioretention acre drains two impervious acres.
12. On-site Filtering	Swales: $3,500/5-acre residential site. Sand filter: $35,000-$75,000/5-ac commercial site. Filter Strips: $13,000/$30,000/acre.	$1,200 $8,700 $2,600		25,875 25,875 25,875	0.05 0.34 0.10	NA 0.72 NA	Swales: 5-acre 80% impervious residential site. Sand Filters: 5-acre 80% impervious commercial site. Filter Strips: Each acre of filter strip serves 5 impervious acres.
13. Pocket Wetlands	$60,000/acre/foot.	$16,000		25,875	0.62	NA	0.5 acre, 3-foot deep pocket wetland serves 5 acres, 1/2 of which is impervious.
14. French Drains and Dry Wells	French drain: $15-$17 linear foot. Dry Well: $900 to $1,400/each	$26,136 $78,400	$29,621 $122,000	12,938 12,938	2.02 6.06	2.29 9.43	Each dry well drains 500 square feet of roof.
15. Infiltration Sumps	$5,000 to $10,000 per sump.	$5,500	$11,000	25,875	0.21	0.43	Each sump serves 1.5 acres @ 60% impervious.
16. Compost Amendments	$1-$2/square foot.	$21,800	$43,600	12,938	1.68	3.37	Each acre of compost amended soil drains two impervious acres.

Notes:
Volume of runoff per impervious acre based on assumption that practices treat between 0.4 and 1.0 inches, depending on the practice. WQv =(Rv)(A)(P), Rv = 0.95 assuming 1ac of impv.
1" yields (0.95)(43560 sqft)(1"/12)(7.5 gal/cuft)=25,875 gal
0.75" yields (0.95)(43560 sqft)(0.75"/12)(7.5 gal/cuft)=19,400 gal
0.5" yields (0.95)(43560 sqft)(0.5"/12)(7.5 gal/cuft)=12,938 gal
0.4" yields (0.95)(43560 sqft)(0.4"/12)(7.5 gal/cuft)=10,345 gal
Street tree assumptions are based on installed costs of b/w $200-$340 per tree,rainfall interception of 0.525 gal/sqft(22,869 gal per canopy ac),average canopy per tree of 314 sq ft (139 trees per canopy acre).
Inlet restrictor assumes 0.75' depth at gutter, 0% longitudinal street slope, and 7260 cuft of runoff.

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Appendix 1

Low Impact Development for Big Box Retailers

LOW IMPACT DEVELOPMENT

for

BIG BOX RETAILERS

Prepared Under EPA Assistance Agreement # AW-83203101
For EPA Office of Water
November 2005

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TABLE OF CONTENTS

I. PURPOSE 3
II. DOCUMENT ORGANIZATION 3
III. INTRODUCTION TO LID STRATEGIES AND TECHNIQUES 4
III.1. LID Background 4
III.2. Big Box Development Considerations 5
III.3. Discussion of LID Opportunities for Big Boxes 7
III.4. LID Design Approach 7
III.4.1.LID Planning and Design Objectives 8
Site Design Elements 9
Stormwater Management Objectives 9
Site Functions 9
Corporate and Community Development 9
LID Site Design Components 10
Site Conditions 10
Planning Codes and Ordinances 10
III.4.2.LID Design Strategies and Techniques 11
III.5. LID BMP Selection Criteria 12
IV. LID CASE STUDIES 16
V. REFERENCES 25
VI. APPENDIX A – Brief description of 14 additional LID BMPs 26
VII. APPENDIX B – Image Gallery 30
VIII. APPENDIX C – Ten LID BMP Fact Sheets 35
VIII.1. Bioretention Basins 36
VIII.2. Bioretention Cells 40
VIII.3. Bioretention Slopes 44
VIII.4. Bioretention Swales 48
VIII.5. Cisterns / Rainbarrels 52
VIII.6. Water Quality Swales 56
VIII.7. Permeable / Porous Pavement 60
VIII.8. Planter Box 64
VIII.9. Tree Box Filters 68
VIII.10. Green Roofs 72

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

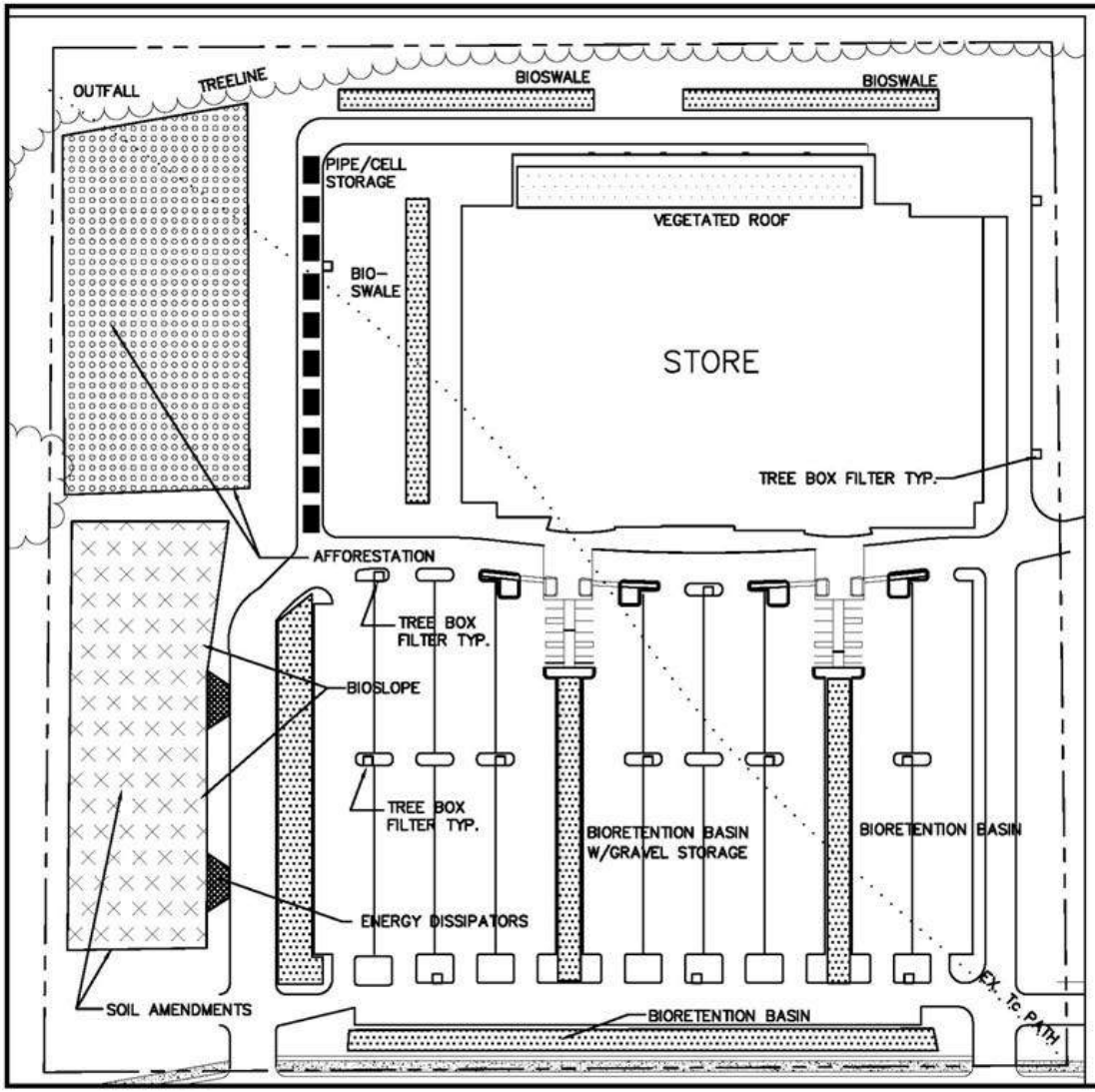
- Detention volume: 2.1 acre feet or 1.1 inches using TR-55 graphical peak method.

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

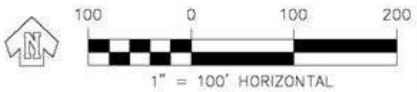
- Afforestation and soil amendments on western portion of site. Increase infiltration capacity to HSG B and change in land cover
- Conservation of woods
- Credit bioretention areas as HSG B and Meadow
- Weighted CN is 86
- Tc is 0.26 hours
- Peak Discharge (cfs): 92
- Runoff Volume (in.): 3.65

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.

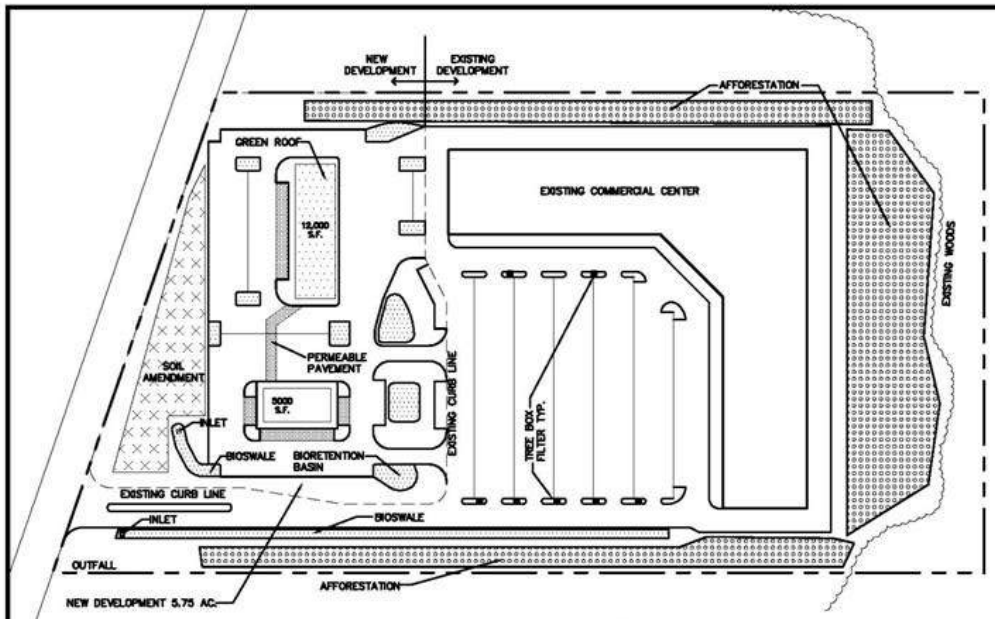
- One 11,000 S.F. green roof.
    - Covers entire 12, 000 S.F. roof of strip retail shops except utility areas and access points.
    - Assume 1.5’ storage within green roof media and no ponding.
    - Additional storage for roof runoff is provided in adjacent BMPs.
- Ten bioretention basins and one 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.

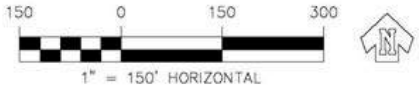
BMPs – Remainder of Site (Existing Development)

- 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.





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 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.

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:

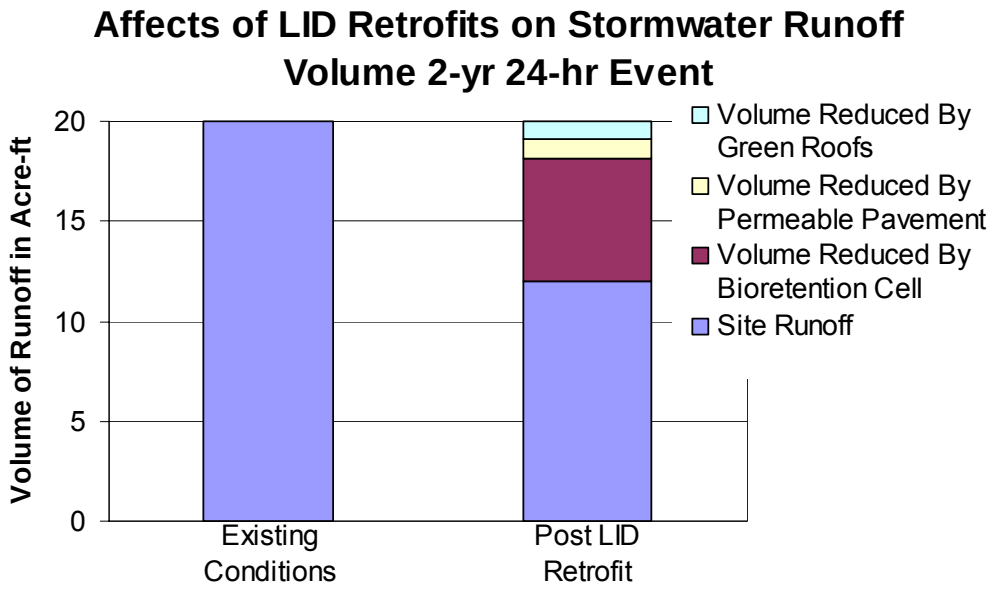
- 2.2 acres of afforestation on western portion of site. Increase infiltration capacity and change in land cover
- Conservation of woods
- Credit bioretention, permeable pavement, and green roofs areas as HSG B and Open Space

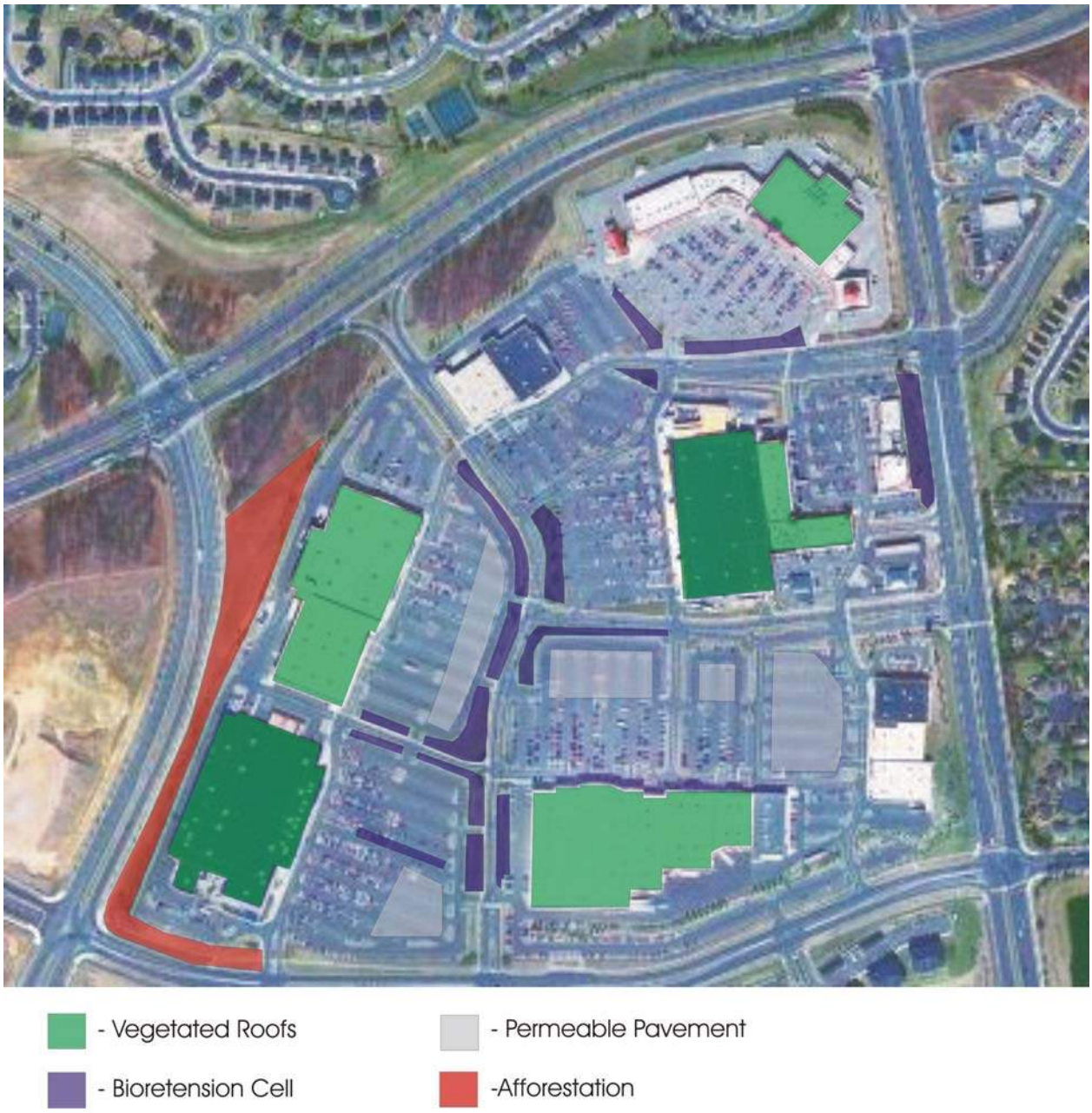
Results:

- 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

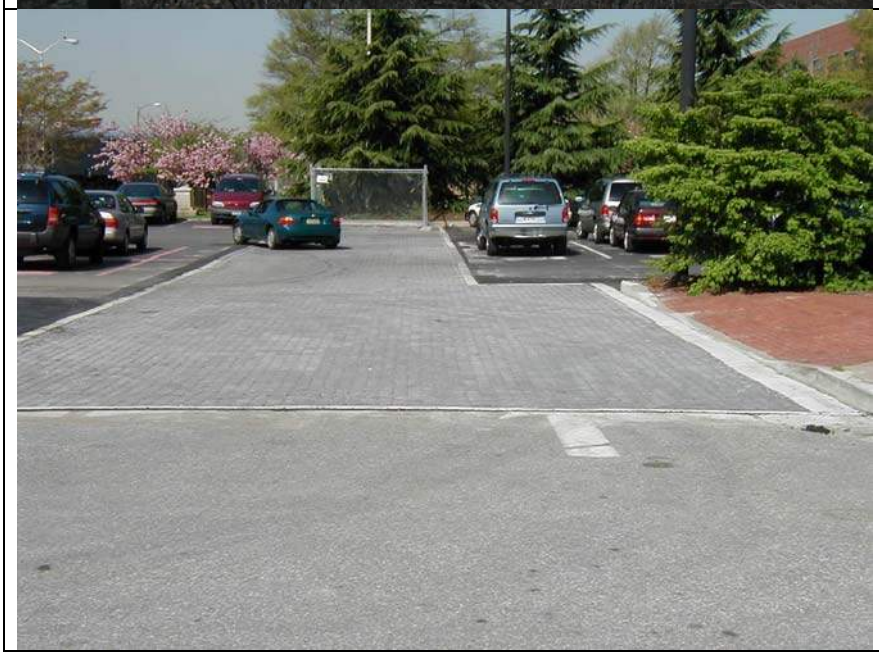
	Description:	A flow splitter allows the runoff volume from a drainage area to be split into two or more quantities ("sub-volumes"). Typically, flow splitters are used to isolate the water quality volume (WQV) in order to provide water quality treatment or manage a portion of a storm event with one or 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.

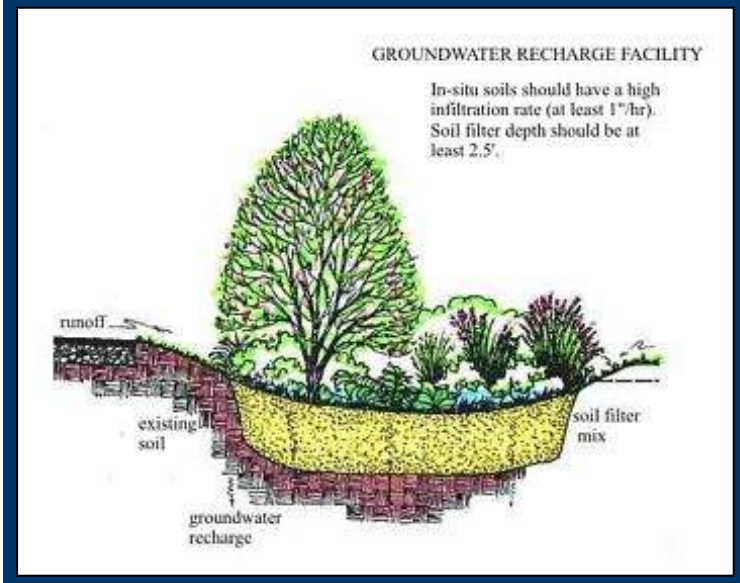
Volume reduction depends upon:

- 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



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 and parking lots.

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

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.

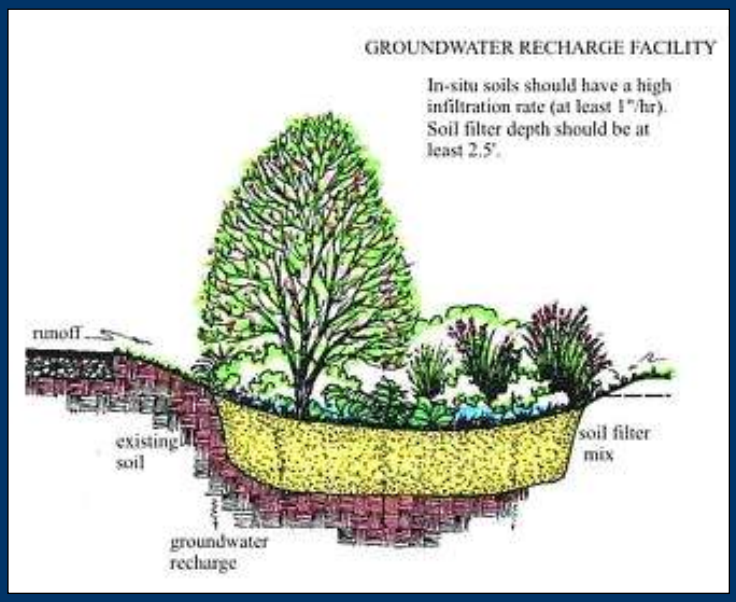
The depth of the gravel layer may be increased to add storage capacity. Exfiltration into the subsoil can reduce the volume of stormwater that ultimately enters the conveyance system.
Volume reduction depends on the available detention storage in the gravel layer and ponding area. It also is a function 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.

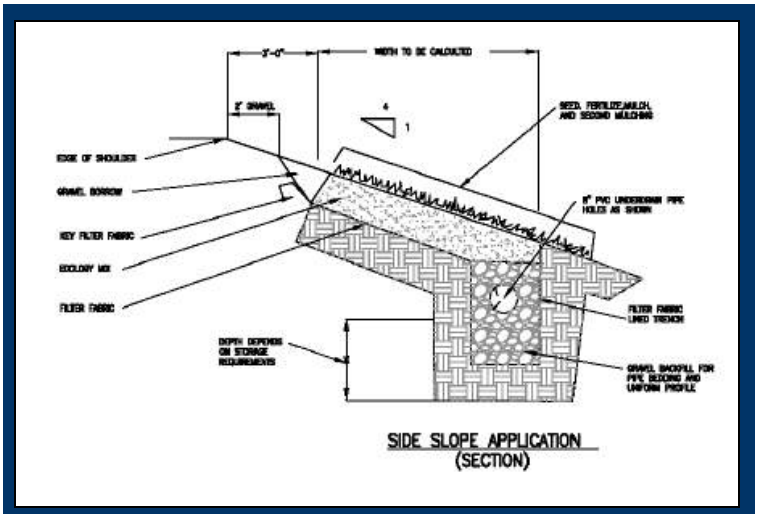
For storms with an intensity greater than the design rainfall intensity, some runoff will not be captured and infiltrated, but will flow over the surface of the bioslope. Stormwater not captured by the bioslope can be detained through additional (sub)surface storage at the base of the bioslope.

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

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.**

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**

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

Bioswale Maintenance
Source: LID Center

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.

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.

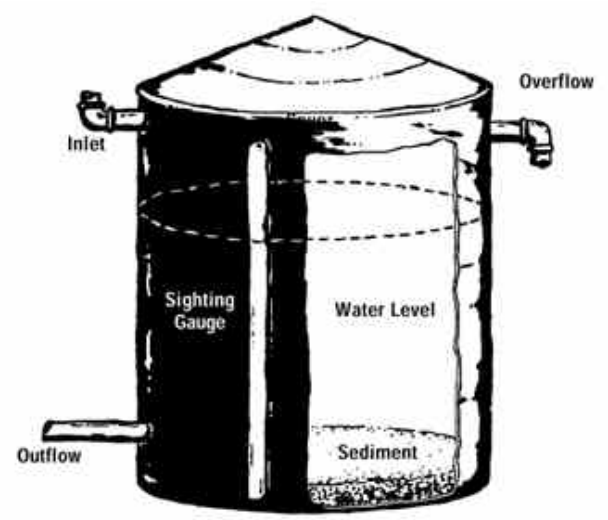
Samples of bioretention media should be assessed if there is poor infiltration to determine the condition of the media (e.g. clay content).

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

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.

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

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.

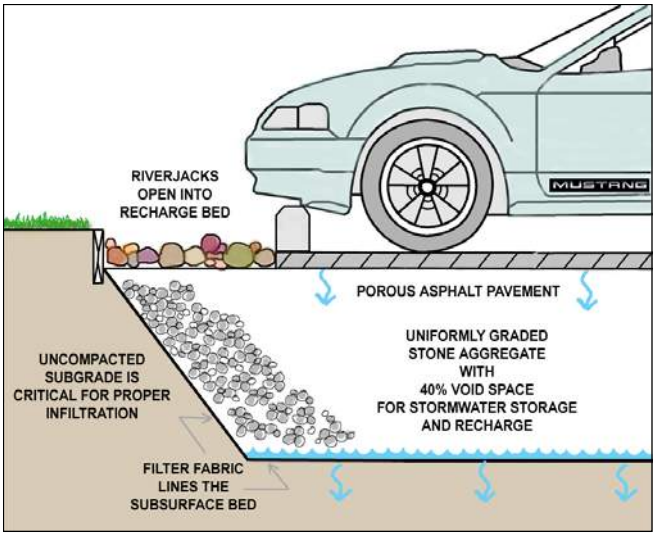
Aeration of a swale should be done every other year to maintain the function of the soils and aid infiltration. Annual inspections should be conducted to determine water infiltration and conveyance.

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.

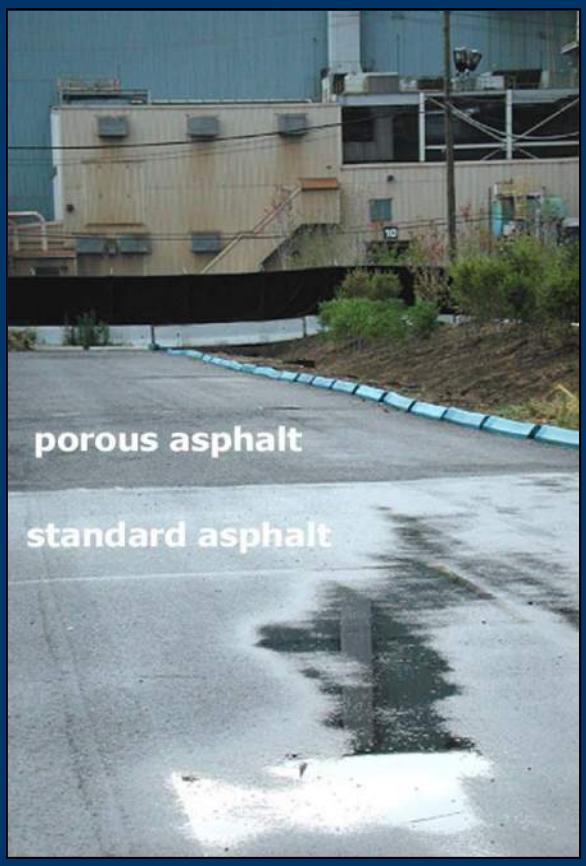
Water Quantity Controls

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

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.

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

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.

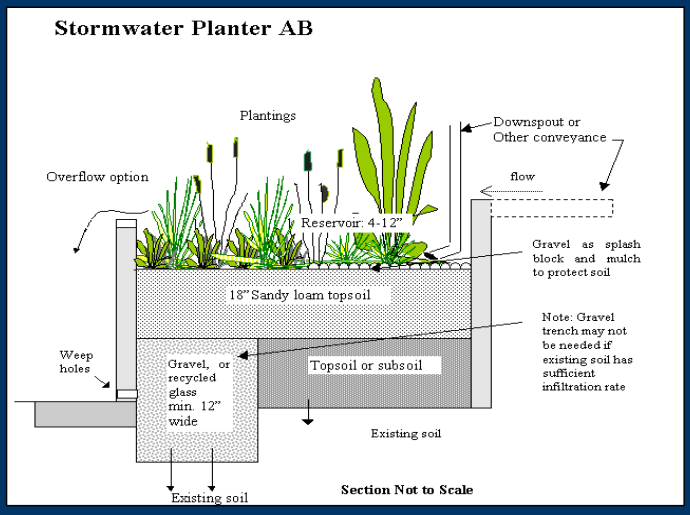
Determination of pollutant load reductions requires an analysis of adsorption and absorption rates for soluble pollutants, as well as decomposition and precipitation rates.

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.



Planter Box Schematic
Source: LID Center

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.

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

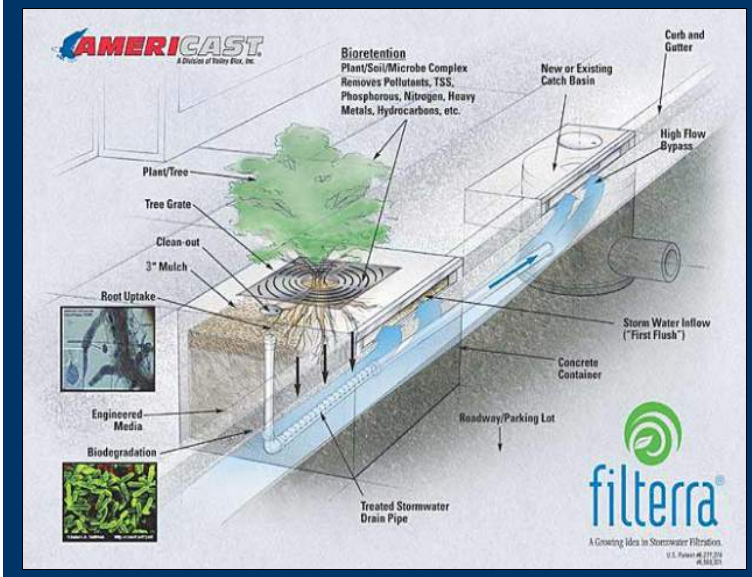
Tree box filters remove pollutants through the same biological, chemical, and physical mechanisms as bioretention cells.

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

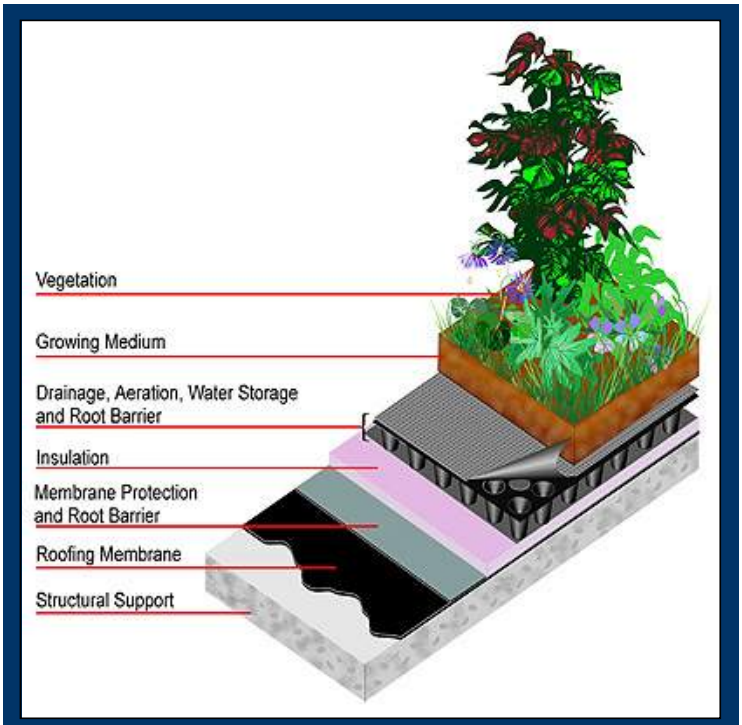
No conclusive water quality information can be presented at this time; research in this area is ongoing.

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
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

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.

Appendix 2

TREMCO: New Life Cycle Calculator Compares the Cost of Green Vegetative Roofs with Conventional Roof Systems

And

Life Cycle Cost Calculator-Phase 1 published by Green Roofs for Healthy Cities from the 2007 Proceedings from the Greening Rooftops for Sustainable Communities Conference, Awards and Trade Show

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FOR IMMEDIATE RELEASE **NEWS RELEASE**

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New Life Cycle Calculator Compares the Cost of Green Vegetative Roofs With Conventional Roof Systems

BEACHWOOD, Ohio (April 30, 2007) — A major obstacle to the proliferation of green vegetative roofs has been that organizations have no effective way to compare the life cycle cost of green roofs with conventional roofs. Professionals concerned with or responsible for sustainability, such as architects, designers and facility managers, will soon be able to use the Life Cycle Costing (LCC) Calculator. The first phase of the LCC Calculator was unveiled today at the Fifth Annual International Greening Rooftops for Sustainable Cities Conference, held at the Hyatt Regency Minneapolis Hotel.

Many varied benefits can be factored into the investment of a green roof, such as lowering energy costs and having an employee-accessible green roof. As many benefits as possible will be incorporated into the LCC Calculator, with additional benefits to be calculated in future versions. The intent is for the LCC Calculator to expand as specific projects are uploaded into the case study memory.

The LCC Calculator is used to compute roofing alternatives having the same purpose (functional utility) over the same time frame, then compare them to determine which has the lowest life cycle cost for the selected study period. Calculating a roof's life cycle cost is particularly useful in determining whether the higher initial cost of an investment is justified by reductions in future costs such as operating, maintenance, repair or replacement costs. The LCC Calculator also takes into consideration whether some roofs have lower initial costs but higher future costs.

"The LCC Calculator determines the lowest cost investment for satisfying a specific roofing requirement over a specific time frame," said Ralph Velasquez, Sustainable Technologies Manager for Tremco Roofing and Building Maintenance, which is one of the country's largest providers of roofing and building envelope systems and a leader in sustainable roofing technology.

In a combined effort, Green Roofs for Healthy Cities (GRHC), a network consisting of public and private organizations, with funding from Tremco, hired the Athena Institute to build the first phase of the LCC Calculator. Velasquez chairs the GRHC's Life Cycle Costing Subcommittee.

-more-

The Athena Institute undertakes and directs various research and development activities that make it possible to factor environmental considerations into the building design process from the conceptual stage onward.

"The value of the LCC Calculator is that it will allow users to explore both the hard and soft costs associated with green roofs versus conventional roofing systems," said Jamie Meil, co-founder and director of the Athena Institute, "thus enabling organizations to better understand the benefits of green roofs from a more robust life cycle cost perspective.

On April 30 and May 1, 2007, at the Sustainable Communities Conference, which GRHC sponsors, attendees will be able to "play" with the calculator and then provide feedback about their experiences. This feedback will be assessed for potential integration into the calculator's functionality prior to its launch later this spring.

The final Web-based version will be designed to allow the end user to consider the study period, discount rate, general inflation rate, energy price inflation, investment cost data, financing data, residual or resale value, recurring operating and maintenance costs, and replacement costs. It is also capable of capturing other possible roof benefits such as storm water and heat island mitigation, extended roof durability, related energy costs and savings, development fee savings, marketing benefits, increased rentability and tenant health and productivity improvements that can be ascribed to a roofing system.

During the first year of its availability, the LCC Calculator will be accessible exclusively from Tremco at www.tremcoroofing.com and from GRHC at www.greenroofs.net.

"The LCC Calculator is truly groundbreaking in that it is a third-party, unbiased tool that can be used to make fully informed decisions about green roof technology as it applies to specific projects and organizations," said Velasquez.

About Ralph Velasquez and Jaime Meil

Ralph Velasquez has been in the roofing industry since 1978. He has been deeply involved in the green vegetative roofing industry since 2000. He has worked on millions of square feet of roofing and re-roofing projects, as well as a large number of building envelope restoration projects for corporations, educational and institutional entities and governmental agencies across the country. Velasquez is a member of ASTM's Sustainable subcommittees, Green Roofs for Healthy Cities, the U.S. Green Building Council (serving his local chapter as board member and Advocacy Co-Chair) and numerous other related organizations.

Jaime Meil is the prime developer of the Athena Institute's Environmental Impact Estimator software – the only commercially available decision-support tool in North America that facilitates life cycle-based whole building environmental assessment.

About Tremco Incorporated

Headquartered in Beachwood, Ohio, Tremco Incorporated helps manage building life cycles while providing roofing and weatherproofing peace of mind to customers in education, healthcare, government, manufacturing and more. In business since 1928, Tremco and its service organization are ISO 9001:2000 certified. To learn more about Tremco North American Roofing and Building Maintenance, visit the Web site at www.tremcoroofing.com, or call toll-free at 800/562-2728.

###

Session 2.2: Stormwater Management and Life Cycle Calculation

LIFE CYCLE COST CALCULATOR – PHASE ONE

Ralph P. Velasquez

Tremco Inc.

Abstract

While many of us have expressed the benefits of green roofs to any and all that would listen over the last several years, the reality is the question often or always, refers back to cost. More fundamentally, the question is why should I spend my money on this course of action, as compared to another course of action? Another way to express this same question is: Can you make the "Business Case" for the utilization of a green roof versus a more conventional roofing approach? Undoubtedly, many of you have either posed the question yourselves or been asked the question by someone else. With this being the proverbial "$64,000" question, the idea of the Life Cycle Cost (LCC) calculator was formulated, a sub-committee formed and the endeavor undertaken.

Sub-committee members and others that were intimately involved included: Steven Peck, Alex Johnston and Flavia Bertram – GRHC, Jamie Meil – Athena Institute, (**www.athenainstitute.com**), Chris Goemans – GreenPath Environmental Design Shop, (**www.gpath.com**), Linda Fischer – Tremco IT Dept., Allen Lee – Quantec LLC, Monica Kuhn – Architect, Glenn MacMillan and Lisa Rocha – Toronto Regional Conservation Authority, Keith Adron – Elevated Landscape Technologies, Leslie Hoffman and Greg Loosvelt – Earth Pledge and myself.

First, what is an LCC calculator? One definition would be " an economic method for evaluating project investment alternatives over a designated study period". It entails computing the LCC for all alternative projects having the same purpose (functional utility) over the same time frame and then comparing them to determine which has the lowest LCC for the selected study period. LCC as a method is particularly suited to determining whether the higher initial cost of an investment is justified by reductions in future costs (e.g., operating, maintenance, repair or replacement expenditures) when compared to an alternative with a lower initial cost but higher future costs. If one alternative has a lower initial *and* lower future costs, an LCC is not needed to determine it is the least capital expense and preferred investment. LCC is about determining the least cost investment for satisfying a specific requirement over a specific time frame.

In a combined effort, GRHC in conjunction with the Athena Institute, with the first phase funded by Tremco Inc., undertook to build this model. The prevailing thought at the outset is to build this

model in two or more phases. The initial "beta version" will be designed to be web-based, have a user guide and tutorial available for the end user. A focus group interface at this conference will provide additional input that will help shape the tool, specifically with the web-based interface. Additional feed back from the marketplace once the tool has been made available to the general public will enable the LCC sub-committee to incorporate specific needs of the market into the next phase of the tool that will be developed over the next 1-2 years.

The initial beta version will be designed to allow the end user to consider the study period, discount rate, general inflation rate, energy price inflation, investment cost data, financing data, residual or resale value, recurring operating and maintenance costs, and replacement costs. In addition, numerous other costs, benefits and "soft" values will be calculated, with some having a "slot" or placeholder for future incorporation into the model. As many slots as can be incorporated into the beta version will be included, given time schedules, data availability and financing constraints. The beta tool will be based on case studies from various regions in the U.S. and Canada. Input for the tool was derived from information already collected by GRHC, the Athena Institute in their other LCC development work, and from other various members of the GRHC association. Members were asked to provide data and their experience with the construction of green roofs, in order to more fully support the underlying basis for the calculator.

This tool will be groundbreaking in it's ability to give owners and their representatives, a third party, unbiased tool, to make more fully informed decisions regarding green roof technology, as it applies to their project and organization. As the first attempt to create such a tool, it is understood the tool is not in its desired final creation but it will serve as the first step in the process of making the selection of a vegetative roof a more financially driven exercise. It is the hope of the sub-committee and GRHC that the tool will continue to grow and be enhanced by the experiences of the market place, thereby creating a more finely tuned tool. This in turn will help grow the market for vegetative roofs, demonstrate the business case for the selection of this approach on this most crucial element of the building envelope and in effect positively impact our cities' environments in an economic, environmental and socially prudent manner.

LCC Project Development Historical Context

The first determination in preparing the calculator was to identify the various private and public benefits that potentially could be included in the tool. Our understanding was that the state of the industry would likely require it being broken into two or more phases. Phase one would identify the existing data that was most easily quantifiable, as well as obtainable, constrained by our time element, in the market place, and incorporate this information into the calculator. We anticipated there would be information that was either not readily available or would need further research in order to provide more detail for the end user of the tool. Therefore, a phase two is envisioned that would take one to two years or longer, to fund, conduct research, obtain results and infuse this data into the calculator. With this in mind we determined it would be critical for "slots" to be built into the calculator that might initially be empty or have minimal usability for the end user in phase one but that could be filled out in the future, as the work was completed. Further, we wanted data infusion from the market that would help the sub-committee in refining the calculator.

The components of the LCC tool are the web-based calculator, workbook/spreadsheets to make the calculations to be entered into the tool, a user guide and a tutorial. This phase one tool is available free of charge, only on the GRHC and Tremco Websites and through the 2007 Green Roofs Conference. The worksheets will be able to be downloaded on the user's computer to be worked on, as they desire. Once the worksheets have been completed, then the data will be uploaded to the calculator, which will be housed online. The executive summary sheet will display the results, comparing the defined three scenarios.

To begin the process, the Athena Institute provided an initial base model for discussion and input from the sub-committee members. A weekly conference call was established so that ongoing dialog could provide the necessary interchange of ideas to refine the calculator in a very short time frame. The first official conference call occurred on Monday, February 12, 2007, to discuss the benefits to be included in the calculator. The initial identified benefits were expanded to include all benefits that would extend both to the end user and the broader community. For phase one, the calculator will only tabulate some of the end user benefits and none of the broader community benefits, even if they in turn provided a benefit back to the end user. The sub-committee felt that while these benefits were real and should be added, time did not allow us to include this in phase one.

The original categories were listed as:

Storm Water Management

Quantity
Quality
Down stream erosion control
reduced municipal infrastructure requirements
reduced water treatment
reduced overflow into water bodies

Energy Savings

Heating load
Cooling load
Peak demand reductions
reduced air emissions
Equip't downsizing
Building integration (e.g., PV oper. temp.

Heat Island Effect Mitigation

energy savings
peak demand reduction

Improved Air Quality

pollution abatement
population health effects

Improved Aesthetics / Livability

Improved building marketability
Increased commercial space rentability
reduced fire insurance
reduced EM fields
Improved health
Improved worker productivity

Waste Diversion

less waste going to landfill

Job Creation

increased demand for labor

After some discussion, the second draft appeared as:

1. Storm Water Management

Quantity reduction society/owner
Offsetting potable water use through irrigation reuse owner
Quality of run-off, e.g., reduced downstream treatment society
Down stream erosion control society
reduced municipal infrastructure requirements society
reduced combined sewer overflow into water bodies society
roof storage vs. other sw storage or mngt methods owner

2. Energy Savings

Heating load owner
Cooling load owner
Peak demand reductions society/owner
HVAC Equip't downsizing owner
Building integration e.g., PV oper. temp. owner

3. Roof Durability / Maintenance

extended roof life owner
reduced annual maintenance owner
less waste going to landfill society

4. Heat Island Effect Mitigation

energy savings society
peak demand reduction society

5. Improved Air Quality

pollution abatement society
population health effects society

6. Improved Aesthetics / Livability

Improved building marketability owner
Increased commercial space salability/rentability owner
public relations benefit owner
other income sources owner
noise abatement owner
reduced EM fields society

7. Development fees

land purchase cost avoidance owner
density bonus owner
Improved site acquisition capability of sensitive sites owner
permitting savings owner

8. Improved worker productivity / health

Improved worker health, less absenteeism/ admin costs owner
Improved worker productivity owner

The final form at the time of printing is:

Impact Category	Impact Sub-Category	Applicable to society or owner
1. Storm Water Management		
	Quantity reduction	society/owner
	Offsetting potable water use through irrigation reuse	owner
	Quality of run-off, e.g., reduced downstream treatment	society
	Down stream erosion control	society
	reduced municpal infrastructure requirements	society
	reduced combined sewer overflow into waterbodies	society
	roof storage vs. other onsite sw storage or mngt methods	owner
2. Energy Savings		
	Heating load	owner
	Cooling load	owner
	Peak demand reduction	owner/society
	HVAC Equip't downsizing	owner
	Building integration e.g., PV oper. temp.	owner
3. Roof Durability / Maintenance		
	extended roof life	owner
	reduced annual maintenance	owner
	less waste going to landfill	owner/society
4. Heat Island Effect Mitigation		
	energy savings	society
	peak demand reduction	society
5. Improved Air Quality		
	pollution abatement	society
	population health effects	society
6. Improved Aesthetics / Livability		
	Improved building marketability	owner
	Increased commercial space salability/rentability	owner
	public relations benefit	owner
	other income sources	owner
	noise abatement	owner
	reduced EM fields	society
7. Development fees		
	land purchase cost avoidance	owner
	density bonus	owner
	Improved site acquisition capability of senstive sites	owner
	permitting savings due to fast-tracking	owner
8. Improved worker productivity / health		
	Improved worker health, less absenteeism/ admin costs	owner
	Improved worker productivity	owner

A second decision had to be made as to what; we were comparing our vegetative roof to. Since the decision is usually made versus a conventional roof assembly, the committee chose two roof systems; a BUR/MB configuration and a single ply assembly, as the basis of comparison, as these are the most common types of conventional roof assemblies installed in the marketplace today. The executive summary sheet will compare these two scenarios against the green roof.

Once the benefits were identified and the comparisons established, then two key components were on the docket next, the designing of the web tool interface and the case study information. The web interface proved to be far more difficult than first imagined for a bunch of roofing and plant people. We quickly had to bring in the IT people from Tremco and the Athena Institute partner, GreenPath Environmental Design Shop to assist the process. Over the next month, numerous phone calls, emails and our weekly conference calls were dominated by the volume of technical and interface issues related to how the tool would function not only now during the "beta" phase, but also into the future. User and business requirements, data management and security issues, as well as overall workability had to be considered. GRHC even had to change some of their internal mechanisms in order to facilitate the future growth of the tool. Roughly some 80 separate web related questions had to be answered to get the first phase built. Some 45 days before conference the first web skeleton was built. A final face-to-face meeting at the Tremco Toronto headquarters finalized the web issues and the IT team went to work to build the web tool, which you will see shortly.

As previously mentioned, the case studies and other data used to build the scenarios have numerous sources, however, the true strength of this tool is the living and growing nature of the calculator, based on the submitted worksheets and future research. As the end user completes the worksheets and re-loads them into the calculator, they will have the option to input the data into the content storage brain of the model. That data will be mined quarterly to update the calculator's current categories, infuse more case study examples and build out the slots that may not be functional at the time of this first release. The intent is to make the calculator as user friendly as possible, backed by the most comprehensive data available in North America on a continual live basis.

Appendix 3

Milwaukee Metropolitan Sewerage District (MMSD)
Quicksheet 1.2

LID QuickSheet 1.2

A Spreadsheet for Determining the Capacity of LID Features
to Meet MMSD Chapter 13 Requirements

USER MANUAL

May 6, 2005

The Milwaukee Metropolitan Sewerage District

Preserving The Environment •
Improving Water Quality

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Acknowledgments

Steering Team for the Milwaukee Metropolitan Sewerage District
Low Impact Development Chapter 13 Guidance Project

Susan Beaumier	Wisconsin Department of Natural Resources
Martha Brown	City of Milwaukee Department of City Development
Bob Brownell	Bielinski Development
Jeff Chase	City of Brookfield
Mike Hahn	Southeastern Wisconsin Regional Planning Commission
Bill Hoppe	City of Mequon
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1.2 Final version.

Table of Contents

1. Introduction.....1

2. General Guidelines.....2

3. Comparison of Conventional and LID Curve Number Calculations.....3

4. Designing with the Spreadsheet.....6

5. Site Summary.....10

6. URR Summary.....16

7. Exporting the LID Hydrograph.....17

8. References.....18

Appendix A. Five Methods of Accounting for the Effect of Distributed Retention 19

Appendix B. Summary of Spreadsheet Contents 27

Appendix C. Curve Numbers and Subsurface Storage for Porous Pavement and Permeable Pavers 28

Appendix D. Runoff Storage Capacity of Vegetated Roofs.....30

Figures

1. Residential LID Case Study Site Plan 4

2. Conventional Site Example.....5

3. LID Site Example 5

4a. First page of the main spreadsheet interface.....8

4b. Second page of the spreadsheet interface 9

5. Moisture retention parameters associated with USDA soil texture classes.....14

6. Example of splitting flow at outlet.....17

Tables

1. Area-Weighted CN Calculation for Conventional Design 6

2. Area-Weighted CN Calculation for LID Design 6

LID QuickSheet 1.2

A Spreadsheet for Determining the Capacity of LID Features
to Meet MMSD Chapter 13 Requirements

USER MANUAL

1. Introduction

MMSD Chapter 13 permits governmental units to require analyses of individual site developments to demonstrate that those developments meet one of two technical requirements for managing runoff. The requirements to be met for the site are:

1. Peak flow control that meets Unit Release Rate (URR) targets. Those targets are 0.15 cfs/acre for the 2-year return period storm and 0.50 cfs/acre for the 100-year return period storm.

2. Volume control that meets the Volumetric Design Procedure (VDP) target. The VDP requires that the amount of runoff that is discharged from the developed site during a critical time period does not exceed the amount generated under predevelopment conditions. The critical time period has been predetermined for different watersheds, as described in the MMSD Surface Water and Storm Water Rules (MMSD 2002).

This spreadsheet estimates the capacity of Low Impact Development (LID) design strategies to help meet the URR requirements and thereby reduce or eliminate the need for conventional detention storage to meet the Chapter 13 requirements. LID design involves:

1. Minimizing the capacity of the land surface to generate runoff.
2. Slowing down and dispersing the runoff.
3. Collecting and retaining the runoff in small, distributed storage volumes.
4. Infiltrating the runoff where possible.

To determine the collective effect of these strategies on the hydrology of a site, the spreadsheet incorporates a subset of the analytic methods described in Technical Release 55 (TR-55), *Urban Hydrology for Small Watersheds* (Soil Conservation Service, 1986)[1] and Technical Release 20 (TR-20), *Computer Program for Project Formulation Hydrology* (Soil Conservation Service, 1983). The spreadsheet is intended to be used in conjunction with these reference documents. Both of these methods are based on the procedures for hydrologic analysis that are presented in the *National Engineering Handbook*, Section 4 (Soil Conservation Service, 1985). Additionally, various LID design features are described in *Memorandum: Evaluation of Stormwater Reduction Practices* (MMSD 2003).

[1] Note: Since the publication of TR-55 and TR-20, the Soil Conservation Service (SCS) has been renamed the National Resources Conservation Service (NRCS). The abbreviations SCS and NRCS are used within this document interchangeably.

Through the use of curve number (*CN*) and time of concentration (*Tc*) parameters, the procedures found in TR-55 and TR-20 can already take into account the manner in which LID influences the rate of runoff generation and the rate at which the runoff is conveyed across a site. Relative to the *CN* value for conventional site design, for example, the *CN* value might be decreased for an LID design because of reductions in the amount of impervious area. Likewise, the *Tc* value for an LID design might be increased on account of the greater use of vegetated swales rather than channelized stormwater conveyance systems.

Beyond the *Tc* and *CN* effects, however, LID design will also take advantage of opportunities for providing distributed retention storage. Retention may be provided, for example, in bioretention cells, in the gravel beds underlying permeable pavements, or on vegetated roofs. To directly account for the effect of distributed retention storage in a manner not currently available in TR-55 or TR-20, this spreadsheet has incorporated an adaptation of the TR-20 unit hydrograph calculations in a manner that treats the site retention volume as a uniform depth of storage across the drainage area.

2. General Guidelines

This spreadsheet requires the input of standard NRCS unit hydrograph parameters and additional information about the runoff storage capacity of specific LID features. These guidelines assume that the user already has a familiarity with the NRCS runoff calculation procedures for developing a composite *CN* value as an area-weighted average and for determining *Tc* values. Please refer to TR-55 and TR-20 for a detailed description of those procedures.

2.1. Terminology

The term *retention* in this document refers to the capture of runoff during a storm event so that it is not discharged from the site as surface flow, but is retained on site and subsequently infiltrated, evaporated, absorbed by vegetation, or withdrawn for consumptive use. *Retention* is carefully distinguished here from *detention*, which refers to runoff that is only temporarily stored, as in a detention pond, before it is released from the site.

The term *rain garden* is here used synonymously with the term *bioretention cell*. A rain garden is a landscaped depression that is designed to capture and infiltrate runoff.

2.2. Technical Issues

The spreadsheet sums the total retention storage volume provided on site and then obtains an average storage depth by dividing the total volume by the drainage area. Only after the runoff depth exceeds the storage depth during a design storm is a component of the runoff hydrograph generated. The rationale for adapting the NRCS unit hydrograph calculations in this manner is presented in Appendix A.

Care should be taken in the design and analysis of a site to ensure that the retention volumes entered into the spreadsheet are actually filled during the storm event. It is conceivable that the amount of runoff going into a rain garden, for example, will not actually fill the storage volume

available. In such a situation, the runoff volume, rather than the full capacity of the rain garden, will represent the amount of water that does not flow to the drainage area outlet.

The analysis of a site will require subdividing it into small drainage subareas and comparing the volume of runoff flowing into each retention feature with the capacity of that feature. The lesser of the runoff volume and the storage capacity should be aggregated with the rest of the on-site retention for input into the hydrograph calculations.

Because the effect of the storage depth is evaluated as if it is uniform across the site, it is left to the analyst and reviewer to determine whether this assumption is appropriate for a particular site design. The more uniform the distribution of retention is, the more appropriate the assumption. Figure 1 is an example of a residential area that makes considerable use of on-lot space for retention storage (as indicated by the small irregular shapes on the site). Although the placement of retention is not perfectly uniform, the wide distribution suggests that treating the storage depth as uniform may not be unreasonable for this design.

While LID features such as rain gardens and permeable pavements may be designed with underdrains, the calculations provided in the Quicksheet assume that no LID feature has an underdrain flow rate that contributes significantly to the peak of the runoff hydrograph. If the rate does become significant, then an additional analysis may be advisable to count that rate as being added to the hydrograph peak, or to route the runoff hydrograph through the device.

As with conventional approaches to stormwater management, some engineering judgment will be required to ensure that the parameter values selected in practice represent actual site conditions. Responsible design and analysis using this tool will seek to fully account for the capacity of LID features to reduce runoff. It is equally important, however, to avoid overestimating their capacity in a manner that would pose an increased risk of flooding and erosion downstream of the modeled drainage area.

3. Comparison of Conventional and LID Curve Number Calculations

Figures 2 and 3 show conventional and LID site plans for a 6.5-acre residential townhouse development. Tables 1 and 2 show the weighted curve number calculations for each site. The reduction in the curve number was achieved primarily by increasing the amount of wooded area. Additionally, the impervious area was somewhat reduced in the LID design by decreasing the road width.

According to the standard NRCS runoff depth calculation, for a 2.57-inch storm the lower curve number will reduce the depth of runoff from 0.9 to 0.6 inches. When the bioretention areas that have an average ponding depth of 6 inches and a subsurface storage capacity of 3 inches, the LID spreadsheet indicates that only 2.2% of the site area is needed to reduce the peak flow to a target level of 0.15 cfs/acre. Without the reduction in curve number, approximately 5.0% of the area would be needed.

For sites with no more than 30% impervious area, additional reductions in the curve number can be gained by disconnecting the impervious coverage. This encourages infiltration by preventing runoff from flowing continuously across hard surfaces from the point of runoff generation to the drainage area outlet.

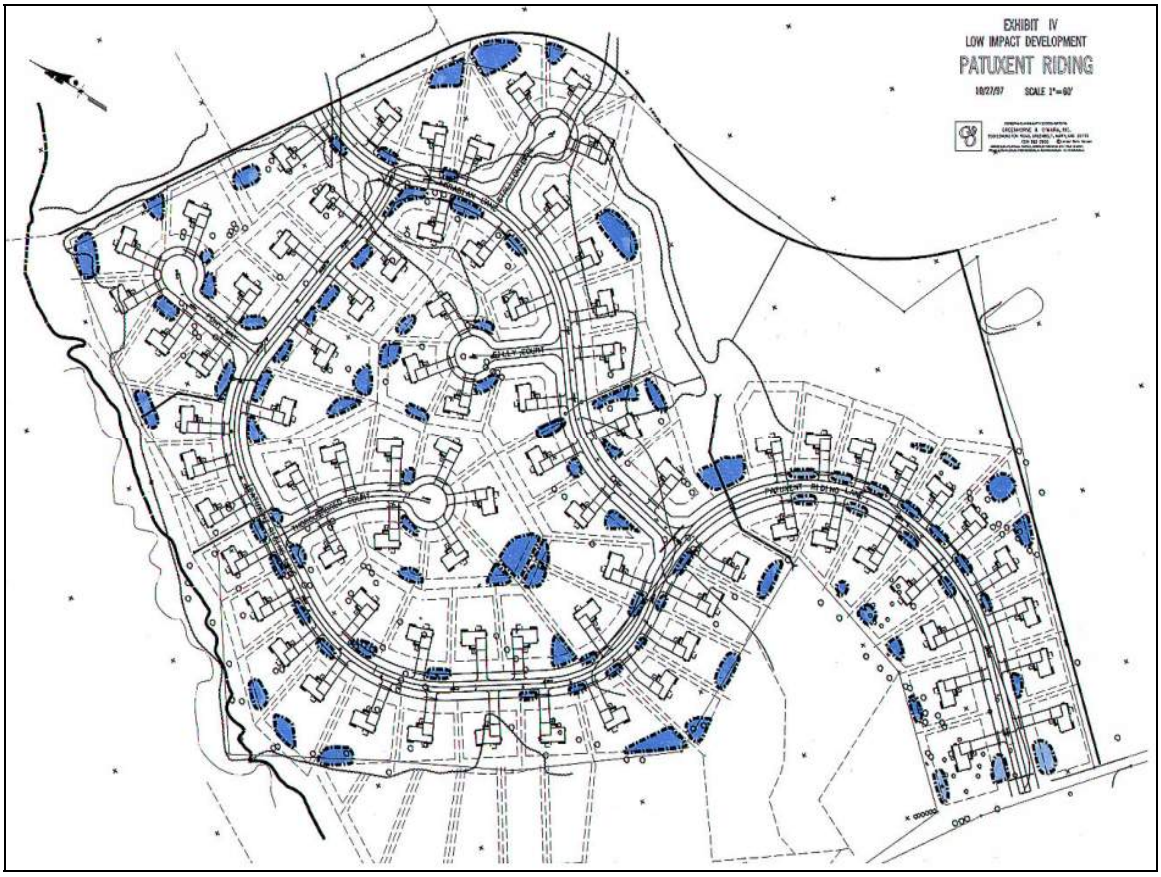


Figure 1. Residential LID Case Study Site Plan
Source: Prince George's County, MD, 1997

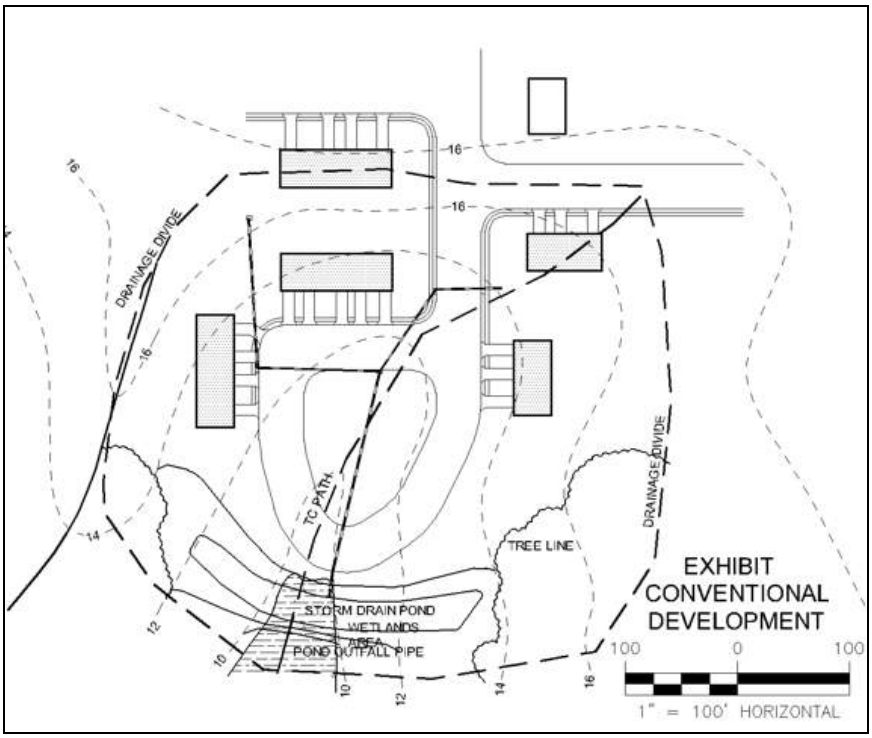


Figure 2. Conventional Site Example

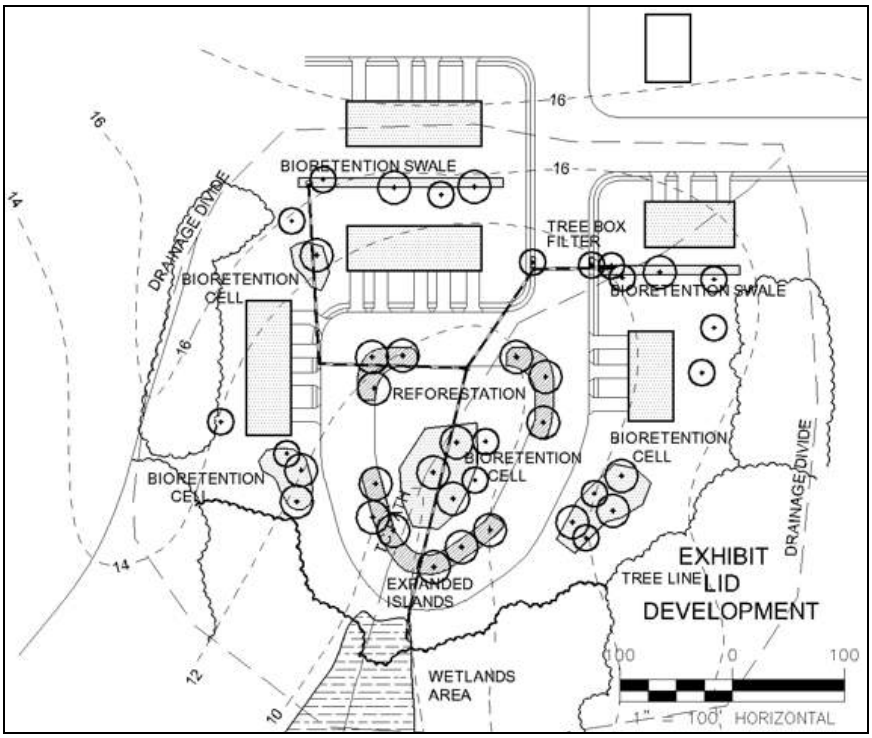


Figure 3. LID Site Example

Hydrologic Soils Group	Cover Description	CN (Table 2-2 TR-55)	Area (Acres)	Product of CN x Area
B	Lawn (fair condition)	69	3.2	220.8
B	Woods, Fair	60	0.7	42.0
B	Impervious	98	2.6	254.8
			Sum of Products	**517.6**
			÷ Drainage Area	6.5
			Weighted CN	**80**

Table 1. Area-Weighted CN Calculation for Conventional Design

Hydrologic Soils Group	Cover Description	CN (Table 2-2 TR-55)	Area (Acres)	Product of CN x Area
B	Lawn (good condition)	61	1.8	109.8
B	Woods, Fair	60	2.5	150.0
B	Impervious	98	2.2	215.6
			Sum of Products	**475.4**
			÷ Drainage Area	6.5
			Weighted CN	**73**

Table 2. Area-Weighted CN Calculation for LID Design

4. Designing with the Spreadsheet

4.a. How the Spreadsheet is Organized

Within the spreadsheet file, five different sheets are available to the user by clicking on tabs at the bottom of the page. The portions of the spreadsheet available for user input and output are as follows:

- *ReadMe* Basic information about the use and function of the spreadsheet.
- *MainPage* The main page used for the input and output (Figures 4a and 4b).
- *SubareaCheck* Justifies use of retention volumes entered into *MainPage*.
- *RainDistribution* Allows the use of different temporal rainfall distributions.
- *OutputHydrograph* Provides LID hydrograph values for export.

4.b. Stepwise Overview of LID Site Design

Here is a brief overview of how to proceed using information available about your site:

1. For the proposed site design, determine drainage area divides, land use, and flow paths.
2. For comparison purposes, estimate the *CN* and *Tc* values assuming that no LID features are used on the site.
3. Enter the *CN* and *Tc* values into the spreadsheet to estimate a detention pond volume when no LID features are used.
4. Minimize the overall *CN* and maximize the *Tc* values for your LID site design, and enter those values into the spreadsheet.
5. Select the LID features that are feasible for the proposed site, considering the options described in *Memorandum: Evaluation of Stormwater Reduction Practices.*
6. Enter into the spreadsheet realistic values for the amount of retention storage that could be provided on site using the selected LID features at identified locations, and observe the calculated reductions in the peak flow runoff rate and detention pond size.
7. Add no more storage when the desired level of reduction in the peak flow value or the detention pond size is achieved, or if no additional storage will be provided due to site constraints.
8. Compare the volume of runoff flowing into each feature with the actual retention volume of that feature, and check to ensure that the volume considered in the calculations is the lesser of the two. The comparisons can be summarized in the sheet *SubareaCheck*.
9. Check the final site plan against spreadsheet input and finalize the two pages of *MainPage* as part of the Chapter 13 submittal.
10. If a detention pond needs to be sized, use the LID hydrograph values provided in the sheet *OutputHydrograph*.

Screenshots of the main page of the user interface are shown on the next two pages. Following the screenshots are line-by-line instructions for providing the input and interpreting the output of the spreadsheet.

LID QuickSheet 1.1

SITE SUMMARY *Enter data into the shaded boxes only.*

Line						
	PRECIPITATION and DRAINAGE AREA					
1a		100	*years*	Return period for this storm event.		
1b	NRCS Type II			Rainfall distribution. *See RainDistribution sheet to change.*		
2a	**P**	5.88	*inches*	Total precipitation.		
2b	**A**	100.0	*acres*	Drainage area.		
2c	**CN minimum**	25		CNs must be greater than this value to generate runoff.		
	NoLID DESIGN					
3a	**CN**	85	Area-weighted average for the NoLID site design.			
3b	**Tc**	30	*minutes*	Cannot be less than 5 minutes.		
	LID DESIGN					
		Standard CN Determination				
4a	**CN**	78	Area-weighted average for the LID site.			
		Optional CN Determination	*If option not used, enter zeroes in Lines 4b-4d.*			
4b	**CN_p**	70	Composite CN_p for pervious areas alone.			
4c	**P_{imp}**	30%	Actual percent impervious.			
4d		0.2	Decimal <= 1.0. Ratio of unconnected impervious area to total impervious area. *(Enter "0" as the ratio if total impervious area is greater than 30% of site.)*			
4e	**CN result:**	77	(The "CN_c" in TR-55 Appendix F)			
4f	**Selected CN**	77	Enter the value from Line 4a or Line 4e.			
4g	**Tc**	45	*minutes*	Cannot be less than 5 minutes.		
	LID Retention Features		*For individual features, compare the contributing runoff with the capacity, and take the lesser of the two. Summarize on SubareaCheck sheet.*			
	Rain Garden Capacity					
5a		6.0	*inches*	Average ponding depth.		
5b		16.0	*inches*	Average soil mix depth available for retention (24 inches or less).		
5c		0.2	*(unitless)*	Average fillable porosity.	**Design**	**Volume**
5d		9.2	*inches*	Storage per unit area.	*acre-feet*	*gallons (thousand)*
5e	**Rain Garden**	4.0%	of drainage area used for rain gardens.		3.07	999
5f	**Coverage**	174240	*sq.ft.*	*(average of top and bottom areas)*		
6a	**Rain**	55.0	*gallons*	Capacity of each rain barrel.		
6b	**Barrels**	100		Number of rain barrels.	0.02	6
7a	**Green Roofs**	3.0	*inches*	Maximum Water Capacity (MWC).		
7b		0.50		Multiplier between 0.33 and 0.67.		
7c		10000	*sq.ft.*	Area.	0.03	9
8	**Cisterns**	1000	*cu.ft.*	Sum of all cistern volumes.	0.02	7
9a	**Permeable**	5.0	*inches*	Storage depth, or capacity per unit area.		
9b	**Pavement**	1600	*sq.ft.*	Paved area.	0.02	5
10	**Other**	80000	*cu.ft.*	Additional storage not listed above.	1.84	598
				Total	4.99	1625

Figure 4a. First page of the main spreadsheet interface (*MainPage* tab)

LID QuickSheet 1.1

URR SUMMARY *Enter data into the shaded boxes only.*

Line	***Unit Release Rate Target***		
20	0.50	*cfs/acre*	*See User Manual to select value.*

Site Runoff

			NoLID	LID	Reduction
21a	**Depth**	*inches*	4.19	2.78	34%
21b	**Volume**	*ac-ft*	34.91	23.13	
22a	**Peak**	*cfs*	352.5	184.1	48%
22b	**Peak/area**	*cfs/acre*	3.52	1.84	

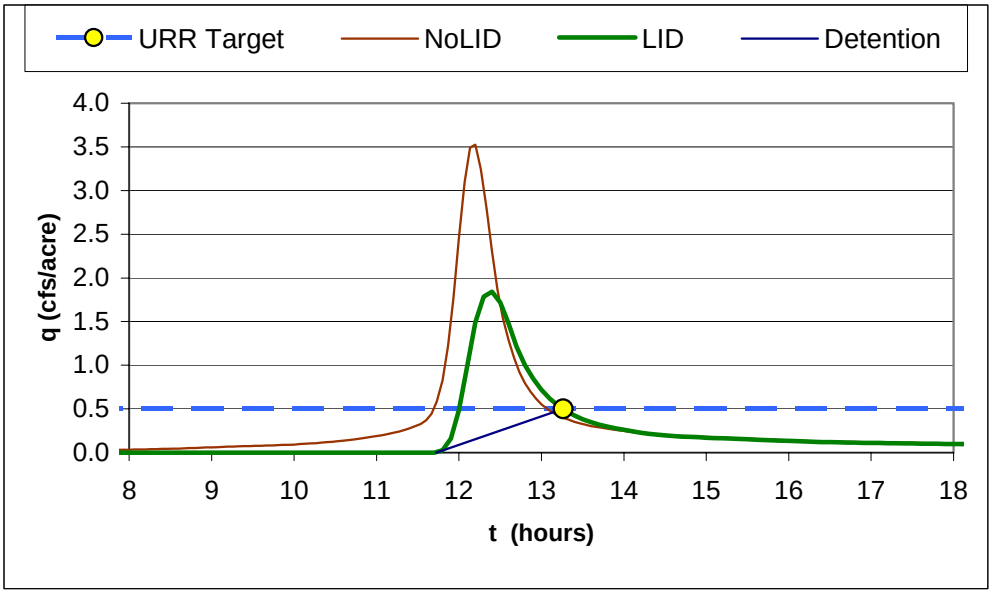
Conventional Detention Needed to Meet Peak Flow Target

			NoLID	LID	Reduction
23a	**Depth**	*inches*	1.98	1.10	44%
23b	**Volume**	*ac-ft*	16.49	9.18	

LID Split Flow Option. *If discharge above target rate is directed into retention at outlet, this retention volume can replace detention pond volume:*

24a	**Depth**	*inches*	0.79	(Compare to Line 23a, LID column)
24b	**Volume**	*ac-ft*	6.59	(Compare to Line 23b, LID column)

25 ***Runoff Hydrographs for URR Analysis***



Input by: _____ Date: _____

Checked by: _____ Date: _____

Figure 4b. Second page of main spreadsheet interface (*Mainpage* tab)

5. Site Summary

The Site Summary page (Figure 4a) is for the user to provide input values for the URR evaluation.

5.1. Precipitation and Drainage Area

1a. Enter the return period associated with the precipitation depth and peak target rate given. Both the 2-year and 100-year 24-hour storm events should be evaluated.

1b. This line shows the name of the design storm distribution that has been entered on the *RainDistribution* sheet.

2a. Input the rainfall depth designated by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) for the 2-year and 100-year 24-hour storm events. For the 2-year event, the rainfall depth is 2.57 inches, and for the 100-year event, the rainfall depth is 5.88 inches.

2b. Input the drainage area. If the site as a whole does not have uniform land cover and soil types, consider dividing it into separate drainage areas and using the spreadsheet multiple times.

2c. This output is for user information as *CN* values are input in the cells below.

5.2. NoLID Design

These values are used to generate a runoff hydrograph and estimate the detention pond volume if no LID strategies are implemented on the site. In Figure 4a, for example, the "No LID" *CN* value of 83 was taken from Table 2-2a of TR-55 as the value associated with 1/4-acre lots on hydrologic soil group C.

Because the LID design does not depend on these numbers, for practical reasons a detailed evaluation of the NoLID design may not be necessary. The calculations for the NoLID design are provided simply for comparison with the LID design.

3a. Enter the curve number for the NoLID design.

3b. Enter the time of concentration for the NoLID design.

5.3. LID Design

Taking Into Account the Preservation of Natural Features

The preservation of natural features on a site often helps to control runoff. Well-established naturally wooded areas or prairie are often characterized by thick vegetation and high levels of organic matter in the soil. These conditions promote rainfall interception and runoff infiltration. Where these features are preserved, a *CN* value can be selected from Table 2-2 of TR-55 to reflect the continued influence of these natural features on the generation of runoff from a site.

Additionally, sheet flow and shallow concentrated flow that is conveyed through naturally vegetated areas flows more slowly than runoff that travels across grassed lawns (for example). Consequently, the preservation of natural features can be taken into account for both the *Tc* and *CN* values selected for the site.

5.3.1. Standard CN Determination

4a. Enter an area-weighted average *CN* value. This *CN* value should include the vegetative cover for bioretention areas assuming that bioretention soils are the same as the surrounding soils. The subsurface porosity of bioretention cells is accounted for in Line 5c.

Accounting for Permeable Pavements in the Standard *CN* Determination

Use one of the following sub-options, but not both.

Sub-Option A. Incorporate permeable pavement *CN* into the Line 4a value as part of the weighted average for the entire site. See Appendix C for a brief discussion of alternative values.

Sub-Option B. Treat the pavement as an *impervious* area when calculating the input for Line 4a but incorporate a determination of the total storage depth in Line 9a.

5.3.2. Optional CN Determination

For urban and residential districts, the *CN* values published in Table 2-2a of TR-55 are based on sites that have the following characteristics:

(a) The percentage of impervious area shown in the table.
(b) The connection of impervious areas directly to the drainage system.
(c) Grass as the primary pervious ground cover.

An LID strategy typically involves reducing and disconnecting impervious areas, and increasing the density of vegetative cover using trees or native plants, for example. Because these methods help to reduce runoff, it is highly desirable to recalculate a composite curve number to fully

account for their effects. Lines 4b through 4e allow for a quick estimate of the effect of reducing and disconnecting the impervious area, assuming that the CN value for the pervious area does not change significantly. This approach is based on TR-55 p. 2-9 and TR-55 Appendix F.

In the example input shown in Figure 4a, the LID *CN* is based on a vegetative land cover of woods in good condition over hydrologic soil group C (*CN*=70). The impervious area has been reduced from an average of 38% for the No LID condition (TR-55 Table 2-2a) down to 30% here, and a portion of that is disconnected. This combination of factors results in a lower overall curve number of 77.

4b. The value entered should be the area-weighted average of the curve numbers associated with the different land covers (native plants, woods, grass, etc.) and should not include any impervious area or vegetated roof area. This *CN* value should include the vegetative cover for bioretention areas assuming that bioretention soils are the same as the surrounding soils. The subsurface porosity of bioretention cells is accounted for in Line 5c.

Accounting for Permeable Pavements in the Optional *CN* Determination

Use one of the following sub-options, but not both.

Sub-option C. Incorporate permeable pavement into the *pervious CN* value calculated in Line 4b and *do not* treat it as part of the impervious area in Line 3a. See Appendix C for a brief discussion of *CN* values for permeable pavement.

Sub-option D. Do not incorporate a permeable pavement *CN* into line 4b. Instead treat the pavement as an *impervious* area in Line 4b but incorporate a determination of the total storage depth in Line 9a.

4c. Use an actual impervious area. Vegetated roofs should be treated as impervious here. Vegetated roof retention is specifically accounted for in Lines 7a-7b.

4d. Treat as disconnected, for example: Roof downspouts that are not directly connected to the drain system, pavement area that conveys runoff into grassed swales rather than down a curb and gutter system. Conventional pavement or other impervious area that conveys runoff onto permeable pavement may be considered disconnected.

4e. This amount is computed automatically, and the letters “N/A” appear if zeroes are entered in Lines 4b and 4c.

4f. This input value must be entered manually and will be identical to the value shown in line 4a or 4e. It is the LID *CN* value used for the hydrograph calculations.

4g. This is the time of concentration for the LID design. All other conditions being equal, an increase in the *Tc* will result in a reduction in the peak runoff rate. A typical approach to LID site design will seek to maximize the *Tc* by using conveyances that slow down travel times without compromising the effectiveness of drainage away from buildings and off roadways. LID favors the use of shallow vegetated conveyances rather than sewer pipes, for example, open section road rather than curb and gutter, and the spreading of flows rather than the

concentration of flows. A discussion of how to determine runoff travel times and to calculate *Tc* values is provided in Chapter 3 of TR-55.

5.3.3. LID Retention Features

The remaining input cells within the spreadsheet can be used for site components that retain runoff. The spreadsheet calculates the total retention volume as a depth across the drainage area, and for each time step checks to see whether that depth has been filled before generating runoff.

> The *SubareaCheck* sheet is provided to compare the capacity of each retention feature with the volume of runoff flowing into that feature. If the runoff volume is less than the capacity of the retention feature, then that runoff volume rather than the capacity should be counted in the *MainPage* input toward the reduction in runoff.
>
> Note that the volume check does not require a detailed analysis that generates an area-weighted *CN* value based for each subarea contributing runoff. It is sufficient only to show that the storage volume will be filled. Consequently, evaluating the runoff from only a portion of the subarea (such as the impervious area) or selecting an obviously low curve number for the subarea may produce a volume that exceeds the retention capacity.
>
> The *SubareaCheck* sheet also serves as a check on the underdrain flow for individual LID features, such as rain gardens and permeable pavements. The peak flow rate that occurs when the device is full may be controlled either by the size of the underdrain orifice or by the flow rate through the subsurface media. In either case, if the underdrain flow is substantial, it is conceivable that it may diminish the effectiveness of that feature in reducing the peak flow rate at the outlet.
>
> An acceptable approach to accounting for the hydrologic influence of underdrains is left here to the judgment of the engineer and the reviewing agency. In some cases, relative to the peak flow rate for the entire site, the underdrain rate may be insignificant. In other situations, as when underdrain rates are significant and retention features are not along the same flow path, it may be acceptable to require the LID hydrograph peak *plus* the sum of the underdrain flow rates to equal the Unit Release Rate (URR) (cfs/ac) target.

5a-5c. These input lines indicate the typical capacity of the rain garden design no matter how many rain gardens are used within the drainage area. The ponding depth should be considered as an approximate average. While the ponding volume available in rain gardens can be readily estimated based on surface contours, estimating the volume of subsurface

storage will require consideration of the soil characteristics and behavior during a storm event.

The spreadsheet allows input of a value for *fillable porosity*. This is the amount of pore space assumed to be available within the soil prior to the design storm event.

The porosity of a soil is the measure of the void space in an oven-dried soil sample. A saturated soil has a water content equivalent to its porosity. As the soil drains by gravity to a moisture level known as the field capacity, more pore space becomes available to hold water. Over time, vegetation will extract moisture still further until the moisture level reaches the wilting point.

Figure 5 shows how soil properties will affect values of the field capacity and the wilting point. These values can be calculated using the software, Soil Water Properties from Texture (Saxton 2003), which is based on research by Saxton et al. (1996).

For the purpose of LID design and analysis, the value of the fillable porosity should be no greater than the difference between the porosity and the field capacity for soils in a rain garden.

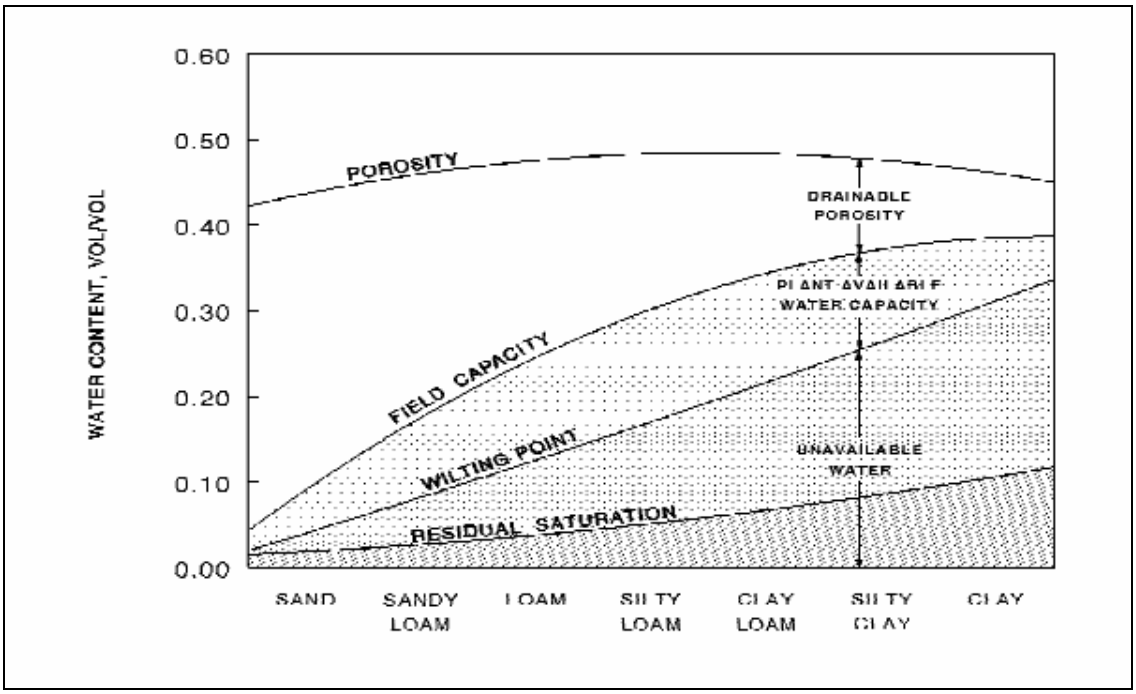


Figure 5. Moisture retention parameters associated with USDA soil texture classes (Source: http://msw.cecs.ucf.edu/AndFiles/hlp2.html)

A question may arise as to whether the overall storage capacity of rain garden soils will diminish significantly over time. It will be reasonable to assume a constant value for the fillable porosity as long as the conditions at or near the soil surface do not impede infiltration

due to silting or surface crusting, and the vegetation is maintained. The use of a vegetated filter strip or grassed area around a rain garden can help reduce the conveyance of sediment into the rain garden.

In light of the various factors that can affect infiltration rates and subsurface storage volumes, some consideration may be given to whether the value selected for the input will more likely err on the side of overestimating or underestimating runoff rates at the outlet during an actual storm event under typical conditions. A conservative approach to the analysis will involve using smaller values for porosity.

Some consideration may also be given to the fact that some of the infiltration capacity in a bioretention cell has been accounted for in the overall *CN* value for the drainage area. Where surrounding soils are sandy with high rates of infiltration, a sandy bioretention soil may add little to the capacity of the bioretention area to reduce runoff and consequently a conservative value for the fillable porosity will be more desirable so that the infiltration capacity of the bioretention area is not double counted. When the surrounding areas have low rates of infiltration, however, larger values for the fillable porosity will be justified.

5d. This value is computed automatically.

5e. This is the area associated with the average design depth, roughly the average of the top and bottom of the ponding area.

5f. This value is computed automatically.

6a-6b. Rain barrels can be situated at roof downspouts to collect runoff.

7a-7c. The capacity of vegetated roofs to absorb rainfall is a function of vegetated roof design, and designs can vary considerably. The Maximum Water Capacity (MWC), is a benchmark number that is discussed in Appendix D. Reasonable values for the multiplier will generally lie between 0.33 and 0.67. The minimum value of the multiplier is the most conservative, because it represents only the initial abstraction, the amount of rainfall quickly absorbed by the roof at the beginning of the storm. Field capacity for a vegetated roof is typically about 0.50 of the MWC, which would leave the other 0.50 of the MWC available to absorb rainfall. Since evapotranspiration between storm events will reduce the moisture content from field capacity as far down as the wilting point, a value higher than 0.50 will tend to be more representative of the condition of the vegetated roof following a dry period. Because the antecedent moisture conditions for a vegetated roof will not generally be known, a median multiplier value of 0.50 is recommended.

8. This input value is the total volume of cistern storage provided on site.

9a-9b. The depth of storage entered here is the total depth of water storage provided in the permeable pavement system. This should take into account pore spaces in the pavement, as well as the aggregate base layers beneath the payment. A gravel layer 8 inches deep with a

typical porosity of 0.40, for example, will provide a water storage depth of 3.2 inches for each unit of pavement area.

10. This cell allows for the input of a combination of other retention volumes not already listed above. This might include, for example, sand filters, infiltration trenches or infiltration swales. The number entered here should be supported by calculations that show how a surface component and subsurface component of storage have been taken into account. As with the other retention volumes, this input value is interpreted as an added depth of storage evenly distributed across the drainage area.

6. URR Summary

The URR Summary page (Figure 4b) shows how the use of LID features affects the runoff hydrograph relative to the URR target.

6.1. Input

To determine whether your site design meets the URR requirements, enter input data required.

20. The MMSD Chapter 13 Uniform Release Rate flow target is 0.15 cfs/acre for the 2-year storm and 0.50 cfs/acre for the 100-year storm.

6.2. Output

The Output Summary and Runoff Hydrographs will change instantaneously in response to user input. (To easily view the input and output at the same time, select menu item *View*, then *Zoom*, and lower the magnification.)

21a-21b. For the NoLID site condition, the runoff depth is calculated using standard NRCS curve number calculations, and is equivalent to the area under the runoff hydrograph shown. For the LID condition, the depth is also equivalent to the area under the corresponding runoff hydrograph. That depth reflects both the curve number calculations based on land surface conditions and the combination of retention volumes associated with the LID components that have been sized on the Input page.

22a-22b. These peak flow values are obtained from the runoff hydrographs.

23a-23b. As illustrated in the hydrograph below the output tables, the detention volume is estimated as the area above a straight diagonal line that starts at the runoff target and runs tangent to the ascending limb of the runoff hydrograph. Drawing a diagonal line to a point near the beginning of the runoff hydrograph is a common approach to estimating detention volume.

24a-24b. Due to site constraints, LID features might not fully achieve the URR target. Such is the case for the example illustrated in Figure 4b. Consequently, a detention pond at the

drainage area outlet may still be seen as necessary. However, rather than routing the entire hydrograph through a detention pond, it may be more desirable to minimize the storage requirement at the outlet by splitting out the flow that exceeds the desired flow rate, placing only that excess flow into a retention area. Figure 6 illustrates the relationship between the split flow retention storage volume and the detention storage requirements at the outlet.

25. As indicated in the legend, the two runoff hydrographs represent the runoff pattern with and without an LID strategy applied. The beginning and ending time have been set at 8 and 18 hours, respectively so that the change in flow rate near the peak can be easily seen.

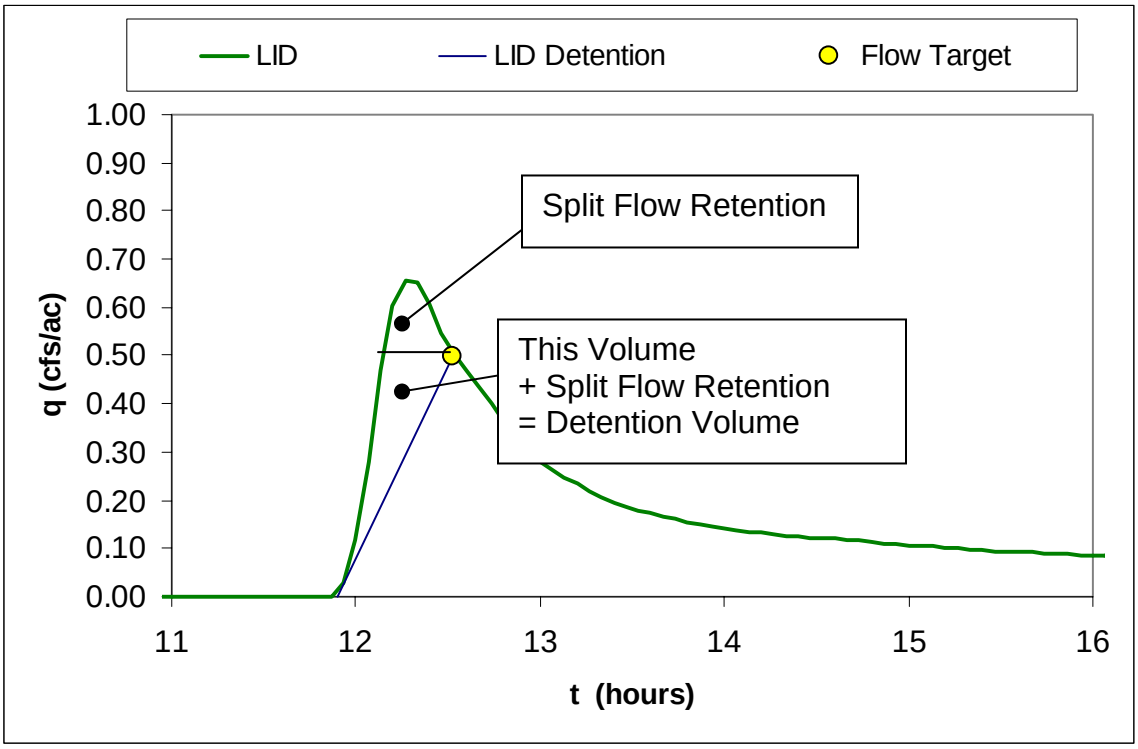


Figure 6. An example of how splitting flow at outlet can achieve a flow target for less than the volume required by detention

7. Exporting the LID Hydrograph

The LID hydrograph can be exported to other programs for subsequent routing calculations, such as those typically required in detention pond design and analysis. The *OuputHydrograph* sheet contains the hydrograph values presented in three different ways:

1. As originally calculated (Columns A and B).
2. Calculated on a user-selected time step (Columns H and I).
3. Arranged and formatted for export to TR-20 READHD records (Column J through N).

See the *OutputHydrograph* sheet itself for more information.

8. References

Milwaukee Metropolitan Sewerage District, 2002. *Surface Water and Stormwater Rules: Interim Guidance Manual.* Accessed on April 28, 2004 at http://www.mmsd.com/stormwaterweb/Startpg.htm.

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Saxton, K. E., Rawls, W. J., Romberger, J. S. and Papendick, R. I. 1986. Estimating generalized soil water characteristics from texture. *Soil Sci. Soc. Amer. J.* 50(4):1031-1036.

Saxton, K.E. 2003. Soil water characteristics from texture. United States Department of Agriculture.

Soil Conservation Service, 1983. *Computer Program for Project Formulation Hydrology, Technical Release 20 (TR-20).*

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Appendix A.

Five Methods of Accounting for the Effect of Distributed Retention on the Runoff Hydrograph

Paul Koch, Ph.D., P.E.

This Appendix describes five options that were considered to account for the retention volume provided within a drainage area. Each of these options is derived in some way from the NRCS unit hydrograph method. A comparison of the options provides a rationale for ultimately selecting the one option incorporated into the spreadsheet.

The first two of these options performs calculations directly on the runoff hydrograph generated without taking into account retention storage. The remaining three options employ calculations that adjust the NRCS runoff depth formula before hydrograph components are generated.

Option 1. Truncated hydrograph

One approach to evaluating the impact of retention on a drainage area is to treat the retention as if it is all provided in-line at the downstream end of the drainage area, just above the outlet. A family of curves illustrating the results of this approach is shown in Figure A1. In that figure, the influence of the retention is represented by a vertical line representing an assumed rising limb of the hydrograph that corresponds to the moment that the retention storage is filled.

Note that for the retention to be expected to have any influence on the peak at all, it must have the capacity to capture all the flow up to and past the peak—an approach which is likely to result in fairly conservative designs. Where storage is provided with some uniformity upstream of the outlet, however, it stands to reason that some of that retention will reduce the peak to some degree even when the retention is provided in relatively small amounts.

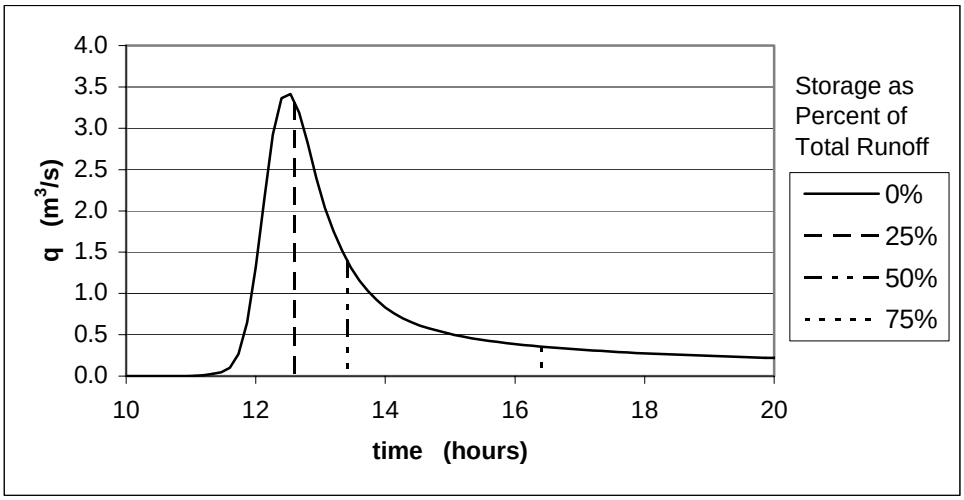

Figure A1. Retention volume evaluated as a truncation of the runoff hydrograph

Option 2. Scalar Multiplication

A second option involves taking the NoLID ordinates and simply multiplying them by the ratio of the LID runoff depth to the NoLID runoff depth. For each flow rate represented in the NoLID runoff hydrograph an adjusted flow rate was calculated as

$$q_{adjust} = q_{NoLID}\left(\frac{Q_{LID}}{Q_{NoLID}}\right) \qquad \text{(A1)}$$

where q_{adjust} = ordinate of adjusted runoff hydrograph
q_{NoLID} = ordinate of runoff hydrograph for NoLID
Q_{LID} = total depth of runoff associated with LID
Q_{NoLID} = total depth of runoff associated with NoLID

A family of curves showing how the runoff hydrograph will be changed using this method with increasing amounts of retention is presented in Figure A2. This method requires only a direct adjustment in the magnitude of the runoff hydrograph. However, rather than reducing runoff by filling the retention capacity toward the beginning of the storm event, this method places the effect of much of the retention well after the hydrograph peak, significantly discounting the degree to which a uniform distribution of retention would actually reduce the peak.

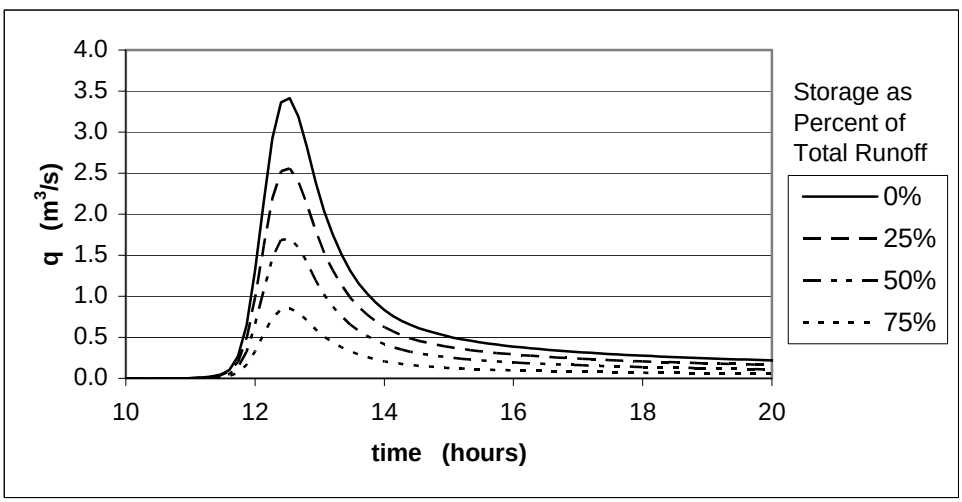

Figure A2. Changes in runoff hydrograph when original hydrograph is multiplied by a scalar to account for retention storage

A Closer Look at Runoff Hydrograph Calculations

The standard method for generating a runoff hydrograph using the SCS unit hydrograph with convolution calculations offers several options for taking into account distributed retention volumes within a drainage area. The calculations involve these steps for each time increment:

1. Within the storm event, calculate the total rainfall up to that point in time.

2. Check the total rainfall against the capacity that needs to be filled on the land surface (the initial abstraction) before runoff can occur.
3. If the total rainfall exceeds the initial abstraction, construct a hydrograph that shows the effect of that single increment of excess rainfall on the runoff pattern at the outlet.
4. Repeat for the next time step within the storm, offsetting the resulting hydrograph by the time increment.
5. Add the components hydrographs to establish a total storm hydrograph for runoff at the outlet.

TR-55 provides this formula for calculating the depth of runoff:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad \text{(A2)}$$

where Q = runoff depth (in.)
P = precipitation depth (in.)
S = potential maximum retention after runoff begins
I_a = initial abstraction, volume that must be filled before runoff begins. $I_a = 0.2\,S$

Additionally, S is related to the *CN* as

$$S = \frac{1000}{CN} - 10\,. \qquad \text{(A3)}$$

Current software implementations of TR-55 and TR-20 calculate Equations A2 and A3.

Option 3. Subtract retention from rainfall

If the retention distributed in a watershed is sufficiently uniform, it might be convenient simply to divide the total retention volume by the drainage area and subtract the result from the rainfall along with I_a.

Letting R represent the total retention volume divided by total drainage area, the calculation of runoff using this approach can be formulated as follows:

$$Q = \frac{(P - I_a - R)^2}{(P - I_a - R) + S} \qquad \text{(A4)}$$

Subsequently, the analyst can perform the usual unit hydrograph calculations. However, the approach is problematic because the volume of retention provided will never be fully accounted for. Just as runoff is always less than rainfall when the standard formula is used, the change in runoff volume will always be less than the volume of retention actually provided when the retention volume is first subtracted from the rainfall before the runoff depth is calculated.

For example, if the depth of precipitation is 2.57 inches over a drainage area having a CN of 80, then the depth of runoff is 0.94 inches. If the distributed retention depth is 0.39 inches, then subtracting the retention from the rainfall leads to a runoff of 0.67 inches. But since 0.94 - 0.67 = 0.27 rather than 0.39, it is clear that not all the retention depth has been accounted for using this approach. If it were, the final runoff value would be approximately 19% less.

A family of curves showing how the runoff hydrograph will be changed using this method with different amounts of retention is shown in Figure 3. It is worth noting that when the retention storage capacity is equated to the total runoff volume without retention, there is still some runoff. At the extreme, Equation 5 indicates that reducing the amount of runoff to zero requires that the amount of excess rainfall (P – Ia – R) be reduced to zero. Because this ignores the infiltration potential of the ground upstream of the retention area, the technical inadequacy of this approach is apparent.

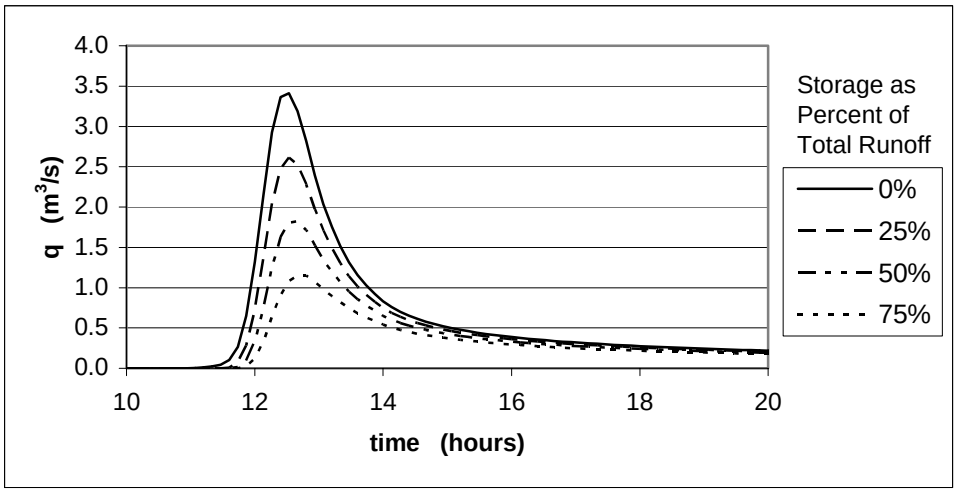

Figure A3. Changes in runoff hydrograph when storage is subtracted from rainfall

Option 4. Subtract retention from runoff

Subtracting retention from the runoff generated by the land surface will account for the retention explicitly, as in this formula:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} - R \qquad \text{(A5)}$$

Within the NRCS convolution calculations, the formula can be applied as follows: First the standard runoff volume is calculated, and then it is checked against the available retention volume to determine whether that volume has been filled. After the total runoff exceeds the total retention volume, a component of the runoff hydrograph is developed to represent the incremental amount of runoff generated in each succeeding time increment.

If the retention is constrained to a small percentage of the total drainage area, it seems reasonable to assume that the S value for the drainage area as a whole will not change. An upward or downward revision of S may be warranted depending on the effect of the retention facility on the local infiltration capacity. For rain gardens, which are typically designed with highly pervious soil mixtures, keeping the S representative of the surrounding land cover will constitute a conservative assumption, more likely leading to an overestimation rather than underestimation of runoff.

A family of curves showing how the runoff hydrograph will be changed using this method with different amounts of retention is shown in Figure A4. While this option is straightforward, current software implementations of TR-55 and TR-20 cannot calculate Equation A5. Adaptation of NRCS methods using the formulation for this option requires other software.

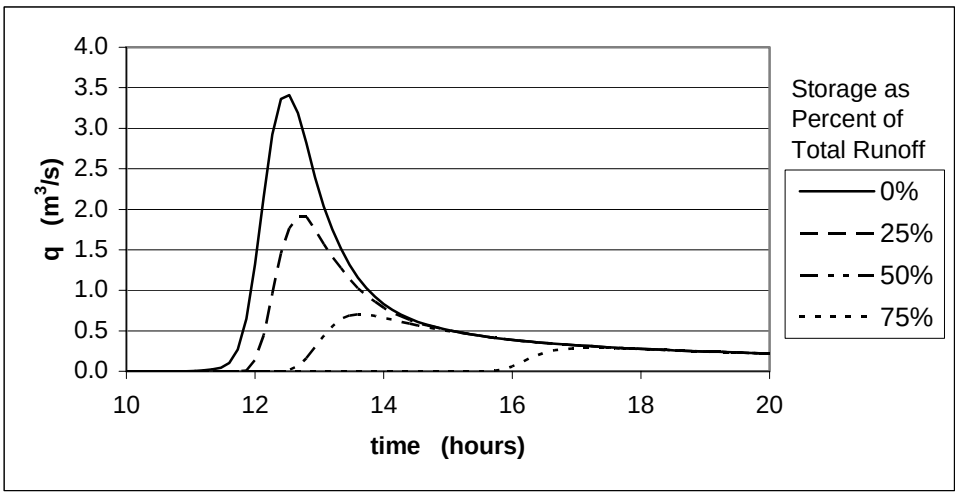

Figure A4. Changes in runoff hydrograph when storage is subtracted from runoff

Option 5. Adjust CN for 24-hour Storm Depth

A standard assumption given in TR-55 is that $I_a = 0.2S$. Consequently, the NRCS standard runoff equation is sometimes expressed as

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad \text{(A5)}$$

Subtracting the total retention from the total runoff at the end of a storm event gives a runoff value that a different S value can be based on. The equation

$$Q - R = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad \text{(A6)}$$

can be solved for a revised value of *S*, which will increase with increases in retention, and then a revised *CN* value can be calculated from the revised *S*. That revised *CN* can subsequently be used to generate a new runoff hydrograph.

This approach does properly account for the effect of the retention volume on the runoff volume for the storm as a whole. That is, the total area under the runoff hydrograph will be equivalent to *Q* minus *R*. The remaining difficulty is that the effect of the retention volume is not fully accounted for until the end of the storm. By design, the placement of retention should typically result in the retention cells being filled well before the end of the storm, so that retention will actually have greater value in reducing the peak flow than a simple *CN* adjustment would indicate.

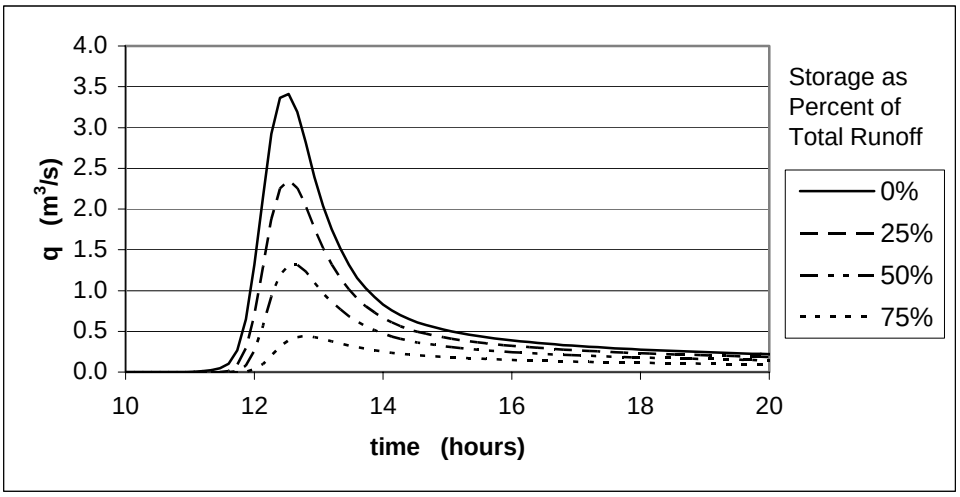

Figure A5. Changes in runoff hydrograph when CN adjustment is made to account for retention storage

Runoff Depth Comparisons

There are significant differences in the depth of runoff calculated for these three different approaches. Figure A6 shows a comparison of depth calculations for Options 3, 4 and 5. Relative to the standard runoff curve, Option 3 moves the runoff curve to the right, and Option 4 moves it downward. Option 5 starts somewhat to the right of the standard curve, and ends where the difference in runoff is equal to the total depth of retention.

It is worth noting that the *CN* adjustment method will produce a different *CN* value for different depths of rainfall, even if the land cover, soil characteristics and amount of added retention remains the same. If, as Figure A6 shows, a *CN* is determined using Equation A6 for a rainfall depth of 80 mm and retention depth of 10 mm, the amount of runoff generated for 60 mm of rainfall is approximately 13 mm. However, if a *CN* is recalculated using Equation A6 for a rainfall depth of 60 mm, the amount of runoff is approximately 10 mm.

This presents a logical difficulty. Since the accumulation of precipitation from 0 to 80 mm passes through the value of 60 mm, it seems reasonable to expect that the runoff depth associated with 60 mm should be the same for the same land use and soil type, regardless of whether the storm lasts longer.

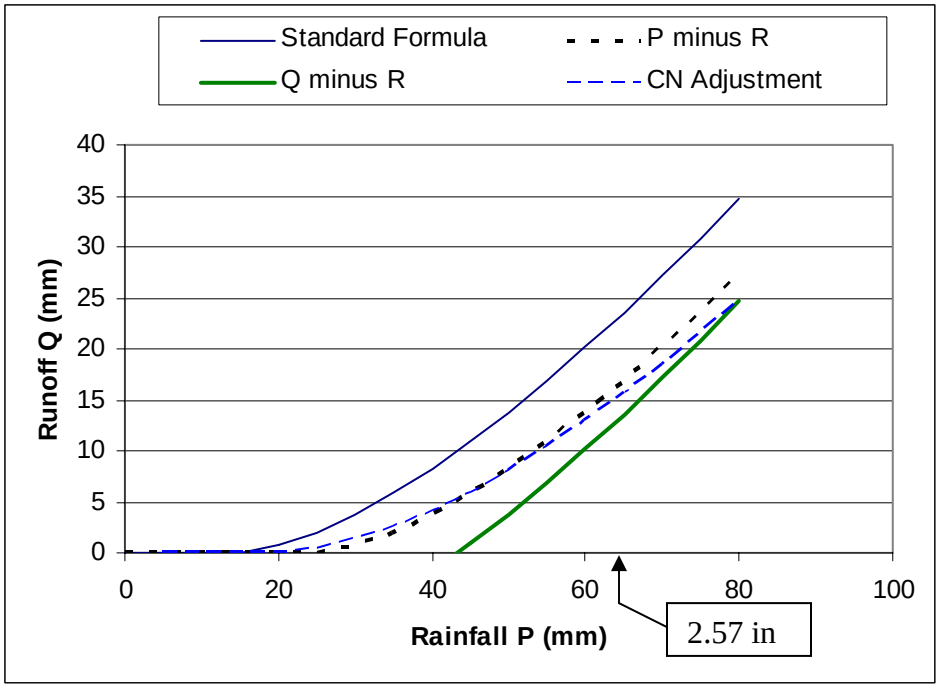

Figure A6. Comparison of depth of runoff calculations
(CN = 80; overall retention depth = 10 mm)

Runoff Peak Comparisons

A comparison of the effect of the five options on the runoff peak is illustrated in Figure A7. The chart shows that accounting for the runoff volume as described in Option 4 results in the least amount of runoff for all but the highest levels of peak runoff reduction, and, overall, is nearly as efficient as detention in terms of achieving a relative reduction in peak flow for a given volume of storage. Option 4 was selected for implementation in the LID spreadsheet.

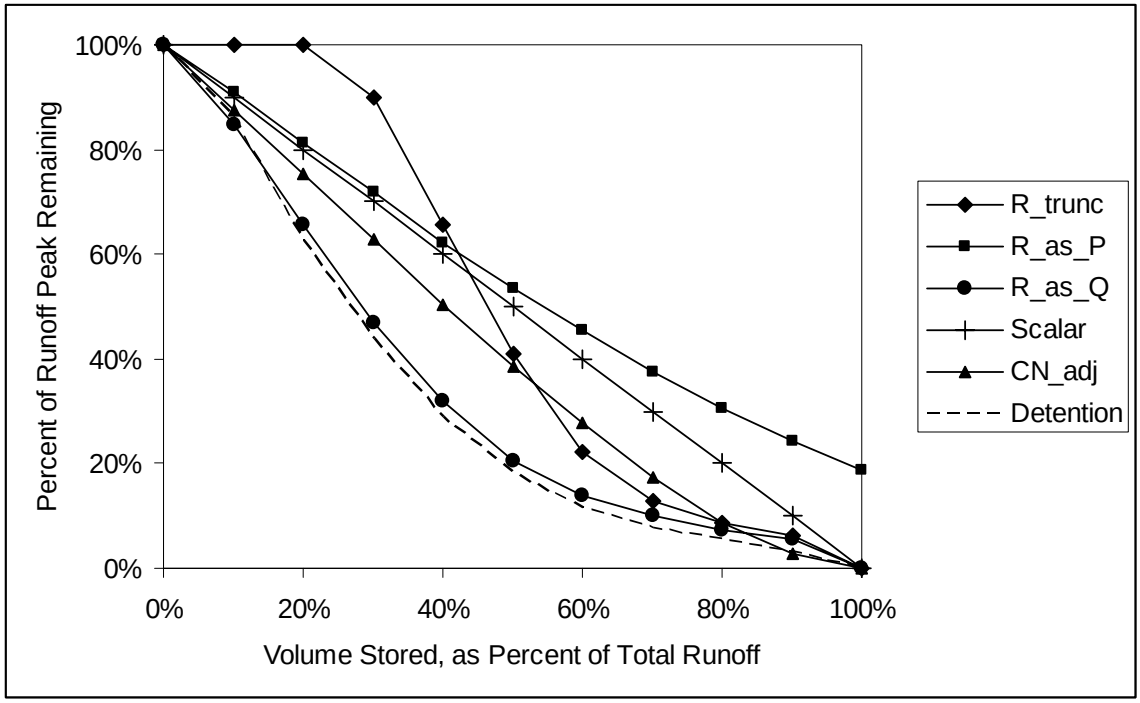

Figure A4. Comparison of different methods to account for runoff storage
(CN = 75, Tc=1 hr, D.A. = 1 km^2)

Appendix B.

Summary of Spreadsheet Contents

Normally visible sheets:

1. *ReadMe* Describes basic program purpose and identifies developer.
2. *MainPage* Two-page user interface.
3. *SubareaCheck* Confirms that all retention volumes will be filled.
4. *RainDistribution* For inputting the temporal rainfall distribution.
5. *OutputHydrograph* Runoff hydrograph for the LID site design.

Normally hidden sheets:

6. *PlotData* Hydrograph data plotted on the output page.
7. *Convolve* Convolution calculations in metric (SI) units.
8. *RainfallPlot* Chart showing cumulative rainfall distribution for Type II storm.
9. *SplitFlow* Calculates area of LID hydrograph above peak flow target.

Convolve receives user input from *MainPage*, performs computations in metric units and returns the output values in English units.

Appendix C.

Curve Numbers and Subsurface Storage for Porous Pavement and Permeable Pavers

NRCS Runoff Curve Numbers for Porous Pavement

Gravel Subbase Thickness	Curve Number for Various Hydrologic Soil Groups			
(inches)	A	B	C	D
10	57	66	69	75
12	56	64	68	74
14	55	63	67	72
16	54	62	65	70
18	53	61	64	69
20	52	60	63	68
24	52	58	61	66
30	49	55	57	61
36	47	52	55	58

Notes

- Source: Engineering Field Manual Notice – NENTC 25, released by the Northeast National Technical Center of the USDA Soil Conservation Service, June 22, 1986.
- The *CN* values are based on Antecedent Moisture Condition II and an I_a of 0.25 inches.
- All the *CN* values are for properly maintained porous pavement. The *CN* values for porous pavement that is not properly maintained is the default *CN* for pavement, which is 98.

Limitations

- The infiltration rate of asphalt layer is not limiting. Minimum infiltration rate is 0.27 in/hr.
- The season high water table is greater than 2.0 feet below the gravel layer.
- There is at least 2.0 feet of soil below the gravel layer.
- The potential maximum retention after runoff begins includes storage in pavement gravel and soil.

General Suggestions Regarding Permeable Paver Systems

“There are […] no specific curve numbers for permeable pavements. […] CN = 65 is an average number based on the fact that virtually all permeable pavements can store about 2 inches of rainfall (in the base layer) before infiltrating it or draining it elsewhere (either into the subgrade, if permeable, or into a drainage system). This is an estimate based on storage capacity within open-graded bases (typically 30-40% of the total base volume).

“Many permeable pavements will be built on A or B soils and we know that thicker bases means more storage capacity, and when placed on A or B soils, there will be infiltration rather than runoff. However in any underlying soil case, the infiltration rate and storage capacity of the base will be greater than that of the underlying soil. Therefore, the *CN* for permeable pavers will be lower than the underlying soil (substantially in some cases). The CN 65 is considered a starting point (conservative) considering the infiltration rate of permeable pavements are based on various factors - design storms, underlying soil, supplemental drainage (if used), pavement load, climate, etc. Unfortunately there isn't one uniform design.

“The 65 number was derived from TR - 55 Urban Hydrology for Small Watersheds, Table 2-1 Runoff depth for selected CNs and rainfall amounts. It is based on the fact that virtually any permeable pavement will infiltrate and store up to 2 inches of rainfall (virtually no runoff). In many cases, as I've mentioned it can store much more, resulting in an even lower curve number. You may be able to extrapolate from this to assign numbers for various soils.

“Though pervious pavements have been around awhile (asphalt and ready-mix concrete), interlocking permeable pavers have only been around (in the U.S.) for about 10 years, with most use over the last few years. Perhaps they will be measured in the future for CN values, though because of the variables, it might take a lot of testing over the entire country to get good average parameters. “

Donna DeNinno
UNI-GROUP U.S.A.
May 15, 2003

Appendix D.

Runoff Storage Capacity of Vegetated Roofs

See paper by Charlie Miller on the following pages.
Edited slightly as indicated by brackets.
Used by permission.

Disclaimer: This paper is provided here for informational purposes only. Providing this information does not constitute an endorsement of Roofscapes, Inc. by MMSD. Nor does it constitute an endorsement by Roofscapes, Inc., of the method of analysis associated with the *LID Quicksheet*.

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Use of Vegetated Roof Covers in Runoff Management

By Charlie Miller, P.E.

The effectiveness of green roofs in reducing runoff impacts, especially in densely developed areas, is one of the principal reasons that they are so popular with city engineers in Germany. In Germany alone, more than 20 million square feet of new green roof are installed every year. Many cities require green roofs for buildings in districts that are plagued by chronic runoff-related problems.

Initial abstraction is an engineering term that describes the quantity of rainfall that must occur before appreciable runoff will commence. An approximate rule-of-thumb for a wide range of green roofs is that the initial abstraction will equal about 1/3 of the maximum water capacity, MWC, of the growing medium. The MWC is a benchmark number that is measured in a specific test used in Europe [and available in the United States]. For example, a green roof with an MWC of 1.5 inches will not generate significant runoff until at least 0.5 inches of rainfall has occurred.

Vegetated roof covers are very effective in reducing total runoff volume. A predictor of the percent reduction in total annual runoff volume is:

$$\text{Pct. Reduction} = 100 \times 0.45 \times \text{MWC}^{1/3}$$

A typical green roof with about 3 inches of growing media can be designed to reduce annual runoff by more than 50 percent. However, it is very important to keep in mind that this information is based on experience in temperate climates with a rainfall pattern similar to the American Northeast. For instance in the Pacific Northwest, where rainfall tends to occur in steady long-duration events, the reduction in runoff volume may be not be as great.

Another property of interest is field capacity. This is the quantity of water absorbed by the green roof during a rainfall event that will <u>not</u> be later released as runoff. This water will eventually be evapotranspired by the plants. The difference between the field capacity and the MWC determines how effective a green roof will be in suppressing peak rates of runoff during storms. For many types of green roof media, the field capacity is equal to about ½ of the MWC.

Runoff Control Using Thin Vegetated Covers

A critical aspect of using vegetated roof covers is to clearly identify the management goals and develop suitable design criteria. It has been demonstrated in Germany that the 3-inch vegetated roof cover has the highest benefit to cost ratio. A properly designed 3-inch vegetated roof cover will provide a durable, low maintenance system that can achieve the objectives of moderating temperature, reducing runoff, and prolonging the life of the underlying waterproofing materials. Furthermore, these systems can be added to most existing buildings, often without having to reinforce or otherwise alter their structural design.

The value of green roofs in reducing the rate of runoff depends upon the design rainfall events that are considered. For communities where runoff rates are computed using the rational method (which emphasizes the impact of intense short-duration rainfall events), thin vegetated covers can typically satisfy runoff management goals for 10-, 25-, and in some cases even 50-year return design storms. Where design storms are based on 24-hour events, it is generally possible to demonstrate control of runoff to pre-development levels for storms up to several inches in magnitude (i.e., a two-year storm magnitude in southeastern Pennsylvania). It is also helpful to keep in mind that in southeastern Pennsylvania 24-hour storms with magnitudes of less than 1.5 inches contribute more than 90 percent of all rainfall.

In Germany the standard design event for urban runoff management is one inch of rainfall falling in 15 minutes. This would be a 10-year return frequency event in southeastern Pennsylvania. In our opinion, the runoff requirements for urban areas that are undergoing redevelopment should be based on the type of the storm that is linked to chronic runoff-related problems (e.g., nuisance flooding, combined serer overflow, TMDL exceedances). By-and-large these are summer downpours. Therefore, runoff abatement programs should focus on these storms. Green roofs can be a powerful tool for achieving this benefit.

Deep Vegetated Covers and Zero Discharge Installations

A typical 14-inch deep green roof can be relied on to reduce total annual runoff by 85 to 95 percent in temperate climates. In combination with other water management techniques, zero discharge is a readily attainable goal. The following are excellent examples of the integration of a variety of techniques to eliminate off-site discharge of rainfall runoff. These techniques include green roofs, cisterns, facade planters, reflecting pools, infiltration beds, and utility water recycling systems. Unfortunately, all of the information concerning these systems is in German. However, we have summarized some of these in English. The important points to remember are that: 1) these integrated building systems are a reality in Germany and that 2) a variety of techniques must be deployed in unison to achieve the goal. Although factors such as climate and geologic conditions will influence the design, there will always be a way to achieve the objective.

Cross Savings Bank (Kreissparkasse) in Weilburg

This building occupies a 3,250 square-foot area. The management system utilizes a combination of green roof landscapes, ranging in size from 2 to 6 inches in thickness. Cisterns are used to capture excess runoff for reuse in irrigation during dry periods.

Europe Park (Europapark) in Rust

This project also has a footprint of 3,250 square feet. Green roofs in combination with cisterns and low-head irrigation pumps, powered by photovoltaic panels, characterize this project.

New Convention Center (Neue Messe) in Munich

The Convention Center is a 409,000 (9 acre) square-foot complex. This is a very exciting project that integrates many management techniques. Green roofs are an essential part of the zero-discharge design and are responsible for up to 85% of the reduction in runoff. The remaining runoff reduction is accomplished by recycling runoff for utility uses and by infiltration. The Optigrün *RWS* computer simulation program was used to estimate the efficiency of the green roofs so that the other practices could be properly sized.

Commercial Center in Bondorf

This is a 40-acre development with zero runoff discharge. This stringent requirement was the result of the inability of the local wastewater treatment plant to absorb additional water from runoff. Fully 70 percent of the total area is covered with impermeable surfaces. In addition to green roofs and water recycling, this project relies on large infiltration galleries and landscape pools to infiltrate water.

[…]The following projects are also noteworthy.

Prisma building in Nurnberg

The water management system for this project incorporates green roofs, cisterns, façade planters, water-curtain climate control, gray water recycling, and infiltration. Water management is made part of an overall artistic statement. This project was described recently in the *ASLA Professional Interest Group Water Conservation*, Vol. III, No. 1, 1999.

Pottsdamer Platz in Berlin

While not strictly an example of zero discharge, this ultra-urban development points the way to the possibilities of integrated runoff design. The design

beautifully integrates extensive green roofs (2 to 3 inches) with reflecting pools, created wetlands, cisterns, and water recycling. The primary limitation of this project was the deliberate decision not to treat runoff from roads and main thoroughfares. Infiltration opportunities were also very limited due to the high water table on the floodplain of the river Sprey.

National Bank of Baden-Würtenberg (Landesbank) in Stuttgart

This is another Optigrün project, which involves covering half of the 43,000 square-foot site with green roofs. A very lovely and diverse roof landscape is used to eliminate all but about 5% of annual runoff. Profiles range form 4 to 16 inches in depth.

[…]

The following table summarizes output from the [empirical Optigrün-]*RWS* computer simulation program for a 3.25-inch thick proto-type installation for the Fencing Academy of Philadelphia. This simulation utilized a one-year, 5-minute digital rainfall record. Two standard design storms were also inserted into the rainfall record. The predictions of the simulation were verified by field observation of the proto-type. The output illustrates that this thin green roof is much more effective in controlling brief rainfall events than long-duration storms. However, significant runoff rate suppression was achieved for all storm events. Similar analyses can be conducted as part of the feasibility phase of other projects.

Selected Storms: *RWS* Simulation of One-Year Rainfall Record

3.25-inch (8 cm) Deep Extensive Vegetated Roof Cover

Rainfall record for Reading, Pennsylvania (1994)

Rainfall 15-min Peak Rate in/hr	Rainfall 24-hour Volume in	15-min Peak Discharge in/hr	Attenuation	Comments
1.6	0.9	negligible	100%	"cloud burst:" peak occurs in first 25 min.
0.4	1.1	0.1	63%	
0.4	1.0	0.2	59%	
0.8	1.2	0.2	72%	
0.8	1.5	0.4	56%	
1.2	0.6	0.4	63%	
1.2	1.3	0.7	39%	
1.6	1.1	0.3	81%	
1.6	1.0	0.5	69%	
2.4	1.3	0.7	71%	
3.2	3.4	1.4	57%	
3.5	2.8	1.3	61%	Standard 2-year: type II rainfall distribution
5.4	4.9	2.8	47%	Standard 10-year: type II rainfall distribution

Urban Watershed Forestry Manual

Part 2: Conserving and Planting Trees at Development Sites

United States Department of Agriculture
Forest Service
Northeastern Area
State and Private Forestry
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May 2006

Urban Watershed Forestry Manual

Part 2. Conserving and Planting Trees at Development Sites

Second in a Three-Part Manual Series on Using Trees to Protect and Restore Urban Watersheds

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ABOUT THIS MANUAL SERIES

This manual is the second in a three-part series on using trees to protect and restore urban watersheds. A brief description of each part follows.

Part 1. Methods for Increasing Forest Cover in a Watershed introduces the emerging topic of urban watershed forestry. This part also presents new methods for the watershed planner or forester, to systematically measure watershed forest cover and select the best methods for maintaining or increasing this cover by protecting, enhancing, and reforesting large parcels of primarily public land across the watershed. These methods are based on extensive review of the latest research and input from experts in a wide range of related fields.

Part 2. Conserving and Planting Trees at Development Sites presents specific ways to enable developers, engineers, or landscape architects to incorporate more trees into a development site. The proposed approach focuses on protecting existing trees, planting trees in storm water treatment practices, and planting trees in other open spaces at a development site. This part introduces conceptual designs for storm water treatment practices that utilize trees as part of the design (referred to as storm water forestry practices.) These designs were developed with input from experts in storm water engineering, forestry, and a range of related fields.

Part 3. Urban Tree Planting Guide provides detailed guidance on urban tree planting that is applicable at both development site and watershed scales. Topics covered include site assessment, planting design, site preparation and other pre-planting considerations, and planting and maintenance techniques. An Urban Tree Selection Guide is included for use in selecting the best tree and shrub species for the planting site.

Urban watershed forestry is a new practice that draws from multiple disciplines, including forestry, hydrology, engineering, landscape architecture, mapping, planning, and soil science. Consequently, some ideas drawn from each discipline have been simplified in this manual series in order to be easily understood by a diverse audience. In addition, the latest and most relevant research from each discipline has been used to support the new practice. The research summarized in these manuals, however, is not intended to provide a comprehensive literature review.

This manual series draws heavily upon research and examples from the Chesapeake Bay watershed and the northeastern region of the United States. The manuals primarily apply to these regions, and may also apply in other humid regions of the country where the natural vegetative cover is predominately forest. Finally, several elements in the manuals are brand new and will require additional testing, research, and analysis. We welcome future additions to the methodology, techniques, and designs presented.

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The preparation of the manual was greatly influenced by two design workshops held in Annapolis, MD, in winter 2004. The first workshop focused on developing conceptual designs for integrating trees and storm water treatment practices, while the second workshop developed guidelines for planting trees in specific urban locations. More than 40 local, regional, and national experts participated in the workshops, including foresters, storm water engineers, landscape architects, arborists, urban soil scientists, watershed planners, and representatives from parks, and transportation and utility companies.

The Center for Watershed Protection project team included:

- Karen Cappiella
- Tom Schueler
- Ted Brown
- Chris Swann
- Tiffany Wright

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Table of Contents

List of Tables ... v
List of Figures ... v
List of Text Boxes ... vii
Acronyms Used ... vii
Chapter 1: Introduction ... 1
Why Conserve and Plant Trees at Development Sites? ... 1
Benefits of Trees at Development Sites ... 2
Economic benefits ... 2
Environmental benefits ... 3
Community benefits ... 5
Regulatory Considerations for Trees at Development Sites ... 6
Unique Properties of the Urban Planting Environment ... 8
Chapter 2. How to Conserve and Plant Trees at Development Sites ... 12
Conserving Existing Trees During Construction ... 12
1. Inventory Existing Forest ... 12
2. Identify Trees to Protect ... 14
3. Design the Development With Tree Conservation in Mind ... 15
4. Protect Trees and Soil During Construction ... 18
5. Protect Trees After Construction ... 20
Planting Trees at Development Sites ... 20
1. Select Planting Sites ... 20
2. Evaluate and Improve Planting Sites ... 21
3. Plant and Maintain Trees ... 23
Chapter 3. Design and Planting Guidelines for Storm Water Forestry Practices ... 24
Wooded Wetland ... 29
Bioretention and Bioinfiltration Facilities ... 35
Alternating Side Slope Plantings (Swale) ... 38
Tree Check Dams (Swale) ... 40
Forested Filter Strip ... 43
Multi-Zone Filter Strip ... 46
Linear Storm Water Tree Pit ... 49
Chapter 4. Planting Trees Along Streets and in Parking Lots ... 53
Planting Trees Along Local Streets ... 57
Planting Trees in Parking Lots ... 61

Appendix A. Forest Stand Delineation A-1
Appendix B. Tree Protection Specifications B-1
References References-1

List of Tables

Table 1. Economic Benefits of Trees at Development Sites 3
Table 2. Environmental Benefits of Trees at Development Sites 5
Table 3. Community Benefits of Trees at Development Sites 5
Table 4. Regulations Related to Conserving and Planting Trees at Development Sites 6
Table 5. Potential Regulatory Barriers to Tree Conservation, Planting, and Growth at Development Sites 7
Table 6. Forest and Tree Inventory Guidance 13
Table 7. Selecting Priority Trees and Forests for Conservation 15
Table 8. Methods for Addressing Urban Planting Constraints 22
Table 9. Pollutant Removal (Median %) by Standard Storm Water Treatment Practices 24
Table 10. Characteristics of Storm Water Treatment Practices That May Limit Tree Growth 25
Table 11. Inundation in Selected Storm Water Treatment Practices 26
Table 12. Potential Engineering Conflicts and Resolutions for Planting Trees in Storm Water Treatment Practices 27

List of Figures

Figure 1. Large tracts of forest and mature trees can be conserved during development. 1
Figure 2. Healthy trees can increase property values and aid home sales. 2
Figure 3. Trees and natural areas provide many recreational opportunities. 5
Figure 4. Stress from harsh urban conditions can kill a street tree. 8
Figure 5. A typical urban tree pit is about 4 feet by 4 feet and does not provide adequate soil volume for most trees. 9
Figure 6. Improper disposal of construction materials and inadequate protection negatively impact trees at a construction site. 9
Figure 7. Deer browsing damages seedlings. 10
Figure 8. Urban heat island effect—Because this tree is surrounded by pavement, it is exposed to high temperatures. 10
Figure 9. A common infrastructure conflict results in tree roots lifting or cracking pavement due to inadequate setbacks between trees and pavement. 11
Figure 10. A map of existing forests on a development site is one product of Forest Stand Delineation—a required inventory in the State of Maryland. 14

Figure 11. An open space design with 72 lots uses less land than a conventional subdivision with the same number of lots. Floodplains and wetlands are considered unbuildable and must be subtracted from gross density. An alternative design provides 66 lots. 16
Figure 12. Site fingerprinting limits site disturbance to the minimum necessary for building..... 17
Figure 13. The trunk diameter method is one of four ways to define the critical root zone. 18
Figure 14. Orange plastic mesh fencing delineates tree protection areas. 18
Figure 15. Fencing surrounds a mature tree that is to be preserved. 19
Figure 16. Development sites offer several potential planting areas. 21
Figure 17. Storm water ponds with trees incorporated offer benefits over a conventional storm water pond with no trees. 24
Figure 18. Swales with trees offer greater benefits than a swale with no trees. 25
Figure 19. A storm water pond or wetland contains four planting zones. 26
Figure 20. Overgrowth of willows in this pond limits maintenance access and essentially creates a monoculture. 28
Figure 21. A wooded wetland incorporates trees into the design. 29
Figure 22. A weir wall with a v-notch and a hood resists clogging by woody debris. 30
Figure 23. A secondary riser helps to keep permanent pools at safe elevations, even when outlets clog. 30
Figure 24. Tree mounds are one feature of a wooded wetland that incorporates trees. 31
Figure 25. Tree clusters increase the soil and water volumes available for trees planted on side slopes. 32
Figure 26. Bioretention and bioinfiltration facilities remove pollutants from storm water runoff using a filter medium. 35
Figure 27. Alternating side-slope plantings are an attractive way to incorporate trees into swales without obstructing channel flow. 39
Figure 28. Tree check dams slow runoff and prevent erosion in swales with slopes of 2 percent to 6 percent. 40
Figure 29. Forested filter strip profile shows how runoff flows through the various zones..... 43
Figure 30. Forested filter strip plan shows its suitability to a linear area. 44
Figure 31. A multi-zone filter strip includes four successive vegetation zones. 46
Figure 32. A multi-zone filter strip requires a minimum width of 25 feet. 47
Figure 33. A linear storm water tree pit collects and treats storm water that is directed from rooftops. 49
Figure 34. Tree pits are connected through a soil trench, and tree pit protection prevents damage from pedestrian traffic. 50
Figure 35. The environment differs drastically in a development with no street trees from one with trees that matured to form a canopy over the street. 53
Figure 36. Non-linear street tree plantings are an alternative to linear roadside plantings. 54

Figure 37. Trees planted in a median strip provide shade, slow traffic, and make a street more attractive than one with little vegetation. 54
Figure 38. A cul-de-sac is typically overlooked as a place to plant trees. 54
Figure 39. Trees planted in holes that are too small may eventually crack nearby pavement. 55
Figure 40. The harsh environment of a parking lot can be tempered by including an interior planting strip that allows trees to share rooting space. 55
Figure 41. Trees can be incorporated into various planting areas along local roads. 57
Figure 42. Tree planting along local roads can utilize wide, linear planting areas to accommodate large, healthy trees. 58
Figure 43. Parking lots can be designed to provide larger spaces to plant trees. 61

List of Text Boxes

Box 1. Benefits of Trees at Development Sites 2
Box 2. Hydrologic and Water Quality Benefits of Trees 4
Box 3. Common Causes of Urban Tree Mortality 8
Box 4. Mapping Data for Forest Inventory 12
Box 5. Maryland's Forest Conservation Act 13
Box 6. Better Site Design Techniques to Conserve Forests 17
Box 7. Factors Assessed During the Urban Reforestation Site Assessment 21
Box 8. Design Principles for Urban Tree Planting 23
Box 9. Desirable Characteristics Of Trees For Storm Water Treatment Practices 27

Acronyms Used

CRZ	Critical root zone
FSD	Forest stand delineation
HOA	Homeowners' association
IVM	Integrated vegetation management
LOD	Limits of disturbance
SFP	Storm water forestry practice
STP	Storm water treatment practice

Chapter 1: Introduction

The purpose of this manual is to present specific strategies and practices that developers, engineers or landscape architects can use to incorporate trees into the design of development sites. This manual outlines three approaches for doing so:

1. Conserving existing trees during construction
2. Integrating trees into storm water treatment practices
3. Planting trees along local roads and in parking lots

Developers, contractors, and landscape architects can conserve and plant trees at new development and redevelopment or infill projects. On forested sites, it is most important to conserve existing forests, particularly high quality stands or large, mature trees (Figure 1). To conserve existing forests, developers should inventory the site to identify the best forested areas to protect, design the development to prevent loss of these trees, and take measures to ensure the protection of remaining trees during and after construction.

Where tree conservation is not an option, development sites provide many opportunities to plant new trees, such as in storm water treatment practices (STPs) and other pervious areas of the site. STPs treat storm water runoff by capturing and temporarily detaining water, allowing pollutants to settle out before entering local receiving waters. While some STPs are not traditionally considered appropriate for tree planting, incorporating trees and shrubs in certain areas of STPs can enhance their esthetic appeal and improve their performance. For the purposes of this manual, STPs that incorporate trees into their design are referred to as **storm water forestry practices (SFPs)**.

The remaining pervious areas of a site that are good but often overlooked candidates for tree planting include local road rights-of-way, landscaped islands in cul-de-sacs or traffic circles, and parking lots. Private lawn areas may also constitute a significant portion of green space at development sites, and developers should certainly strive to conserve or plant trees in lawns as well. Many development sites may have harsh soil and environmental conditions that need to be overcome through appropriate tree selection and proper site preparation before planting.

Figure 1. Large tracts of forest (left) and mature trees (right) can be conserved during development.
Photos: Left—Maryland Department of Natural Resources; Right—District of Columbia Department of Forestry

Why Conserve and Plant Trees at Development Sites?

Conserving or planting trees can address forest conservation, landscaping, or other site design requirements. Forest conservation and tree planting enhance the appeal of a development, increase land and housing values, and can reduce costs for construction and storm water management. Trees

also provide a wide range of environmental, economic, and community benefits (such as air and water quality improvement, reduction of storm water runoff, and wildlife habitat). These additional benefits of trees at development sites are summarized below.

BOX 1. BENEFITS OF TREES AT DEVELOPMENT SITES

Economic benefits
- Decrease heating and cooling costs
- Reduce construction and maintenance costs
- Increase property values
- Positively influence consumer behavior

Community benefits
- Improve health and well-being
- Provide shade and block ultraviolet radiation
- Buffer wind and noise

Environmental benefits
- Reduce urban heat island effect
- Enhance function of STPs

Benefits of Trees at Development Sites

Part 1 of this manual series summarizes urban forest benefits that affect watershed health. This part reviews the benefits that urban trees provide at the parcel scale, particularly those realized by the developer or homeowner. An important note is that some benefits may not be fully realized until the trees reach maturity. Benefits of trees at development sites are listed in Box 1.

Economic benefits

The values of houses in neighborhoods with abundant trees are usually higher than those of comparable houses in neighborhoods without trees (Morales, 1980; Morales and others, 1983; Anderson and Cordell, 1988) (Table 1 and Figure 2). Neighborhood natural areas also increase the value of properties located nearby (Kitchen and Hendon, 1967; More and others 1983; Correll and others, 1978) (Table 1). Additional cost benefits to the developer and ultimately the homeowner can result from conserving existing trees at a development site. Tree conservation can reduce the amount of clearing and grading, paving, and storm water management needed at sites, reducing infrastructure costs as well as reducing mowing costs in the future. Table 1 summarizes the economic benefits of trees at development sites.

Figure 2. Healthy trees can increase property values and aid home sales.

Table 1. Economic Benefits of Trees at Development Sites		
Benefit	**Supporting Information**	**Source**
Decrease heating and cooling costs	• Properly placed trees can reduce heating and cooling costs by 10% to 20% on average within 10-15 years after planting • Trees properly planted next to buildings can reduce summer air conditioning costs by 40%. Direct shading of an air conditioner can increase efficiency up to 10% • Energy use in a house with a treed lot can be 20% to 25% lower per year than for the same house in an open area	Heat Island Group (1996) Parker (1983) Heisler (1986)
Reduce construction and maintenance costs	• Developers who conserve trees can save up to $5,000 per acre for clearing, grading, and installing erosion control practices • Developers who conserve trees can save $2,000 to $50,000 to treat the quality and quantity of storm water from a single impervious acre • Developers who conserve trees can save $270 to $640 per acre on annual mowing and maintenance costs	Schueler (1995) Schueler (2000) WHEC (1992)
Increase property values	• Property values of homes with trees are an average of 5% to 7% and as much as 20% higher than equivalent properties without trees • Two regional economic surveys document that conserving forests on residential and commercial sites can enhance property values by an average of 6% to 15% and increase the rate at which units are sold or leased.	MD DNR (n.d.) Morales (1980) and Weyerhaeuser Company (1989)
Positively influence consumer behavior	• Consumer ratings of retail establishments was up to 80% higher for business districts with street trees and other landscaping • Survey results indicated that consumers were more willing to travel farther, visit more frequently, stay longer, and pay for parking in business districts that have trees • Survey participants priced goods an average of 11% higher in landscaped business districts than in districts with no trees	University of Washington (1998)

Environmental benefits

Trees reduce air temperatures due to the shading effect provided by their canopy and the release of water vapor through evapotranspiration. Even relatively sparse parking lot canopies can exert a significant cooling effect on parking lot climate and vehicle temperatures (Scott and others, 1998). This temperature reduction reduces the volatilization of smog precursors formed in parking lots and also translates into energy savings when trees are planted in appropriate locations near buildings (e.g., the south and west sides of the building and near air conditioning units).

Trees further increase comfort by blocking harmful ultraviolet radiation, reducing windspeed, and reducing noise from lawnmowers, traffic, and other urban sounds. To be effective at reducing noise,

a dense, tall, and wide forested buffer should be planted close to the source of the noise. Contiguous rows of trees in widths of 16 feet or more are especially effective (Trees Atlanta, n.d.). Trees also create background noise, such as rustling leaves and wind through the branches, that help to muffle other more offensive noises (Harris, 1992).

Planting trees in storm water treatment practices can increase nutrient uptake, reduce storm water runoff through rainfall interception and evapotranspiration (ET), enhance soil infiltration, provide bank stabilization, increase esthetic appeal, provide wildlife habitat, provide shading, discourage geese, and reduce mowing costs (Shaw and Schmidt, 2003). While few studies exist that directly quantify these benefits, research is available on rainfall interception and ET rates, as well as pollutant removal for individual trees. This data, presented in Box 2, suggests that incorporating trees into STPs may increase their pollutant removal efficiencies. Median pollutant removal efficiencies for standard STPs are presented in Chapter 3. The environmental benefits of trees at development sites are summarized in Table 2.

BOX 2. HYDROLOGIC AND WATER QUALITY BENEFITS OF TREES

This box summarizes data on rainfall interception, evapotranspiration, and nutrient uptake for a single tree. Based on this data, the potential reduction of storm water runoff by each tree planted in an STP is 860 gallons per year, and the potential nitrogen reduction by each tree is 0.05 pounds per year.

Hydrologic and Water Quality Benefits of Trees		
Benefit	**Per Tree Annual Quantification of Benefit**	**Source and Description**
Rainfall interception	760 gallons of water per tree per year	Annual rainfall interception by a large deciduous front yard tree* (CUFR, 2001)
Evapotranspiration	100 gallons of water per tree per year	Transpiration rate of poplar trees for one growing season (EPA, 1998)
Nutrient uptake	0.05 pounds nitrogen per tree per year	Based on daily rate of nitrogen uptake by poplar trees (Licht, 1990)

*A 40-year-old London plane tree growing in a semi-arid climate

Trees also show enormous potential to remove other pollutants, such as metals, pesticides, and organic compounds. The process of using plants to remove contamination from soil and water is called **phytoremediation.** This process has mainly been applied to soil and groundwater but could easily be applied to storm water runoff. Trees such as poplars that can absorb large quantities of water through evapotranspiration are typically used for phytoremediation because this type of consumption contains and controls the migration of contaminants (EPA, 1998). Many other plants have the ability to absorb excess nutrients, filter sediments, and break down pollutants commonly found in storm water runoff. One sugar maple (1 foot in diameter) along a roadway was shown to retain 60 milligrams (mg) cadmium, 140 mg chromium, 820 mg nickel and 5,200 mg lead from the environment in one growing season (Coder, 1996).

Table 2. Environmental Benefits of Trees at Development Sites		
Benefit	**Supporting Information**	**Source**
Reduce urban heat island effect	• Air temperatures can be 4 to 8 degrees Fahrenheit (°F) cooler in well-shaded parking lots than in unshaded parking lots. Similarly, air temperatures in neighborhoods with mature canopy were 3 to 6 °F lower in daytime than in newer neighborhoods with no trees. • Trees reduce surface asphalt temperatures by up to 36 °F, and vehicle cabin temperatures by 47 °F	McPherson (1998), Akbari and others (1992) CUFR (2001)
Enhance function of STPs	• Trees in storm water treatment practices influence evapotranspiration and capacity for nutrient uptake, aid infiltration, provide bank stabilization, increase esthetic appeal, provide wildlife habitat, provide shading, and reduce mowing costs	Shaw and Schmidt (2003)

Community benefits

Trees at development sites also provide benefits to the community that are equally important but difficult to quantify. These benefits include increased physical comfort due to reduction of wind and noise and provision of shade, esthetic and sentimental value, improved physical and psychological well-being, enhanced sense of community, and increased opportunities for recreation (Figure 3). Overall, trees increase the livability of a community. Trees create a sense of privacy in urban environments, reduce stress, and have been linked to less crime. Table 3 summarizes some of the research on community benefits of trees in neighborhoods.

Figure 3. Trees and natural areas provide many recreational opportunities. *Photo: NRCS photo gallery*

Table 3. Community Benefits of Trees at Development Sites		
Benefit	**Supporting Information**	**Source**
Improve health and well-being	• Recuperation rates were faster for patients whose windows offered views of a wooded landscape. • Less violence occurred in urban public housing where there were trees.	Ulrich (1984) Sullivan and Kuo (1996)
Provide shade and block ultra-violet radiation	• Trees with the right shade and density can block up to 95% of incoming radiation. • Even leafless trees can intercept up to 50% of the sun's energy.	Akbari and others (1992)
Buffer wind and noise	• Depending on housing density, an added 10% tree cover can reduce windspeed by 10% to 20%, while an added 30% tree cover can reduce windspeed by 15% to 35%. Even in winter, trees can reduce windspeeds by as much as 50% to 90% of summer values. • A belt of trees 98 feet wide and 49 feet tall has been shown to reduce highway noise by 6 to 10 decibels, a rate of almost 50%.	Heisler (1989) Akbari and others (1992)

Regulatory Considerations for Trees at Development Sites

Conserving existing trees and planting new ones at development sites can have regulatory implications, in the form of both incentives and barriers. Depending on local codes and ordinances regulating site design, several regulations may be met by preserving or planting trees at a development site. Additional voluntary or incentive programs may exist that can provide even more reasons to conserve trees, such as tax breaks or density bonuses. Part 1 of this manual series provides details and examples of these regulatory and incentive programs that relate to forest conservation. Table 4 summarizes regulations related to conserving and planting trees at development sites.

The same local codes and ordinances governing site development can also limit tree preservation or tree planting in particular areas of a development site, whether intentional or not. For example, guidelines provided for design of planting strips, such as medians and islands, may not produce an environment conducive to supporting healthy, mature trees. Table 5 summarizes the potential barriers to conserving and planting trees at development sites. While these barriers can sometimes be addressed, it is important to become familiar with local codes before planting.

Table 4. Regulations Related to Conserving and Planting Trees at Development Sites

Regulation	Description
Landscaping	Landscaping is typically required in parking lots in the form of a minimum percentage of the total area. Landscaped buffers may also be required to screen parking lots and other land uses from adjacent roads and developments. Street trees may be required along local roads. Conserving existing trees within these locations or planting new ones will meet most landscaping requirements.
Storm water management	Through a storm water credit program, developers can get credits for conserving tracts of forest and may be allowed to subtract this area from the total site area when computing storm water runoff volumes to treat. In addition, required landscaped areas can also be used for storm water treatment, meeting both landscaping and storm water management requirements.
Forest conservation and protection	Regulations may state that a certain percentage of forest must be preserved at each site or that trees of a certain size must be protected.
Conservation of natural areas	Certain regulations, such as stream buffer ordinances and floodplain ordinances, may exist that require natural areas such as stream buffers, floodplains, steep slopes, or otherwise unbuildable areas be protected and preserved during development.
Open space design for subdivisions	Requires clustering of homes on a development site to conserve a certain percentage of natural area such as forest.
Canopy requirements	Typically apply to parking lots or street trees and require a certain percentage of canopy cover to be met within a specified time frame.
Erosion and sediment control	Temporary tree protection devices installed before construction can be combined with erosion and sediment control devices, and can potentially save money.

A recommended approach to address regulatory barriers to tree conservation is to conduct a local site planning roundtable in the community. As part of the local site planning roundtable process, an audit of codes and ordinances governing site development is conducted to identify potential barriers to implementing environmental-friendly site design techniques, such as forest conservation and tree planting. In addition, roundtables help identify language that discourages the use of environmentally friendly techniques by requiring extra costs or a longer review process, even though the technique may not specifically be prohibited. The goal of the site planning roundtable is to make recommendations for revising the codes and ordinances to allow and encourage the use of the desired site design practices. Additional guidance on site planning roundtables is provided in CWP (1998).

Table 5. Potential Regulatory Barriers to Tree Conservation, Planting, and Growth at Development Sites

Regulation	Description
Street trees	Required width of planting area may not provide adequate soil volume for trees. Buffer strip is typically required to be located between the sidewalk and street, further limiting potential rooting space. Setbacks between trees and infrastructure may not be adequate to prevent damage to trees.
Parking lot landscaping	Required size of parking lot islands may not provide adequate soil volume for trees. Setbacks between trees and infrastructure may not be adequate to prevent damage to trees.
Lot design	Required building setbacks and frontages may limit placement of buildings and pavement on the site and decrease the feasibility of conserving remaining forest areas.
Septic systems	Regulations may require clearing of reserve fields at the time of development.
Landscaping for STPs	Guidance may prohibit trees in some or all practices, or within certain areas of practices, such as pond embankments.
Floodplain	Within designated floodways, trees may be prohibited (usually regulated by U.S. Army Corps of Engineers).
Subdivision design	Conventional subdivision design standards may not allow for conservation of natural areas such as forest. Road design standards for subdivision may prohibit use of landscaped island in cul-de-sac.
Parking ratios	Excessive minimum parking ratios can create large unused parking areas that limit potential for tree conservation.
Utilities, signs, and lighting	Regulations may not allow tree planting within utility easements or rights-of-way. In urban environments, adequate space for necessary setbacks between infrastructure and trees may not exist, which can result in limited growing space for trees and potential conflicts between trees and infrastructure.

Unique Properties of the Urban Planting Environment

The average life expectancy of newly planted urban trees has been reported to be 10 to 15 years (Urban, 1999). Urban street trees may have an even lower life expectancy of 7 to 10 years (Appleton and others, 2002). Planted in a better environment, these same trees would have a life expectancy of 60 to 200 years. Why is there such a significant difference? One reason is the harsh planting environment in urban areas that often provides poor conditions for tree growth (Figure 4).

Another major reason for lowered tree life expectancy can be the lack of maintenance provided for urban street trees. Many municipalities actually find it easier and cheaper to replace street trees on a regular cycle rather than to provide adequate conditions and care needed to allow for long-term tree survival. Replacing urban street trees, however, does not offset the additional loss of trees from land development and mortality due to a harsh urban microclimate. A study of tree mortality rates in Baltimore found an annual rate of 6.6%. Even when combined with reforestation efforts, this mortality rate resulted in a net loss of 4.2% in the number of city trees (Nowak and others, 2004). This reality reinforces the need to prioritize retention of existing established urban trees rather than relying on replanting.

Figure 4. Stress from harsh urban conditions can kill a street tree. *Photo: Edward F. Gilman*

Some common causes of urban tree mortality are listed in Box 3 and described below. While not presented in any particular order, one study of urban tree mortality concluded that drought was the most common factor (Foster, 1978). Causes of tree mortality are often difficult to pinpoint because the decline from many impacts can take years to appear.

BOX 3. COMMON CAUSES OF URBAN TREE MORTALITY

- Limited soil volume
- Poor soil quality
- Air pollution
- Construction activities
- Physical damage from lawnmowers, vandalism, or vehicles
- Damage from insects or animals
- Soil compaction from heavy foot traffic
- Exposure to pollutants in storm water runoff
- Soil moisture extremes
- Exposure to wind and high temperatures
- Competition from invasive plant species
- Improper planting and maintenance techniques
- Conflicts with infrastructure
- Disease
- Poor nursery production practices

Limited soil volume

Urban areas often have limited space available for planting due to the presence of infrastructure. Highly compacted soils also effectively prevent tree roots from growing outside the tree pit (Figure 5). The average urban tree pit contains only 40 cubic feet of soil; however, a large tree needs at least 400 cubic feet—and optimally 1,000 cubic feet—of soil to thrive (Urban, 1999).

Figure 5. A typical urban tree pit is about 4 feet by 4 feet and does not provide adequate soil volume for most trees.

Poor soil quality

Most urban soils are highly compacted, have poor drainage, and are low in organic matter and nutrients (Craul, n.d.). The pH is often elevated from calcium deposits from building rubble, irrigation water, and road salt (Craul, n.d.). Soil compaction from construction and heavy use limits root growth and starves the tree of oxygen, nutrients, and water.

Air pollution

Air pollutants such as ozone damage tree foliage and impair photosynthesis (MD DNR, n.d.). Ozone levels as low as 40 to 60 parts per billion have been shown to be harmful to sensitive plant species (Stormcenter Communications, Inc., 2003).

Construction activities

During construction, trees can be damaged by soil compaction, grade changes, root crushing and pruning, damage to the bark, improper pruning of branches, incorrect storage of construction material, and dumping of construction wastes (PSU, 1999; Figure 6). Even if the tree does not appear to be physically harmed, underground root damage may kill the tree later on, which is why protecting the root zone is so important. Some trees will decline slowly over a number of years after construction damage occurs, while others may die quickly. An indirect impact to trees from construction activities results from changing conditions when exterior or interior trees are removed from a group of trees. Trees growing in groups are adapted to each other and to their light, wind, and soil conditions. After a removal, the remaining trees are subject to windthrow, sunscald, and altered soil conditions.

Physical damage from lawnmowers, vandalism, or vehicles

Damage to trees caused by mowers is common, particularly where turf is planted around trees. Vandalism may be common in highly urban areas. Damage to trees from vandalism was found to be highest in areas of high child use, such as playgrounds, or near pubs and bars (Foster, 1978). This same study found that the most common injury to curbside trees was caused by automobiles. Autos may damage 81%

Figure 6. Improper disposal of construction materials and inadequate protection negatively impact trees at a construction site.

Figure 7. Deer browsing damages seedlings.

Figure 8. Urban heat island effect—Because this tree is surrounded by pavement, it is exposed to high temperatures.

of sidewalk trees in a business area, particularly those located near the curb (Foster, 1978). Injury leads to fungal decay, which can kill a tree.

Damage from insects or animals

Damage to trees from deer overbrowsing is common in urban or suburban areas where deer populations are uncontrolled (Figure 7). Where beavers are present, they may cut down many trees in urban riparian areas to build dams. Rodents and other animals may chew on bark, effectively girdling a tree. Poor planting conditions and other urban stressors can make urban trees more susceptible to disease and to pests such as insects.

Soil compaction from heavy foot traffic

Heavy foot traffic in tree planting areas can compact soils, and limit soil drainage and root growth. Street trees are particularly susceptible to trampling damage if appropriate measures are not taken to restrict foot traffic over tree roots.

Exposure to pollutants in storm water runoff

Urban storm water runoff can contain moderate to high levels of pollutants such as salt and other de-icers, metals, bacteria, pesticides, and nutrients. Many tree species cannot tolerate elevated levels of these constituents.

Soil moisture extremes

Paved surfaces are engineered to quickly shed water, often in directions that either deprive trees of adequate soil moisture or leave their roots submerged in excess water (Appleton and others, 2002). An increase in impervious surfaces has also been linked to a decline in baseflow and groundwater (CWP, 2003), which further reduces available water for trees. Poor soil drainage, clogged drainage systems, lack of proper tree maintenance, and significant variation in properties of rootball soil, backfill soil, and site soil can also contribute to soil moisture extremes (Hammerschlag and Sherald, 1985). Damage to

trees from flooding and drought is most pronounced during the growing season and includes decline in tree growth, disruption of food production, and poor nutrient uptake (Coder 1994, 1999).

Exposure to wind and high temperatures

Urban trees are often planted in the open and lack protection. Increased exposure to wind affects tree stability and increases susceptibility to drought. Air temperatures in urban areas are generally higher than those in non-urban areas due to the urban heat island effect (Figure 8). Urban trees also have increased exposure to solar radiation when planted alone because they receive sunlight from all sides. Urban trees are exposed to lighting at night, which further increases temperature.

Competition from invasive plant species

Invasive plants are common in disturbed urban areas, such as roadsides and riparian areas, and can outcompete desirable trees by using up already limited water and nutrients.

Improper planting and maintenance techniques

Improper planting and maintenance techniques or lack of maintenance can damage or even kill a tree. For example, improper pruning techniques can make trees more susceptible to disease and pests. Improper use of stakes can also cause tree damage or death.

Figure 9. A common infrastructure conflict results in tree roots lifting or cracking pavement due to inadequate setbacks between trees and pavement. *Photo: Edward F. Gilman*

Conflicts with infrastructure

When trees come in contact with pavement or utilities, they can cause damage such as downed powerlines, sidewalk cracking (Figure 9), and heaving or clogged sewer pipes. Preventative or remedial measures to correct such damage may injure the tree or cause the offending tree to be removed.

Disease

Poor planting conditions and other urban impacts place urban trees under stress and can make them more susceptible to disease and to pests such as insects.

In addition to the above-mentioned constraints of urban environments, planting trees in STPs presents a unique set of considerations, such as increased exposure to urban pollutants and frequent and extended inundation. These conditions are described and addressed further in Chapter 3. Part 3 of this manual series provides additional detail on identifying and addressing limitations of specific planting environments.

Chapter 2. How to Conserve and Plant Trees at Development Sites

This chapter describes in detail the steps that can be taken to conserve existing trees during construction and to plant trees at development sites.

Conserving Existing Trees During Construction

The preferred method for increasing tree cover at a development site is to conserve existing trees during construction, particularly where mature trees are present. Existing trees are conserved during construction through a five-step process:

1. Inventory existing forest.
2. Identify trees to protect.
3. Design the development with tree conservation in mind.
4. Protect trees and soil during construction.
5. Protect trees after construction.

More guidance on conserving trees at development sites can be found in MN DNR (2000), Greenfeld and others (1991), PSU (1999), and Johnson (2005).

1. Inventory Existing Forest

A natural resource professional such as a forester or arborist should conduct an inventory of existing trees and forested areas at the development site before any site design, clearing, or construction takes place. Some communities may require a forest inventory, while it may be optional in others. The extent of the inventory will depend on local regulations, lot size, vegetative cover, and the extent of development activity. In some cases, the inventory may survey each individual tree, while in others, it may entail a limited sampling of forest stands. Tree preservation ordinances will often dictate the size and types of trees that must be inventoried.

The inventory begins with a site map that includes legal, infrastructure, physical, ecological, cultural, and historical features listed in Box 4.

BOX 4. MAPPING DATA FOR FOREST INVENTORY

- Property boundaries
- Roads
- Utilities
- Easements and covenants
- Topography
- Streams
- Soils
- Steep slopes
- Stream buffers
- Critical habitats
- Adjacent land uses
- Cultural and historical sites
- 100-year floodplains
- Non-tidal wetlands

The next step in the inventory is to survey existing trees and determine their species, condition, and ecological value. Locations of trees and forest stands are marked on maps, along with sampling points, and tree and forest health data are recorded on appropriate field sheets.

The State of Maryland is unique in that it requires an inventory of existing forest at certain development sites under the Forest Conservation Act (Box 5). This inventory, called the Forest Stand Delineation (FSD), is used to characterize and map the existing forest on a development site. The FSD results in a map of existing forest, a site vicinity map, forest stand summary sheets, and a narrative of forest stand conditions.

The site inventory process required in Maryland provides a useful model for evaluating forest conservation priorities at development sites elsewhere. Additional guidance on other methods to inventory existing forest conditions is presented in Table 6. Figure 10 presents a typical FSD map, while copies of FSD forms and field methods are provided in Appendix A.

BOX 5. MARYLAND'S FOREST CONSERVATION ACT

The Forest Conservation Act of 1991 was enacted to protect the forests of Maryland by making the identification and protection of forests and other sensitive areas an integral part of the site planning process. The Act provides guidelines for the amount of forested land retained or planted after the completion of development projects. These guidelines vary for each development site and are based on land-use categories. Where little or no forest exists, the Conservation Act requires that new forests be established by planting trees.

To meet these requirements, information on the condition of the existing forest and a plan for conserving the most valuable portions of the forest are required. Therefore, a qualified resource professional must conduct a Forest Stand Delineation (FSD) and create a forest conservation plan for all development disturbing more than 40,000 square feet.

Table 6. Forest and Tree Inventory Guidance

Forest Inventory Method/Guidance	Applicability	Source
Maryland Forest Stand Delineation	Method used to delineate and characterize forests on a development site	Greenfeld and others (1991)
Trees Approved Technical Manual	Methods for natural resources inventory and forest stand delineation used in Montgomery County, MD	MNCPPC (1992)
Volunteer Training Manual	Method used to inventory and evaluate the health of street trees	USDA Forest Service (1998)
A Guide to Preserving Trees in Development Projects	Provides guidance for conducting a tree inventory at a development site	PSU (1999)
Conducting a Street Tree Inventory	Method used to inventory and evaluate the health of street trees	Cornell University (2004)
Conserving Wooded Areas in Developing Communities	Provides guidance for conducting a natural resources assessment at the landscape, subdivision, and lot level	MN DNR (2000)

The inventory of existing forest has three goals: to comply with local tree preservation or other ordinances, to identify the highest quality trees and forest stands on the site for protection, and to identify and address problems such as invasive species and pest or disease outbreaks. The field assessment portion of the inventory typically collects basic information about the tree species, size, and age, as well as the condition of individual trees and suitability for preservation of forest stands.

If the site contains large forest stands, sample individual points at a sampling intensity sufficient to characterize the entire stand. Select sampling site locations at random and draw them on the map before going to the site, and then flag them in the field. Specific forest stand information collected may include dominant species and forest association, size class of dominant trees, total number of tree species, number of trees per acre, common understory trees, and a forest structure rating. Appendix A contains forest stand summary sheets and methods for calculating forest structure rating from the Maryland FSD.

The results of the forest inventory should be provided to site engineers and landscape architects before site design and layout.

2. Identify Trees to Protect

The forest inventory identifies priority trees or forest stands to conserve and protect during site development. Trees and forest identified for protection should include the minimum needed to comply with local tree preservation regulations and trees located within easements, covenants, or other protected areas. Additional selection criteria include tree species, size, condition, and location (Table 7). Greenfeld and others (1991) provide additional guidance on prioritizing forest areas to retain during development.

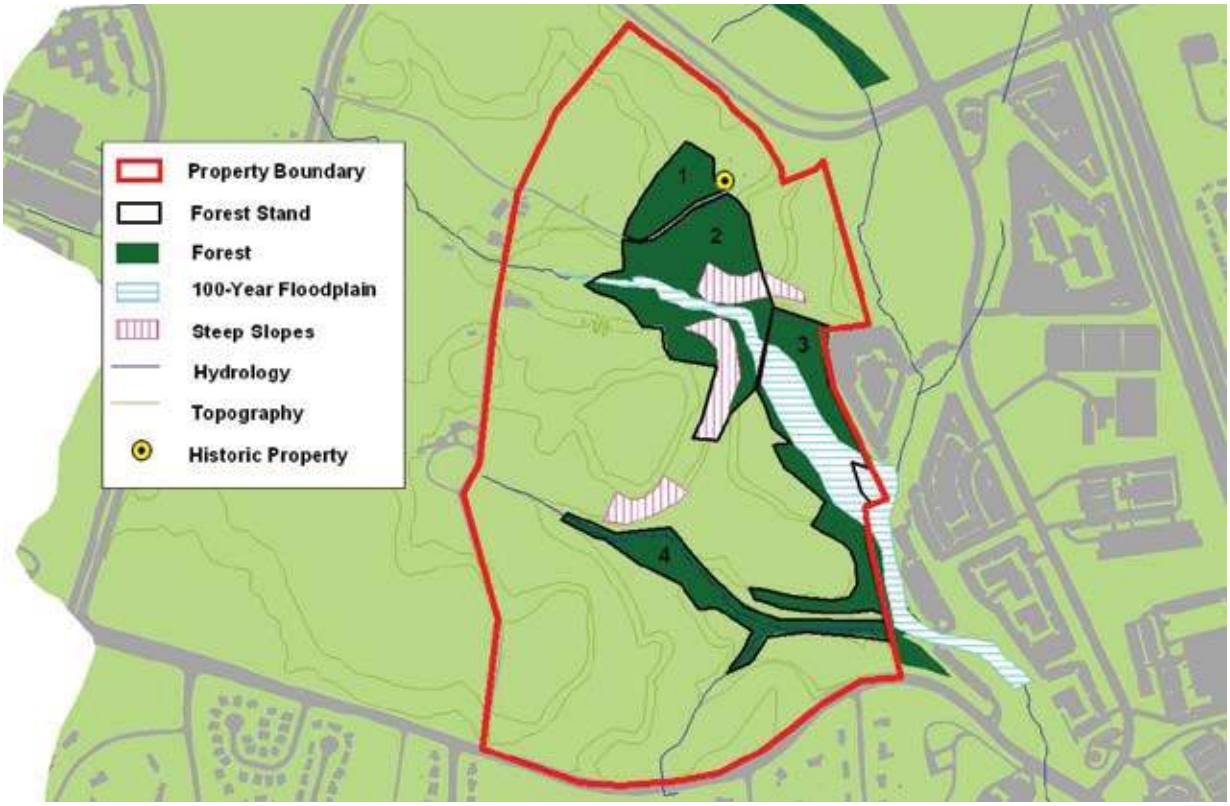

Figure 10. A map of existing forests on a development site is one product of Forest Stand Delineation—a required inventory in the State of Maryland.

Table 7. Selecting Priority Trees and Forests for Conservation	
Selection Criteria for Tree Conservation	**Examples of Priority Trees and Forests to Conserve**
Species	Rare, threatened, or endangered species Specimen trees High quality tree species (e.g., white oaks and sycamores because they are structurally strong and live longer than trees such as silver maple and cottonwood) Desirable landscaping species (e.g., dogwood, redbud, serviceberry) Species that are tolerant of specific site conditions and soils
Size	Trees over a specified diameter at breast height (d.b.h.) or other size measurement Trees designated as national, state, or local champions Contiguous forest stands of a specified minimum area
Condition	Healthy trees that do not pose any safety hazards High quality forest stands with high forest structural diversity
Location	Trees located where they will provide direct benefits at the site (e.g., shading, privacy, windbreak, buffer from adjacent land use) Forest stands that are connected to off-site forests that create wildlife habitat and corridors Trees that are located in protected natural areas such as floodplains, stream buffers, wetlands, erodible soils, critical habitat areas, and steep slopes. Forest stands that are connected to off-site nonforested natural areas or protected land (e.g., has potential to provide wildlife habitat)

Trees and forests selected for protection should be clearly marked both on construction drawings and at the actual site. Flagging or fencing are typically used to protect trees at the construction site. Areas of trees to save should be marked on the site map and walked during preconstruction meetings.

If it is not feasible to conserve all of the desired trees at a site, one option to consider is transplanting some of the trees to another location on the site. Transplanting should be done by a licensed arborist or natural resource professional and may be done with equipment that is already available at the site. Guidance on transplanting trees is provided in Bassuk and others (2003).

3. Design the Development With Tree Conservation in Mind

Once trees and forests are identified for protection, the layout of the site should be designed to conserve these areas, using:

- Open space design techniques to minimize impervious cover and conserve a larger proportion of forest
- Site fingerprinting to minimize clearing and land disturbance
- Setbacks from the critical root zone of trees to be conserved.

Developments should be designed to conserve the maximum amount of forest possible by locating buildings and roads away from priority forest conservation areas and by reducing the total area of graded surfaces. One technique that both reduces grading and conserves forested areas is open space design. Also known as cluster development, open space design is a compact form of development that concentrates density on one portion of the site by clustering lots in exchange for reduced density elsewhere (Figure 11). Minimum lot sizes, setbacks, and frontage distances are relaxed to provide conservation of natural areas such as forests. Open space developments cost less to build because of reduced clearing, paving, storm water management, and infrastructure costs. Open space subdivisions can also bring in higher premiums since people will typically pay more to have a wooded lot or live next to a natural area (see Chapter 1). Open space designs reduce impervious cover by 40% to 60%, thereby conserving significant portions of forest on a site (Schueler, 1995). More guidance on open space design can be found in Schueler (1995), CWP (1998), and Arendt (1996).

Site designers should be creative. For example, houses do not always have to be located in the center of the lot, and the design can take advantage of trees and forests for window views and focus of outdoor decks and recreational spaces. If open space design is not allowed under existing local site development codes, other techniques can still be applied to reduce impervious cover (CWP, 1998). Some examples of Better Site Design techniques to reduce impervious cover and maximize conservation potential are listed in Box 6.

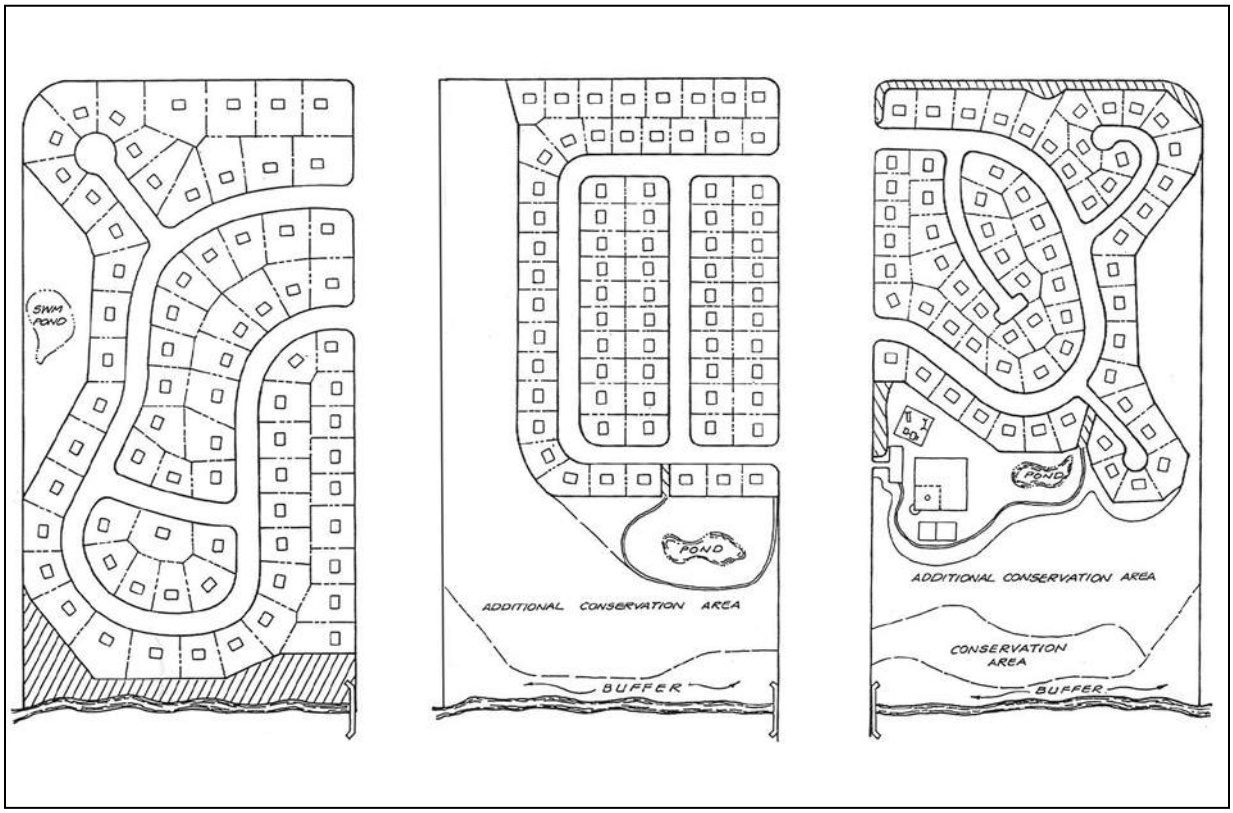

Figure 11. An open space design with 72 lots (center) uses less land than a conventional subdivision with the same number of lots (left). Floodplains and wetlands (hatched lines) are considered unbuildable and must be subtracted from gross density. An alternative design (right) provides 66 lots.
(Source: Schueler, 1995, p. 57-58)

BOX 6. BETTER SITE DESIGN TECHNIQUES TO CONSERVE FORESTS

- Design structural elements such as roads and utilities to minimize soil disturbance and take advantage of natural drainage patterns.
- Where possible, place several utilities in one trench in order to minimize soil disturbance.
- Reduce building footprints by building up, not out.
- Use the minimum required street and right-of-way widths.
- Use alternative turnarounds instead of cul-de-sacs.
- Use efficient street layouts.
- Consider shared driveways for residential lots.
- Use the minimum required number of parking spaces instead of creating additional spaces.

Another method to conserve forests during site design is called site fingerprinting. Also known as site footprinting, site fingerprinting minimizes the amount of clearing and grading conducted at a site by limiting disturbance to the minimum area needed to construct buildings and roadways (Figure 12). A suggested limit of disturbance (LOD) around structures is 5 to 10 feet outward from the building pad (Greenfeld and others, 1991). No clearing, grading, or siting and construction of utility lines, access roads, staging, storage or temporary parking areas, storm water management practices or impervious surfaces should be located within the LOD. This requires that designated areas for temporary parking, material storage, and construction spoil, and holding areas for vegetation and topsoil be established outside the LOD. Designing the site to have only one access point, which coincides with planned roadways, driveways, or utilities also limits the amount of clearing necessary. The LOD should be clearly marked both on site plans and at the site.

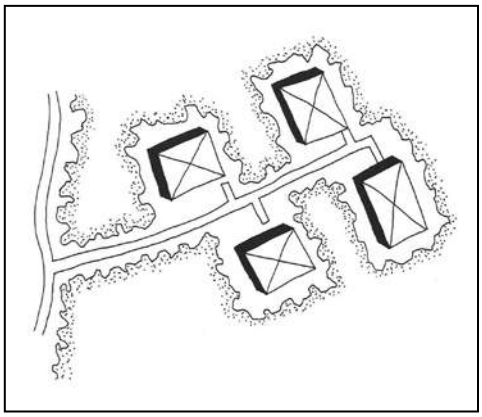

Figure 12. Site fingerprinting limits site disturbance to the minimum necessary for building. *(Source: Greenfeld and others, 1991, p. 51)*

The LOD should incorporate a field delineation of the critical root zone (CRZ) for trees to be conserved. The CRZ, also called the protected root zone, is a circular region measured outward from a tree trunk representing the essential area of the roots that must be maintained or protected for the tree's survival (Greenfeld and others, 1991). In order to adequately protect the tree, no disturbance should occur within the CRZ. There are four methods for delineating the critical root zone:

1. *Trunk diameter method* – Measure the tree diameter in inches at breast height (54 inches above the ground). For every inch of tree diameter, the CRZ is 1 foot of radial distance from the trunk, or 1.5 feet for specimen or more sensitive trees (Greenfeld and others, 1991; Coder, 1995). Figure 13 illustrates the trunk diameter method.

2. *Site occupancy method* – Predict the tree diameter at breast height in inches for that tree at 10 years old. Multiply the number by 2.25 and convert the result into feet to obtain the radius of the CRZ (Coder, 1995).

3. *Minimum area method* – Protect an area of approximately 6 feet in radius around the trunk of the tree as the CRZ (MN DNR, 2000).

4. *Dripline method* – Measure the distance of the branch that extends horizontally farthest from the trunk and multiply by 1.5 to obtain the CRZ radius. Another option is to project the dripline downward to the ground and delineate the area beneath the tree branches or crown as the CRZ (MN DNR, 2000).

The natural resource professional should select the method of delineation. In general, the trunk diameter method is best for trees growing in a forest or with a narrow growth habitat, the minimum area method is preferred for very young trees, and the dripline method is preferred for protecting mature open-growing trees (MN DNR, 2000). These methods do not protect the tree's entire root system but represent a good compromise between tree survival or growth and available space. Other considerations when delineating protected root zone include the following (Greenfeld and others, 1991):

- *Species sensitivity* – Certain species are more tolerant to disturbance or compaction than others. For sensitive species, delineate the CRZ based on species and site evaluation.

- *Tree age* – Younger trees are generally more tolerant of disturbance than older ones. For mature trees, delineate a slightly larger CRZ.

4. Protect Trees and Soil During Construction

Physical barriers must be properly installed around the LOD to protect trees to be conserved and their associated CRZ. The barriers should be maintained and enforced throughout the construction process. Tree protection barriers include highly visible, well-anchored temporary protection devices, such as 4-foot fencing, blaze orange plastic mesh fencing (see Figure 14), two- to three-strand barbed wire fence, or snow fencing (Figure 15) (Greenfeld and others, 1991). Specifications for tree protection methods are provided in Appendix B.

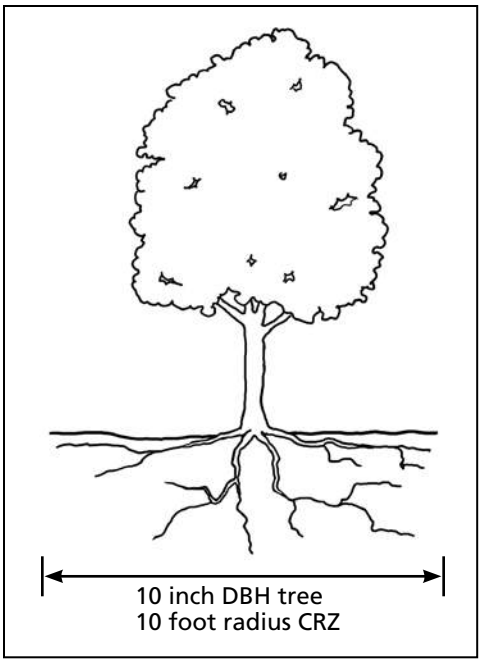

Figure 13. The trunk diameter method is one of four ways to define the critical root zone (CRZ). *(Source: Greenfeld and others, 1991, p. 62)*

Figure 14. Orange plastic mesh fencing delineates tree protection areas.

All fencing should have highly visible flags and include posted signs clearly identifying the tree protection area. No equipment, machinery, vehicles, materials, excessive pedestrian traffic, or trenching for utilities should be allowed within protection areas. It may be necessary to install temporary drainage and irrigation for trees and other plants to be preserved.

All protection devices should remain in place throughout construction, and penalties for violation should be enforced. A landscape protection contract signed by the builder, developer, contractor, and all subcontractors will help ensure compliance.

Tree conservation begins by preserving the native soils throughout the site, especially in areas that will be used for planting. Soil stockpiling and mulching can be used to protect the infiltration capacity of these native soils. Soil stockpiling is the temporary storage of topsoil that has been excavated from a construction site. This soil is then reused on the site in planting areas to provide a higher quality growing medium for new vegetation, which also saves the builder from having to purchase and haul in new topsoil. Applying a layer of mulch at least 6 inches thick over areas that will be used for traffic or material storage during construction also helps to prevent soil compaction in areas that will be used for future planting of trees and other vegetation.

Figure 15. Fencing surrounds a mature tree that is to be preserved.

5. Protect Trees After Construction

Developers should educate both current and new residents about the existence and benefits of trees in their development. Developers should ensure that a responsible entity is created to maintain forest conservation areas and enforce their boundaries. Some methods used to educate residents include posting of signs and constructing fences to serve as boundary markers; use of covenants that define homeowners' associations (HOA) as being responsible for maintenance of trees; enforcement mechanisms to protect forests from encroachment; and incorporating individual tree maintenance agreements into real estate plats and deeds.

HOAs can distribute pamphlets and other educational materials about the benefits and location of protected forests in their neighborhoods; inform residents of forest protection policies at HOA meetings; organize urban forest walks or inspections to monitor the condition of the urban forest and to search for pests and invasive species; and organize planting days to engage residents in tree planting. HOAs can also enforce forest protection policies by inspecting forest conservation areas and mailing correction notices requiring reforestation or other measures, depending on the type of violation. As a last resort, civil fines can be used if notices do not result in cooperation.

Local governments also play an important role in protecting forests after construction by ensuring that appropriate ordinances are enforced to adequately protect forest conservation areas. For example, a community's open space design or forest conservation ordinance should provide specific criteria for the long-term protection and maintenance of natural areas (e.g., restrictions on tree clearing except for safety reasons), and should establish appropriate enforcement measures. A third party, such as a local land trust, may be designated responsible to hold and manage forest conservation easements. Land trusts are effective groups to monitor the site and enforce its boundaries, and the third party land trust option should be specifically allowed in the local ordinance. Model ordinances for open space design and tree protection are provided at the links below:

- Open Space Design Model Ordinance:
  www.stormwatercenter.net/Model%20Ordinances/open_space_model_ordinance.htm

- Forest Conservation Ordinance from Frederick County, MD:
  www.stormwatercenter.net/Model%20Ordinances/misc__forest_conservation.htm

Planting Trees at Development Sites

New development sites provide many opportunities to plant new trees, such as in STPs, along local roads, and in parking lots. While some STPs are not traditionally considered appropriate for tree planting, planting trees and shrubs in certain areas of specific STPs can enhance their attractiveness and improve their performance. Planting trees at new development sites is done in three steps:

1. Select planting sites.
2. Evaluate and improve planting sites.
3. Plant and maintain trees.

1. Select Planting Sites

Potential planting sites in a new development or redevelopment site include portions of local road rights-of-way, such as buffer areas, islands and median strips, parking lot interiors and perimeters,

and certain types of storm water treatment practices (Figure 16). In many communities, some type of landscaping is required in and around parking lots and along residential streets. As such, the developer may have to meet these requirements anyway. Other areas of a development site that may be a priority for planting trees include stream valleys and floodplains, areas adjacent to existing forest, steep slopes, and portions of the site where trees would provide buffers, screening, noise reduction, or shading.

2. Evaluate and Improve Planting Sites

It is important to evaluate and record the conditions at proposed planting sites to ensure they are suitable for planting, select the appropriate species, and determine if any special site preparation techniques are needed. A method for evaluating urban tree planting sites is The Urban Reforestation Site Assessment (URSA). Box 7 lists the factors evaluated using the URSA, while Part 3 of this manual series contains the full field form and accompanying guidance for completing it.

Figure 16. Development sites offer several potential planting areas.

BOX 7. FACTORS ASSESSED DURING THE URBAN REFORESTATION SITE ASSESSMENT

- General site information
- Climate
- Topography
- Vegetation
- Soils
- Hydrology
- Potential planting conflicts
- Planting and maintenance logistics
- Site sketch

Site characteristics determine what tree species will flourish there and whether any of the conditions, such as soils, can be improved through the addition of compost or other amendments. Improvements to the planting site generally apply only to smaller spaces. Therefore, when reforesting large tracts of land, it is probably not feasible from a cost and labor standpoint to apply soil amendments over the entire planting area. Table 8 presents methods for addressing common constraints to urban tree planting. Part 3 of this manual series provides more detail on each method.

In general, the best way to address urban planting constraints is to ensure each planting project meets the design principles in Box 8, which are adapted from Urban (1999) and GFC (2001).

Table 8. Methods for Addressing Urban Planting Constraints

Potential Impact	Potential Resolution
Limited soil volume	Use planting arrangements that allow shared rooting space Provide at least 400 cubic feet of soil per tree
Poor soil quality	Test soil and perform appropriate restoration Select species tolerant of soil pH, compaction, drainage, etc. Replace very poor soils if necessary
Air pollution	Select species tolerant of air pollutants
Damage from lawnmowers	Use mulch or tree shelters to protect trees
Soil compaction from heavy foot traffic	Use mulch to protect trees Plant trees in low-traffic areas
Damage from vandalism	Use tree cages or benches to protect trees Select species with inconspicuous bark or thorns Install lighting nearby to discourage vandalism
Damage from vehicles	Provide adequate setbacks between vehicle parking stalls and trees
Damage from animals such as deer, rodents, rabbits, and other herbivores	Use tree shelters, protective fencing, or chemical retardants
Exposure to pollutants in storm water and snowmelt runoff	Select species that are tolerant of specific pollutants, such as salt and metals
Soil moisture extremes	Select species that are tolerant of inundation or drought Install underdrains if necessary Select appropriate backfill soil and mix thoroughly with site soil Improve soil drainage with amendments and tillage if needed
Increased temperature	Select drought tolerant species
Increased wind	Select drought tolerant species
Abundant populations of invasive species	Control invasive species prior to planting Continually monitor for and remove invasive species
Conflict with infrastructure	Design the site to keep trees and infrastructure separate Provide appropriate setbacks from infrastructure Select appropriate species for planting near infrastructure Use alternative materials to reduce conflict
Disease or insect infestation	Select resistant species

BOX 8. DESIGN PRINCIPLES FOR URBAN TREE PLANTING
Adapted from Urban (1999) and GFC (2001)

Provide adequate soil volume to support the tree at maturity. A general guideline is to provide 2 cubic feet of usable soil for every square foot of mature canopy. Design soil volumes of planting areas to be interconnected so trees can share rooting space.

Preserve and improve soil quality. Limit use of heavy equipment in planting areas to protect native soils from compaction. Soil volume should be accessible to air, water, and nutrients. This is best achieved by separating paving from the tree's rooting area, which also allows for periodic inspection of the planting area. Soils should be amended if necessary to improve drainage and fertility.

Provide adequate space for tree to grow. Design surrounding infrastructure to accommodate long-term growth of tree. Space trees to allow for long-term growth and management, including thinning and replacement of the stand.

Select trees for diversity and site suitability. Plant a variety of species that are tolerant of the climate and soil conditions as well as any urban impacts at the site.

Protect trees from other impacts. Develop designs that protect the tree over its entire life from pedestrian traffic, toxic runoff, high temperatures, and other urban impacts.

Part 3 of this manual series provides guidance on tree species selection in the form of an Urban Tree Selection Guide. A useful source for tree selection is the USDA PLANTS database, which can be accessed at http://plants.usda.gov.

3. Plant and Maintain Trees

Planting trees at new development sites requires prudent species selection, design modifications, a maintenance plan, and careful planning to avoid impacts from nearby infrastructure, runoff, vehicles or other urban elements. Chapter 3 provides specific guidance on planting trees in various storm water treatment practices—storm water wetlands, swales, bioretention and bioinfiltration facilities, and filter strips.

Chapter 4 provides specific guidance for planting trees at development sites in pervious areas along local roads and in parking lots.

Part 3 of this manual series provides additional detail on tree planting, site preparation, and maintenance techniques.

Chapter 3. Design and Planting Guidelines for Storm Water Forestry Practices

This chapter provides detailed guidance for planting trees in storm water treatment practices (STPs), known as storm water forestry practices (SFPs). Guidelines are presented with conceptual designs for the following SFPs:

- Wooded wetland
- Bioretention and bioinfiltration facilities
- Alternating side slope plantings (swale)
- Tree check dams (swale)
- Forested filter strip
- Multi-zone filter strip
- Linear storm water tree pit.

The SFP concept designs presented in this chapter are graphical representations only and do not necessarily incorporate all of the items needed for the final design and engineering. Those will require additional testing, research, and analysis; and we welcome future additions to the designs presented here.

SFPs incorporate trees and shrubs into the design of storm water wetlands, swales, bioretention or bioinfiltration facilities, and filter strips. Alternatively, conventional tree pit designs can be modified to accept and treat storm water runoff, thereby functioning as an STP. Traditional landscaping guidance either does not allow or does not address planting trees in storm water practices (Figures 17 and 18). Despite the fact that tree planting is rare in STPs, there are many potential benefits to doing so. Research on rainfall interception, evapotranspiration, and pollutant uptake of trees indicate that trees in STPs could significantly increase the efficiency of the traditional practice designs (see Box 2 on page 4 for hydrologic and water quality benefits of trees). Median pollutant removal efficiencies for standard STPs are presented in Table 9.

Table 9. Pollutant Removal (Median %) by Standard Storm Water Treatment Practices

Storm Water Treatment Practice	Total Suspended Solids	Total Phosphorus	Soluble Phosphorus	Total Nitrogen	Nitrate + Nitrite
Storm Water Wetland	76	49	36	30	67
Bioretention Facility	N/A	65	N/A	49	16
Dry Swale	93	83	70	92	90
Filter Strip (150 foot width)	84	40	N/A	N/A	20

N/A = not available
Sources: Winer (2000), Yu and others (1993)

Figure 17. Storm water ponds with trees incorporated offer benefits over a conventional storm water pond with no trees (left).

Figure 18. Swales with trees offer greater benefits than a swale with no trees (left).

The SFP designs presented in this chapter were developed during a series of design workshops attended by storm water engineers, foresters, arborists, and landscape architects. The goal of the workshops was to identify potential limitations to planting trees in STPs, both from an engineering perspective and from the standpoint of tree survival and health. The resulting SFP designs were intended to address these limitations through design modifications, species selection, or other methods.

To identify which species of trees and shrubs would be best suited to each STP, it was necessary to first identify the conditions within each practice. In addition to the typical urban planting constraints, STPs have other planting constraints that may limit tree growth (Table 10).

Table 10. Characteristics of Storm Water Treatment Practices that May Limit Tree Growth

Characteristic	Storm Water Treatment Practice			
	Storm Water Wetland	Bioretention, Bioinfiltration	Swale (dry)	Filter Strip
Extremely compacted soils (limited soil volume)	X		X	
Exposure to high winds and high temperatures	X			
Exposure to inundation (frequency, duration and depth varies)	X	X	X	X
Loose, unconsolidated soils, high in organic matter, possibly anaerobic	X	X		
Ice damage and scour	X			
Potential for damage from mowers	X		X	X
Competition from invasive species	X			
High chloride levels		X	X	X
Exposure to high flows during storms (2-6 cubic feet per second)			X	X
Exposure to drought during dry periods	X	X	X	
May be used for snow storage		X	X	X
Exposure to moderate to high levels of urban storm water pollutants (e.g., metals)	X	X	X	X
High sand content of soils (filter medium)		X	X	

Perhaps the most common planting constraint in STPs is periodic inundation or saturation of soils by storm water runoff. Table 11 provides details on the frequency, duration, and depth of inundation that trees and shrubs might be exposed to within each of the four groups of STPs. Figure 19 illustrates the four planting zones in storm water ponds and wetlands.

Many of the tree planting constraints within STPs listed in Table 10 can be addressed by selecting species that are tolerant of less than optimal conditions. In addition, species planted in STPs should be able to reduce storm water runoff (through rainfall interception and evapotranspiration) and mitigate pollutants commonly found in this runoff. Metro (2002) defined a list of characteristics of trees that best perform these functions. Based on this list and on the characteristics presented in Table 10, several desirable characteristics of trees to plant in STPs were defined (Box 9). Trees used in STPs should

Table 11. Inundation in Selected Storm Water Treatment Practices

Inundation Characteristics[1]		Storm Water Treatment Practice						
		Storm Water Pond and Wetland Planting Zones[2]				Bioretention, Bioinfiltration	Swale (dry)	Filter Strip
		Zone I	Zone II	Zone III	Zone IV			
Frequency	Continuous	N/A	X					
	Frequent			X		X	X	X
	Infrequent				X			
Duration	Continuous		X					
	Extended			X	X			
	Brief					X	X	X
Depth	< 6 inches							X
	6-12 inches		X			X		
	Depends on planting elevation			X	X		X	

[1]Frequent inundation = 10-50 times per year or more
Infrequent inundation = a few times per year to once every 100 years
Extended inundation = 2-3 days or more
Brief inundation = a few to several hours
[2]See Figure 19 for an illustration of planting zones.

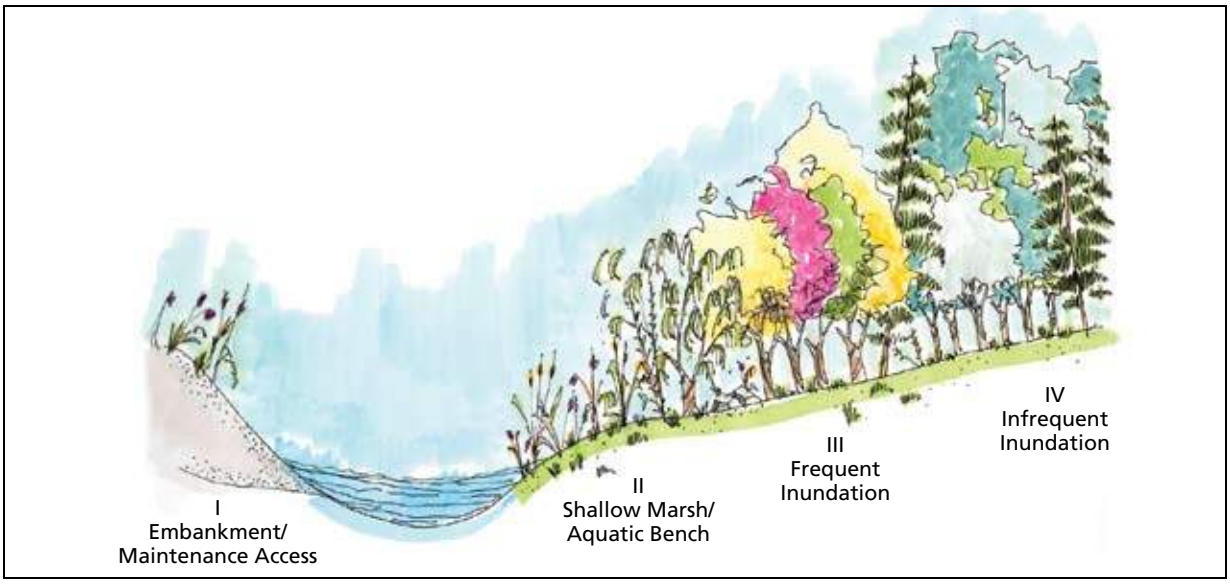

Figure 19. A storm water pond or wetland contains four planting zones.

have several of these characteristics. Additional detail on which tree characteristics are appropriate for specific SFPs is provided later in this chapter. Part 3 of this manual series provides further guidance on species selection.

Table 12 presents the potential engineering conflicts associated with trees in STPs that were identified during the design workshops, and some corresponding design methods to reduce or eliminate these conflicts. These engineering design methods have been incorporated into subsequent SFP concept designs in this chapter.

BOX 9. DESIRABLE CHARACTERISTICS OF TREES FOR STORM WATER TREATMENT PRACTICES

- Persistent foliage
- Wide-spreading, dense canopies
- Long-lived
- Fast growing
- Tolerant of drought
- Tolerant of inundation or saturated soils
- Resistant to urban pollutants (air and water)
- Tolerant of poor soils
- Extensive root systems
- Rough bark
- Tomentose or dull foliage surface
- Vertical branching structure

Table 12. Potential Engineering Conflicts and Resolutions, for Planting Trees in Storm Water Treatment Practices

Potential Engineering Conflict	Resolutions
Tree litter may clog outlets and drainage pipes, increasing maintenance, and potentially drowning trees if not unclogged.	Use alternative outlet structures that do not clog. Select species that do not produce excessive litter.
It may be difficult to remove sediment from practices that require periodic sediment removal without harming or removing trees.	Modify practice design so that trees are separate from areas where sediment is deposited (e.g., use a forebay in a wetland).
Trees may shade out grass and contribute to erosion in practices with higher flows.	General consensus was that this should not be a concern. As a precaution, plant shade-tolerant ground covers where possible.
Tree roots may puncture filter fabric or underdrains.	Increasingly, designers are moving away from the use of filter fabric between the filter media and site soil, as it may create an undesirable soil-water interface. To replace the function of the filter fabric where needed, a sand or pea gravel layer may be used. Tree roots clogging or puncturing underdrains should not be a major concern. As a precaution, do not plant trees directly over underdrains.
Presence of trees in practice may reduce storage or conveyance capacity.	Modify practice design to account for trees (e.g., make it slightly larger).
Mowing around trees, where required, may be more difficult.	Cluster trees where possible to allow easier mowing. Cease mowing where it is not necessary and allow regeneration. Use meadow grasses that do not require frequent mowing (if appropriate for the region).
Overgrowth of trees in maintenance areas may limit access.	Limit trees in maintenance access areas and within 15 feet of these areas.
Trees on embankments may compromise stability.	Do not plant trees within 15 feet of embankment.
Trees with excessive fruits, nuts, and other litter may be nuisances, particularly adjacent to impervious surfaces.	Select species that do not produce excessive litter, particularly when planting near impervious surfaces.

Seven concept designs for SFPs are presented in the remainder of this chapter in fact sheet format. These designs are graphical representations only and do not include all of the items needed for final design and engineering. Each fact sheet contains the following sections:

Description – brief description of practice, where it applies and benefits of incorporating trees.

Design Modifications – modifications to the standard STP to improve planting environment or reduce tree-engineering conflicts.

Species Selection – guidance on desirable species characteristics for planting trees and shrubs in the practice. Part 3 of this manual series includes an urban tree selection guide with tree species and their characteristics.

Planting Guidance – general and specific guidance on exactly how to incorporate trees into the practice.

Maintenance – recommended maintenance for tree-planting areas.

Topics for Future Research – unresolved issues or areas for further research or discussion.

Further Resources – resources for additional information.

This guidance on incorporating trees into STPs is provided as a better alternative either to having no trees at all or to allowing uncontrolled growth of volunteer species (Figure 20), which may conflict with the function of the practice and does not necessarily provide ideal habitat conditions.

Figure 20. Overgrowth of willows in this pond limits maintenance access and essentially creates a monoculture.

Wooded Wetland

Description

A wooded wetland is a variant of a standard storm water wetland design that provides detention and water quality treatment of storm water runoff. Most traditional storm water wetlands contain few, if any, large trees. The wooded wetland design incorporates trees and shrubs into planting zones II, III and IV shown in Figure 19 (page 26).

A wooded wetland is a fairly large practice and typically treats a minimum drainage area of 10 acres or more. This size makes it an ideal practice for highway cloverleaves, large residential subdivisions, and other large open areas such as parks and schools. The wooded wetland design is shown in Figure 21.

Planting trees in a storm water wetland can increase water use through evapotranspiration and may increase pollutant removal through nutrient uptake and biological soil processing. Additional benefits include habitat for wildlife, reduced mowing costs, shading of the permanent pool, deterrent of Canada geese, and bank stabilization.

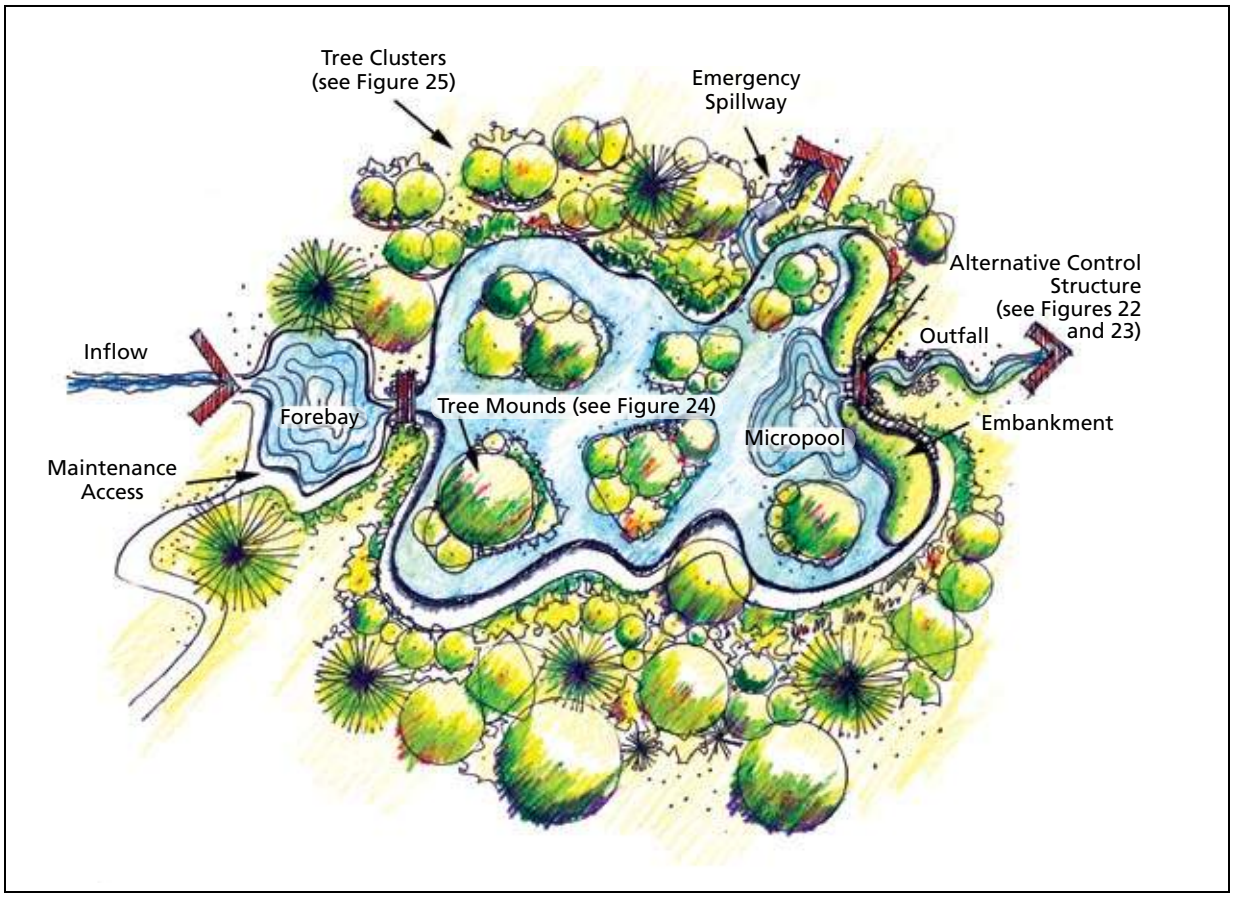

Figure 21. A wooded wetland incorporates trees into the design.

Wooded Wetland *Continued*

Design Modifications

- ☐ Use an alternative control structure such as a weir with a v- or rectangular-notch and a hood to prevent clogging by woody debris (Figure 22). This control structure should be designed to address seepage and uplift on the weir wall, for example, by providing for seepage through the structure by using weep holes or by allowing sufficient travel distance along the base of the weir wall (so it behaves as an anti-seep collar). See USACE (1989) for additional guidance on floodwall and retaining wall design.
- ☐ Include measures to keep permanent pools at relatively safe elevations even when outlets clog. This alternative, used in Montgomery County, MD, incorporates perforated underdrains surrounded by stone along the face of each dam. The underdrains connect to flow restrictors within the embankment to ensure that the required flow controls are met. The designs also include a small (secondary) riser, which the underdrains and flow restrictors tie into (Figure 23). This secondary riser allows for a small amount of ponding if the underdrains become clogged. The resulting water surface elevation increase is relatively small and still allows for unclogging of underdrain flows without much problem.
- ☐ Use a forebay to trap sediment and allow for sediment removal without removing or injuring trees.

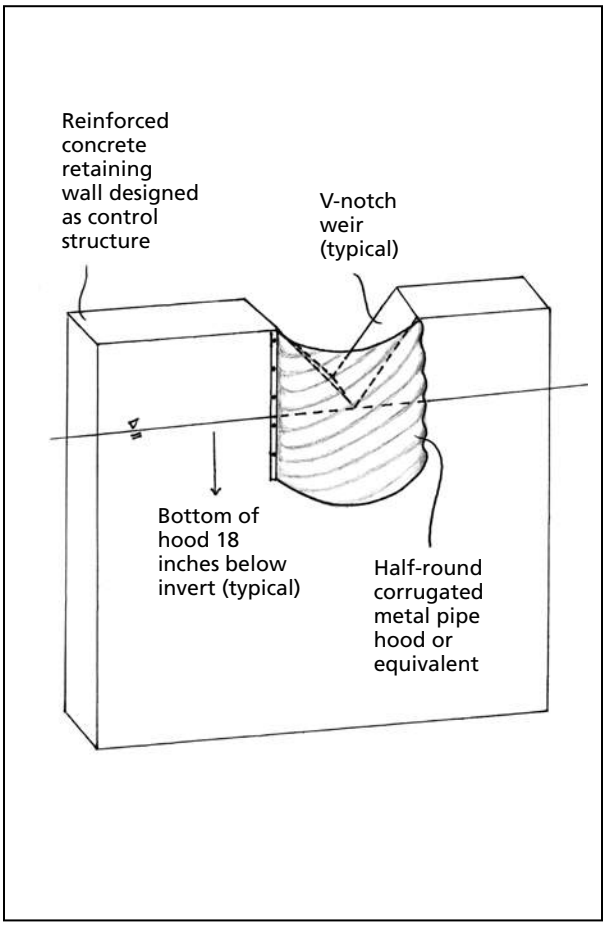

Figure 22. A weir wall with a v-notch and a hood resists clogging by woody debris.

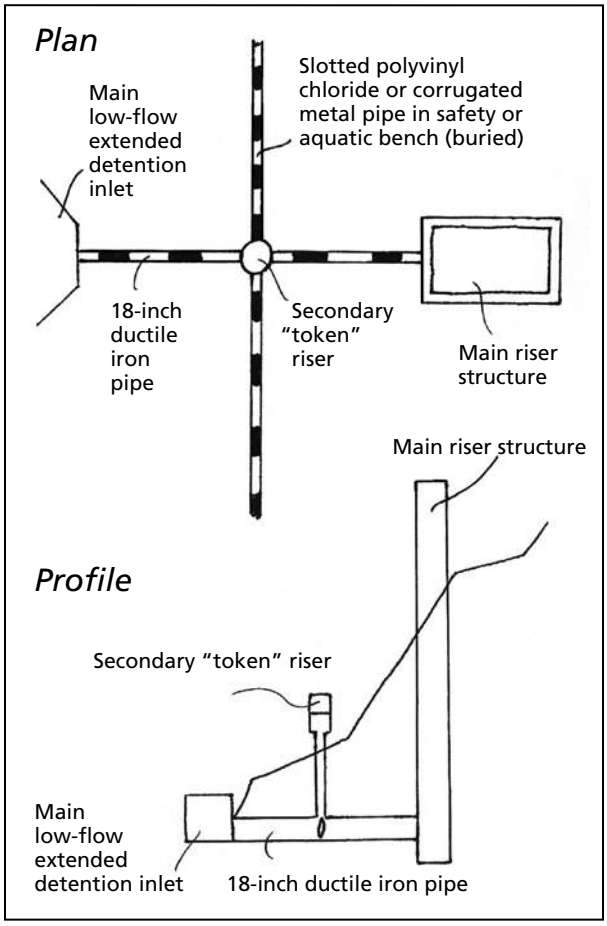

Figure 23. A secondary riser helps to keep permanent pools at safe elevations, even when outlets clog.

Species Selection

Species selection is key because most site conditions can be addressed by selecting appropriate tree species, rather than by trying to modify site conditions. Select a diverse mix of hardy, preferably native species (minimum of three), that are adapted to soils and site conditions.

Other desirable species characteristics include the following:

- ☐ Tolerant of compacted soils
- ☐ Tolerant of drought
- ☐ Tolerant of inundation
- ☐ Tolerant of urban pollutants

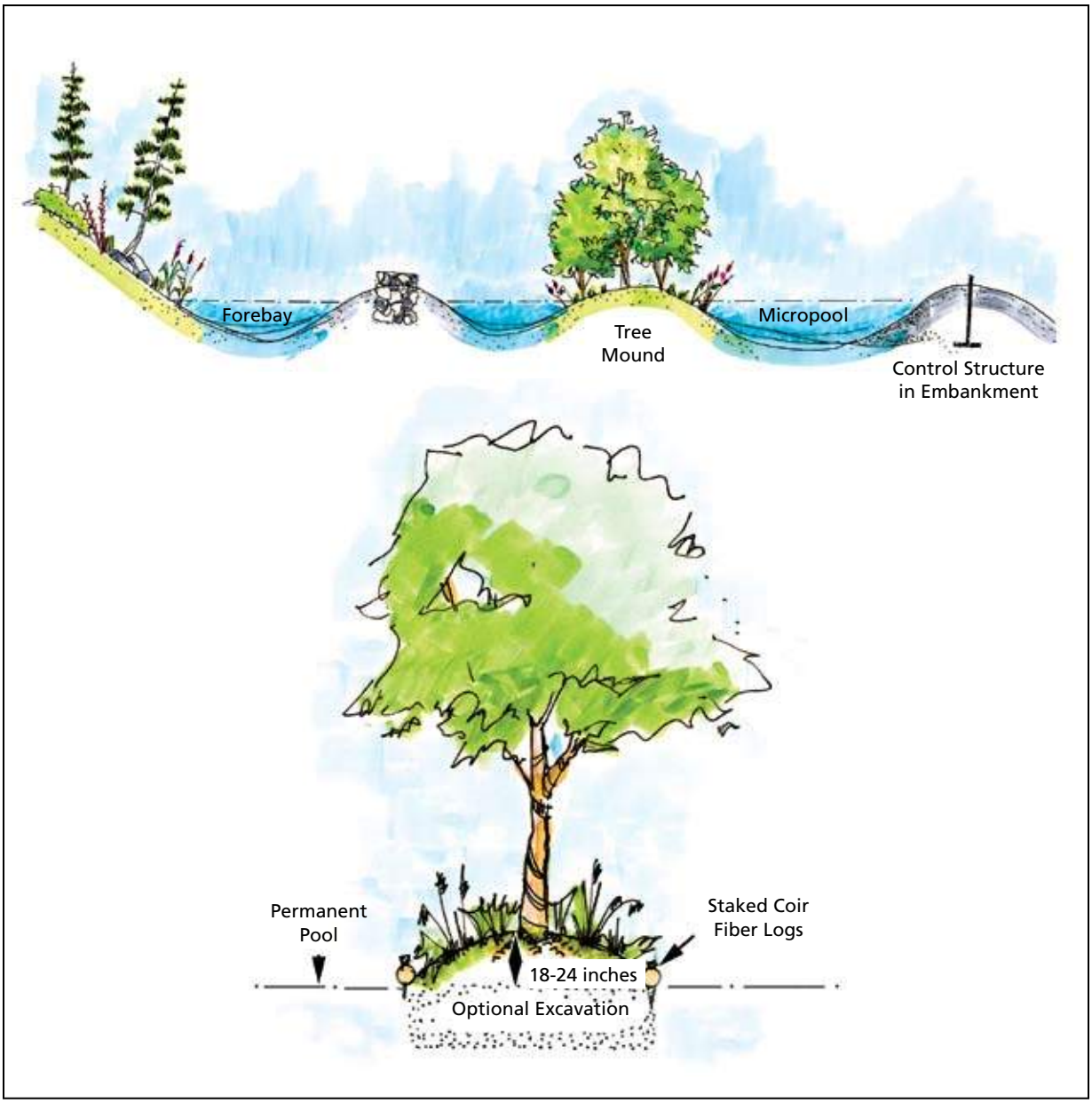

Figure 24. Tree mounds are one feature of a wooded wetland that incorporates trees.

Wooded Wetland *Continued*

General Planting Guidance

- ☐ Do not allow trees on embankment or in maintenance access area. Some small shrubs may be allowed (e.g., dogwoods or other "manageable" vegetation).
- ☐ Do not allow trees within 15 feet of embankment toe or maintenance access areas. Use a permanent pool to enforce this setback.
- ☐ Plant trees on mounds in shallow marsh area (Figure 24 on previous page).
- ☐ Plant trees in clusters on side slopes (Figure 25).

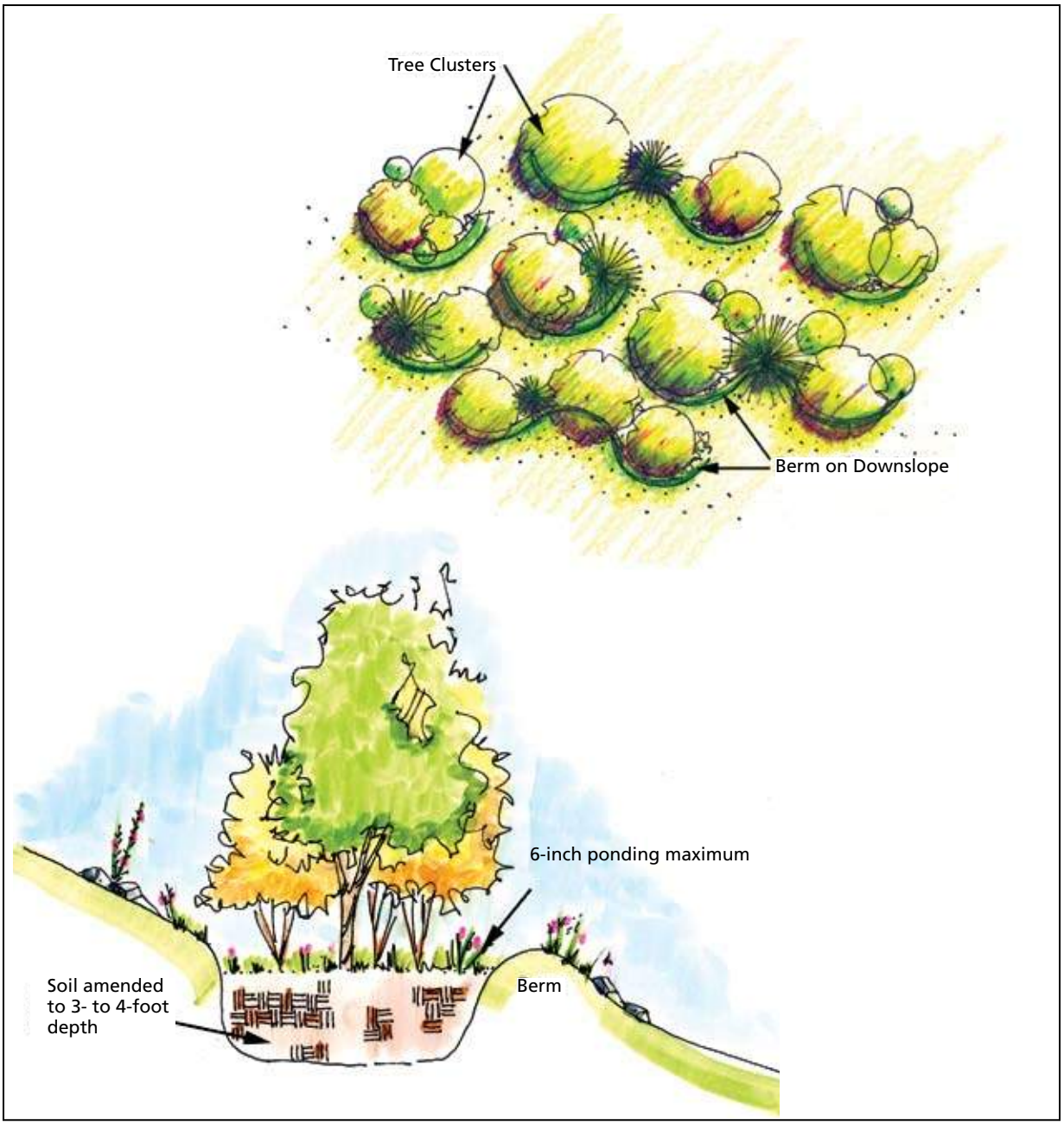

Figure 25. Tree clusters increase the soil and water volumes available for trees planted on side slopes.

Specific Planting Guidance

Tree Mounds

Tree mounds are islands located in the shallow marsh area of the wetland that are planted with trees (Figure 24). Mound placement should be such that a long internal flow path is created within the shallow marsh area. After initial wetland construction, mark boundaries of mound locations. Excavate the area of tree mounds 2 feet deep, if compacted. Stake coir fiber logs or hay bales, or use rock to form the boundaries of the mound. Backfill holes with amended soil. Mound elevation should be 12-18 inches above the permanent pool based on typical dimensions of coir fiber logs. However, the center of the mound where trees are planted may be 18-24 inches above the permanent pool, to reduce the duration of inundation.

Tree mounds should incorporate one large shade tree and several small trees or shrubs, depending on the size of the island. Seedlings may be planted, but if larger stock is used, a dedicated water source must be available, and the stock should be from a wetland. Size of islands should relate directly to the size and number of trees desired (e.g., provide sufficient soil volume for each tree—usually at least 400 cubic feet).

Tree Clusters

Tree clusters should be used on side slopes ranging from 10:1 to 3:1 to provide additional soil volume and water for trees (Figure 25). Clusters should have a minimum of three trees and contain trees that have the same tolerance for the anticipated degree of inundation. Tree clusters should be used at various elevations all the way around the slopes and arranged so that any runoff from the sides of the cluster will be directed downhill to the next cluster. Tree clusters should consist of a series of interconnected planting holes to increase available soil volume.

After constructing wetland side slopes, excavate planting holes that are 3-4 feet deep for each tree cluster. The size of the hole depends on the ultimate size of the tree but should provide adequate soil volume, and holes should be adjacent to each other so trees can share rooting space. Backfill the hole with amended soil. Use spoils to construct a berm on the downslope side of the tree cluster. Elevation of planting hole should be 6 inches below the top of the berm to allow for some ponding during storm events. Overplant with seedlings for fast establishment and to compensate for mortality.

Wooded Wetland *Continued*

Maintenance

- ☐ Plan for minimal maintenance of trees (e.g., frequent watering may not be feasible).
- ☐ Use tree shelters to protect seedlings from mowers and deer where needed.
- ☐ Use Integrated Vegetation Management (IVM) to control vegetation in embankment and maintenance access areas. IVM entails maintaining low-growing vegetation (e.g., 6 feet high) through mowing, hand removal of vegetation, or selection spraying (with herbicide approved for aquatic use) of individual trees in early growing stage (Genua, 2000).
- ☐ Do not mow wetland side slopes except for initial mowing required when native grasses are used.

Topics for Future Research

- ☐ Additional guidance is needed on weir wall design or design of an alternative outlet structure that resists clogging and addresses seepage and uplift.
- ☐ Need additional guidance on designing ponds and wetlands to preserve existing trees.
- ☐ May need alternative to coir fiber logs for mounds near a permanent pool.
- ☐ Measure changes in water quality due to trees in wetlands.

Further Resources

Genua, S. M. 2000. Converting power easements into butterfly habitats. Washington, DC: Potomac Electric Power Company (PEPCO). www.butterflybreeders.org/pages/powerease_sg.html

Schueler, T. R. 1992. Design of stormwater wetland systems: guidelines for creating diverse and effective stormwater wetlands in the mid-Atlantic Region. Washington, DC: Metropolitan Washington Council of Governments.

U.S. Army Corps of Engineers. 1989. Retaining and flood walls. Engineer Manual No. 1110-2-2502. Washington, DC: U.S. Army Corps of Engineers.

Bioretention and Bioinfiltration Facilities

Description

Bioretention and bioinfiltration facilities are shallow, landscaped depressions that contain a layer of prepared soil, a mulch layer, and vegetation. These facilities provide filtering of storm water runoff by temporarily ponding water during storms. Bioretention facilities have underdrain systems, while bioinfiltration facilities allow runoff to infiltrate into existing site soils (infiltration rates greater than 0.5 inches per hour).

The standard bioretention and bioinfiltration designs sometimes incorporate trees, but mainly as a landscaping "afterthought." The concept design presented here not only incorporates trees and shrubs, but has also been modified to improve growing conditions and decrease potential engineering conflicts (Figure 26). Planting trees and shrubs in bioretention and bioinfiltration facilities may increase nutrient uptake and evapotranspiration.

Bioretention and bioinfiltration facilities are typically small (footprints are generally 5% of the impervious area they receive drainage from, drainage areas are less than 2 acres) and can be used in many applications. Where space is available, a forested or multi-zone filter strip may be used as pretreatment for bioretention and bioinfiltration facilities.

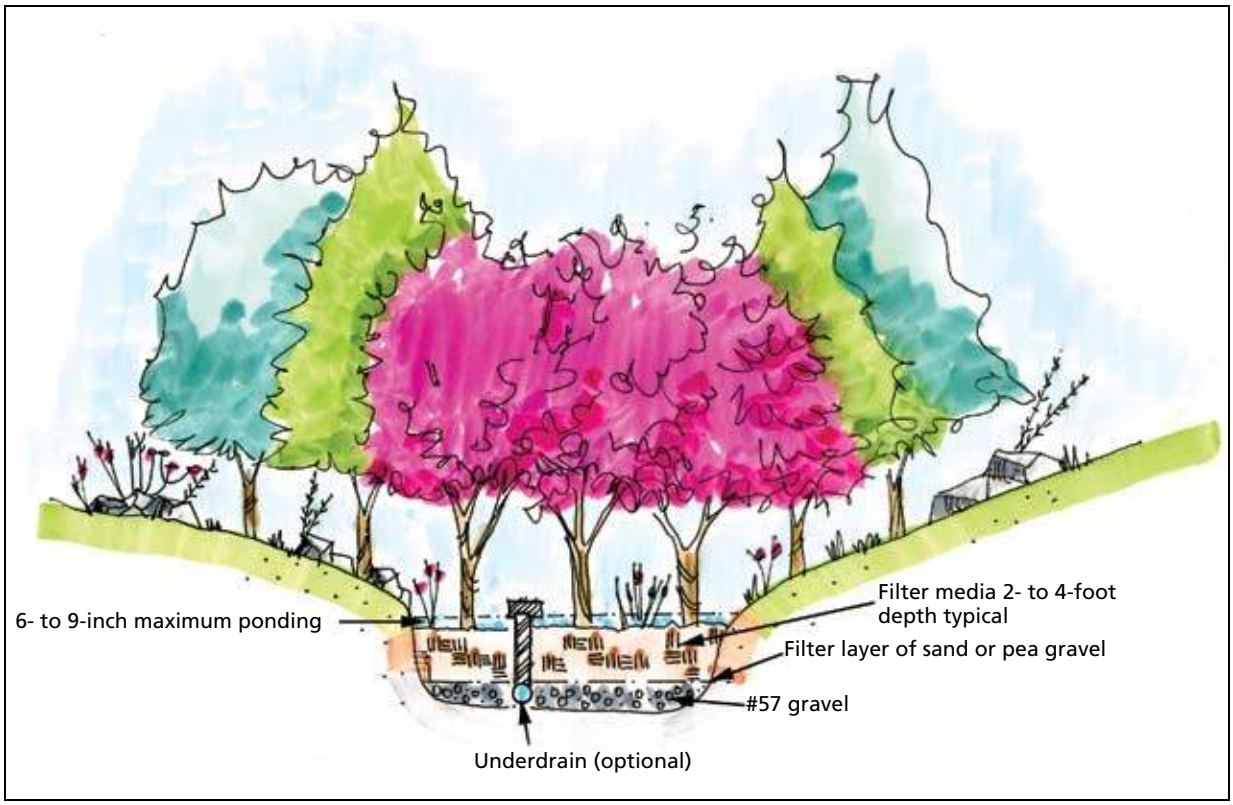

Figure 26. Bioretention and bioinfiltration facilities remove pollutants from storm water runoff using a filter medium.

Bioretention and Bioinfiltration Facilities *Continued*

Design Modifications

- ☐ Filter fabric should not be used between the filter media and the gravel jacket around the underdrain, as it creates an undesirable soil/water interface. A filter layer of sand or pea gravel may be used in lieu of filter fabric in this area to prevent the migration of fines into the gravel layer below. Ferguson (1994) provides a formula for determining the composition of this sand layer, and Prince George's County (2001) provides guidance on use of a pea gravel layer. Filter fabric may not be necessary along the sides of the excavated area unless there is concern about lateral movement of water into the adjacent soil (e.g., in applications where lateral seepage may cause upheaval of adjacent pavement).
- ☐ Use #57 (i.e., 1 ½-inch diameter) gravel instead of #2 around underdrain to provide some filtering. The underdrain may be suspended within #57 gravel to provide enhanced recharge and infiltration by increasing the stone reservoir.
- ☐ Allow for 6-9 inches of ponding during storm events.

Species Selection

Species selection is key in bioretention designs since it is more efficient than trying to change the site characteristics. Select a minimum of three hardy, native tree species that are adapted to soil and site conditions.
Other desirable species characteristics may include the following:

- ☐ Tolerant of inundation
- ☐ Tolerant of drought
- ☐ Wide spreading canopy
- ☐ Tolerant of salt

General Planting Guidance

- ☐ Have a landscape architect create a planting plan for the facility.
- ☐ Do not plant trees directly over the underdrain as a precautionary measure.
- ☐ Excavate the center only to a depth of 4 feet and backfill with filter media (infiltration rate of at least 0.5 feet per day). Use existing soil on side slopes (minimum 4:1 slopes). Use a filter medium with a lower sand ratio, or plant large trees only on side slopes to reduce potential for upheaval.
- ☐ Overplant with bare root seedlings for fast establishment and to account for mortality. Alternatively, plant larger stock when a dedicated water source is available using desired spacing intervals (35-50 feet for large and very large trees) and random spacing, or use a mix of seedlings and larger stock.
- ☐ Provide adequate soil volume for trees: in general, 2 cubic feet of useable soil for every square foot of mature canopy (Urban, 1999). Assume some shared rooting space between trees.

Maintenance	☐	Use tree shelters to protect seedlings where deer predation is a concern.
	☐	Use mulch to retain moisture.
Topics for Future Research	☐	Quantify increased pollutant removal due to trees in facility.
Further Resources		Center for Watershed Protection. 1996. Design of stormwater filtering systems. Ellicott City, MD. Ferguson, B. K. 1994. Stormwater infiltration. Boca Raton, FL: CRC Press, Inc. Prince George's County. 2001. Bioretention manual. Upper Marlboro, MD: Department of Environmental Resources Program and Planning Division. Urban, J. 1999. Room to grow. Treelink 11: 1-4.

Alternating Side Slope Plantings (Swale)

Description	Alternating side slope plantings are trees planted on the side slopes of a dry swale or other open channel conveyance system in an alternating pattern. Alternating side slope plantings can be used in open channels with longitudinal slopes up to 2%, to provide shade, rainfall interception, limited slope stabilization, and esthetic value.
Design Modifications	None.
Species Selection	Species selection is key because it is more efficient than trying to change the site characteristics. Select a diverse mix of hardy, native species with the following characteristics: ☐ Tolerant of inundation ☐ Tolerant of salt ☐ Wide spreading canopy.
General Planting Guidance	☐ Trees should be planted singly or in clusters in an alternating pattern on the side slopes. As a general rule, tree or cluster spacing should be six times the channel width (Figure 27), to impose meanders on channel flow. ☐ Stock can be seedlings (overplant for fast establishment and to account for mortality) or larger stock planted at desired spacing intervals. ☐ Excavate planting hole to a depth of 2-4 feet and backfill with amended soil if existing soil is compacted. ☐ The channel bottom and side slopes may be planted with turf or with native grasses (if able to withstand the runoff velocity the swale is designed to convey). ☐ Establish a defined edge on the top slope of the channel using trees, shrubs, or spaced rock. This edge protects trees from mowers and provides a visual border to let residents know the plantings are intentional.
Maintenance	☐ Use mulch to retain moisture ☐ Mow around trees regularly if turf, or twice a year if native grasses. ☐ Use mulch, tree shelters, or rock borders to protect trees from lawn mowers.

Topics for Future Research

- ☐ Is there potential for trees to shade out grass and contribute to erosion?
- ☐ What species can be planted on channel bottom and around trees as an alternative to turf that can also withstand the runoff velocity the swale is designed to convey?

Further Resources

Center for Watershed Protection. 1996. Design of stormwater filtering systems. Ellicott City, MD.

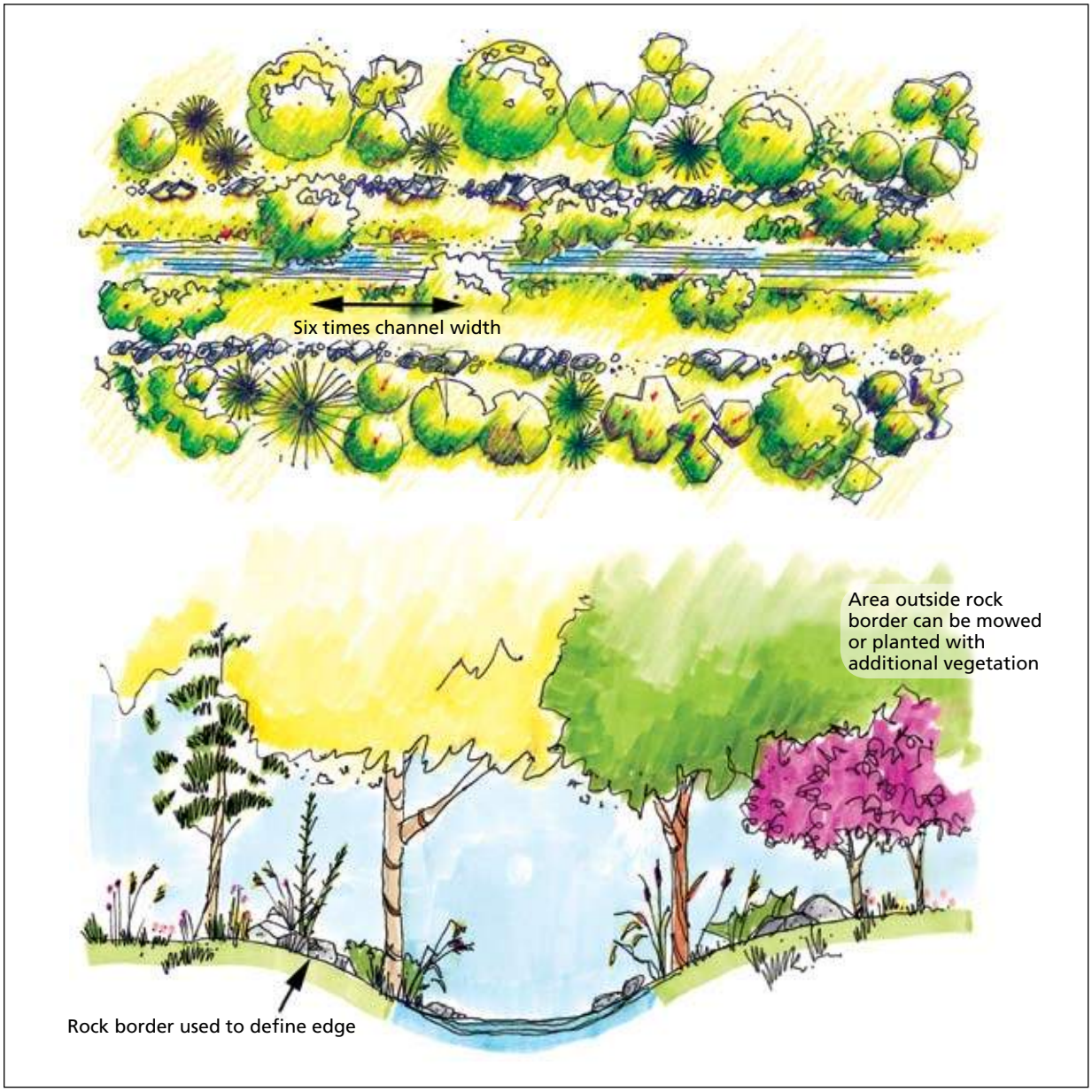

Figure 27. Alternating side-slope plantings are an attractive way to incorporate trees into swales without obstructing channel flow.

Tree Check Dams (Swale)

Description

Open channel conveyance systems such as dry swales often incorporate check dams to slow runoff and prevent erosion, when longitudinal slopes range from 2% to 6%. Traditional check dams are constructed of rock, railroad ties, or other material. Tree check dams (Figure 28) use tree mounds (Figure 24 on page 31) to dissipate velocity. Tree check dams may also increase evapotranspiration and pollutant removal in the swale soils.

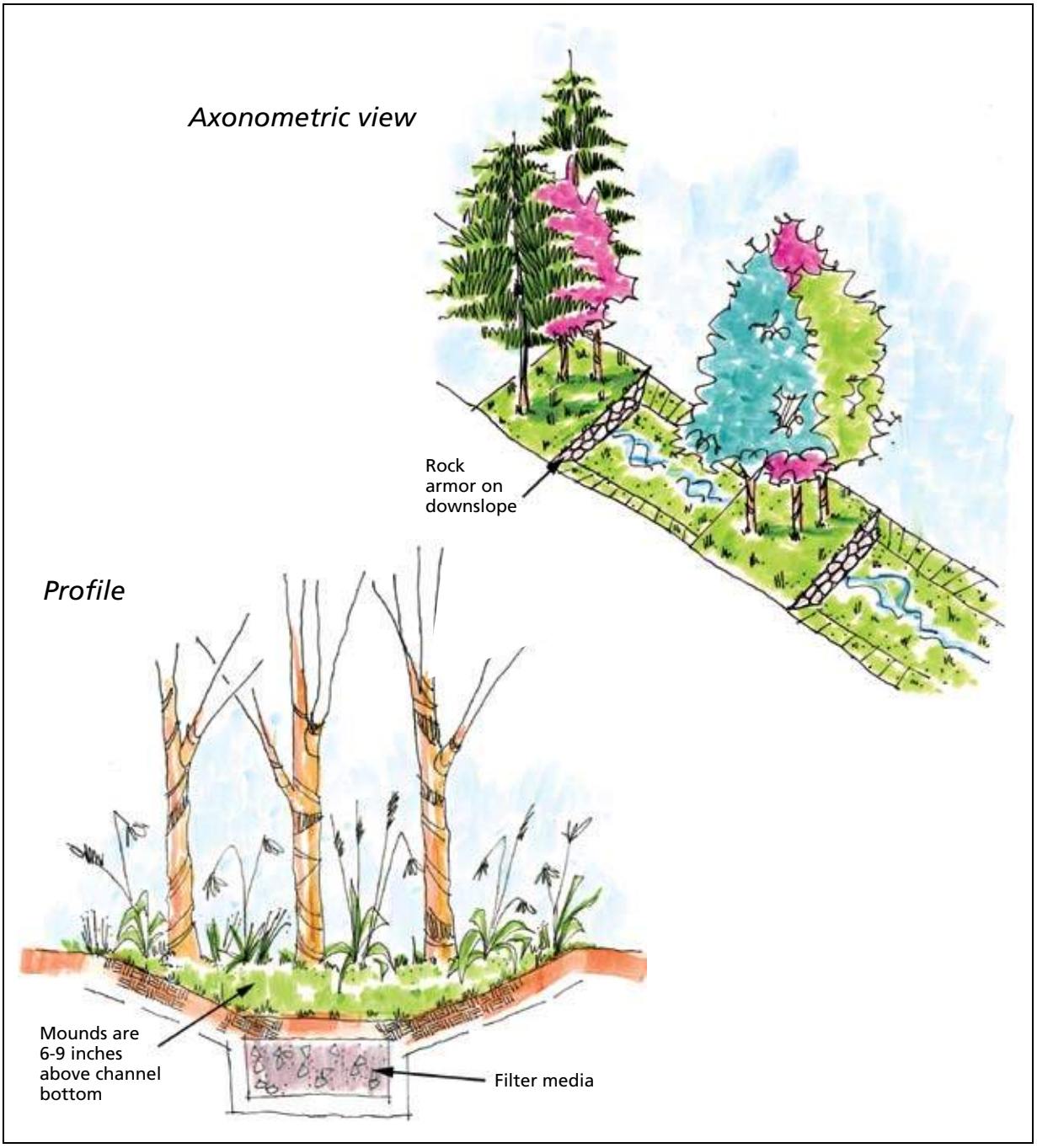

Figure 28. Tree check dams slow runoff and prevent erosion in swales with slopes of 2% to 6%.

Design Modifications	Account for increased roughness and reduced capacity by subtracting the cross-sectional area of trees from the channel cross-section when computing channel capacity.
Species Selection	Species selection is key because it is more efficient than trying to change the site characteristics. Select a diverse mix of hardy, native species that are adapted to soils and site conditions. In particular, consider the size of trees at maturity in relation to channel width. Trees that are too large may block flow across the channel, so small trees and shrubs may be best for check dams. Other desirable species may have these characteristics: ☐ Tolerant of inundation ☐ Tolerant of salt
General Planting Guidance	☐ Spacing of check dams should be such that the toe of the upstream dam is at the same elevation as the top of the downstream dam. ☐ Check dam mounds should be no higher than 6-9 inches above the bottom (invert) of the channel. ☐ The mound should be constructed across the entire width of the channel, and have a weep hole or armored opening to allow ponded water to seep through the mound. Mounds should be armored with rock on the downslope side, particularly on steeper slopes, to protect from erosion. ☐ Excavate to a depth of 3-4 feet and backfill with amended soil if existing soil is compacted. ☐ Plant trees and shrubs on the mounds, using bare root seedlings to minimize transplant stress to roots. ☐ Plant turf grass or native grasses (if able to withstand the runoff velocity the swale is designed to convey) along the channel bottom and side slopes.
Maintenance	☐ Use mulch to retain moisture. ☐ Periodically remove debris and trash from the check dams. ☐ Use mulch, tree shelters, or rock to protect the tree from lawnmower damage. ☐ Mow turf regularly or native grasses twice a year.

Tree Check Dams (Swale) *Continued*

Topics for Future Research

- ☐ Will tree mounds be stable enough to withstand high flows?
- ☐ Should larger stock be used to prevent seedlings from washing away?
- ☐ Is there potential for trees to shade out grass and contribute to erosion?
- ☐ What species can be planted on the channel bottom and around trees as an alternative to turf that can also withstand the runoff velocity the swale is designed to convey?
- ☐ Can dimensions of tree mounds be further defined?

Further Resources

Center for Watershed Protection. 1996. Design of stormwater filtering systems. Ellicott City, MD.

Metro. 2002. Green streets: innovative solutions for stormwater and stream crossings. Portland, OR.

Forested Filter Strip

Description

A traditional filter strip is a grass area that is intended to treat sheet flow from adjacent impervious areas. Sheet flow is runoff that flows over land with no defined channels. Filter strips function by slowing runoff velocities, filtering out sediment and other pollutants, and providing some infiltration into underlying soils.

A forested filter strip provides a similar function but incorporates trees and a small ponding zone (optional) into the design (Figures 29 and 30). The ponding zone is a small depression with a low berm where water ponds during most storm events (e.g., around a 1-inch rainfall). The entire filter strip is planted with trees and shrubs, but since the depression is wetter than the remainder of the practice, the two zones are distinguished by referring to them as the ponding zone and the forested zone. Additional benefits provided by a forested filter strip include evapotranspiration, wildlife habitat, and infiltration promoted by macropore formation.

Forested filter strips may be used as follows:

- ☐ In linear areas such as stream buffers and transportation corridors.
- ☐ As pretreatment for a stream buffer or other storm water treatment practice.
- ☐ Where visual screening or a buffer is desired.

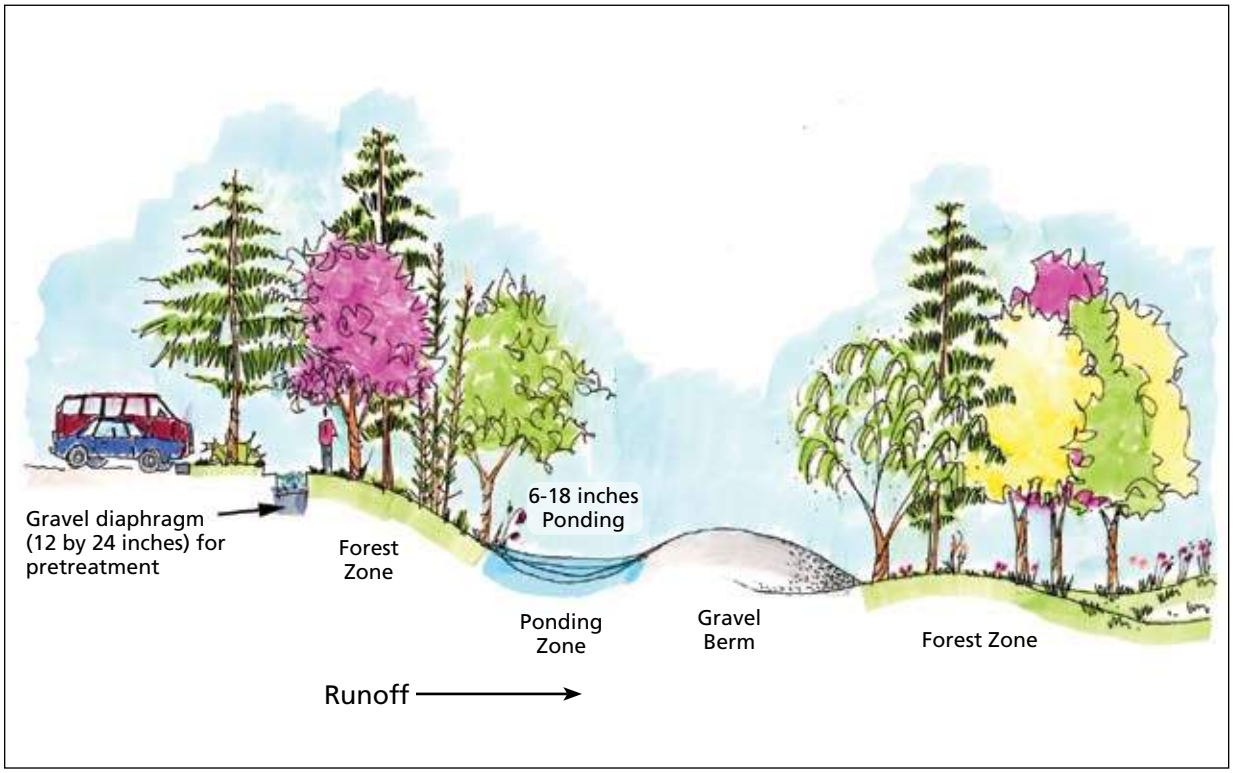

Figure 29. Forested filter strip profile shows how runoff flows through the various zones.

Forested Filter Strip *Continued*

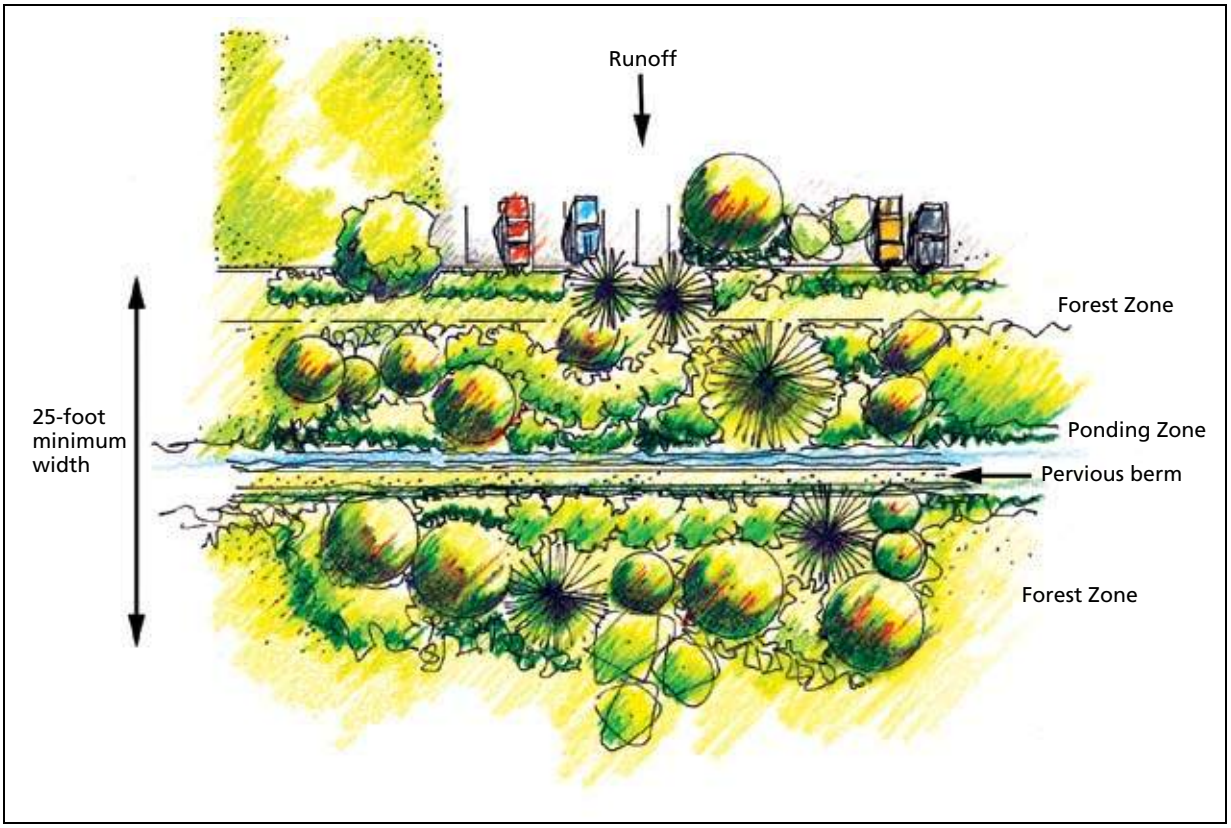

Figure 30. Forested filter strip plan shows its suitability to a linear area.

Design Modifications

- ☐ Unlike a traditional grass filter strip, the forested filter strip is not limited to accepting sheet flow runoff. If runoff is concentrated, the filter strip inlet should be armored with rock.
- ☐ Use a gravel diaphragm for pretreatment (acts as a level spreader and allows fine sediment to settle out where sheet flow is present).
- ☐ When a significant volume of storm water runoff is expected, the forested filter strip should have a small berm constructed of pervious material such as gravel, rock, or earth. If the berm is earthen, insert weep hole pipes so ponded water filters to the other side. If the berm is gravel, gabions may be used. A gabion is a wire mesh cage filled with rock and is used to prevent erosion. The height of the berm should be 6-18 inches above the bottom of the depression and at least 6 inches below the lowest inflow elevation.
- ☐ Overall dimensions should provide surface storage for the water quality volume. During larger storms, runoff will overtop the berm. Minimum width of the filter strip should be 25 feet. The slope should range from 2% to 6%.

Species Selection	Existing trees should be incorporated into the design where possible. Otherwise, select a diverse mix of native species (minimum of three) that have these characteristics: ☐ Tolerant of salt ☐ Tolerant of inundation (standing water in ponding zone, fluctuating water levels in forested zone).
General Planting Guidance	☐ Shrubs and small trees can be incorporated into the ponding zone, and larger trees can be incorporated into the forested zone. ☐ Conserve existing soil, if undisturbed, and use soil amendments if site soils are compacted. ☐ Overplant with seedlings for fast establishment and to account for mortality. Alternatively, plant larger stock at desired spacing intervals (35-50 feet for large and very large trees) using random spacing.
Maintenance	☐ Use mulch to retain moisture. ☐ Use tree shelters to protect seedlings.
Topics for Future Research	☐ Quantify increased pollutant removal due to trees in filter strip.
Further Resources	Center for Watershed Protection. 1996. Design of stormwater filtering systems. Ellicott City, MD. Maryland Department of the Environment. 2000. Maryland stormwater design manual. Baltimore, MD.

Multi-Zone Filter Strip

Description

A traditional filter strip is a grass area that is intended to treat sheet flow from adjacent impervious areas. Sheet flow is runoff that flows over land with no defined channels. Filter strips function by slowing runoff velocities and filtering out sediment and other pollutants, and providing some infiltration into underlying soils.

A multi-zone filter strip provides a similar function but incorporates trees and shrubs into the design. A multi-zone filter strip features several vegetation zones that provide a gradual transition from turf to forest (Figures 31 and 32). The zones are turf, meadow, shrub, and forest. The multi-zone filter strip can be effectively designed as a transition filter zone to an existing forest area. Additional benefits provided by a multi-zone filter strip include evapotranspiration, wildlife habitat, and infiltration promoted by macropore formation.

Multi-zone filter strips may be used as follows:

- ☐ In linear areas such as stream buffers and transportation corridors.
- ☐ As pretreatment for a stream buffer or other storm water treatment practice.
- ☐ Where runoff is present as sheet flow and travels over short distances (a maximum of 75 feet of impervious area, or 150 feet of pervious area).
- ☐ Where safety and visibility are concerns (e.g., next to parking lot or public area)

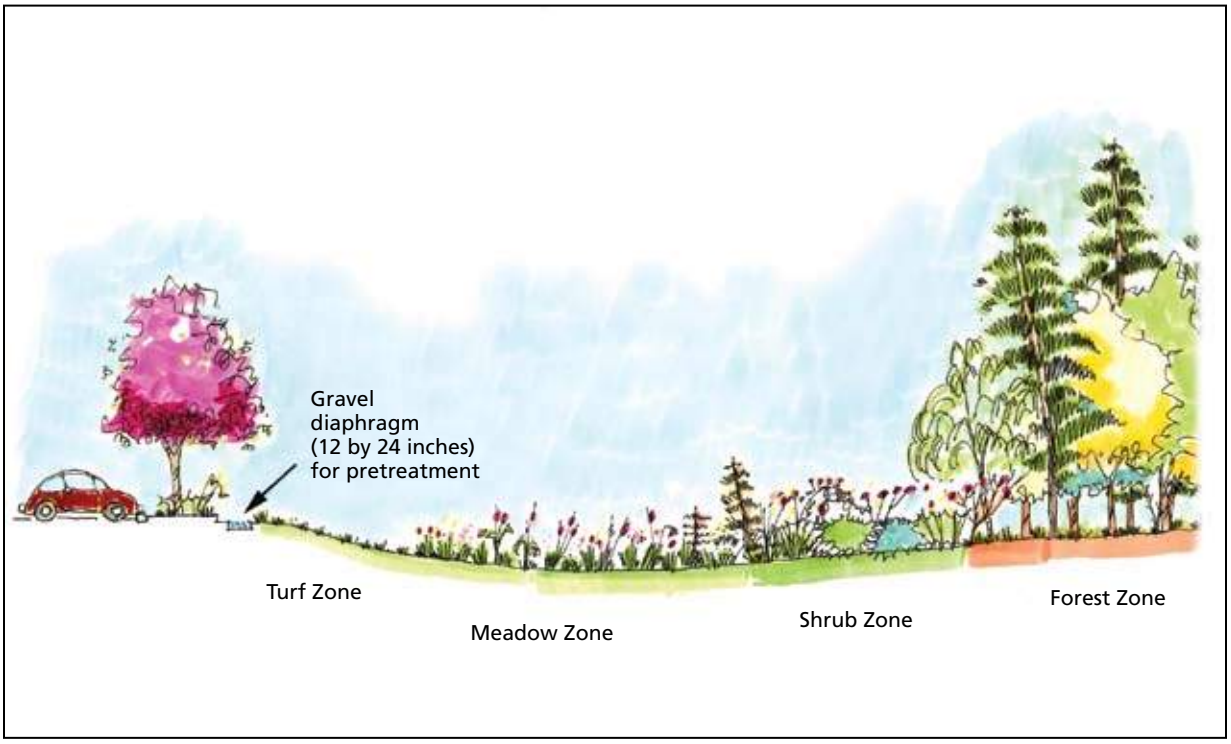

Figure 31. A multi-zone filter strip (profile) includes four successive vegetation zones.

Design Modifications	☐	Use curb stops or parking stops to keep cars from driving on the grass area, if next to a parking lot.
	☐	Use a gravel diaphragm for pretreatment.
	☐	Minimum width of filter strip should be 25 feet.
	☐	When a significant volume of stormwater runoff is expected, a small berm and ponding area may be incorporated as described in the Forested Filter Strip.
Species Selection	Existing trees should be incorporated where possible. Otherwise, select and plant a minimum of three native species with these characteristics:	
	☐	Tolerant of inundation
	☐	Tolerant of salt
General Planting Guidance	☐	Plant each zone with the desired vegetation. Widths of each vegetative zone may vary. Shrub zone may ultimately become a tree zone.
	☐	Conserve existing soil, if undisturbed, and use soil amendments if compacted.
	☐	Overplant with seedlings for fast establishment and to compensate for mortality, or plant larger stock at desired spacing intervals (35-50 feet for large and very large trees) using random spacing.
Maintenance	☐	Use mulch to retain moisture.
	☐	Use tree shelters to protect seedlings.
	☐	Mow turf zone regularly and reseed as needed.
	☐	Mow meadow zone twice a year.

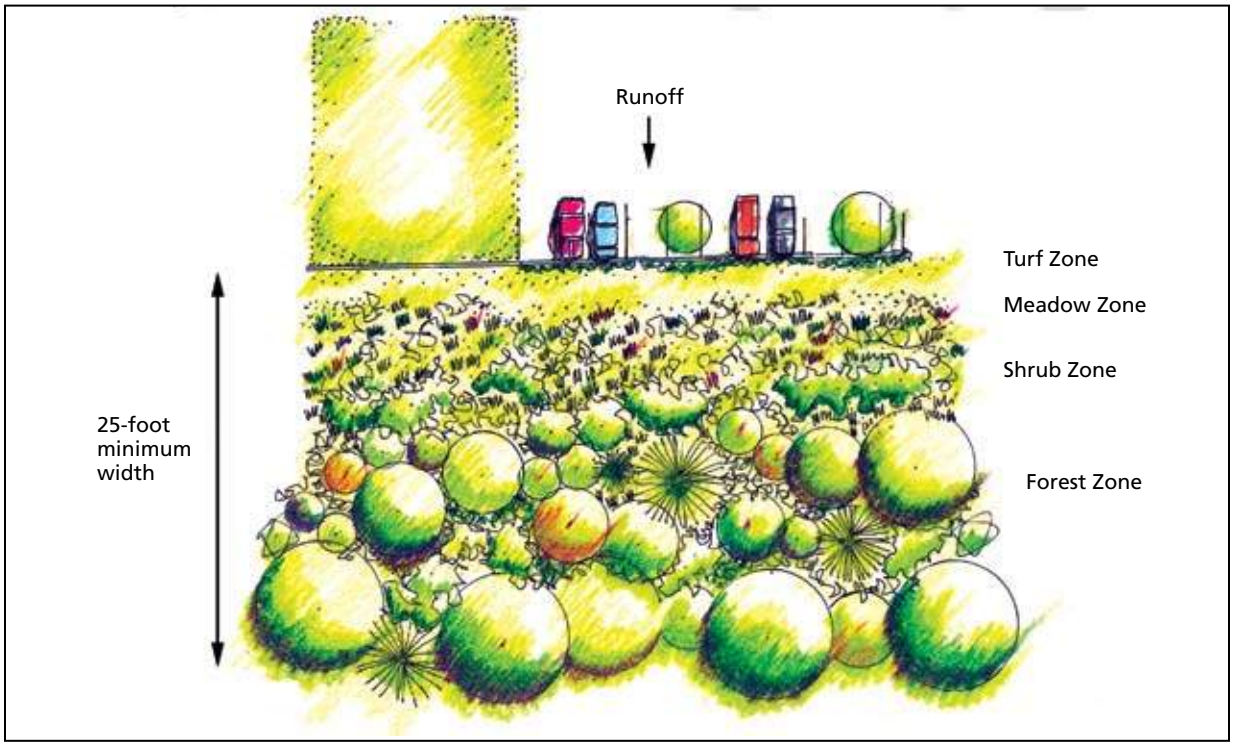

Figure 32. A multi-zone filter strip (plan) requires a minimum width of 25 feet.

Multi-zone Filter Strip *Continued*

Topics for Future Research

- ☐ Quantify additional pollutant removal due to trees in filter strip.

Further Resources

Center for Watershed Protection. 1996. Design of stormwater filtering systems. Ellicott City, MD.

Maryland Department of the Environment. 2000. Maryland stormwater design manual. Baltimore, MD.

Linear Storm Water Tree Pit

Description

A linear storm water tree pit is similar to a traditional street tree pit design, but is modified so the pit accepts and treats storm water runoff and provides an improved planting environment for the tree. A storm water tree pit has additional soil volume, regular irrigation, and better drainage to promote tree growth. A continuous soil trench underneath the pavement connects individual tree pits (Figures 33 and 34).

Linear storm water tree pits are most useful for the following conditions:

- ☐ Where existing soils are very compacted or poor.
- ☐ Where open space for planting is limited (e.g., highly urban areas) and rooting space can be provided for trees underneath pavement.
- ☐ In street tree or other linear applications (although it can be adjusted for a different application, such as clustered plantings in a courtyard).
- ☐ New development, or as a retrofit of existing development, when done in conjunction with repair of underground utilities or a streetscaping project that requires sidewalk excavation.

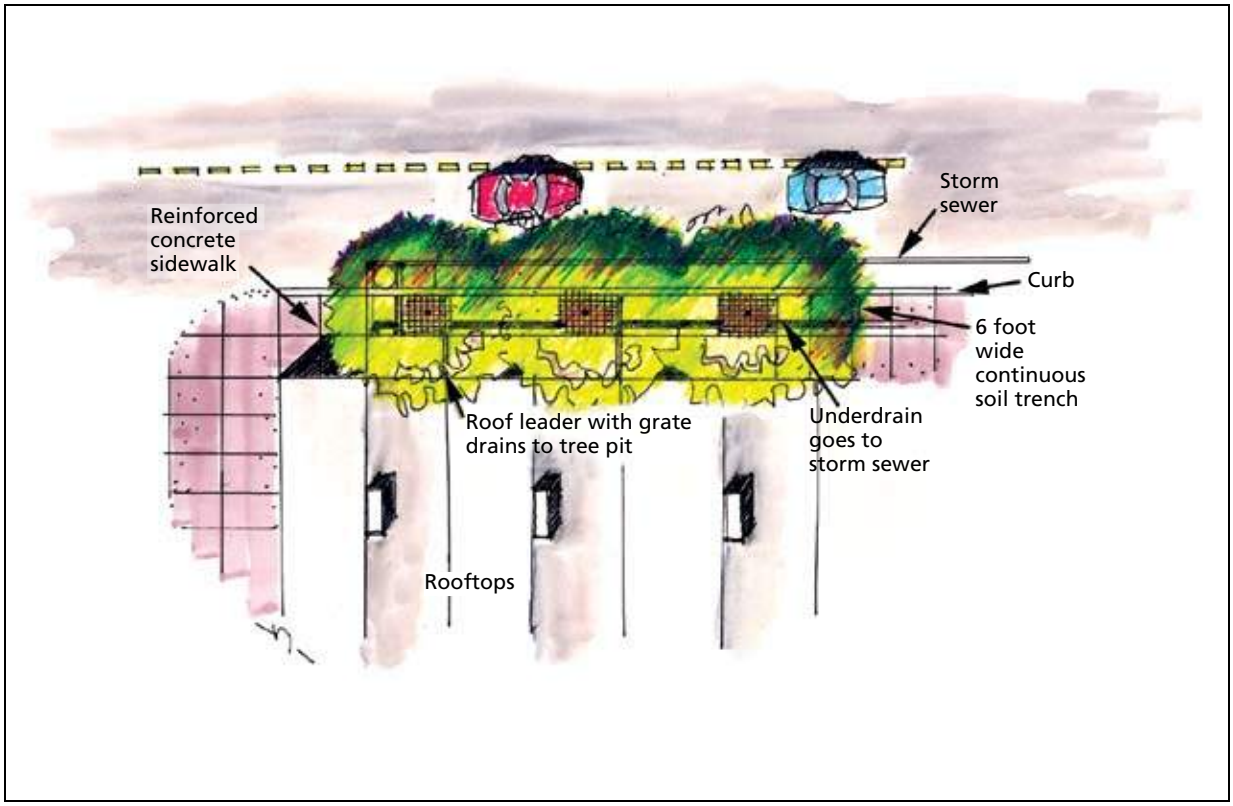

Figure 33. A linear storm water tree pit (plan view) collects and treats storm water that is directed from rooftops.

Linear Storm Water Tree Pit *Continued*

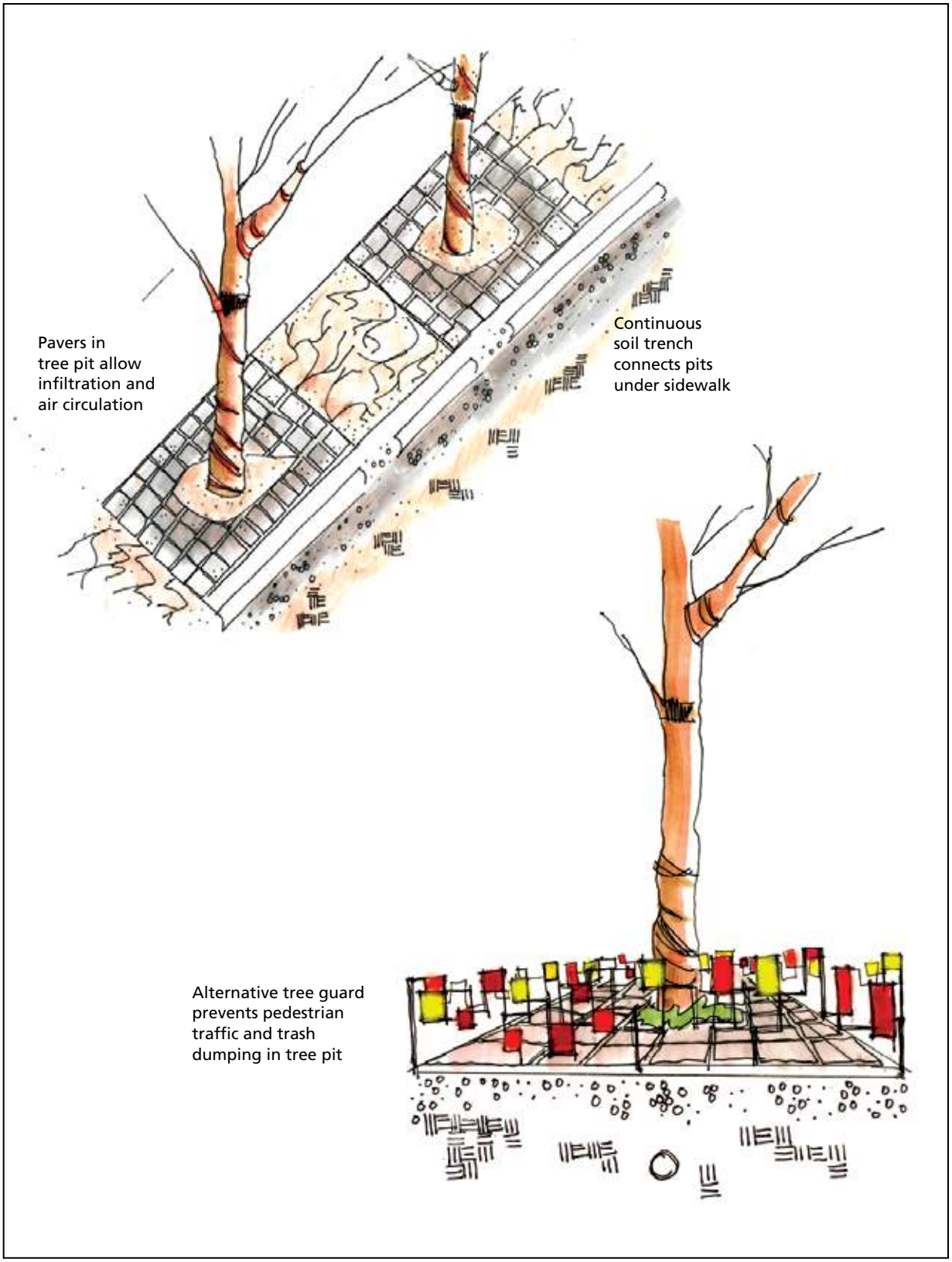

Figure 34. Tree pits are connected through a soil trench, and tree pit protection prevents damage from pedestrian traffic.

Design Modifications

- ☐ Storm water is directed from rooftops to tree pits using sunken roof leaders covered with grates. An alternative is to use curb cuts to direct street runoff to the pits for added water quality benefits. In this case, a filter screen or cleanout device must be provided to capture trash and litter.
- ☐ An underdrain that connects either to existing storm drain inlets or to the storm sewer is installed under tree pits. The underdrain is surrounded by a layer of gravel to provide some filtering. A variation is to add a gravel base under the underdrain to allow some infiltration.
- ☐ Trees are planted within a linear trench with filter medium to allow filtering of storm water and shared rooting space for trees underneath pavement.
- ☐ Reinforced concrete sidewalks should have wide surface openings to accommodate the mature size of the trees (sidewalks will be cantilevered over planting holes).
- ☐ Consider use of structural soils under pavement, which allows tree roots to grow in it and also meets engineering specifications (see Bassuk and others (n.d.) and Part 3 of this manual series for more information).

Species Selection

Species selection is critical in storm water tree pits because unmodified site conditions are often highly stressful to healthy tree growth. A mix of hardy species should be selected that are adapted to the following soil and site conditions:

- ☐ Tolerant of poor, compacted soils
- ☐ Tolerant of salt
- ☐ Tolerant of urban pollutants
- ☐ Tolerant of inundation
- ☐ Tolerant of drought
- ☐ Wide spreading canopy

General Planting Guidance

- ☐ Excavate a planting trench 3-4 feet deep and a minimum of 6 feet wide. The volume for each tree should be adequate for the mature size of the tree, assuming some shared soil volume. Backfill trench with filter medium. The top of the planting trench should be slightly below grade to allow space for air circulation.
- ☐ Plant at desired spacing intervals.
- ☐ Install concrete posts, fencing, or other structures (see Figure 34) to prevent pedestrians from stepping in tree pit (tree grates are not recommended since they can damage the tree if they are not adjusted as it grows).

Linear Storm Water Tree Pit *Continued*

Maintenance	☐	Use mulch to retain moisture.
Topics for Future Research	☐	Need better method to prevent use of tree pits as trash cans.
	☐	Develop guidance on sizing and volume of tree pits so as not to direct too much water into pits.

Further Resources

Bassuk, N.; Grabosky, J.; Trowbridge, P.; Urban, J. [N.d.]. Structural soil: an innovative medium under pavement that improves street tree vigor. Ithaca, NY: Cornell University, Urban Horticulture Institute. www.hort.cornell.edu/department/faculty/bassuk/uhi/outreach/csc/article.html

Hammerschlag, R. S.; Sherald, J. L. 1985. Traditional and expanded tree pit concepts. In: METRIA 5: Selecting and Preparing Sites for Urban Trees. Proceedings of the Fifth Conference of the Metropolitan Tree Improvement Alliance. University Park, PA: The Pennsylvania State University.

Hoke, J. R., Jr., ed. 2000. Architectural graphic standards, 10th ed. New York, NY: John Wiley and Sons, Inc.

Urban, J. 1999. Room to grow. Treelink 11: 1-4.

Chapter 4. Planting Trees Along Streets and in Parking Lots

This chapter provides guidance on planting trees along local streets and within parking lots at new development sites. Pervious portions of a development site that make good candidates for tree planting and are often overlooked include local road rights-of-way, landscaped islands in cul-de-sacs or traffic circles, and parking lots. Many local landscaping ordinances often require developers to plant street trees or to landscape a certain percentage of every parking lot.

One of the most common features of highly desirable neighborhoods is the presence of large street trees that form a canopy over the road. Many newer developments either do not incorporate street trees or use small, ornamental trees or other types of vegetation within the planting strip (Figure 35). Street trees are traditionally planted in a linear fashion along either side of the road. Alternatives to this design include these: planting trees in clusters along the side of the road (Figure 36), planting trees within median strips (Figure 37), or planting trees in islands located in cul-de-sacs or traffic circles (Figure 38). Each planting area has specific considerations for incorporating trees to ensure adequate space is provided and to address common concerns about visibility and conflicts with overhead wires or pavement (Figure 39).

Figure 35. The environment differs drastically in a development with no street trees (top) from one with trees that matured to form a canopy over the street (bottom).

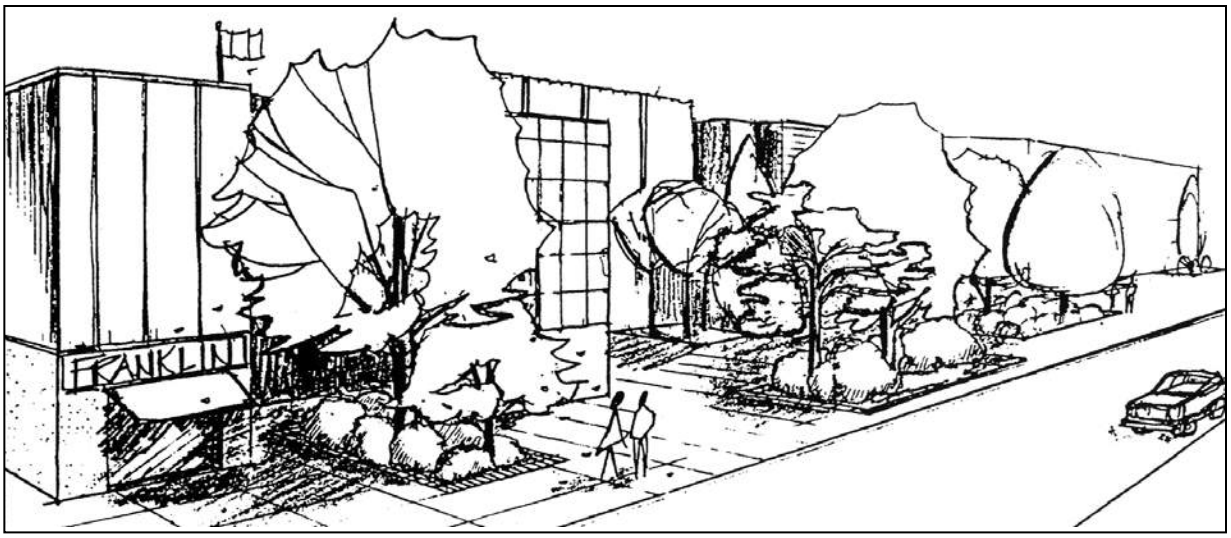

Figure 36. Non-linear street tree plantings are an alternative to linear roadside plantings. (Source: Meyer, n.d., p. 32)

Figure 37. Trees planted in a median strip provide shade, slow traffic, and make a street more attractive (left) than one with little vegetation (right).

Figure 38. A cul-de-sac (left) is typically overlooked as a place to plant trees (right) .

Figure 39. Trees planted in holes that are too small may eventually crack nearby pavement.

Trees in parking lots reduce the urban heat island effect, remove pollutants, provide shade and habitat for wildlife, and increase the esthetic value of the parking lot. Many commercial parking lots, however, use a "cookie cutter" design that does not incorporate trees (Figure 40). Because a parking lot can be a very harsh climate for a tree, several important design considerations are necessary.

Figure 40. The harsh environment of a parking lot (left) can be tempered by including an interior planting strip that allows trees to share rooting space (right).

Planting guidance for trees along streets and in parking lots is presented in the remainder of this chapter in fact sheet format. Each fact sheet contains the following sections:

Description – brief description of the planting concept.

Pre-Planting Considerations – potential conflicts with planting trees at the site or unique features that drive plant selection and planting procedures. Most of these considerations are addressed in the Species Selection, Site Preparation, Planting Guidance, or Maintenance sections.

Species Selection – desirable characteristics of species to be planted at the site. Part 3 of this manual series includes an Urban Tree Selection Guide with tree and shrub species and their characteristics.

Site Preparation – recommendations for preparing the site for planting.

Planting Guidance – recommendations for stock selection, planting zones, plant spacing and arrangements, and planting methods.

Maintenance – recommendations for tree maintenance.

Potential for Storm Water Treatment – potential for integrating trees and storm water treatment practices in that particular location.

Further Resources – resources for additional information.

Planting Trees Along Local Streets

Description

Local roads offer three areas to incorporate trees: the buffer, the median strip, and landscaped islands in cul-de-sacs or traffic circles (Figures 41 and 42). The buffer consists of the area between the edge of the road pavement and adjacent private property. The median strip is the area between opposing traffic lanes. Cul-de-sacs are large diameter bulbs that enable vehicles to turn around at the end of streets. They often involve large areas of pavement but present a good opportunity to plant trees in neighborhoods.

Trees planted along local roads can reduce air pollution and storm water runoff, provide habitat for wildlife such as birds, provide shade for pedestrians, reduce air temperatures, stabilize the soil, provide a visual screen and barrier from noise and highway fumes, and make for a visually pleasing environment for drivers and homeowners.

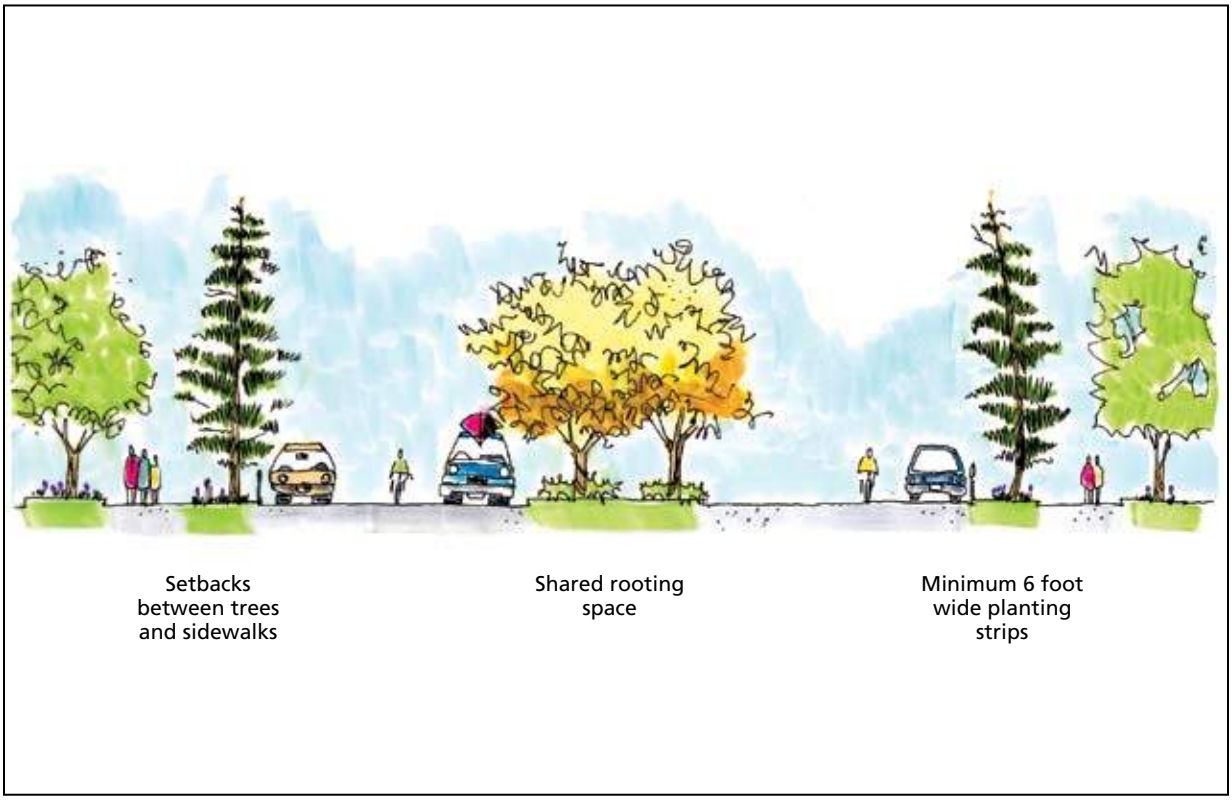

Figure 41. Trees can be incorporated into various planting areas along local roads.

Planting Trees Along Local Streets *Continued*

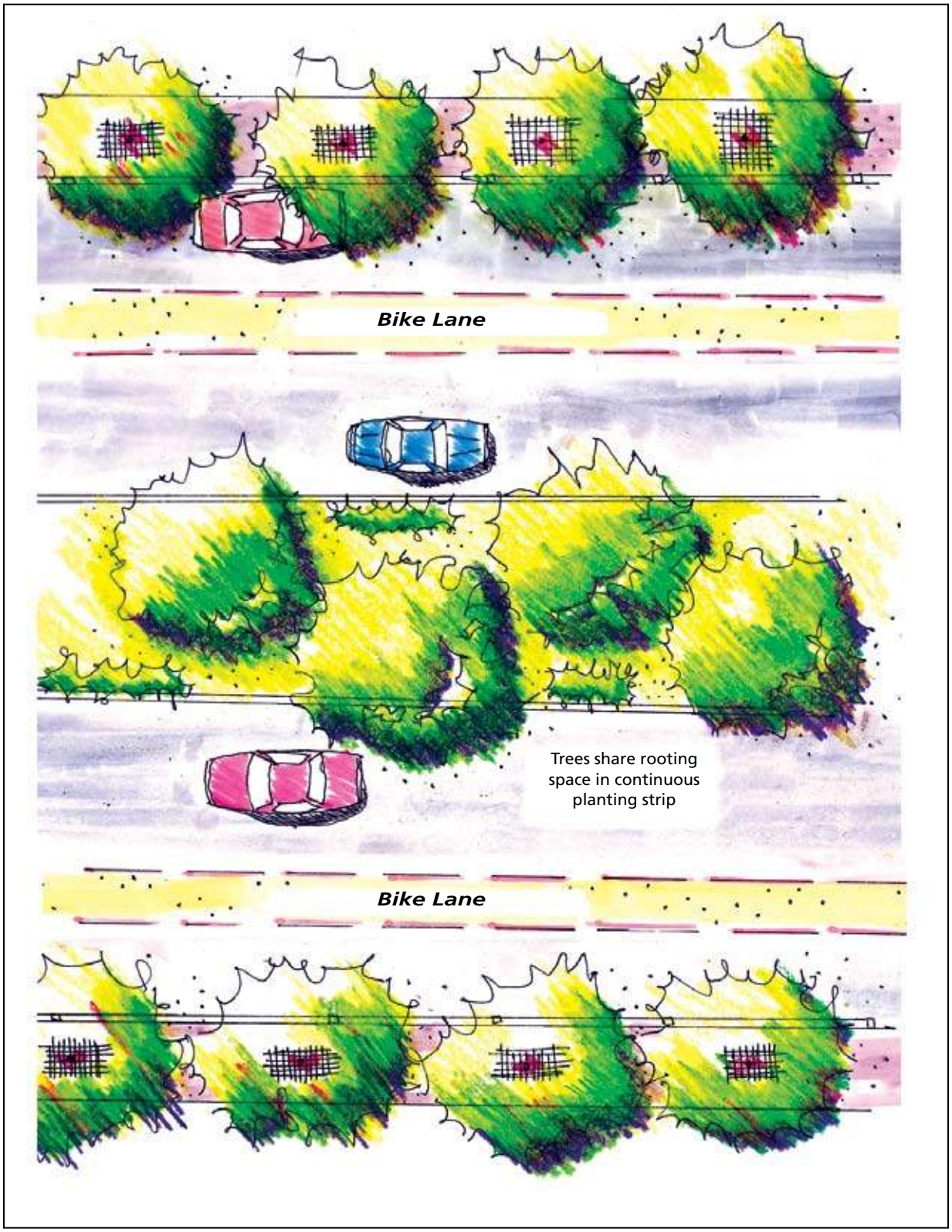

Figure 42. Tree planting along local roads (plan view) can utilize wide, linear planting areas to accommodate large, healthy trees.

Pre-Planting Considerations

Before planting trees along local roads, designers need to address some important considerations:

- ☐ How to provide clear lines of sight, safe travel surfaces, and overhead clearance for pedestrians and vehicles
- ☐ How to prevent compaction of planting area soils by construction and foot traffic
- ☐ How to resolve potential conflicts between trees and utilities, pavement, and lighting
- ☐ How to make the road corridor more attractive with plantings
- ☐ How to reduce tree exposure to auto emissions, polluted runoff, wind, and drought
- ☐ How to provide enough future soil volume for healthy tree growth
- ☐ How to prevent damage to trees from cars
- ☐ How to address concerns about increased tree maintenance, damage to cars from trees (e.g., sap, branches) and roadway snow removal and storage

Species Selection

Species selection is very important in the road corridor, because of the many potential urban stressors associated with roadway planting. A diverse mix of hardy species should be selected that are adapted to soil and site conditions and are tolerant of the following:

- ☐ Drought
- ☐ Poor or compacted soils
- ☐ Inundation (if used for storm water treatment)
- ☐ Urban pollutants (oil and grease, metals, chloride)

In addition, select tree species with these characteristics:

- ☐ Do not produce abundant fruits, nuts, or leaf litter
- ☐ Have fall color, spring flowers, or some other esthetic benefit
- ☐ Can be limbed up to 6 feet to provide pedestrian and vehicle traffic underneath.

Site Preparation

- ☐ Clean up trash.
- ☐ Improve soil drainage by tilling and adding compost.
- ☐ Remove invasive plants if present.

Planting Trees Along Local Streets *Continued*

General Planting Guidance	☐	Provide adequate soil volume, preferably by having at least a 6-foot wide planting strip, or locating sidewalks between the buffer and street to allow more rooting space for the trees in adjacent property.
	☐	Provide adequate setbacks from utilities, signs, lighting, and pavement.
	☐	Use tree clusters as an alternative to linear plantings, which will provide shared rooting space.
	☐	Use structural soil under pavement to provide shared rooting space.
	☐	Use groupings of species that provide fall color, flowers, evergreen leaves, and varying heights to create an esthetically pleasing landscape.
Maintenance	☐	Use mulch to retain moisture.
	☐	Plan for minimal maintenance of trees (watering may not be feasible).
	☐	Water trees during dry periods if possible.
	☐	Have trees pruned by a qualified arborist to maintain sight lines and overhead clearance.
	☐	Monitor and control invasive species.

Potential for Storm water Treatment

Local road buffers and median strips are ideal locations to treat storm water runoff from roads. Trees planted in these areas can be incorporated in storm water forestry practices such as bioretention and bioinfiltration facilities, alternating side slope plantings, tree check dams, forested filter strips, multi-zone filter strips, and linear storm water tree pits.

Trees planted in landscaped islands can be used to intercept rainwater and treat storm water runoff from the surrounding pavement. Bioretention and bioinfiltration facilities may be well suited to cul-de-sac islands. See Chapter 3 for more detail on storm water forestry practices.

Further Resources

Bassuk, N.; Grabosky, J.; Trowbridge, P.; Urban, J. [N.d.]. Structural soil: an innovative medium under pavement that improves street tree vigor. Ithaca, NY: Cornell University, Urban Horticulture Institute. www.hort.cornell.edu/department/faculty/bassuk/uhi/outreach/csc/article.html

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Georgia Forestry Commission. 2002. Community tree planting and establishment guidelines. Macon, GA. www.gfc.state.ga.us/Publications/UrbanCommunityForestry/CommunityTreePlanting.pdf

Gerhold, H. D.; Wandell, W. N.; Lacasse, N. L. 1993. Street tree factsheets. University Park, PA: The Pennsylvania State University College of Agricultural Sciences.

Metro. 2002. Green streets: innovative solutions for stormwater and stream crossings. Portland, OR.

Planting Trees in Parking Lots

Description

Parking lots have two distinct areas where trees can be planted—the interior and the perimeter—each of which has unique planting requirements and considerations (Figure 43). The parking lot interior can be a very harsh planting environment for trees, due to higher temperatures of the pavement, little water, exposure to wind, air pollution, and potential damage from automobiles. Landscaped islands are typically used within parking lots to provide a separation between parking bays and to meet landscaping requirements. These islands may be planted with grass, trees, or other vegetation and can be designed to accept storm water. Typically, most traditional parking lot islands do not provide adequate soil volumes for trees.

Trees planted along the perimeter of a parking lot provide a screen or buffer between the lot and an adjacent land use or road. Perimeter planting areas often provide a better planting environment for trees and good opportunities for conserving existing trees during parking lot construction.

The many benefits of incorporating trees in parking lots include shade for people and cars, reduction of the urban heat island effect, interception of storm water, improved esthetics, improved air quality and an increase in or creation of habitat for birds.

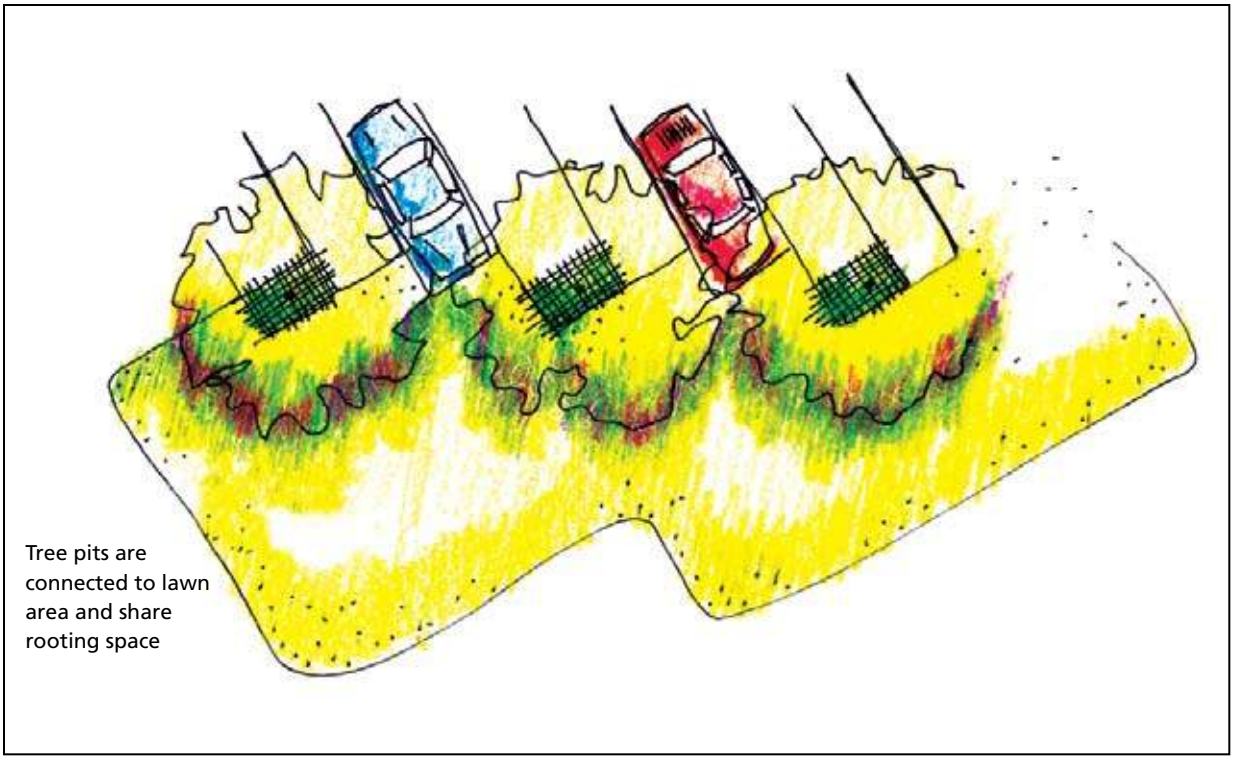


Figure 43. Parking lots can be designed to provide larger spaces to plant trees.

Planting Trees in Parking Lots *Continued*

Pre-Planting Considerations

Before planting trees in parking lots, designers need to address some important considerations:

- ☐ How to provide clear lines of sight, safe travel surfaces, and overhead clearance for movement of pedestrians and vehicles within the lot
- ☐ How to prevent compaction of planting area soils by construction and foot traffic
- ☐ How to resolve potential conflicts between trees and surrounding utilities, pavement, and lighting
- ☐ How to maximize canopy coverage and shading in the lot and make it more attractive with plantings
- ☐ How to reduce exposure of trees to auto emissions, polluted runoff, wind and drought
- ☐ How to provide adequate soil volume for trees in the confined space of a parking lot
- ☐ How to prevent damage to trees from cars
- ☐ How to address concerns about safety, increased maintenance due to tree litter, damage to cars from trees (e.g., sap, branches), and snow removal and storage
- ☐ How to maximize plantings for visual screening and buffers, at the same time offering view corridors to merchants

Species Selection

Species selection is important in urban parking lots because it is such a stressful environment. Tree species that comprise a diverse mix of hardy, native species that are adapted to soils and site conditions are needed.

The following characteristics should be sought when selecting a parking lot tree:

- ☐ Tolerant of salt
- ☐ Tolerant of drought and extreme temperatures
- ☐ Tolerant of poor, highly compacted soils
- ☐ Tolerant of urban pollutants
- ☐ Tolerant of inundation, if used for storm water treatment
- ☐ Does not produce abundant fruits, nuts, or leaf litter
- ☐ Wide-spreading canopy

Site Preparation

- ☐ Improve soil drainage by tilling soils and adding compost.

General Planting Guidance	☐	Use structural soils below pavement to allow for root growth where possible.
	☐	A few great trees are better than a lot of smaller ones.
	☐	Design concave planting areas to discourage pedestrian traffic.
	☐	Provide adequate setbacks from utilities, signs, lighting, and pavement.
	☐	Plant only species that are appropriate for parking lots.
	☐	Maintain appropriate setbacks from edge of planting strip or island to allow clear sight lines and reduce heat impact on trees (generally 4 feet).
	☐	Maintain an adequate setback between parking stalls and trees to prevent damage from cars.
	☐	Plant large balled and burlapped stock.
	☐	Have a landscape architect design the parking lot planting plan.

Specific Planting Guidance	*Interior*	Use alternative planting clusters in parking lot islands that allow shared rooting space and provide additional soil volume for trees.
		Employ "better site design" techniques, which include reducing the size of parking stalls to make the parking lot more efficient and to provide more room for trees (CWP, 1998)
	Perimeter	Use trees to provide shade over pedestrian walkways.
		Maintain a 6- to 8-foot overhead clearance for pedestrian walkways.
		When planting on steep slopes, use tree clusters and create small earthen berms around the group to retain moisture.
		When planting along a flatter slope, use linear spacing for safety and functionality

Maintenance	☐	Use mulch to retain moisture.
	☐	Plan for minimal maintenance (watering may not be feasible).
	☐	Have trees pruned by a qualified arborist to maintain sight lines and overhead clearance.
	☐	Monitor and control invasive species.

Potential for Storm Water Treatment

Ordinances usually require developers to landscape a minimum percentage of parking lot interiors. When properly built, these landscaped areas can double as storm water treatment facilities, which can result in cost savings for the developer. Storm water forestry practices for parking lots include:

- ☐ Parking lot interiors—Bioretention and bioinfiltration facilities, alternating side slope plantings or tree check dams, linear storm water tree pits
- ☐ Parking lot perimeters—Bioretention and bioinfiltration facilities, forested filter strips, and multi-zone filter strips

See Chapter 3 for more detail on storm water forestry practices.

Planting Trees in Parking Lots *Continued*

Further Resources

Appleton, B.; Horsley, J.; Harris, V.; Eaton, G.; Fox, L.; Orband, J.; Hoysa, C. 2002. Trees for parking lots and paved areas. In Trees for problem landscape sites. Publication No. 430-028. Blacksburg, VA: Virginia Cooperative Extension. www.ext.vt.edu/pubs/trees/430-028/430-028.html.

Center for Urban Forest Research. 2002. Fact Sheet #3: Making parking lots more tree friendly. Davis, CA: USDA Forest Service, Pacific Southwest Research Station. http://cufr.ucdavis.edu/products/CUFR_181_UFfactsheet3.pdf.

Center for Urban Forest Research. 2002. Where are all the cool parking lots? Davis, CA: USDA Forest Service, Pacific Southwest Research Station. http://cufr.ucdavis.edu/products/3/cufr_151.pdf.

Center for Watershed Protection. 1998. Better site design: a handbook for changing development rules in your community. Ellicott City, MD.

City of Sacramento, CA. 2003. Parking lot tree shading design and maintenance guidelines.

Costello, L. R.; Jones, K. S. 2003. Reducing infrastructure damage by tree roots: a compendium of strategies. Cohasset, CA: Western Chapter of the International Society of Arboriculture.

Appendix A. Forest Stand Delineation

This appendix contains the following field sheets, which were created as part of Maryland's Forest Conservation Act requirements, for use in delineating forest stands before developing a site:

- Forest Conservation Worksheet
- Field Sampling Data Sheet
- Explanation of Terms
- Techniques for Forest Structure Data Collection
- Forest Structure Data Sheet
- Forest Structure Analysis
- Forest Stand Summary Sheet.

These field sheets and guidance were originally published in Darr (1991) and were redrawn and/or adapted from Appendix D in the Maryland Forest Conservation Manual (Greenfeld and others 1991). These sheets can be used outside Maryland. See the Maryland manual for further guidance on conducting a Forest Stand Delineation (FSD).

Forest Conservation Worksheet

Input Data

A. Total site area: _____
B. Area within 100 year floodplain: _____
C. Area of agricultural land (no change in status): _____
D. Net tract area (A – B – C): _____

E. Land use category: _____
F. Afforestation threshold: _____
G. Conservation threshold: _____

H. Current forest cover: _____
I. Forest area above afforestation threshold: _____
J. Forest area above conservation threshold: _____

K. Above conservation threshold to be cleared: _____
L. Below conservation threshold to be cleared: _____
M. Total forested area to be cleared: _____
N. Forested area above conservation threshold to be saved: _____

Calculations

Break-Even Point:
O. Acres above conservation threshold to be retained for no required reforestation: J * 20% = _____acres

Afforestation Requirement:
P. Forested acres required: D * F = _____
Q. Acres to be afforested: P – H = _____

Reforestation Requirements:
R. Acres cleared above threshold: K * ¼ = _____
S. Acres cleared below threshold: L * 2 = _____
T. Reforestation credit: N * 1.25 = _____
U. Total reforestation requirements: R + S – T = _____ acres

Source: Greenfeld, J.; Herson, L.; Karouna, N.; Bernstein, G. 1991. Forest conservation manual: guidance for the conservation of Maryland's forests during land use changes, under the 1991 Forest Conservation Act. Washington, DC: Metropolitan Washington Council of Governments. Figure D-1, p. D-3.

Field Sampling Data Sheet

Property Name: *Prepared by:*
Stand # *Plot #* *Date:*

Tree Species (note dominant and co-dominant species)	**Size Class of Trees Within the Sample Plot**				
	Number of Trees 2-6 in. dbh	Number of Trees 7-10 in. dbh	Number of Trees 11-17 in. dbh	Number of Trees 18-29 in. dbh	Number of Trees >30 in. dbh
Number of trees per size class					
List of understory species					
Basal area					
Number of dead trees per plot					
Comments					

Source: Greenfeld, J.; Herson, L.; Karouna, N.; Bernstein, G. 1991. Forest conservation manual: guidance for the conservation of Maryland's forests during land use changes, under the 1991 Forest Conservation Act. Washington, DC: Metropolitan Washington Council of Governments. Table D-1, p. D-4.

Explanation of Terms

Forest Stand Information

Stand # – divide the vegetative cover into different stands depending on species groups, size groups, cover types, etc.

Acres – measure the acreage in each separate stand and open areas. Round off to the nearest 1/20 acre.

Species – list the four or five most common, dominant and co-dominant species tallied.

Size class – use the following size classes: 2-6 in. dbh, 7-10 in. dbh, 11-17 in. dbh, 18-29 in. dbh, and greater than 30 in. dbh.

Basal area – this is a density measurement and should be expressed on a per acre basis for each stand.

Number of Trees – count all trees 2 in. dbh or greater occurring on the plot.

Number of Tree Species – count the total number of tree species occurring on the plot.

Number of Dead Trees – count the total number of dead trees occurring on the plot.

Understory Species – record the 3 to 5 most commonly occurring understory species on the plot.

Forest Cover Type – use the Society of American Foresters classification, the Maryland Forest Association Species List, and the species tallied on site to determine this.

Forest Structure Data Sheet

Number of Understory Shrubs – count the total number of shrubs occurring on the plot.

Percent canopy closure – estimate the canopy closure using the method described.

Percent Understory Herbaceous Ground Cover – estimate the herbaceous ground cover using the method described.

Percent Down Woody Debris (greater than 2 inches in diameter) – estimate the amount of dead and down woody debris on the ground using the method described.

Source: Greenfeld, J.; Herson, L.; Karouna, N.; Bernstein, G. 1991. Forest conservation manual: guidance for the conservation of Maryland's forests during land use changes, under the 1991 Forest Conservation Act. Washington, DC: Metropolitan Washington Council of Governments. Table D-2, p. D-5.

Techniques for Forest Structure Data Collection

To measure canopy coverage, herbaceous coverage, dead and downed woody debris, material present and exotic species, it will be necessary to sample in the following way:

1. Construct a sampling tube from a paper towel or toilet paper roll. Attach wires or string on one end of the tube in the configuration of a cross with four evenly spaced openings (see A below).

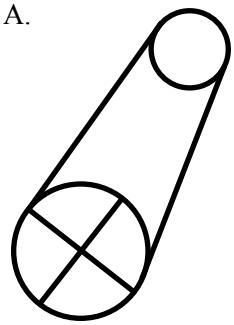
2. Select one random sampling point within each forest stand. To do this, construct a circular sampling plot of 1/10 acre. Take samples from four points around the circle and one within the circle (see B below).

3. Walk to each sample point and look through the sampling tube at each sample point.
   a. For canopy coverage, record "yes" or "no" for green seen through the tube when pointed up (tube must be held vertically; count only trees 7 in. dbh and larger).
   b. For herbaceous coverage, record "yes" or "no" for green seen through the tube when pointed down (tube must be held vertically).
   c. For dead and down woody material, record "yes" or "no" for any root wads, logs, downed limbs, or bark seen through the tube (tube must be held vertically).
   d. For exotic or invasive species, record "yes" or "no" for any of these species seen through the tube (tube must be held vertically).

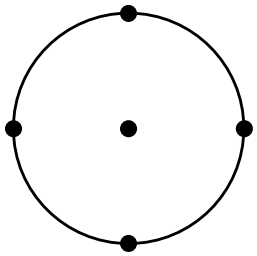
4. Calculate the percentage of sample points at each sample site which were answered by "yes." Use the above information and additional information provided in the forest stand summary sheet to calculate the forest structure value to be assigned to the site for each individual parameter.

5. Count number of shrubs found within a 1/100-acre plot. Shrubs can be most easily counted if the central stem can be identified.

A.



B.



Source: Greenfeld, J.; Herson, L.; Karouna, N.; Bernstein, G. 1991. Forest conservation manual: guidance for the conservation of Maryland's forests during land use changes, under the 1991 Forest Conservation Act. Washington, DC: Metropolitan Washington Council of Governments. Figure D-2, p. D-6.

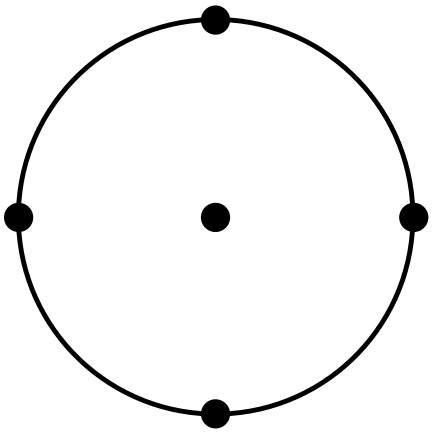
Forest Structure Data Sheet

Property: *Prepared by:*
Stand#: *Plot #:* *Date:*

Forest Structure Variable	Sample point 1	Sample point 2	Sample point 3	Sample point 4	Sample point 5	% yes
Canopy coverage						
Herbaceous ground cover						
Downed woody debris						
Invasive plant cover						
Number of shrub species (1/100 acre)						

Forest Structure Sampling Method:

1/10-acre plot,
5 sample points



Source: Greenfeld, J.; Herson, L.; Karouna, N.; Bernstein, G. 1991. Forest conservation manual: guidance for the conservation of Maryland's forests during land use changes, under the 1991 Forest Conservation Act. Washington, DC: Metropolitan Washington Council of Governments. Table D-3, p. D-7.

Forest Structure Analysis

The following parameters will be measured and evaluated at each site according to the Techniques for Forest Structure Data Collection. Each parameter at each sample site will be given a value of 3, 2, 1, or 0; 3 represents the most valuable structure and 0 the least valuable. Upon completion of the sampling, the person preparing the forest stand delineation will calculate the forest structure value for each stand. This analysis along with the other forest stand data will be used to determine the retention potential of the stand.

To determine the total habitat value use the following scale:

Range of total habitat numbers from samples taken April – October:

15-21	Priority forest structure
7-14	Good forest structure
0-6	Poor forest structure

In the winter and late fall, from November – March, only numbers 1, 3, 4, 5, 7 can be measured. During that time, the range of total habitat numbers will be:

11 – 15	Priority forest structure
6 – 10	Good forest structure
0 – 5	Poor forest structure

1. Percent Canopy Closure of trees with a dbh greater than 7 inches	
70% - 100%	3
40% - 69%	2
10% - 39%	1
0% - 9%	0

2. Number of Understory Shrubs per 1/100 acre	
6 or more	3
4 - 5	2
2 - 4	1
0 - 1	0

3. Number of Dead Trees per 1/10-acre plot	
3 or more	3
2	2
1	1
0	0

4. Percent of Dead and Downed Woody Material Present	
15% - 100%	3
5 in. – 14 in.	2
0-1	1
0	0

5. Size Class of Dominant Trees	
Greater than 20 inches	3
7 in. - 19.9 in.	2
3 in. - 6.9 in.	1
Less than 3 in.	0

6. Percent of Understory Herbaceous Coverage	
75% - 100%	3
25% - 74%	2
5% - 24%	1
0% - 4%	0

7. Number of Tree Species with a dbh greater than 7 in. per plot	
6 or more	3
4 - 5	2
2 - 4	1
0 - 1	0

Source: Greenfeld, J.; Herson, L.; Karouna, N.; Bernstein, G. 1991. Forest conservation manual: guidance for the conservation of Maryland's forests during land use changes, under the 1991 Forest Conservation Act. Washington, DC: Metropolitan Washington Council of Governments. Figure D-3, p. D-8.

Forest Stand Summary Sheet

Property Name: *Prepared by:*
Date:

Stand Variable	Stand # Acreage	Stand # Acreage
Forest Association (SAF cover type)		
Size class of dominant trees		
Number of trees/acre		
Number of tree species/plot		
Basal area		
Number of dead trees/acre		
List of common understory species		
Number of shrubs 1/100 acre plot		
Percent canopy coverage		
Percent herbaceous cover		
Percent downed woody material		
Percent exotic or invasive species		
Forest Structure Value		
Comments		

Source: Greenfeld, J.; Herson, L.; Karouna, N.; Bernstein, G. 1991. Forest conservation manual: guidance for the conservation of Maryland's forests during land use changes, under the 1991 Forest Conservation Act. Washington, DC: Metropolitan Washington Council of Governments. Table D-4, p. D-9.

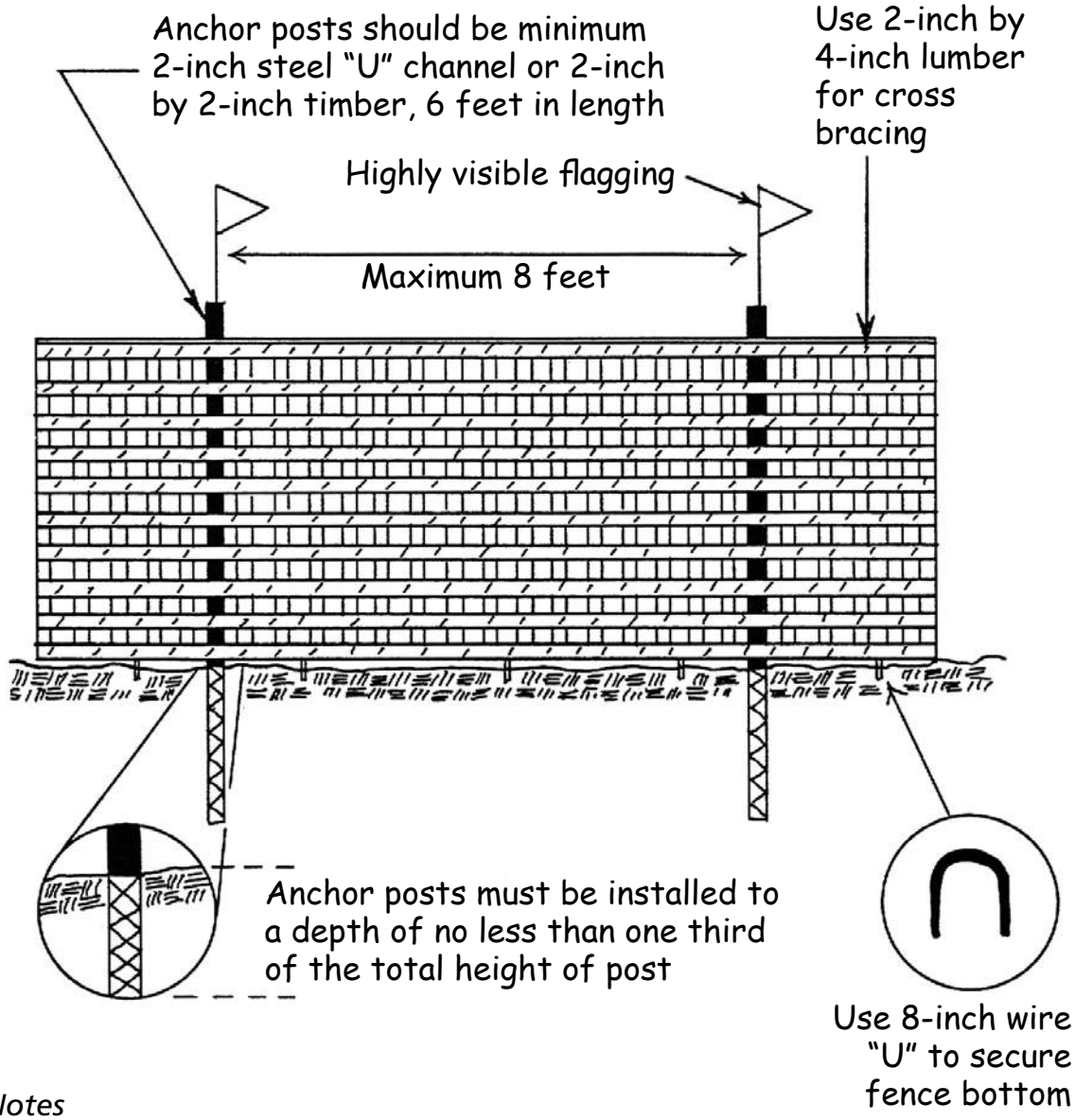
Appendix B. Tree Protection Specifications

This appendix contains specifications for the following tree protection techniques, for use during construction:

- Blaze orange plastic mesh
- Three strand barbed wire
- Snow fence
- Signage
- Filter cloth on wire mesh
- Staked straw bale dike
- Earthen dike and swale.

These specifications were originally published in Darr (1991) and were redrawn and/or adapted from Appendix J in the Maryland Forest Conservation Manual (Greenfeld and others, 1991). These techniques and specifications can be used outside Maryland. See the Maryland manual for more information on using these techniques.

Blaze Orange Plastic Mesh

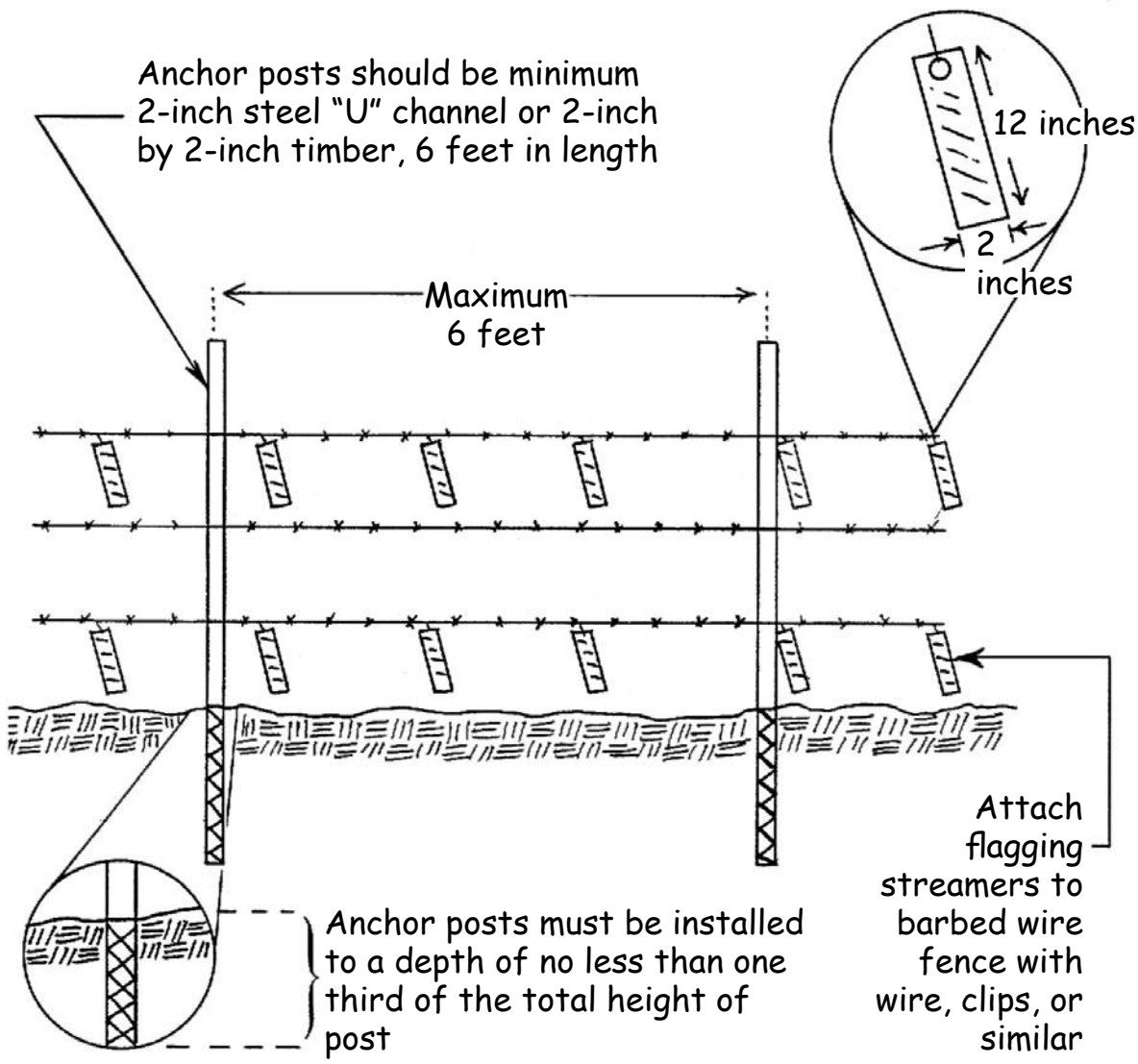


Notes

1. Forest protection device only.
2. Retention Area will be set as part of the review process.
3. Boundaries of Retention Area should be staked and flagged prior to installing device.
4. Root damage should be avoided.
5. Protective signage may also be used.
6. Device should be maintained throughout construction.

Source: Greenfeld, J.; Herson, L.; Karouna, N.; Bernstein, G. 1991. Forest conservation manual: guidance for the conservation of Maryland's forests during land use changes, under the 1991 Forest Conservation Act. Washington, DC: Metropolitan Washington Council of Governments. Figure J-4, p. J-6.

Three Strand Barbed Wire

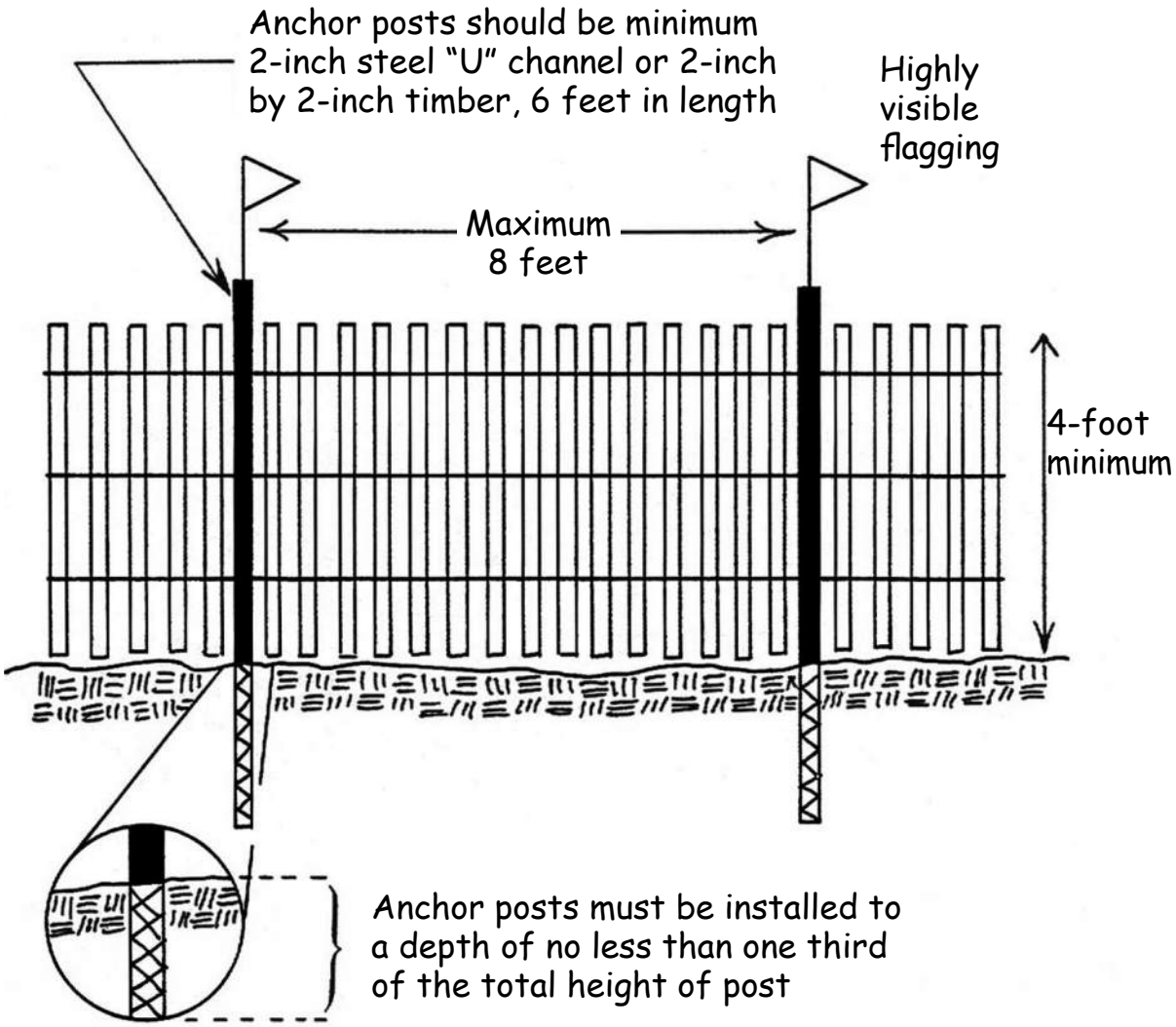


Notes

1. Forest protection device only.
2. Retention Area will be set as part of the review process.
3. Boundaries of Retention Area should be staked and flagged prior to installing device.
4. Avoid root damage when placing anchor posts.
5. Barbed wire should be securely attached to posts.
6. Device should be properly maintained during construction.
7. Protective signage is also recommended.

Source: Greenfeld, J.; Herson, L.; Karouna, N.; Bernstein, G. 1991. Forest conservation manual: guidance for the conservation of Maryland's forests during land use changes, under the 1991 Forest Conservation Act. Washington, DC: Metropolitan Washington Council of Governments. Figure J-5, p. J-7.

Snow Fence



Notes

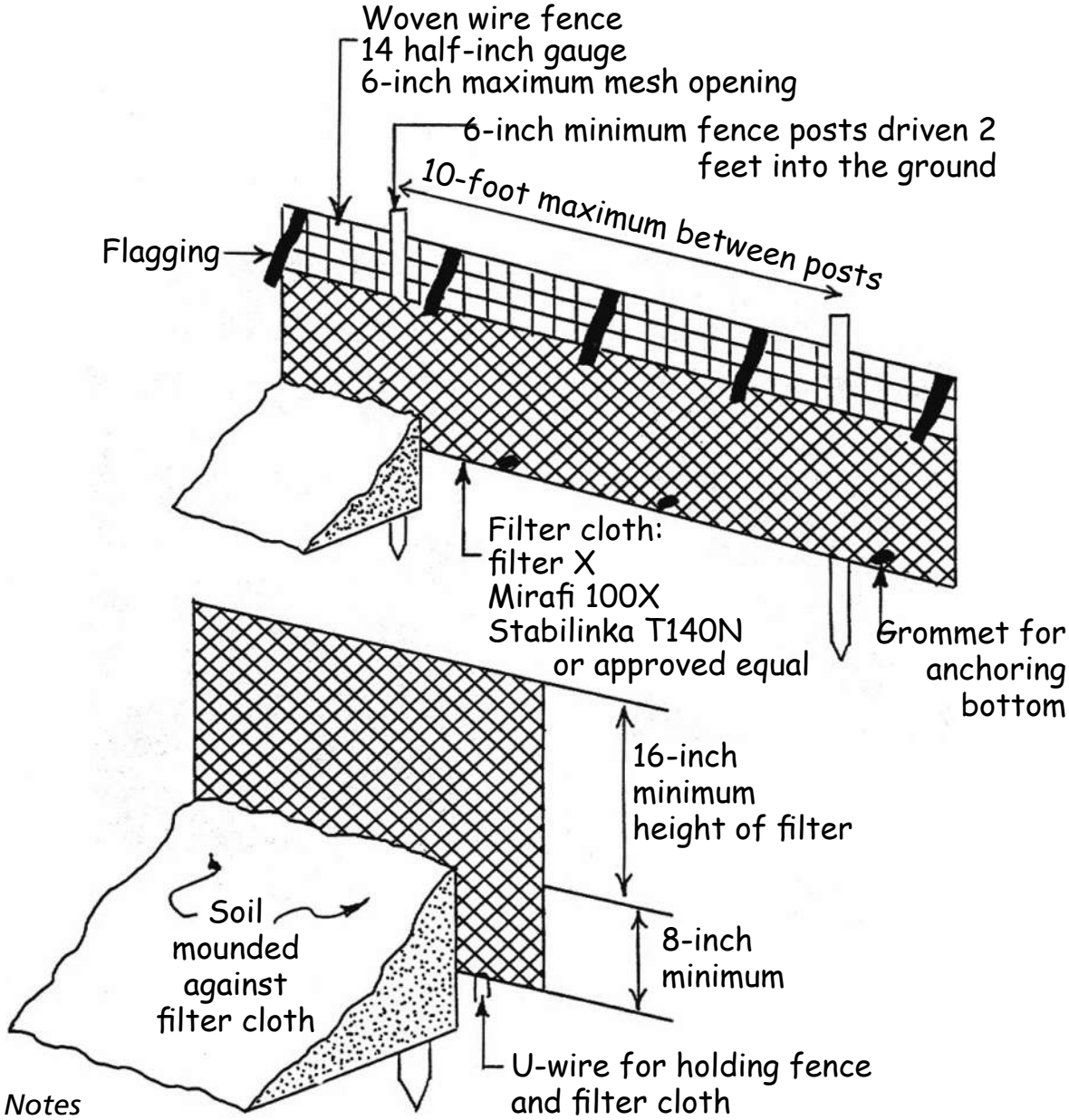
1. Forest protection device only.
2. Retention Area will be set as part of the review process.
3. Boundaries of Retention Area should be staked prior to installing protective device.
4. Avoid root damage when placing anchor posts.
5. Device should be properly maintained during construction.
6. Protective signage is also recommended.

Source: Greenfeld, J.; Herson, L.; Karouna, N.; Bernstein, G. 1991. Forest conservation manual: guidance for the conservation of Maryland's forests during land use changes, under the 1991 Forest Conservation Act. Washington, DC: Metropolitan Washington Council of Governments. Figure J-6, p. J-8.

Signage

Source: Greenfeld, J.; Herson, L.; Karouna, N.; Bernstein, G. 1991. Forest conservation manual: guidance for the conservation of Maryland's forests during land use changes, under the 1991 Forest Conservation Act. Washington, DC: Metropolitan Washington Council of Governments. Figure J-7, p. J-9.

Filter Cloth on Wire Mesh

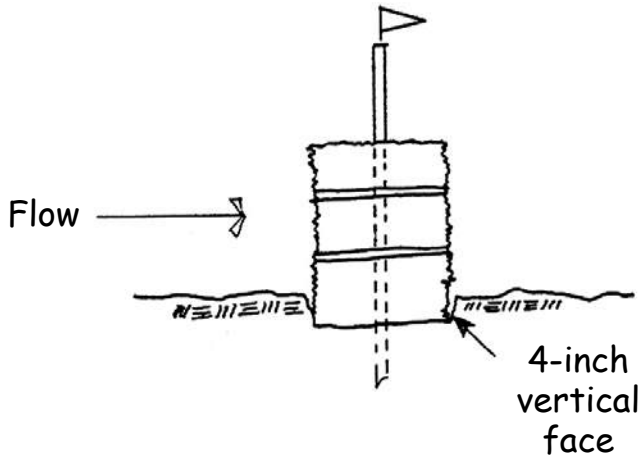


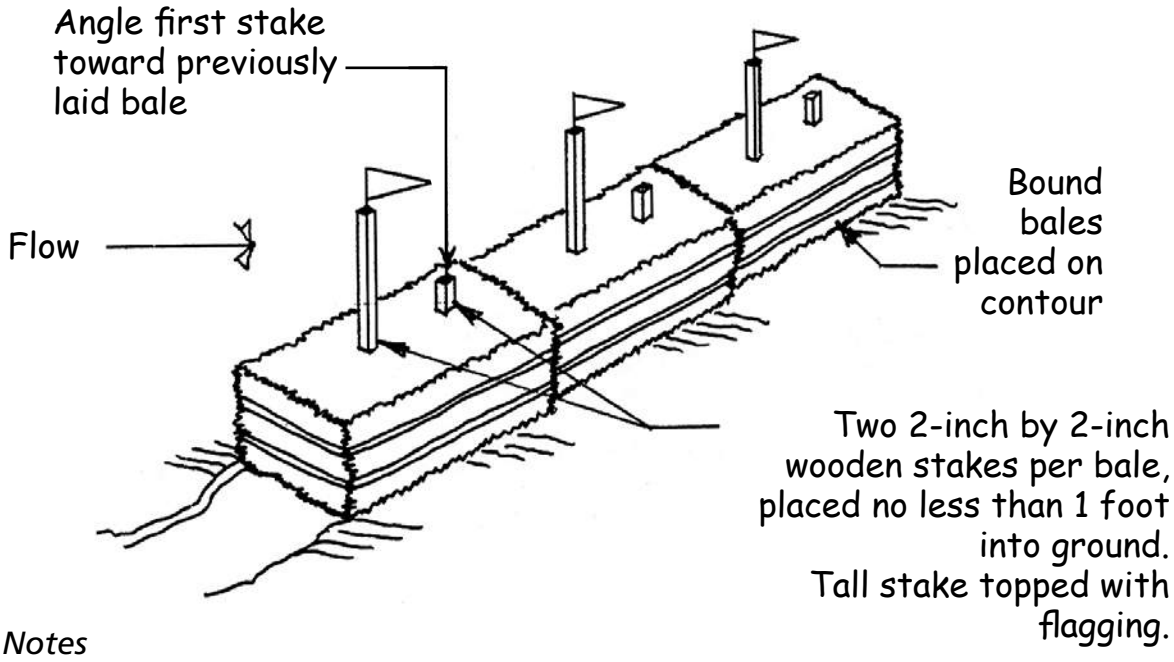
Notes

1. Combination sediment control and protective device.
2. Retention Area will be set as part of the review process.
3. Boundaries of Retention Area should be staked prior to installing protective device.
4. Root damage should be avoided.
5. Mound soil only within the limits of disturbance.
6. Protective signage is also recommended.
7. All standard maintenance for sediment control devices applies to these details.

Source: Greenfeld, J.; Herson, L.; Karouna, N.; Bernstein, G. 1991. Forest conservation manual: guidance for the conservation of Maryland's forests during land use changes, under the 1991 Forest Conservation Act. Washington, DC: Metropolitan Washington Council of Governments. Figure J-8, p. J-10.

Staked Straw Bale Dike



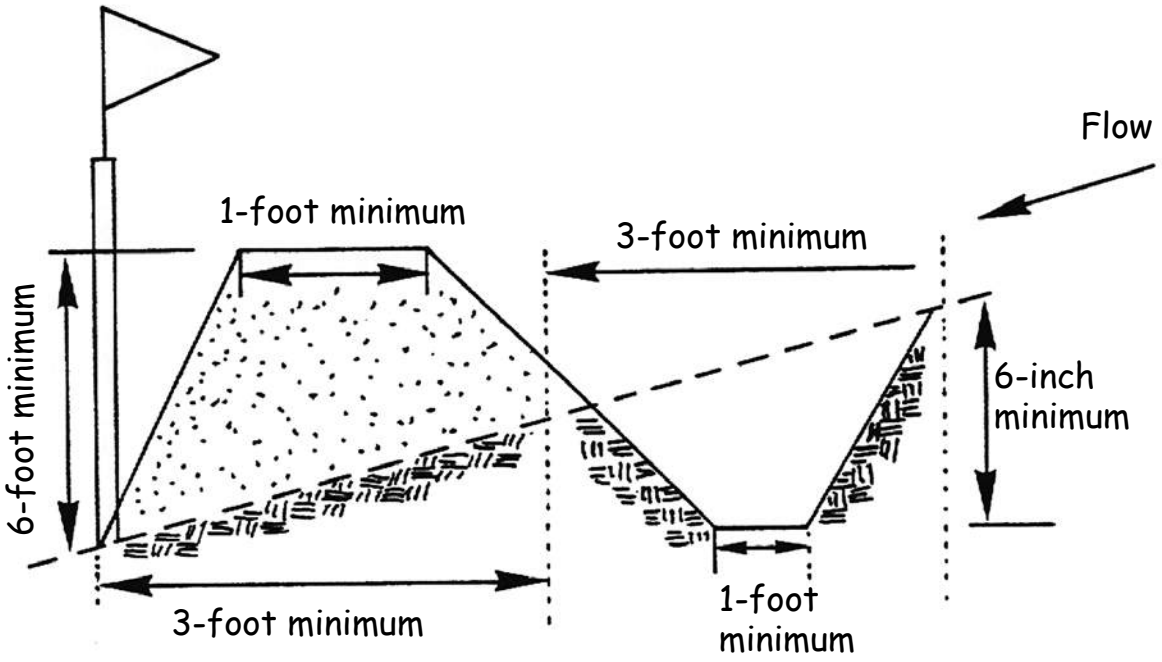


Notes

1. Combination sediment control and protective device.
2. Retention Area will be set as part of the review process.
3. Boundaries of Retention Area should be staked prior to installing protective device.
4. Root damage should be avoided.
5. This device should only be placed within the limit of disturbance.
6. Protective signage is also recommended.
7. All standard maintenance for sediment control devices applies to these details.

Source: Greenfeld, J.; Herson, L.; Karouna, N.; Bernstein, G. 1991. Forest conservation manual: guidance for the conservation of Maryland's forests during land use changes, under the 1991 Forest Conservation Act. Washington, DC: Metropolitan Washington Council of Governments. Figure J-9, p. J-11.

Earthen Dike and Swale



Notes

1. Combination sediment control and protective device.
2. Retention Area will be set as part of the review process.
3. Boundaries of Retention Area should be staked prior to installing protective device.
4. Root damage should be avoided.
5. The top or toe of slope should be within the limit of disutrbance.
6. Equipment is prohibited within critical root zone of retention area; place dike accordingly.
7. All standard maintenance for earthen dikes and swales applies to these details.
8. All standard reclamation practices for earthen dikes and swales shall apply to these details.

Source: Greenfeld, J.; Herson, L.; Karouna, N.; Bernstein, G. 1991. Forest conservation manual: guidance for the conservation of Maryland's forests during land use changes, under the 1991 Forest Conservation Act. Washington, DC: Metropolitan Washington Council of Governments. Figure J-10, p. J-12.

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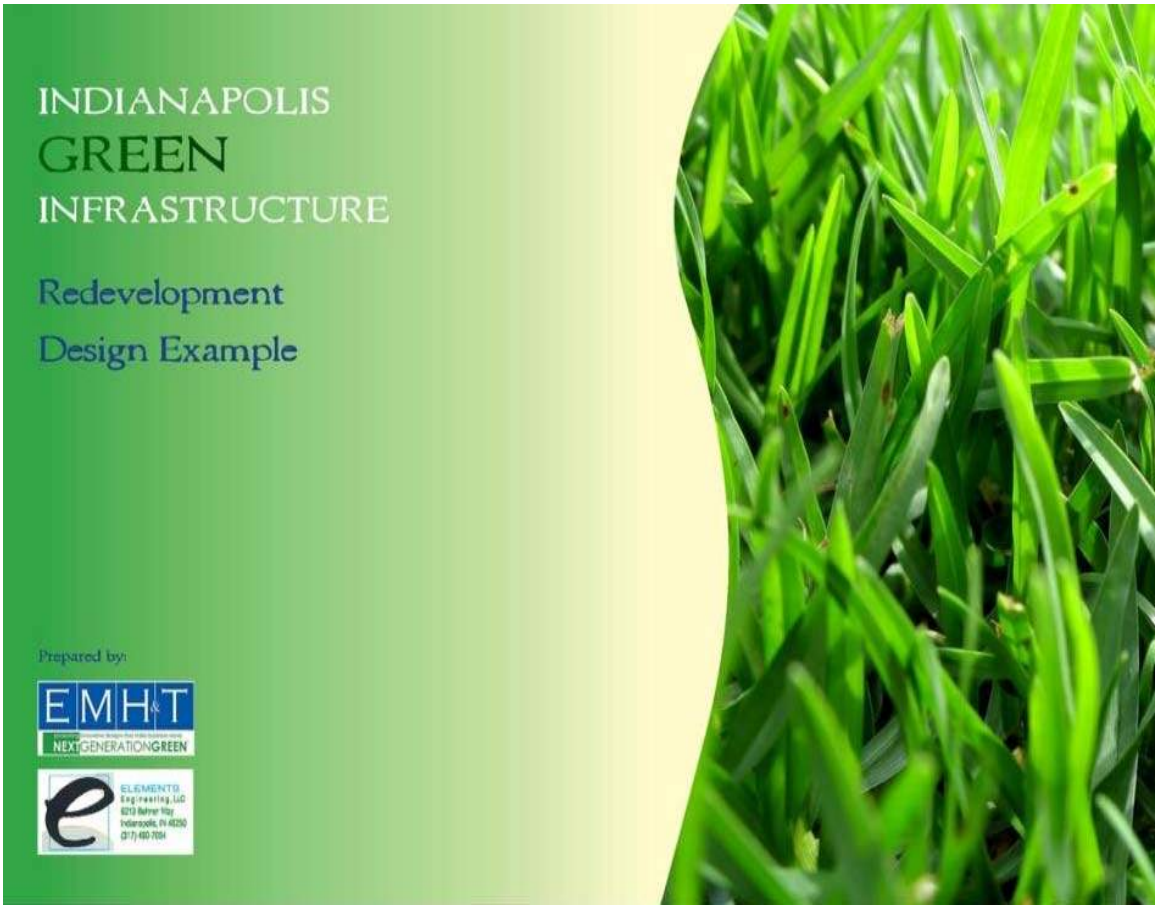


TABLE OF CONTENTS

1.0 Introduction..... 1

2.0 Design Conditions..... 1

3.0 Results……..... 2

TABLE 1 – Existing, Conventional and Green Integrated Site Comparison……..3

Integrated Green Design Condition Landscape Plan……4

Appendix A – Existing Conditions

Appendix B – Conventional Design Conditions

Appendix C – Green Integrated Design Conditions

1. INTRODUCTION

Elements Engineering, Inc. and Evans, Mechwart, Hambleton and Tilton Engineering (EMH&T) has completed a drainage analysis for the theoretical site located in the downtown urban environment of the City of Indianapolis, Marion County, Indiana. The intent of this design example is to provide a comparison of drainage between conventional design methods with those integrating green site and building components as related to stormwater runoff. The design team utilized an existing approximate 1-acre site for the drainage comparison of existing use, conventional and green design conditions.

The existing, conventional and green site designs were performed to meet the City of Indianapolis drainage standards for water quality volume and discharge allowances. Each site design also meets current City of Indianapolis zoning and landscaping requirements. For this exercise, offsite drainage facilities are found within the Combined Sewer system and are assumed to be readily available, such that all design techniques are to be evaluated only for onsite drainage improvements. It is assumed that the building footprints are identical for useable space and the parking provided is equivalent. The soil conditions are assumed to be type B with a water table that is 4' or greater below the surface. Costs for actual building construction is not being considered within the cost impact comparison, assuming similar conditions for both design alternatives.

2. DESIGN CONDITIONS

Existing Site:

The existing site is assumed to be completely developed, being utilized for warehousing and office activities. The existing site is considered to be almost completely impervious surface with a combination of building, parking and minimal landscaping or green space. For this re-development condition, it is assumed that the existing site will be completely demolished and no existing above ground features will remain.

Proposed Site:

A) CONVENTIONAL DESIGN

The conventional design will use a single-story commercial office building with impervious parking surfaces and minimal landscaping or lawn areas. Due to need to maximize above ground land use and in consideration of the value/cost of land, there is no recognized economically viable space for above ground detention. Typical site piping will direct storm runoff from the building roof, parking area, driveways and remaining site to an underground detention. An underground mechanical Post Construction water quality Best Management Practice (BMP) will

be used. BMPs of this type are typically vortex solids removal mechanical equipment.

B) GREEN INTEGRATED DESIGN

The green integrated design will use a two-story commercial office building with permeable pavement while maximizing the integration of Post Construction Water Quality BMPs into the landscaping. The two-story building will have the same leasable space as the conventional design alternative, but will provide a smaller building footprint upon the overall redevelopment site. The building layout and alignment will be such that the energy consumption for the building will be optimized. Primary green site features include unpaved green space, porous pavement and bioretention via rain gardens.

It should be noted that the exercise evaluated the use of a green roof technology for the Green Integrated Design option in order to evaluate the benefit-cost impacts for the site's storm runoff management. The green roof evaluated incorporated an average depth of 6" over 75% of the roof surface. The results indicate that for stormwater benefits only, the cost of the greenroof was not economically viable or needed to meet the current City of Indianapolis water management requirements. This result was directly related to the green integrated design efficiency in utilizing a smaller building footprint and subsequent green site space utilization. Essentially, the green space around the building was less expensive and very efficient in water quality and quantity management then green roof alternatives. Ironically, the green roof technology seems best suited for the conventional design condition (low percentage green space around building) as a hybrid site development technique. Further evaluation of this type of hybrid site development was outside the intent of this study and was not performed.

3. RESULTS

The comparison of the existing, conventional and integrated green site design is tabulated in Table 1, below. Of greatest interest are the values of observed Combined Sewer System. The existing and conventional site do not retain, store, infiltrate or appreciably reduce the peak runoff for the majority of the storm events. The existing and conventional site layouts and designs provide a continual discharge rate up to 2.1 cubic feet per second (cfs) until all water is drained into the Combined Sewer system.

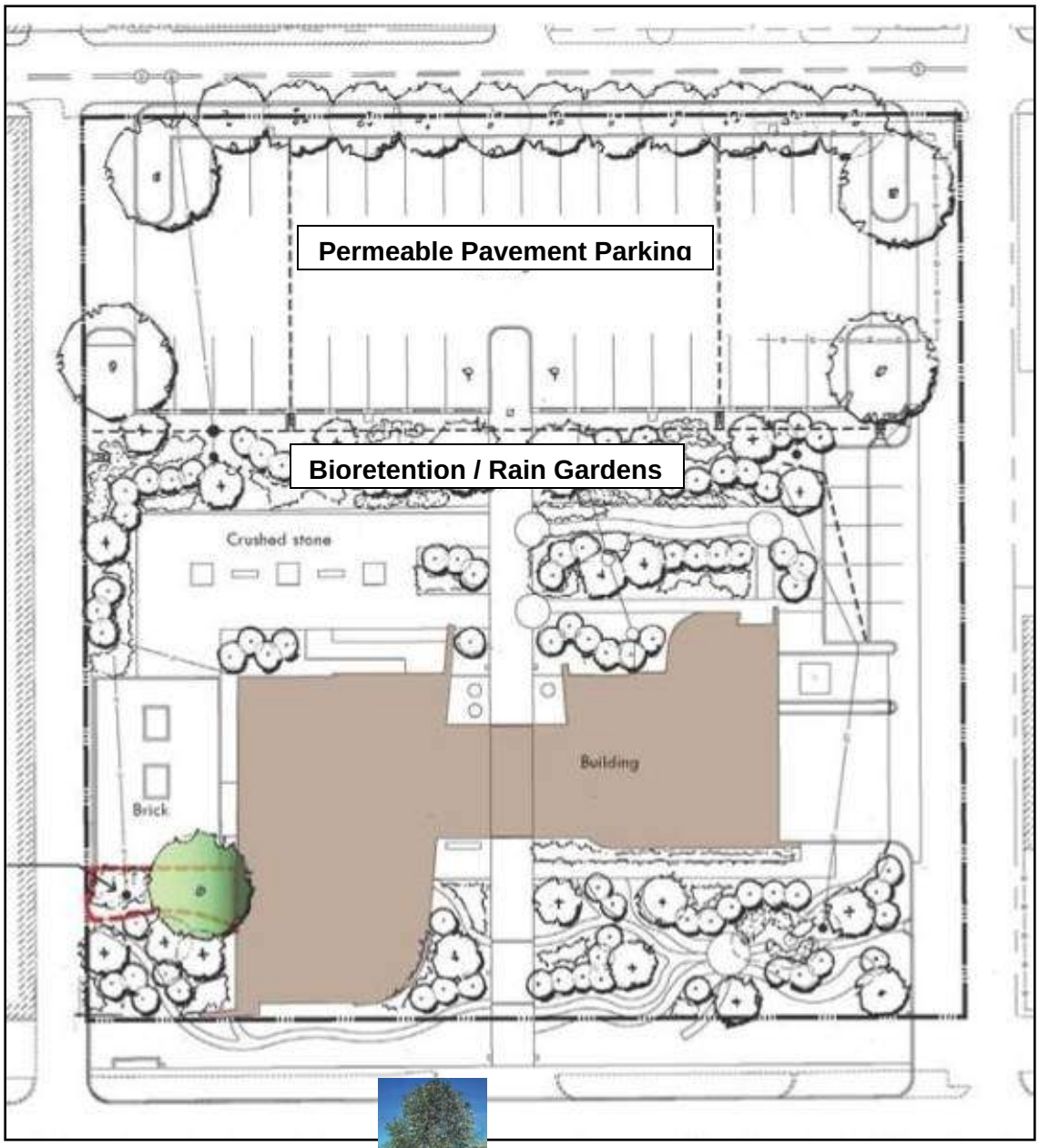
The Green Integrated site design stores, treats and/or delays the storm runoff prior to discharge to the Combined Sewer system. The distributed storage of the bioretention (rain gardens) provides a positive removal volume from the combined sewer system. The temporary storage and conveyance of stormwater runoff through the porous paved parking areas in combination with the use of green space for breaking up impervious

area runoff significantly reduces the discharge rate of the site's runoff (1.1 cfs) as compared to the conventional site design.

Given the capital cost of combined sewer peak flow storage and the annual cost for transporting and treating all captured Combined Sewer flow, the green integrated site design has the potential to provide direct economic benefit to the City of Indianapolis. The green integrated design also provides direct environmental benefit to the water quality of the streams and/or rivers due to the treated volume that can be removed from the combined sewer system by infiltration and/or evapotranspiration. Additional potential benefits through the use of stormwater re-direction out of the combined sewer system were not evaluated for this exercise. However, it can be directly implied that for every gallon removed and treated from the combined sewer system, a direct economic and environmental benefit can be observed.

TABLE 1 - Existing, Conventional and Green Integrated Site Design Comparison			
	Existing Site	**Conventional**	**Green Integrated**
Total Site (sq. ft.)	42,889		
Impervious (sq. ft.)	41,901	38,177	23,615
Pervious (sq. ft.)	988	4,712	19,274
% Green (pervious) Space	2%	11%	45%
Average Curve Number	97.1	93.9	77.7
Cost ($)/ Sq. Ft.	n/a	$ 3.03	$ 3.86
Discharge Rate (cfs)	2.11	2.10	1.10
Volume of Stormwater Removed from Combined Sewer System*			
1" Storm (gal.)	0	0	26,703
Annual Total (gal)	0	0	650,000
Potential Combined Sewer Cost Savings (per Acre)			
Annual Operation	$0	$0	$6,500
CSO Storage Reduction**	$0	$0	$18,692
*estimated from Indianapolis Rain Data, 2001-2005			
**estimated 20% total volume reduction for peak detention			

Green Integrated Design Condition
Landscape Plan



1. River Birch

6. Iris species

4. Hibiscus species

2. Willow species

5. Lily varieties

2. Vardar Valley Boxwood

6. Purple Coneflower

4. Golden Vicary Privet

7. Golden Queen Globeflower

5. Kelsey Dogwood

3. Knockout Rose

1. Knockout Rose (yellow variety)

APPENDICES

APPENDIX A – Existing Conditions

- Site Plan Drainage
- Model Output

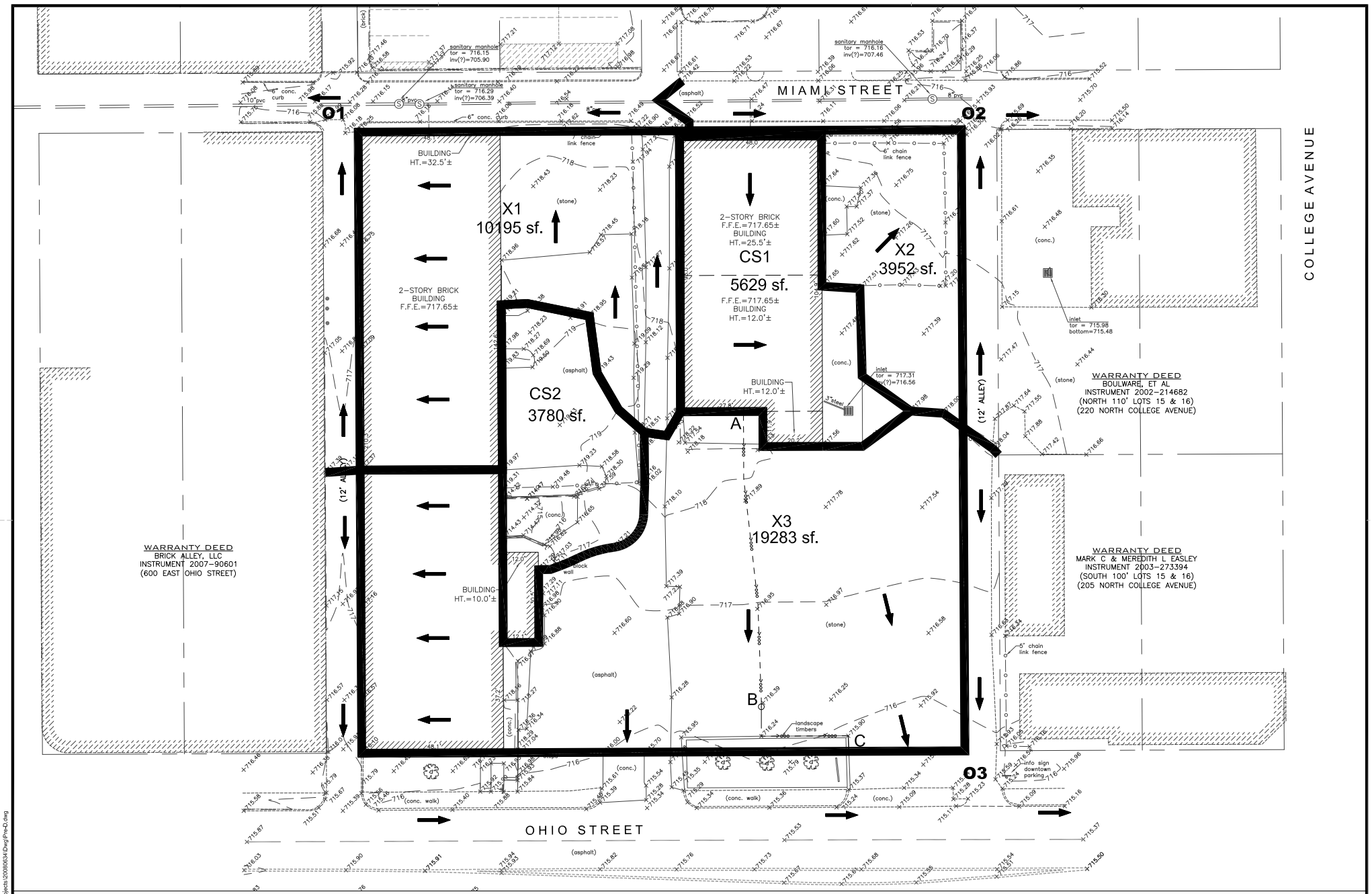
APPENDIX B – Conventional Design Conditions

- Site Plan Drainage
- Typical Landscape Design
- Model Output

APPENDIX C – Green Integrated Design Conditions

- Typical Cupped Landscape Design
- Without Green Roof
  - Site Plan Drainage
  - Model Output
- With Green Roof
  - Site Plan Drainage
  - Model Output

Appendix A
Existing Conditions



PREPARED BY:

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Engineers • Surveyors • Planners • Scientists
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M C M X X V I

LEGEND

ROOF	15,157 sf.
PAVEMENT	9,673 sf.
STONE	17,021 sf.
PERVIOUS	988 sf.
TOTAL PROJECT AREA	42,839 sf

PROJECT:

Green Design Example - Commercial Office Site
Indianapolis, Marion County Indiana

PRE-DEVELOPED EXISTING DRAINAGE CONDITIONS

EMH&T JOB NO. 2008-0237

DATE: 06-11-2008

SCALE: 1" = 20'

SHEET No. **X2**

Jul 13, 2009 - 4:00pm - Q:\Project_2008\Projects\20080934\Dwg\Pre-D.dwg

Existing Conditions - Land Use

EXISTING CONDITION			
Surface	Area	CN	C
Roof	15157	98	0.90
Pavement	9673	98	0.85
Stone	17021	98	0.85
Pervious	988	61	0.25
Total =	**42839**	**97.1**	**0.85**

X1			
Surface	Area	CN	C
Roof	5488	98	0.90
Pavement	2138	98	0.85
Stone	2569	98	0.85
Pervious	0	61	0.25
Total =	**10195**	**98.0**	**0.88**

X2			
Surface	Area	CN	C
Roof	0	98	0.90
Pavement	165	98	0.85
Stone	3787	98	0.85
Pervious	0	61	0.25
Total =	**3952**	**98.0**	**0.85**

CS1			
Surface	Area	CN	C
Roof	4706	98	0.90
Pavement	729	98	0.85
Stone	194	98	0.85
Pervious	0	61	0.25
Total =	**5629**	**98.0**	**0.89**

X3			
Surface	Area	CN	C
Roof	4597	98	0.90
Pavement	3788	98	0.85
Stone	10420	98	0.85
Pervious	478	61	0.25
Total =	**19283**	**97.1**	**0.85**

CS2			
Surface	Area	CN	C
Roof	366	98	0.90
Pavement	2853	98	0.85
Stone	51	98	0.85
Pervious	510	61	0.25
Total =	**3780**	**93.0**	**0.77**

EXISTING CONDITION			
Surface	Area	CN	C
Roof	15157	98	0.90
Pavement	9673	98	0.85
Stone	17021	98	0.85
Pervious	988	61	0.25
Total =	**42839**	**97.1**	**0.85**

Existing Conditions - Peak Release

X1			
Event	2-year	10-year	100-year
30	**0.67**	**1.17**	1.70
1	0.47	0.79	1.19
2	0.31	0.52	0.78
3	0.24	0.39	0.59
6	0.14	0.24	0.34

X2			
Event	2-year	10-year	100-year
30	**0.26**	**0.45**	0.66
1	0.18	0.30	0.46
2	0.12	0.20	0.30
3	0.09	0.15	0.23
6	0.06	0.09	0.13

CS1			
Event	2-year	10-year	100-year
30	**0.37**	**0.65**	0.94
1	0.26	0.43	0.66
2	0.17	0.29	0.43
3	0.13	0.22	0.32
6	0.08	0.13	0.19

X3			
Event	2-year	10-year	100-year
30	**1.15**	**2.08**	3.09
1	0.80	1.40	2.18
2	0.54	0.93	1.43
3	0.41	0.71	1.08
6	0.26	0.43	0.64

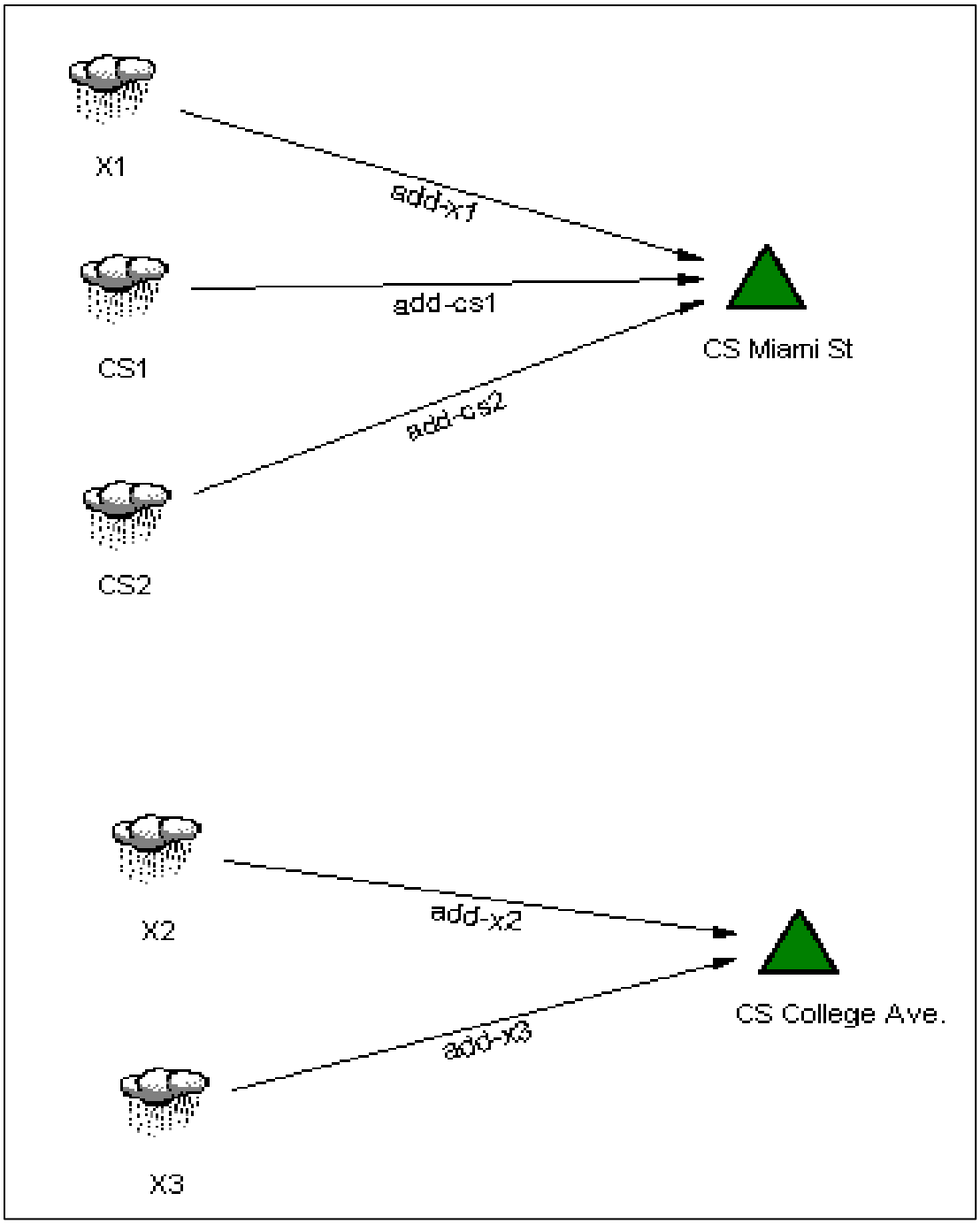
CS2			
Event	2-year	10-year	100-year
30	**0.14**	**0.30**	0.50
1	0.11	0.22	0.36
2	0.08	0.14	0.24
3	0.06	0.11	0.19
6	0.04	0.07	0.11

CS - Miami Street			
30	2-year	10-year	100-year
1	**1.18**	**2.11**	3.13
2	0.82	1.42	2.20
3	0.55	0.95	1.44
6	0.42	0.72	1.09
Total =	0.26	0.44	0.65

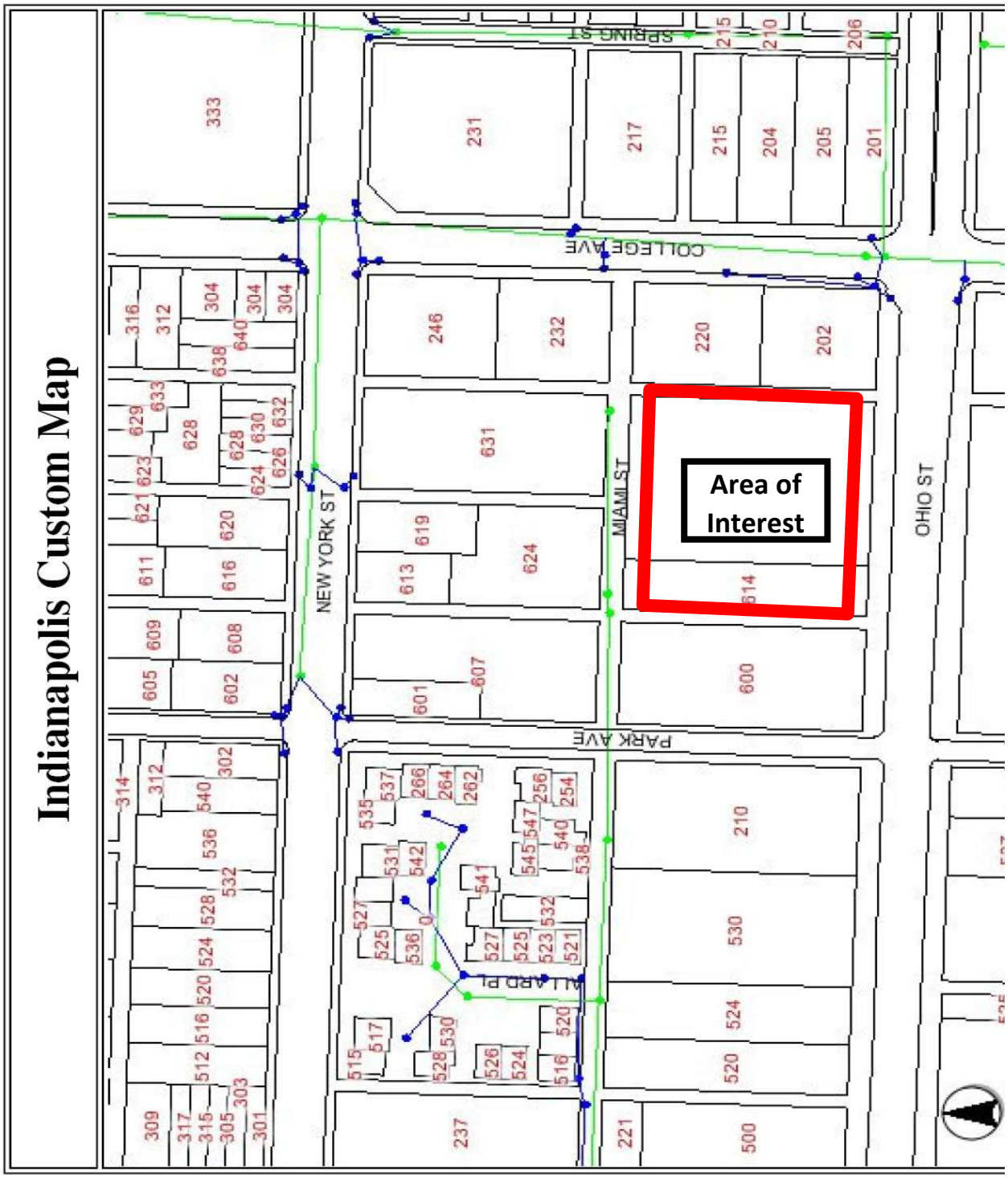
CS - College Avenue			
30	2-year	10-year	100-year
1	**1.41**	**2.53**	3.74
2	0.98	1.70	2.64
3	0.66	1.13	1.73
6	0.51	0.86	1.31
Total =	0.31	0.52	0.77

	CS Miami	**CS College**
Post-D 0-10-year Allowable Release	**1.18**	**1.41**
Post-D 11-100-year Allowable Release	**2.11**	**2.53**

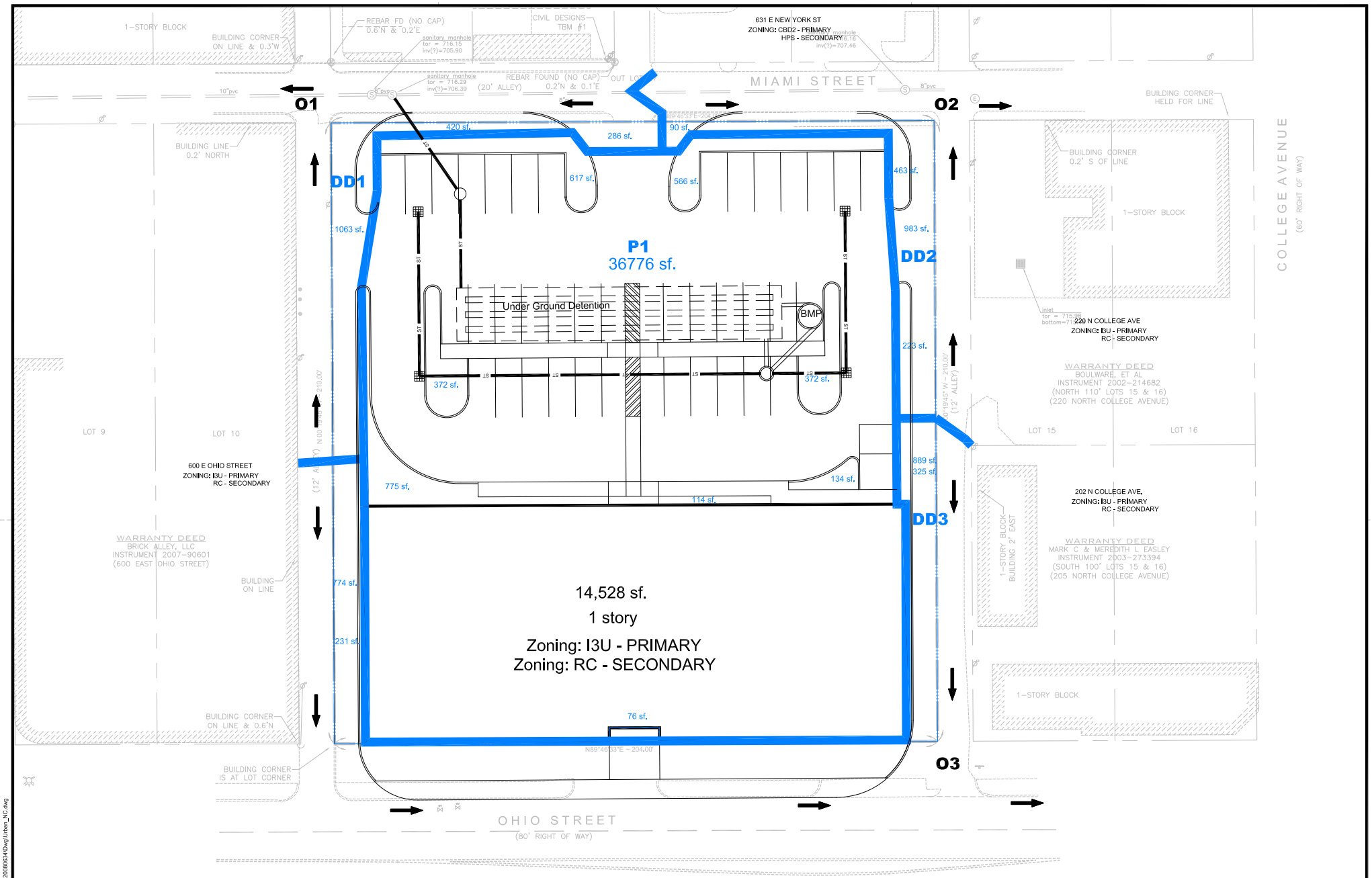
Existing Conditions - Model Diagram



Existing Conditions - Area of Interest Map



Appendix B
Conventional Design Conditions



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M C M X X V I

PROJECT:

Green Design Example - Commercial Office Site
Indianapolis, Marion County Indiana

POST-DEVELOPED CONVENTIONAL DRAINAGE CONDITIONS

EMH&T JOB NO. 2008-0237

DATE: 06-11-2008

SCALE: 1" = 20'

SHEET No. C1

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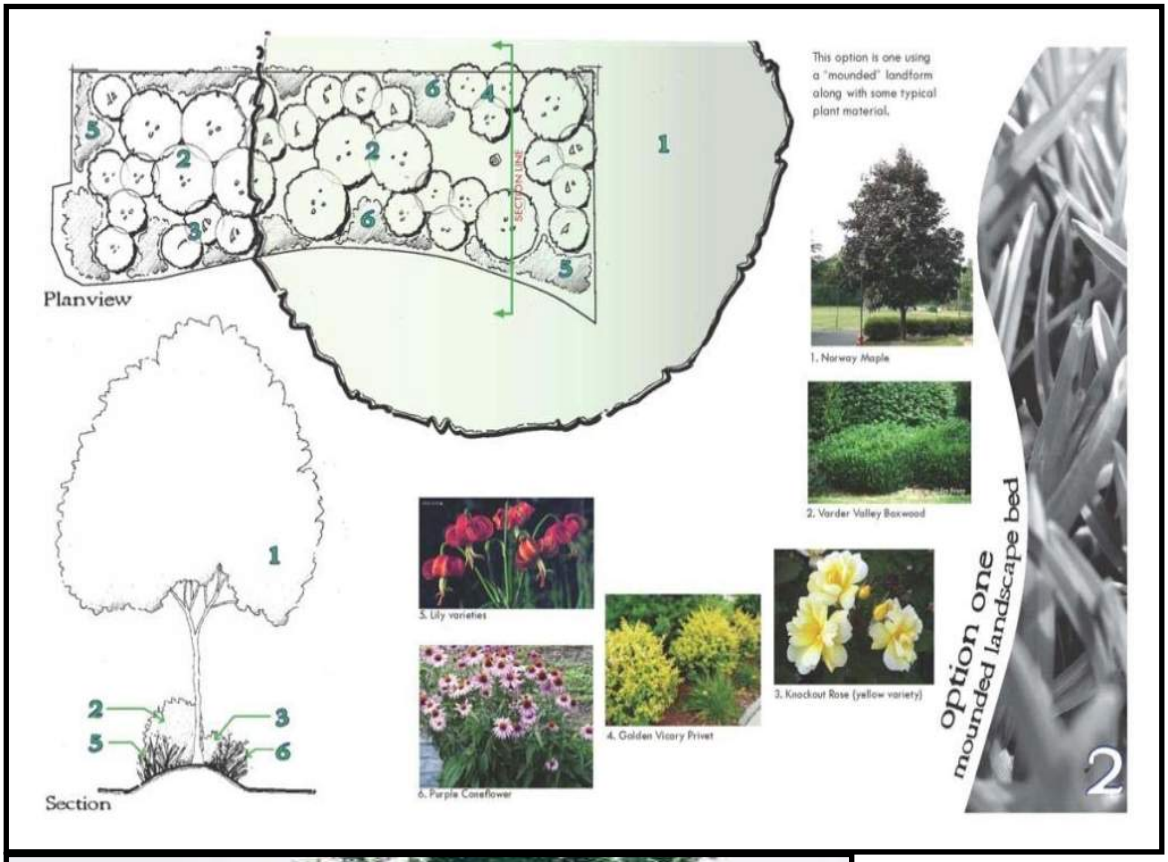
Conventional Site Design Condition
Mounding Landscape Design Typical



Conventional Conditions - Land Use

CONVENTIONAL CONDITIONS

Surface	Area	CN	C
Roof	14604	98	0.90
Pavement	23523	98	0.85
Pervious	4712	61	0.25
Total =	**42839**	**93.9**	**0.80**

COMPARISON

Condition	CN	c
Existing	97.1	0.85
Conventional	93.9	0.80

reduction due to Landscape Requirements

CN % Reduction	C % Reduction
3.31	6.18

P1

Surface	Area	CN	C
Roof	14604	98	0.90
Pavement	19222	98	0.85
Pervious	2950	61	0.25
Total =	**36776**	**95.0**	**0.82**

DD1

Surface	Area	CN	C
Roof	0	0	0.00
Pavement	1407	98	0.85
Pervious	520	61	0.25
Total =	**1927**	**88.0**	**0.69**

DD2

Surface	Area	CN	C
Roof	0	0	0.00
Pavement	1173	98	0.85
Pervious	686	61	0.25
Total =	**1859**	**84.3**	**0.63**

DD3

Surface	Area	CN	C
Roof	0	0	0.00
Pavement	1721	98	0.85
Pervious	556	61	0.25
Total =	**2277**	**89.0**	**0.70**

Conventional Conditions - Peak Release

P1			
Event	2-year	10-year	100-year
30		1.14	2.01
1		1.09	1.97
2		0.99	1.75
3		0.89	1.49
6		0.66	0.95
		0.43	0.62

DD2			
Event	2-year	10-year	100-year
30		0.07	0.15
1		0.06	0.12
2		0.05	0.09
3		0.04	0.07
6		0.02	0.04

DD1			
Event	2-year	10-year	100-year
30		0.10	0.19
1		0.08	0.15
2		0.06	0.10
3		0.04	0.08
6		0.03	0.05

DD3			
Event	2-year	10-year	100-year
30		0.13	0.24
1		0.10	0.19
2		0.07	0.12
3		0.05	0.09
6		0.04	0.06

CS - Miami Street			
Event	**2-year**	**10-year**	**100-year**
30		**1.18**	**2.10**
1		1.14	2.06
2		1.03	1.83
3		0.93	1.56
6		0.69	0.99
Total =		0.44	0.64

Hydrograph addition

CS Miami - Allowable	**1.18**	**2.11**

CS - College Avenue			
Event	**2-year**	**10-year**	**100-year**
30		**0.21**	**0.39**
1		0.17	0.31
2		0.12	0.21
3		0.09	0.16
6		0.06	0.10
Total =		0.04	0.06

Hydrograph addition

CS College - Allowable	**1.41**	**2.53**

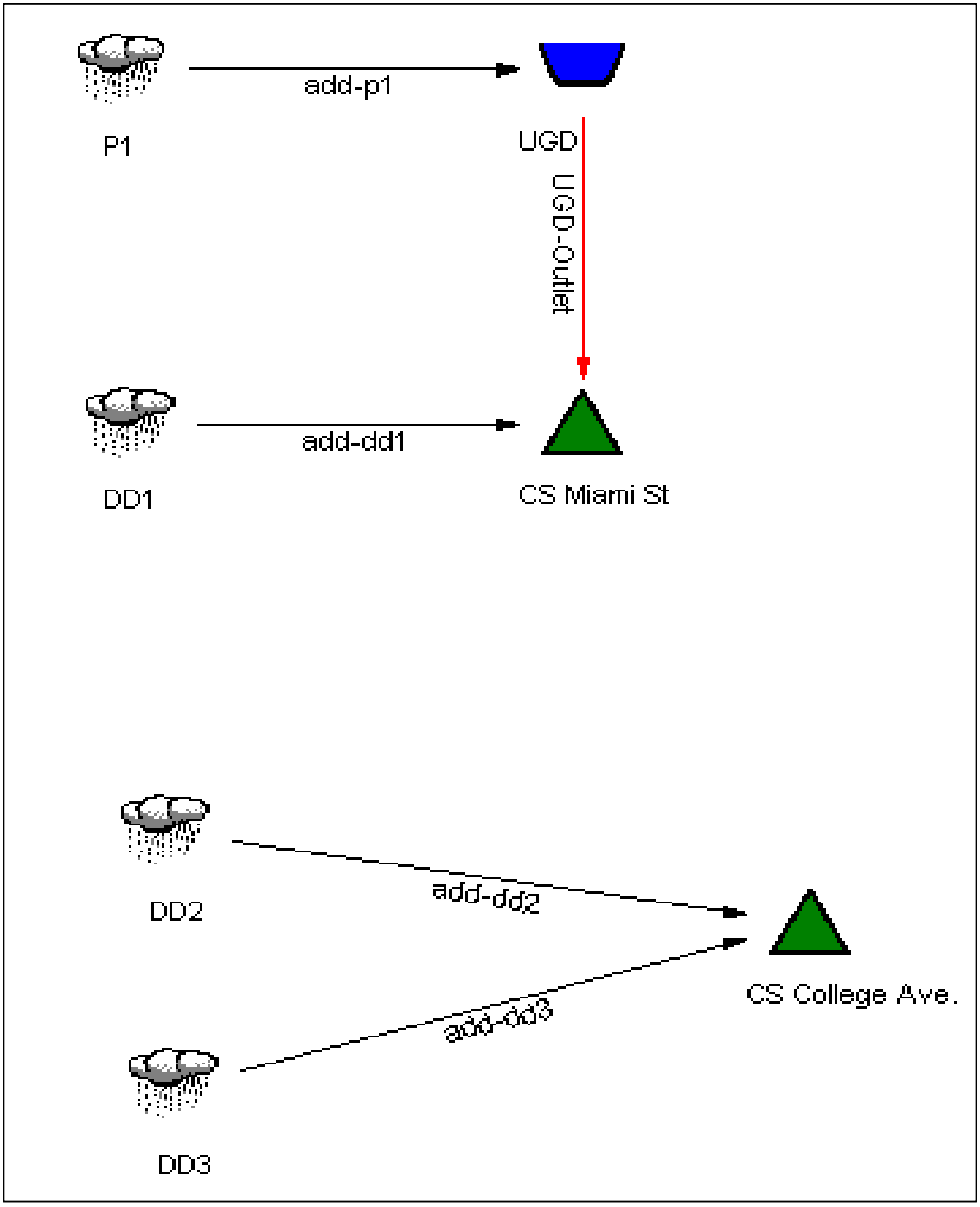
Under Ground Detention System			
P1 to CS Miami Street			
Event	**cfs**	**stage**	**volume**
10-year	**1.14**	**801.70**	**1951**
100-year	**2.08**	**802.65**	**2986**

4 x 36" Barrels x 110 feet in length **3110-cft**

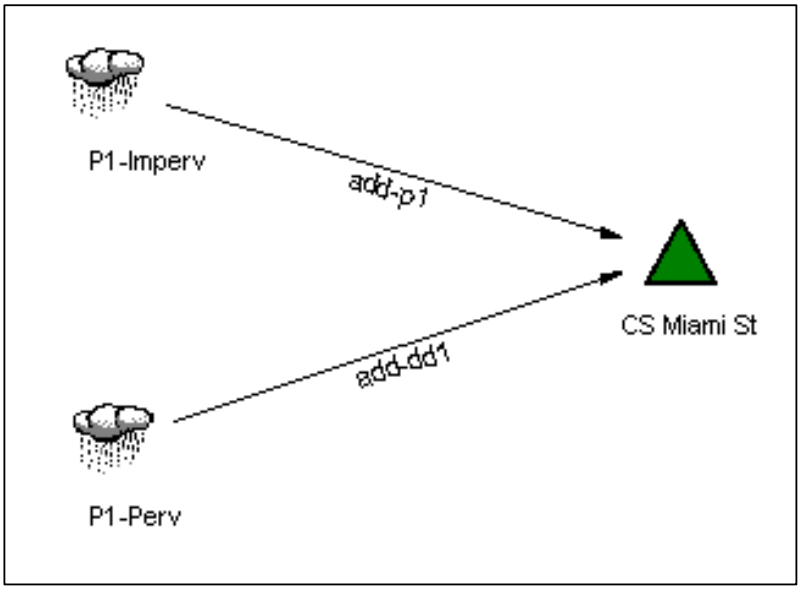
Outlet: **1 x 6" dia. Orifice**
1 x 5" dia.Orifice
1 x 12" dia. Conduit

Water Quality Treatment Unit		
Event	**cfs**	**Aqua-Swirl**
huff 1 Qrt.	**1.47**	**AS-6**

Conventional Design Conditions - DRAINAGE SCHEMATIC



Conventional Design Conditions - DRAINAGE SCHEMATIC - Water Quality



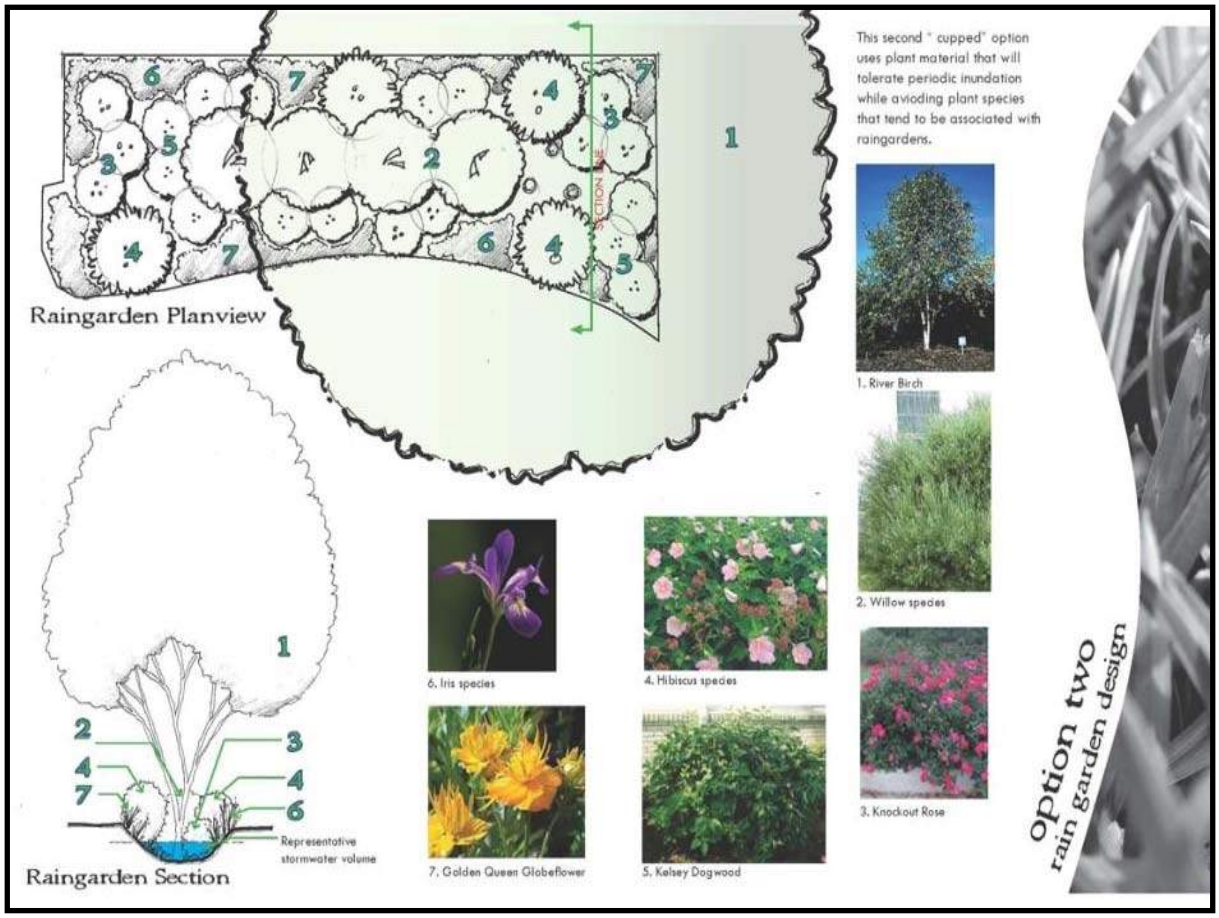
Water Quality Treatment Unit		
Event	cfs	Aqua-Swirl
huff 1 Qrt.	1.47	AS-6

Aqua-Swirl™ 2	AS-2	0.29
	AS-3	0.50
	AS-4	0.75
	AS-5	1.20
	AS-6	1.70
	AS-7	2.30
	AS-8	3.00
	AS-9	3.80
	AS-10	4.70
	AS-12	6.80

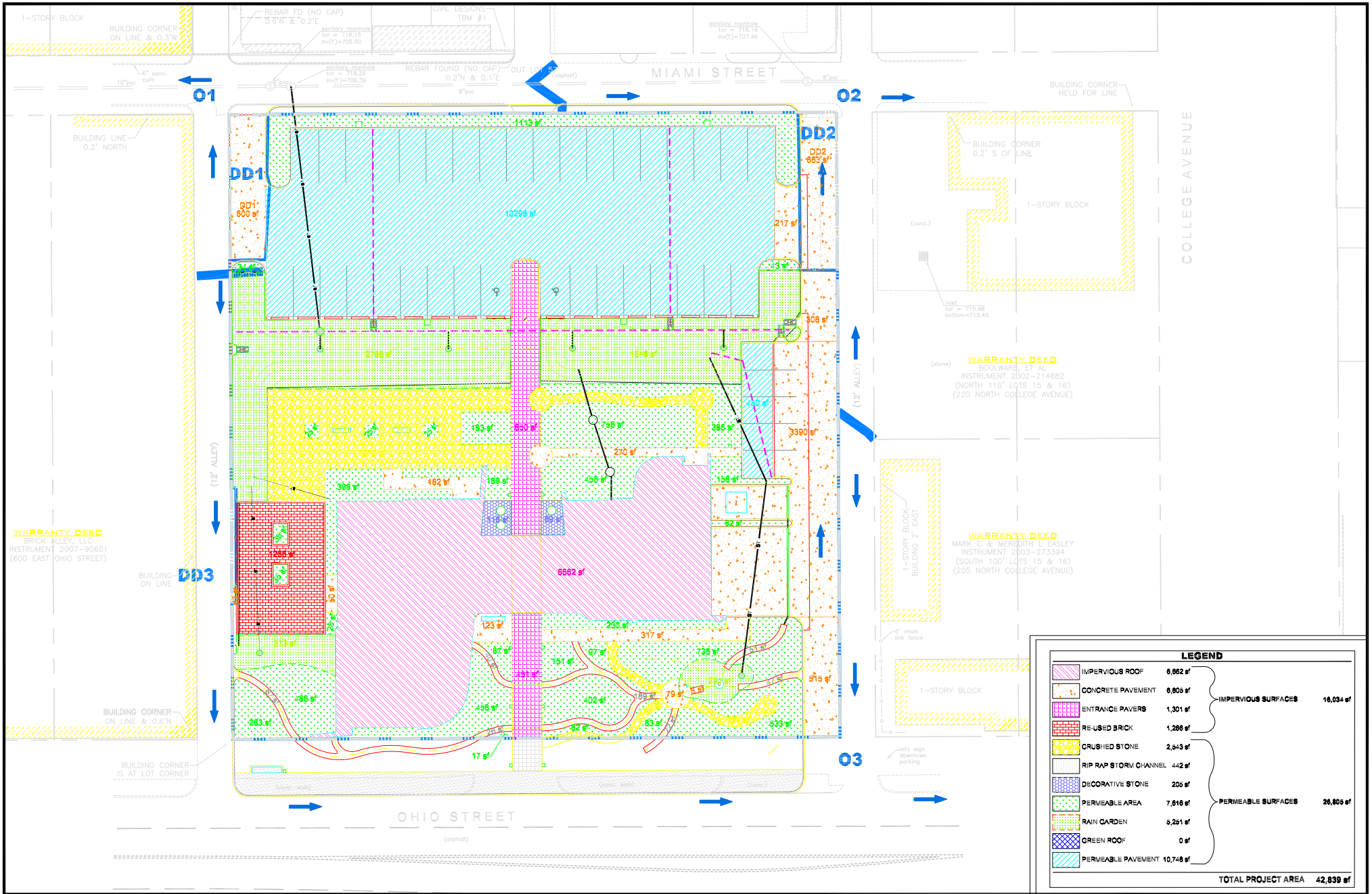
Appendix C

Green Integrated Design Conditions

Green Integrated Site Design Condition
Cupping Landscape Design Typical



Without Green Roof



PREPARED BY:

ELEMENTS Engineering, LLC
6213 Banner Way
Indianapolis, IN 46250
(317) 490-7054

Nature Conservancy Headquarters
Indianapolis, Marion County Indiana

POST-DEVELOPED - INTEGRATED SITE DESIGN OPTION 1
PROPOSED SURFACE CONDITIONS

ELEMENTS JOB NO. 08-29-001

DATE: 07-27-2008

SCALE: 1" = 20'

SHEET No. P1

Green Integrated Design Conditions - Without Green Roof

INTEGRATED CONDITIONS - OVERALL			
Surface	Area	CN	C
Roof	6662	98	0.90
Imp. Pavement	5459	98	0.85
Porous Pavement	10748	85	0.80
Crushed stone	2543	85	0.80
Paver stones	1301	85	0.80
Rip rap channel	442	85	0.80
Brick pavers	1266	98	0.90
Dec. stone	205	85	0.80
Rain Garden	5251	61	0.25
Pervious	7616	61	0.25
DD1 Imp. Pav't	600	98	0.85
DD2 Imp. Pav't	663	98	0.85
DD3 Imp. Pav't	83	98	0.85
Total =	**42839**	**82.3**	**0.66**
Total pervious =	12867		
Total Impervious =	29972		

COMPARISON		
Condition	CN	c
Existing	97.1	0.85
Integrated "A"	82.3	0.66
	CN	C
	% Reduction	% Reduction
	15.32	22.56

Water Quality Volume:		
I=	69.96	%
Rv=	0.68	
A=	0.983	ac
WQv=	0.0557	ac-ft

Rain Garden Stage Storage:		
Stage	Volume	
806	0.0438	ac-ft
806.16	0.056	ac-ft
807	0.1198	ac-ft

Rain Garden Overflow Elevation

SE RG LAWN			
Surface	Area	CN	C
Roof	0	98	0.90
Imp. Pavement	1042	98	0.85
Porous Pavement	0	85	0.80
Crushed stone	282	85	0.80
Paver stones	451	85	0.80
Rip rap channel	375	85	0.80
Brick pavers	0	98	0.90
Dec. stone	0	85	0.80
Rain Garden	244	61	0.25
Pervious	2876	61	0.25
Total =	**5270**	**73.4**	**0.5**

PCPC SIDE			
Surface	Area	CN	C
Imp. Pavement	3698	98	0.85
Porous Pavement	450	85	0.80
Pervious	240	61	0.25
Total =	**4388**	**94.6**	**0.8**

PCPC PAVEMENT			
Surface	Area	CN	C
Imp. Pavement	217	98	0.85
Porous Pavement	10298	85	0.80
Pervious	1113	61	0.25
Total =	**11628**	**82.9**	**0.7**

SW RG LAWN			
Surface	Area	CN	C
Roof	0	98	0.90
Imp. Pavement	50	98	0.85
Porous Pavement	0	85	0.80
Crushed stone	0	85	0.80
Paver stones	0	85	0.80
Rip rap channel	67	85	0.80
Brick pavers	0	98	0.90
Dec. stone	0	85	0.80
Rain Garden	373	61	0.25
Pervious	797	61	0.25
Total =	**1287**	**63.7**	**0.3**

BLDG ROOF			
Surface	Area	CN	C
Roof	6662	98	0.90
Green Roof 6" depth	0	92	0.84
Pervious	0	61	0.25
Total =	**6662**	**98.0**	**0.9**

DD1			
Surface	Area	CN	C
Roof	0	0	0.00
Pavement	600	98	0.85
Pervious	0	61	0.25
Total =	**600**	**98.0**	**0.85**

REAR YARD			
Surface	Area	CN	C
Roof	0	98	0.90
Imp. Pavement	452	98	0.85
Porous Pavement	0	85	0.80
Crushed stone	2261	85	0.80
Paver stones	850	85	0.80
Rip rap channel	0	85	0.80
Brick pavers	1266	98	0.90
Dec. stone	205	85	0.80
Rain Garden	4634	61	0.25
Pervious	2590	61	0.25
Total =	**12258**	**72.7**	**0.5**

DD2			
Surface	Area	CN	C
Roof	0	0	0.00
Pavement	663	98	0.85
Pervious	0	61	0.25
Total =	**663**	**98.0**	**0.85**

DD3			
Surface	Area	CN	C
Roof	0	0	0.00
Pavement	83	98	0.85
Pervious	0	61	0.25
Total =	**83**	**98.0**	**0.85**

Green Integrated Design Conditions - Without Green Roof - Peak Release

BLDG ROOF (to Rain Garden)			
Event	2-year	10-year	100-year
30		0.74	1.11
1		0.51	0.78
2		0.34	0.51
3		0.26	0.38
6		0.15	0.23

REAR YARD (to Rain Garden)			
Event	2-year	10-year	100-year
30		0.14	0.37
1		0.14	0.40
2		0.15	0.34
3		0.13	0.28
6		0.10	0.19

SE LAWN RG (to Rain Garden)			
Event	2-year	10-year	100-year
30		0.07	0.17
1		0.07	0.18
2		0.07	0.15
3		0.06	0.13
6		0.04	0.09

SW LAWN RG (to Rain Garden)			
Event	2-year	10-year	100-year
30		0.01	0.02
1		0.01	0.02
2		0.01	0.02
3		0.01	0.02
6		0.01	0.01

PCPC PAVEMENT (to Rain Garden)			
Event	2-year	10-year	100-year
30		0.39	0.86
1		0.37	0.73
2		0.28	0.52
3		0.22	0.40
6		0.15	0.25

PCPC SIDE (to Rain Garden)			
Event	2-year	10-year	100-year
30		0.40	0.64
1		0.28	0.46
2		0.19	0.30
3		0.15	0.23
6		0.09	0.14

DD1			
Event	2-year	10-year	100-year
30		0.07	0.10
1		0.05	0.07
2		0.03	0.05
3		0.02	0.04
6		0.01	0.02

DD2			
Event	2-year	10-year	100-year
30		0.07	0.11
1		0.05	0.08
2		0.03	0.05
3		0.03	0.04
6		0.02	0.02

DD3			
Event	2-year	10-year	100-year
30		0.13	0.24
1		0.10	0.19
2		0.07	0.12
3		0.05	0.09
6		0.04	0.06

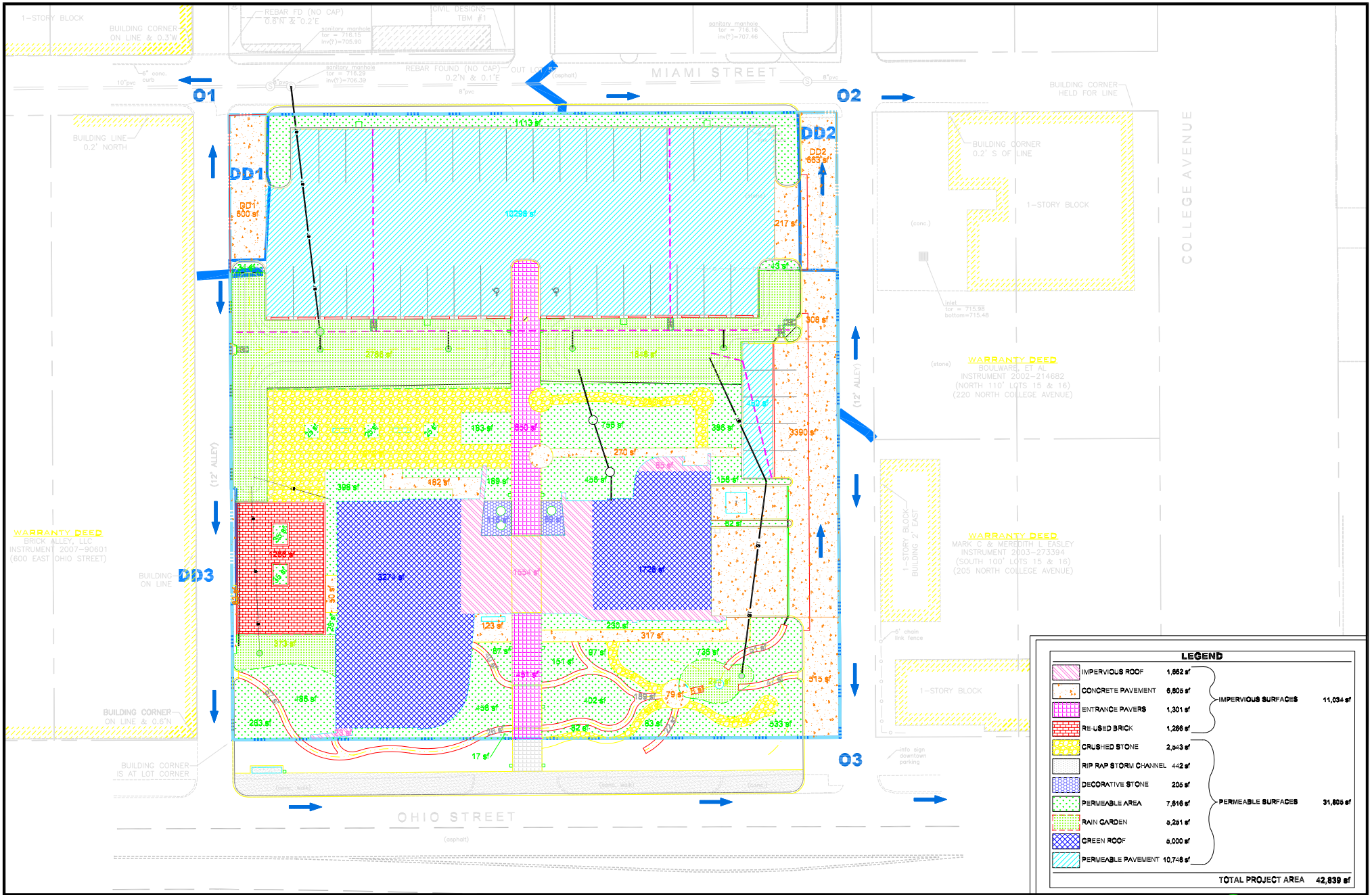
Outfall - Miami Street			
Event	**2-year**	**10-year**	**100-year**
30		0.07	0.96
1		0.24	**1.09**
2		**0.94**	1.05
3		0.94	1.03
6		0.94	0.95
Hydrograph addition			
CS Miami - Allowable		**1.18**	**2.11**

Outfall - College Avenue			
Event	**2-year**	**10-year**	**100-year**
30		**0.08**	**0.12**
1		0.06	0.09
2		0.04	0.06
3		0.03	0.04
6		0.02	0.03
Hydrograph addition			
CS College - Allowable		**1.41**	**2.53**

Flow Reduction Comparison over Existing Conditions			
Miami Street	**2-Year**	**10-Year**	**100-Year**
Max flow-proposed	0.091	0.94	1.09
Max flow-existing	1.18	2.11	3.13
% flow reduction	**92.29**	**55.45**	**65.18**

Surface Detention & Water Quality in Rain Garden			
Rain Garden to Stone Detention Section			
Event	**cfs (out)**	**stage**	**volume**
10-year	**0.47**	**806.35**	
100-year	**1.26**	**806.48**	

With Green Roof



LEGEND

IMPERVIOUS ROOF	1,662 sf	IMPERVIOUS SURFACES	11,034 sf
CONCRETE PAVEMENT	6,805 sf		
ENTRANCE PAVERS	1,301 sf		
RE-USED BRICK	1,266 sf		
CRUSHED STONE	2,543 sf	PERMEABLE SURFACES	31,805 sf
RIP RAP STORM CHANNEL	442 sf		
DECORATIVE STONE	205 sf		
PERMEABLE AREA	7,616 sf		
RAIN GARDEN	5,251 sf		
GREEN ROOF	5,000 sf		
PERMEABLE PAVEMENT	10,748 sf		
TOTAL PROJECT AREA	42,839 sf		

PREPARED BY:
ELEMENTS Engineering, LLC
6213 Banner Way
Indianapolis, IN 46250
(317) 490-7054

Nature Conservancy Headquarters
Indianapolis, Marion County Indiana

POST-DEVELOPED - INTEGRATED SITE DESIGN OPTION 2
PROPOSED SURFACE CONDITIONS

ELEMENTS JOB NO.
08-29-001

DATE:
07-27-2008

SCALE:
1" = 20'

SHEET No.
P2

Green Integrated Design Conditions - With Green Roof

INTEGRATED CONDITIONS - OVERALL			
Surface	Area	CN	C
Roof	1662	98	0.90
Imp. Pavement	5459	98	0.85
Roof-Green 6" depth	5000	92	0.84
Porous Pavement	10748	85	0.80
Crushed stone	2543	85	0.80
Paver stones	1301	85	0.80
Rip rap channel	442	85	0.80
Brick pavers	1266	98	0.90
Dec. stone	205	85	0.80
Rain Garden	5251	61	0.25
Pervious	7616	61	0.25
DD1 Imp. Pav't	600	98	0.85
DD2 Imp. Pav't	663	98	0.85
DD3 Imp. Pav't	83	98	0.85
Total =	**42839**	**70.8**	**0.56**
Total pervious =	17867		
Total Impervious =	24972		

COMPARISON		
Condition	CN	c
Existing	97.1	0.85
Integrated "B"	70.8	0.56
	CN	C
	% Reduction	% Reduction
	27.10	34.86

Water Quality Volume:		
I=	58.29 %	
Rv=	0.57	
A=	0.983	ac
WQv=	0.0471	ac-ft

Rain Garden Stage Storage:		
Stage	Volume	
806	0.0438	ac-ft
806.04	0.0471	ac-ft
807	0.1198	ac-ft

Rain Garden Overflow Elevation

SE RG LAWN			
Surface	Area	CN	C
Roof	0	98	0.90
Imp. Pavement	1042	98	0.85
Porous Pavement	0	85	0.80
Crushed stone	282	85	0.80
Paver stones	451	85	0.80
Rip rap channel	375	85	0.80
Brick pavers	0	98	0.90
Dec. stone	0	85	0.80
Rain Garden	244	61	0.25
Pervious	2876	61	0.25
Total =	**5270**	**73.4**	**0.5**

PCPC SIDE			
Surface	Area	CN	C
Imp. Pavement	3698	98	0.85
Porous Pavement	450	85	0.80
Pervious	240	61	0.25
Total =	**4388**	**94.6**	**0.8**

PCPC PAVEMENT			
Surface	Area	CN	C
Imp. Pavement	217	98	0.85
Porous Pavement	10298	85	0.80
Pervious	1113	61	0.25
Total =	**11628**	**82.9**	**0.7**

SW RG LAWN			
Surface	Area	CN	C
Roof	0	98	0.90
Imp. Pavement	50	98	0.85
Porous Pavement	0	85	0.80
Crushed stone	0	85	0.80
Paver stones	0	85	0.80
Rip rap channel	67	85	0.80
Brick pavers	0	98	0.90
Dec. stone	0	85	0.80
Rain Garden	373	61	0.25
Pervious	797	61	0.25
Total =	**1287**	**63.7**	**0.3**

BLDG ROOF			
Surface	Area	CN	C
Roof	1662	98	0.90
Green Roof 6" depth	5000	98	0.85
Pervious	0	61	0.25
Total =	**6662**	**98.0**	**0.9**

DD1			
Surface	Area	CN	C
Roof	0	0	0.00
Pavement	600	98	0.85
Pervious	0	61	0.25
Total =	**600**	**98.0**	**0.85**

REAR YARD			
Surface	Area	CN	C
Roof	0	98	0.90
Imp. Pavement	452	98	0.85
Porous Pavement	0	85	0.80
Crushed stone	2261	85	0.80
Paver stones	850	85	0.80
Rip rap channel	0	85	0.80
Brick pavers	1266	98	0.90
Dec. stone	205	85	0.80
Rain Garden	4634	61	0.25
Pervious	2590	61	0.25
Total =	**12258**	**72.7**	**0.5**

DD2			
Surface	Area	CN	C
Roof	0	0	0.00
Pavement	663	98	0.85
Pervious	0	61	0.25
Total =	**663**	**98.0**	**0.85**

DD3			
Surface	Area	CN	C
Roof	0	0	0.00
Pavement	83	98	0.85
Pervious	0	61	0.25
Total =	**83**	**98.0**	**0.85**

Green Integrated Design Conditions - With Green Roof - Peak Release

BLDG ROOF (to Rain Garden)			
Event	2-year	10-year	100-year
30		0.18	0.28
1		0.13	0.20
2		0.09	0.13
3		0.06	0.10
6		0.04	0.06

REAR YARD (to Rain Garden)			
Event	2-year	10-year	100-year
30		0.14	0.37
1		0.14	0.40
2		0.15	0.34
3		0.13	0.28
6		0.10	0.19

SE LAWN RG (to Rain Garden)			
Event	2-year	10-year	100-year
30		0.07	0.17
1		0.07	0.18
2		0.07	0.15
3		0.06	0.13
6		0.04	0.09

SW LAWN RG (to Rain Garden)			
Event	2-year	10-year	100-year
30		0.01	0.02
1		0.01	0.02
2		0.01	0.02
3		0.01	0.02
6		0.01	0.01

PCPC PAVEMENT (to Rain Garden)			
Event	2-year	10-year	100-year
30		0.39	0.86
1		0.37	0.73
2		0.28	0.52
3		0.22	0.40
6		0.15	0.25

PCPC SIDE (to Rain Garden)			
Event	2-year	10-year	100-year
30		0.40	0.64
1		0.28	0.46
2		0.19	0.30
3		0.15	0.23
6		0.09	0.14

BLDG GREEN ROOF (to Rain Garden)			
Event	2-year	10-year	100-year
30		0.34	0.59
1		0.27	0.45
2		0.18	0.30
3		0.14	0.23
6		0.09	0.14

DD2			
Event	2-year	10-year	100-year
30		0.07	0.11
1		0.05	0.08
2		0.03	0.05
3		0.03	0.04
6		0.02	0.02

DD1			
Event	2-year	10-year	100-year
30		0.07	0.10
1		0.05	0.07
2		0.03	0.05
3		0.02	0.04
6		0.01	0.02

DD3			
Event	2-year	10-year	100-year
30		0.13	0.24
1		0.10	0.19
2		0.07	0.12
3		0.05	0.09
6		0.04	0.06

Outfall - Miami Street			
Event	**2-year**	**10-year**	**100-year**
30		0.07	0.96
1		0.32	**1.14**
2		**0.94**	1.09
3		0.94	1.05
6		0.94	0.95
Hydrograph addition			
CS Miami - Allowable		**1.18**	**2.11**

Outfall - College Avenue			
Event	**2-year**	**10-year**	**100-year**
30		**0.08**	**0.12**
1		0.06	0.09
2		0.04	0.06
3		0.03	0.04
6		0.02	0.03
Hydrograph addition			
CS College - Allowable		**1.41**	**2.53**

Flow Reduction Comparison over Existing Conditions			
Miami Street	**2-Year**	**10-Year**	**100-Year**
Max flow-proposed	0.1	0.94	1.14
Max flow-existing	1.18	2.11	3.13
% flow reduction	**91.53**	**55.50**	**63.61**

Surface Detention & Water Quality in Rain Garden			
Rain Garden to Stone Detention Section			
Event	**cfs (out)**	**stage**	**volume**
10-year (max stage)	**0.90**	**806.20**	
10-year (max Q)	**1.16**	**806.17**	
100-year (max stage)	**2.29**	**806.34**	
100-year (max Q)	**2.59**	**806.30**	

TABLE OF CONTENTS

Section 4 - Stormwater Drainage Technical Report Page

1.0 Introduction 1

2.0 Existing Conditions 1

3.0 Developed Conditions and Proposed Storm Water Design 2

4.0 Water Quality Illustration 3

5.0 References 5

Appendix A - Conventional Model Output
Appendix B - Distributed Storage Model Output
Appendix C - Cost Differential Illustration
Appendix D - Green Roof Evaluation
Appendix E - Stormwater BMP Inspection Fee Calculation
Appendix F - Landscape Plan

1.0 INTRODUCTION

Williams Creek Consulting (WCC) has completed a drainage analysis for a theoretical SITE within Marion County, Indiana in order to compute the relative advantages of Low Impact Development strategies. WCC used a conventional layout for a 5.2 acre retail SITE in Indiana which was to be used as the baseline for the comparative analysis and has used the general release rate requirements found in section 302.03 of the Indianapolis Draft Stormwater Standards. The conventional pipe networking as well as inlet spacing was copied from an existing plan completed by others. Therefore, detailed pipe sizing calculations were not performed but presumed to be more or less adequate. The Wet Pond and outlet control structure was then sized in order to meet allowable outfall rates. The distributed storage alternative modified the existing conventional layout in order to demonstrate the effectiveness of source control of stormwater and the associated reduced infrastructure costs.

2.0 EXISTING CONDITIONS

This example assumes the pre-development state to be fallow field containing primarily 'C' type soils with a curve number of 74, with a pre-development Time of Concentration of 31.2 minutes. All regulatory storm events were run in HydroCAD v. 8.00 in order to develop pre-development peak flows for a variety of storm durations in order to assess the critical duration storm event. A CN of 74 was assumed for the pre-development condition, and a 31 minute time of concentration was computed based upon an existing 1% slope across the 5.2 acre site. The peak outfall results are summarized below in Table 1.

Table 1

	Duration	Existing (cfs)		Duration	Existing (cfs)		Duration	Existing (cfs)		Duration	Existing (cfs)
2 yr	1 hr.	1.24	10 yr	1 hr.	3.45	25 yr	1 hr.	4.27	100 y	1 hr.	10.54
	2 hr.	1.29		2 hr.	3.1		2 hr.	4.23		2 hr.	6.36
	3 hr.	1.04		3 hr.	2.61		3 hr.	3.54		3 hr.	5.17
	6 hr.	0.84		6 hr.	1.9		6 hr.	2.41		6 hr.	3.41
	12 hr.	0.63		12 hr.	1.3		12 hr.	1.64		12 hr.	2.35
	24 hr.	0.11		24 hr.	0.82		24 hr.	1.03		24 hr.	1.43

Per section 302.03 of the Draft City of Indianapolis Stormwater Specifications Manual, the post-development release rates should meet the requirements listed in Table 2:

Table 2

$Q_{2p} = 0.5\ Q_{2e}$	0.65
$Q_{10p} = 0.5\ Q_{10e}$	1.73
$Q_{25p} = 0.75\ Q_{10e}$	2.59
$Q_{100p} = Q_{10e}$	3.45

3.0 PROPOSED CONDITIONS AND STORMWATER DESIGN

3.1 Conventional Approach:

This example assumes the conventional approach of routing parking lot areas to inlet structures which pipe to a proposed wet pond. The roof of the retail facility is also presumed to outlet to pipes which similarly are routed to the wet pond. No storage is distributed across the site, with all attenuation requirements being accomplished by the wet pond. The wet pond is also the sole source for meeting water quality requirements mandated by the City of Indianapolis. In order to promote long term bank stability, stage depths of greater than four feet are generally avoided. Preserving a 100 year stage depth of less than four feet requires a pond footprint greater than that required on the plan layout. Specifically, 4,000 square feet were added to the theoretical pond in order to meet allowable outfall rates. The hundred year stage depth was multiplied by the theoretical pond expansion in order to project the quantity of underground storage that would need to be specified in order to develop costs associated with the conventional layout.

The modeling results were based upon the Huff 2nd Quartile storm distribution. Appendix A provides the modeling output for the Conventional approach. In each case, the critical duration storm was used. The results for the 2, 10, 25, and 100 year storm events are provided in Table 3.

Table 3

Event	Rate	
2 year	0.57	cfs
10 year	1.40	cfs
25 year	2.26	cfs
100 year	3.27	cfs

3.2 Distributed Storage Approach:

This example utilizes open space in the site layout which conventionally consists of raised landscape islands or berms. In this approach, all open spaces are depressed in order to accept stormwater run-off. These depressions serve three functions. First, the storage volumes within the depressions serve to attenuate surface runoff. Second, the lengths of the depressions serve to convey surface runoff to subsequent depressions, eliminating the need for pipe infrastructure; the exception being road crossings which require a culvert crossing. Thirdly, the depressions can be designed to meet water quality design criteria of dry basins, infiltration basins, or constructed wetlands, etc… depending on Owner's preference. In this example, the design prescribes bioretention basins and dry basins. Specifically, the bioretention basins are specified in the parking lot to facilitate robust vegetative growth and healthy rooting. These are built by over-excavating during construction and backfilling with 2' of top soil with a sandy amendment in order to raise the void ratio within the subgrade to approximately 0.3 which is utilized as storage in the calculations. Dry basins are specified around the perimeter of the Site. Both types of BMPs are designed with zero longitudinal slope and are therefore prescribed underdrains with 6" of cover in order to completely drain the facilities after storm events. Note that downstream receiving basins are typically 1' lower than their upstream counterpart. This provides for a 4" underdrain with a minimum of 6" of cover.

This particular arrangement prescribes a retaining wall raised above the bottom of the basins. The strategy is to force runoff into the underdrain up to an overflow represented by the retain wall. At this point, the underdrain is short-circuited and the runoff is directed straight to the culvert outlet. Enclosed details and renderings attempt to show an example of this system.

Utilizing space that would have been raised conventionally and converting these into stormwater management facilities has multiple advantages. First, the storage in the wet pond is no longer necessary. Second, the design intent of the bioretention basins is not to require frequent mowing, but to be left, literally, as a rain garden decreasing annual maintenance costs. Thirdly, the monthly or bi-weekly discharge of grass clippings (TSS) is no longer evident in the Site discharge. The regulation of nutrient excesses is not yet regulated by the City of Indianapolis, but the affect of nutrient laden stormwater and the associated algal blooms are usually evident in stagnant water bodies throughout the County. Most importantly for the Owner of the development is that the usage of conventionally ignored stormwater capacity within and around parking lots frees up additional space for development.

The modeling results were based upon the Huff 2nd Quartile storm distribution. Appendix B provides the modeling output for the Distributed Storage approach. In each case, the critical duration storm was used. The results for the 2, 10, 25, and 100 year storm events are provided in Table 4.

Table 4

Event	Rate	
2 year	0.13	cfs
10 year	0.15	cfs
25 year	0.22	cfs
100 year	0.54	cfs

4.0 Water Quality Illustration

4.1 Conventional Layout

Chapter 700 of the Draft Stormwater Standards provides little guidance for the sizing of Wet Pond BMPs for the purposes of water quality. Of the 23 design criteria listed, it appears that only criteria 1, 2, 3, and 13 of the design criteria apply to water quality. So long as the inlet to the Wet Pond is reasonably separated from the outlet, and if a forebay sized to contain 0.1 inches of runoff from the entire upstream watershed, 85% TSS can be claimed. However, no outlet rate from the forebay is mandated except that the exit velocities should be non-erosive. Since stormwater can flow out of the forebay as it is flowing in, it is difficult to quantify the actual forebay size required; exit velocities into ponds are rarely erosive to the wet pond.

Detailed specifications of the Wet Pond design are beyond the scope of this theoretical analysis. However, it appears space requirements are available for the specification of the 23 design criteria and for water quality requirements to be met.

4.2 Distributed Storage

The concept of distributed storage will typically increase TSS removal above that claimed via conventional layout methods. With distributed storage, the BMPs do not just store, but also convey the water which provides a treatment train affect.

4.2.1 Bioretention

A detailed proof of all 16 design criteria is outside the scope of this theoretical analysis. However, the distributed storage design may fail to meet design criteria 1 and/or 2 which provide guidance for acceptable bioretention area size and acceptable drainage area. These two design criteria should not be viewed

separately as it should be written as comparative. That is, the Standards allow for a 5 acre watershed draining to a 200 square foot bioretention area, or conversely, a 0.5 acre watershed draining to a 5 acre bioretention area. Additionally, the distributed storage design does not comply with a four foot minimum planting soil depth; this is not necessary. Nearly all of the dissolved metals, fecal coliform, and suspended solids will be removed in the top few inches of organic compost mulch (references available). If the four feet of planting soil is required, these bioretention areas would likely be designed as "biofilters" or "water quality swales".

4.2.2 Dry Detention Basins

Given the selection of BMPs provided in the Standards, the exterior BMPs would likely be classified as either a "water quality swale" or a "biofilter". This selection would be made based upon Owner preference. It appears that ample space is required in order to bring these BMPs into line with the Draft Standards, and a detailed proof is outside the scope of this theoretical analysis.

4.3 Results

As an example theoretical calculation, assuming the BMP design conforms to the Draft Standards, the typical removal rate of TSS in stormwater exiting the SITE would be as follows:

4.3.1 Conventional

Water Quality Volume Calculation

Watersheds to Wet Pond	S curb	S roof	N roof	N Curb	srv dr	SE Park	E Park	NE Park	Direct Pond	Totals	ac-ft
A	0.136	0.313	0.313	0.125	0.553	1.535	0.835	1.096	0.292	5.198	
Rv	0.95	0.95	0.95	0.95	0.95	0.815	0.815	0.77	0.95		
P	1	1	1	1	1	1	1	1	1		
WQv	0.011	0.025	0.025	0.010	0.044	0.104	0.057	0.070	0.023	0.368	ac-ft

Since the entire WQv is routed to the Wet Pond, if designed properly, this would yield an overall TSS removal rate of 85%.

4.3.2 Distributed Storage

The distributed storage alternative is a more complex calculation as the stormwater may be treated once, twice, or three times depending on location. Specifically, watersheds Parking areas B, C, and D will be routed to bioretention before discharge to the North Swale. Parking areas F, G, H, I, and J will be routed to bioretention before discharge to the South Swale. Parking areas E and K are routed first to the South Swale before discharge to the North Swale, while the service drive, roof, and parking area A are routed directly to the North Swale. The water quality calculation by watershed is shown below:

Watershed to bioretention areas	Park B	Park C	Park D	Park F	Park G	Park H	Park I	Park J	total
A	0.327	0.25	0.14	0.148	0.15	0.39	0.138	0.145	1.688
Rv	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	
P	1	1	1	1	1	1	1	1	
WQv	0.026	0.020	0.011	0.012	0.012	0.031	0.011	0.011	0.134

Watersheds directly to South Swale	Park E	Park K	total
A	0.589	0.511	1.1
Rv	0.95	0.95	
P	1	1	

WQv	0.047	0.040	0.087		
Watersheds directly to North Swale	srv dr	Roof N	Roof S	Park A	total
A	0.765	0.488	0.488	0.674	2.415
Rv	0.95	0.95	0.95	0.95	
P	1	1	1	1	
WQv	0.061	0.039	0.039	0.053	0.191

Assuming the BMP meet acceptable design criteria within the Draft Standards an illustration of the treatment train affect on TSS removal rate would be computed as shown below.

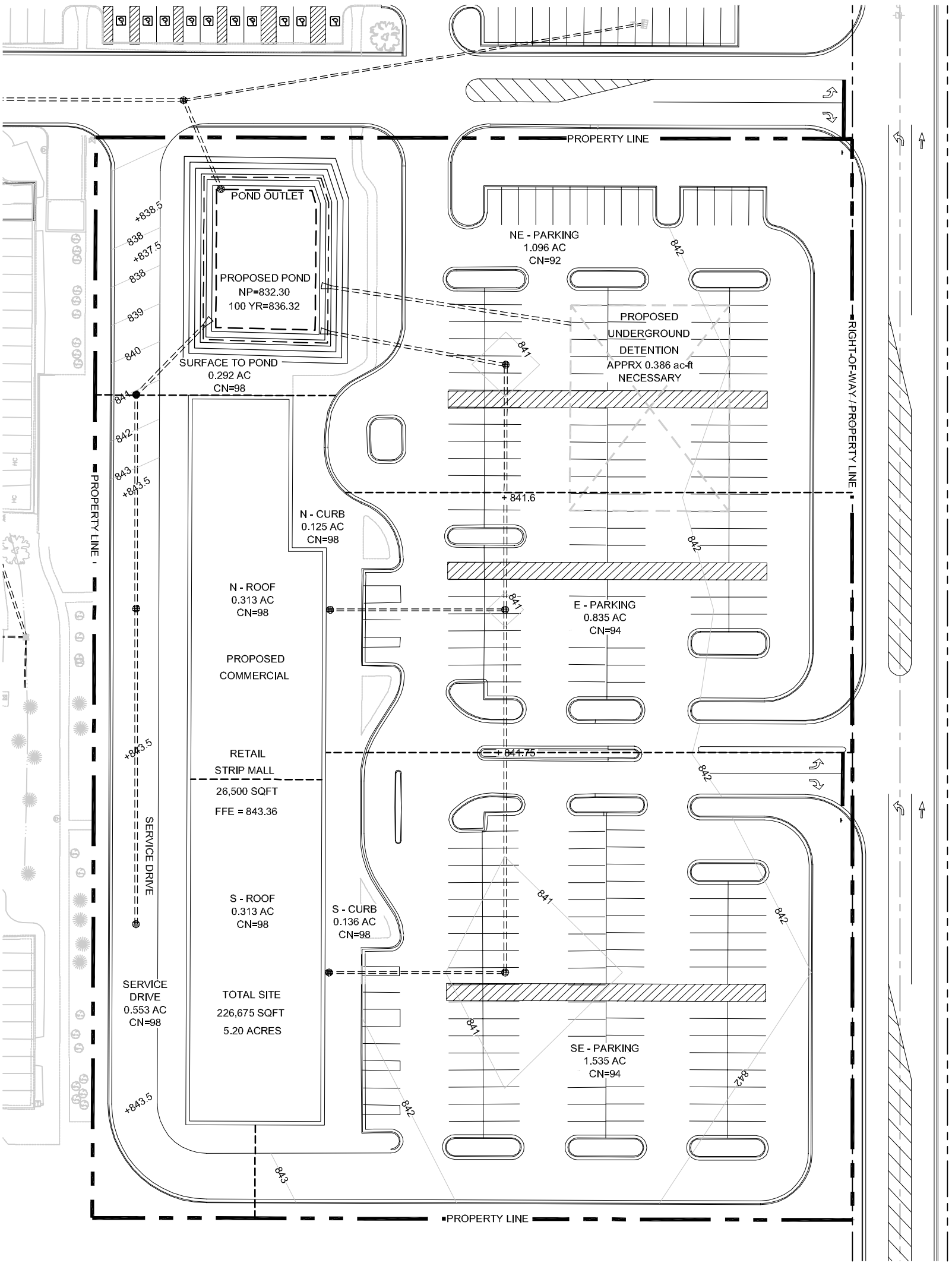
	WQv	Bioretention treatment Removal	%TSS Remaining	South Swale Removal	%TSS Remaining	North Swale Removal	%TSS Remaining
Parking Areas B, C, and D	0.057	0.81	19.0%	N/A	19.0%	0.8	3.8%
Parking Areas F, G, H, I, and J	0.077	0.81	19.0%	0.8	3.8%	0.8	0.8%
Parking Areas E, and K	0.087	N/A	100.0%	0.8	20.0%	0.8	4.0%
Areas directly to North Swale	0.191	N/A	100.0%	N/A	100.0%	0.8	20.0%
Weighted Average TSS Removal							95.6%

5.0 References

1. City of Indianapolis Stormwater Specifications Manual.
2. NRCS Web Soil Survey.
3. Technical Reference 55.
4. HydroCAD v. 8.00
5. City of Indianapolis and Marion County GIS

Appendix A

Conventional Model Output



LEGEND

TYPICAL STORMWATER INLET STRUCTURE AND CONCRETE PIPE

UNDERGROUND STORMWATER DETENTION

PROPERTY BOUNDARY / RIGHT-OF-WAY

DRAINAGE AREAS

NORTH

1 INCH = 60FT.

(IN FEET)

60 30 0 30 60

GREEN INFRASTRUCTURE

SITE EXAMLPES

CONVENTIONAL LAYOUT

WATERSHED AREAS

DWN BY: EEK
CHKD. BY: JTB
SCALE: 60
DATE: AUGUST 2008

CITY OF INDIANAPOLIS

AMEC EARTH & ENVIRONMENTAL

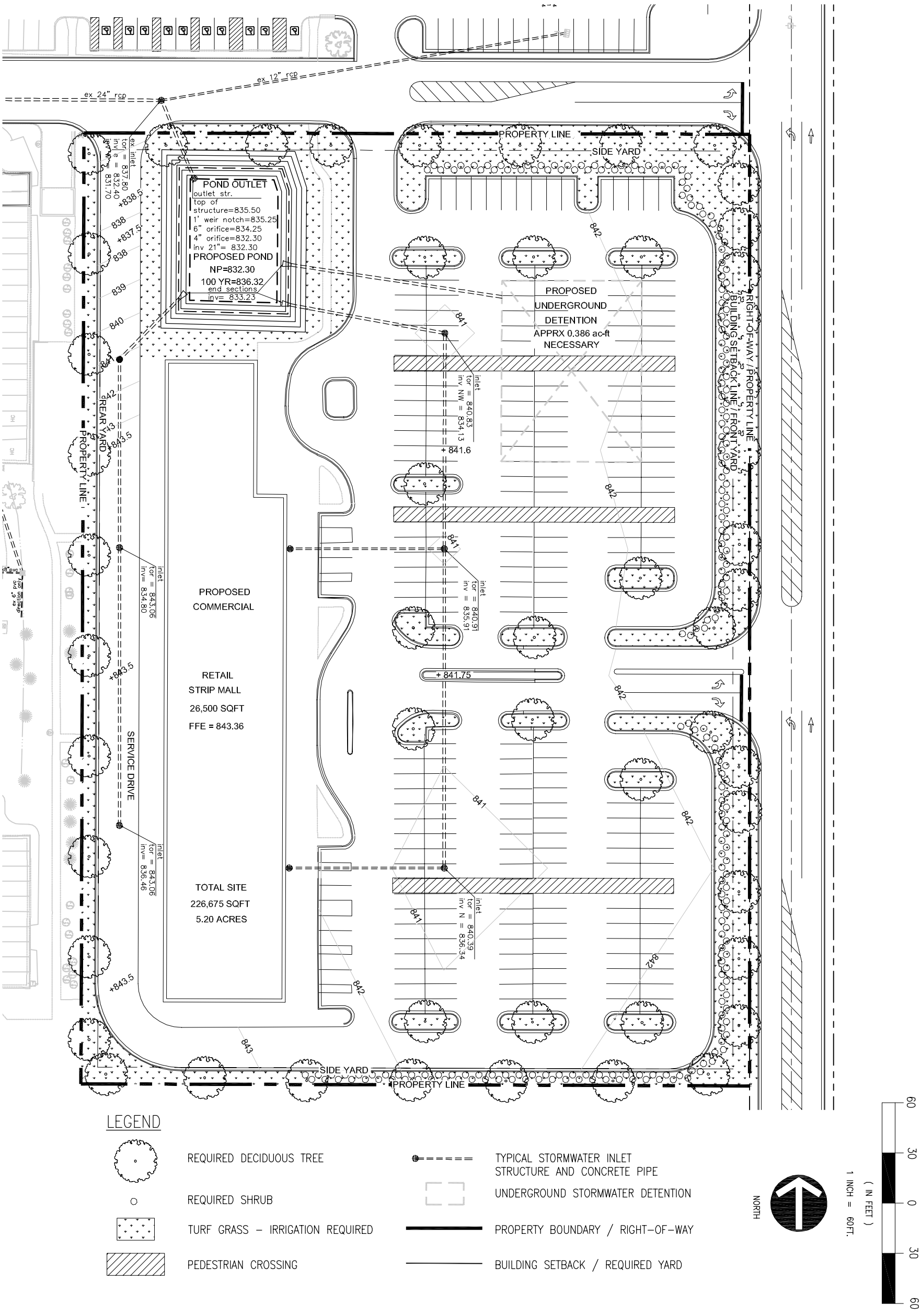
INDIANAPOLIS, INDIANA

WILLIAMS CREEK CONSULTING, INC.
919 NORTH EAST STREET
INDIANAPOLIS, INDIANA 46202
Ph: (317) 423-0690 Fax: (317) 423-0696

PROJECT NUMBER
01.0026.A.1

DRAWING NUMBER
C.3

SHEET 3 OF 4



GREEN INFRASTRUCTURE

SITE EXAMLPES

CONVENTIONAL LAYOUT

SITE PLAN

PROJECT NUMBER
01.0026.A.1

DRAWING NUMBER
C.1
SHEET 1 OF 4

DWN BY: EEK
CHKD. BY: JTB
SCALE: 60
DATE: AUGUST 2008

CITY OF INDIANAPOLIS

AMEC EARTH & ENVIRONMENTAL
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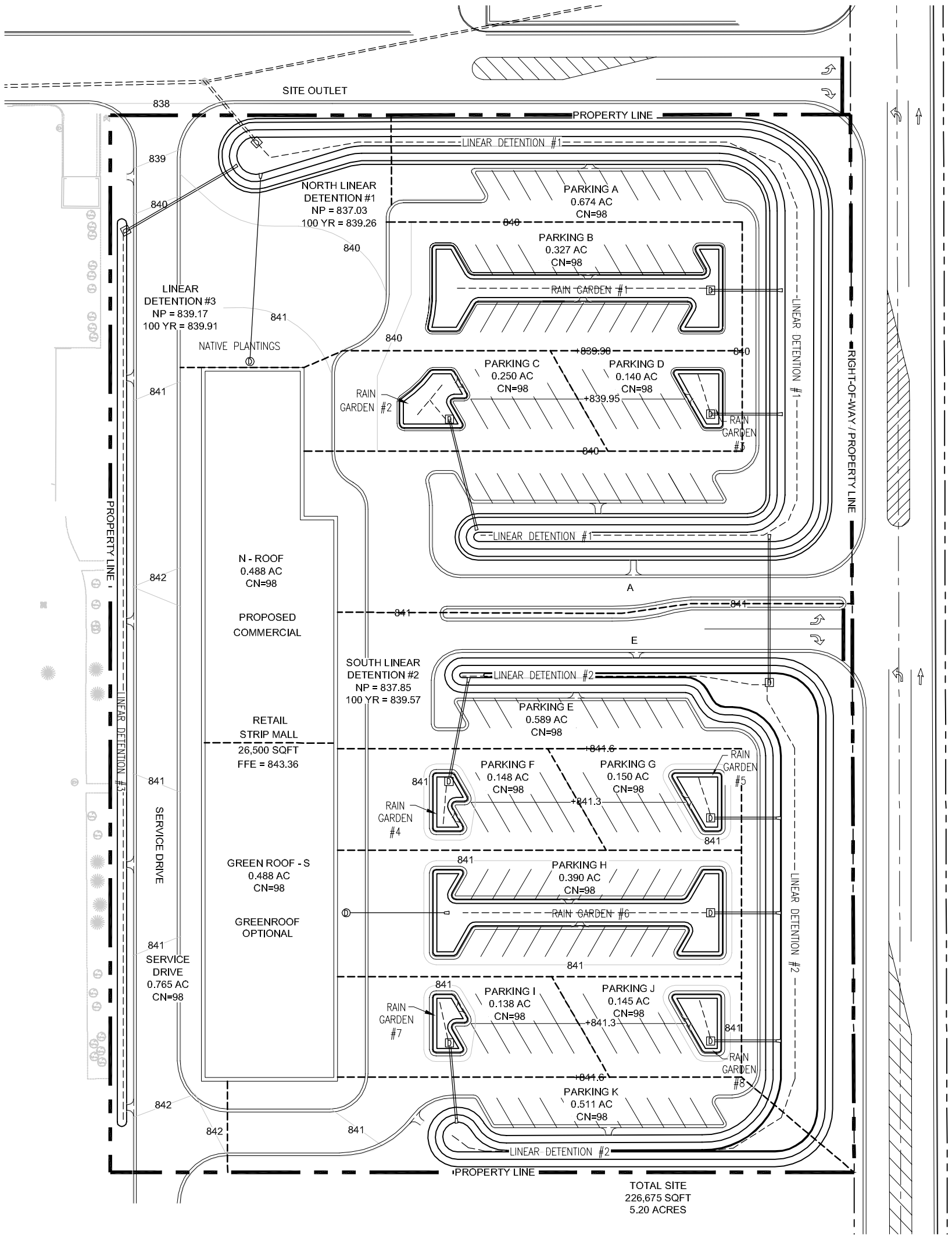
Appendix B

Distributed Storage Model Output



LEGEND

- 4" PERFORATED UNDERDRAIN – RAIN GARDENS AND LINEAR DETENTION
- TYPICAL STORMWATER OUTLET STRUCTURE, PIPE AND END SECTION
- TYPICAL ROOF STORMWATER PIPE AND END SECTION INTO RAIN GARDEN OR LINEAR DETENTION
- CURB TURNOUT / CONCRETE FLUME
- DRAINAGE AREAS
- PROPERTY BOUNDARY / RIGHT-OF-WAY

GREEN INFRASTRUCTURE

SITE EXAMLPES

LID LAYOUT

WATERSHED AREAS

PROJECT NUMBER 01.0026.A.1

DRAWING NUMBER C.4

SHEET 4 OF 4

DWN BY: EEK
CHKD. BY: JTB
SCALE: 60
DATE: AUGUST 2008

CITY OF INDIANAPOLIS

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INDIANAPOLIS, INDIANA

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919 NORTH EAST STREET
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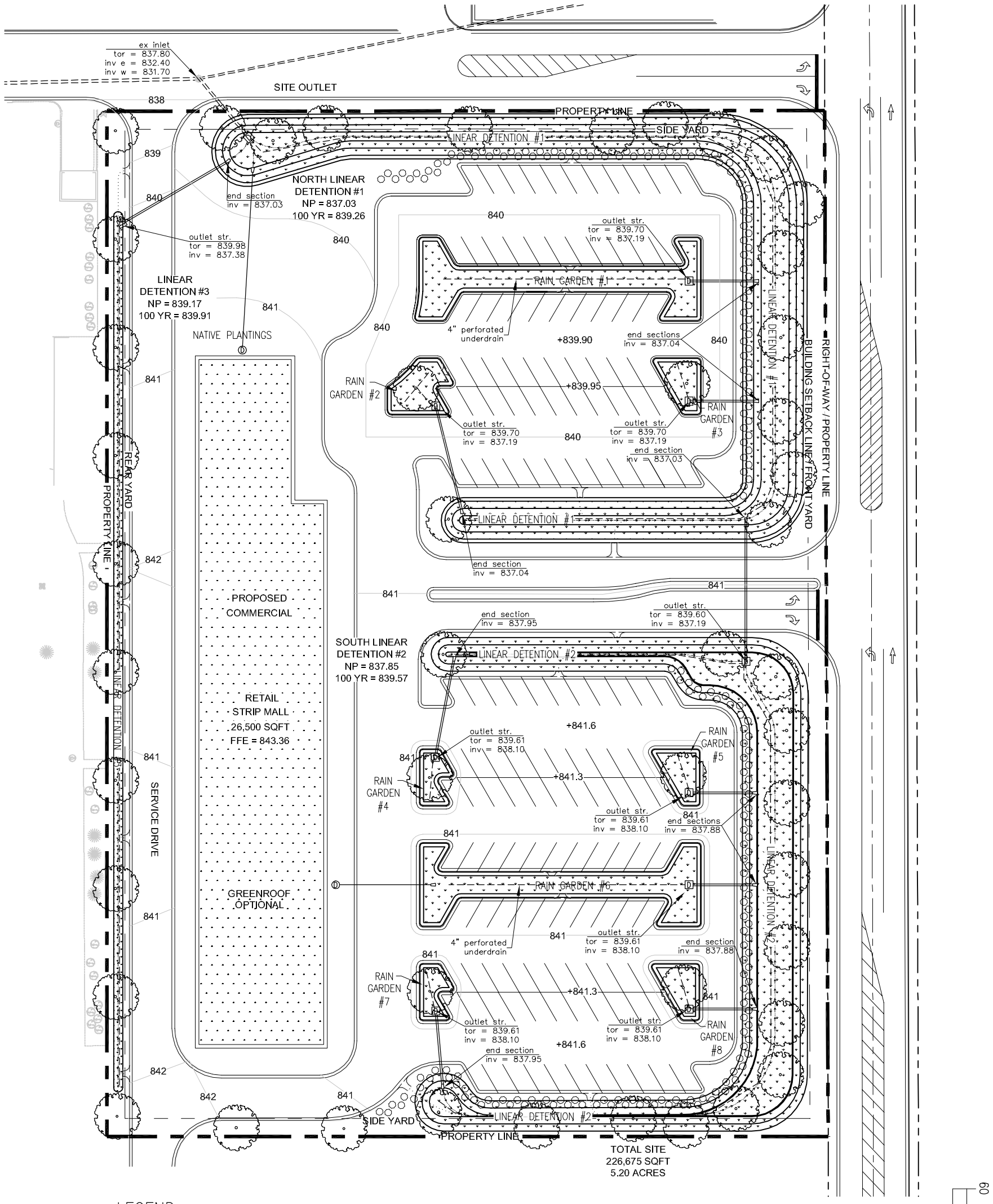
Ph: (317) 423-0690 Fax: (317) 423-0696



GREEN INFRASTRUCTURE

SITE EXAMLPES

LID LAYOUT

SITE PLAN

PROJECT NUMBER
01.0026.A.1

DRAWING NUMBER
C.2
SHEET 2 OF 4

DWN BY: EEK
CHKD. BY: JTB
SCALE: 60
DATE: AUGUST 2008

CITY OF INDIANAPOLIS

AMEC EARTH & ENVIRONMENTAL
INDIANAPOLIS, INDIANA

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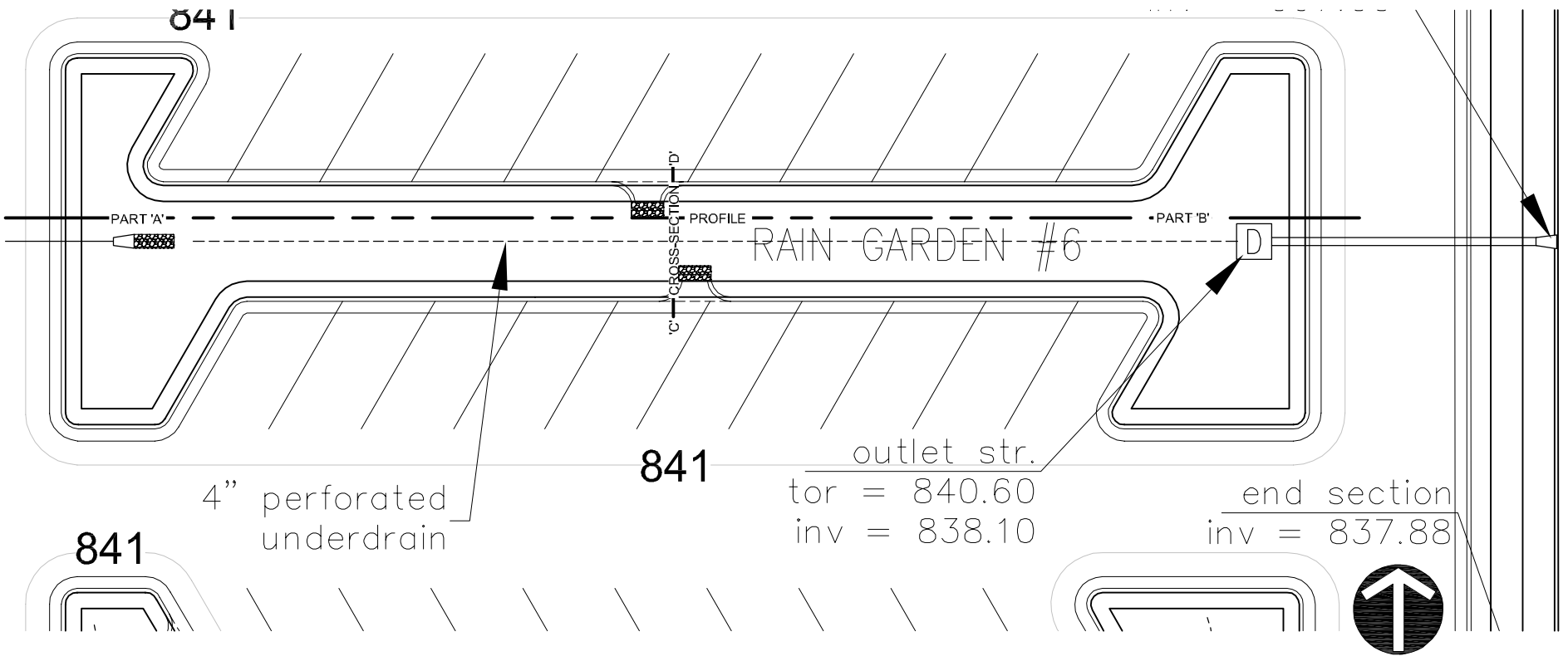
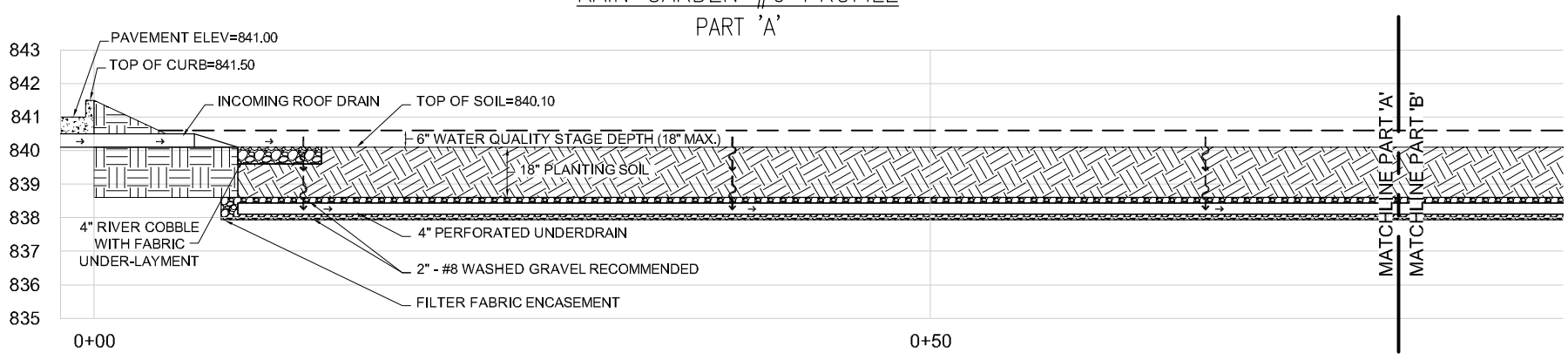


20 10 0 10 20

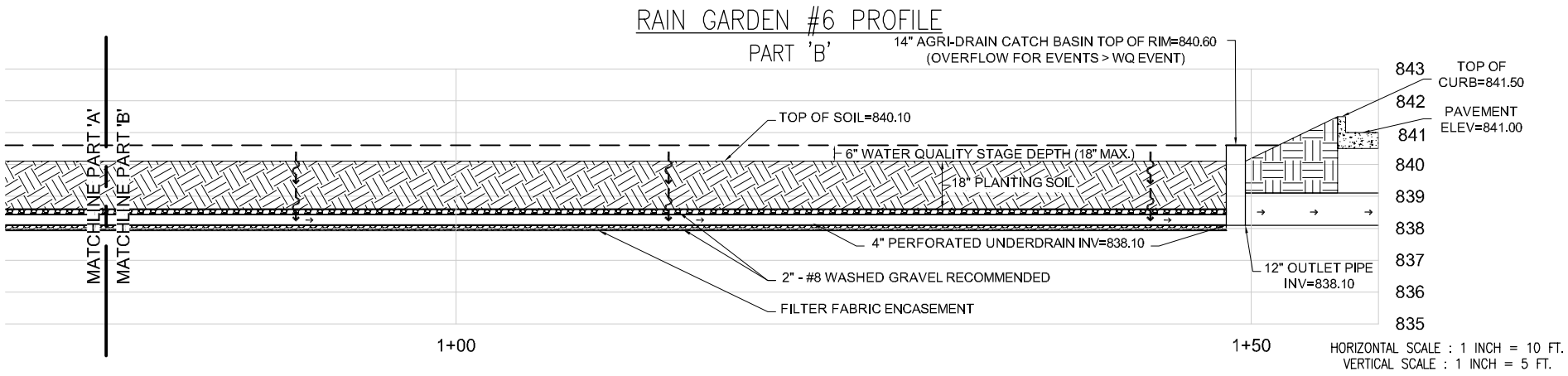
(IN FEET)

1 INCH = 20FT.

RAIN GARDEN #6 PROFILE
PART 'A'

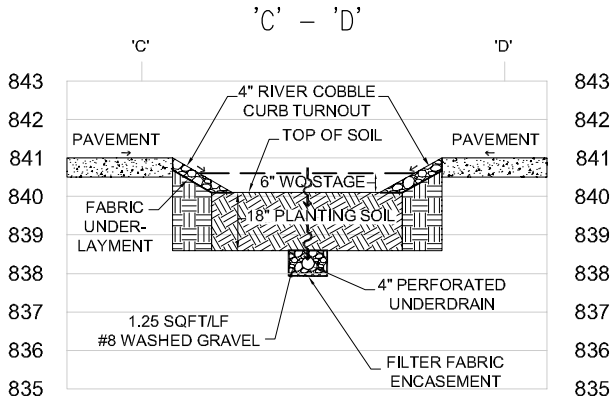


RAIN GARDEN #6 PROFILE
PART 'B'



HORIZONTAL SCALE : 1 INCH = 10 FT.
VERTICAL SCALE : 1 INCH = 5 FT.

RAIN GARDEN #6
CROSS-SECTION
'C' – 'D'



HORIZONTAL SCALE : 1 INCH = 10 FT.
VERTICAL SCALE : 1 INCH = 5 FT.

PLANTING SOIL – NOTES

THE SOIL SHALL BE A UNIFORM MIX, FREE OF STONES, STUMPS, ROOTS OR OTHER SIMILAR OBJECTS LARGER THAN TWO INCHES. NO OTHER MATERIALS OR SUBSTANCES SHALL BE MIXED OR DUMPED WITHIN THE BIORETENTION AREA THAT MAY BE HARMFUL TO PLANT GROWTH, OR PROVE A HINDRANCE TO THE PLANTING OR MAINTENANCE OPERATIONS. THE PLANTING SOIL SHALL BE FREE OF BERMUDA GRASS, QUACKGRASS, JOHNSON GRASS, OR OTHER NOXIOUS WEEDS. THE PLANTING SOIL FOR BIORETENTION FACILITIES SHALL CONSIST OF A MIXTURE OF SAND, TOPSOIL, AND COMPOST WITH A PH RANGE OF 5.5 AND 6.5. IN ADDITION, THE SOIL SHALL HAVE INFILTRATION RATES NO LESS THAN 0.5 INCHES PER HOUR, ACHIEVED THROUGH THE FOLLOWING STANDARDS:

A. 1 PARTS SAND (PER CMSC 703.06),
B. 1 PARTS TOPSOIL (PER CMSC 653.02), AND
C. 1 PARTS COMPOST (PER ODOT CMSC 659.06).

ADDITIONAL RECOMMENDATIONS FOR THE PLANTING SOIL INCLUDE A 1.5 TO 3 PERCENT ORGANIC CONTENT AND A MAXIMUM 500 PPM CONCENTRATION OF SOLUBLE SALTS.

IF THE EXISTING SOIL DOES NOT MEET THE ABOVE CHARACTERISTICS, THEN IT SHALL EITHER BE ADJUSTED TO MEET THE CRITERIA OR REMOVED AND REPLACED WITH AN ACCEPTABLE PLANTING SOIL. SOIL TESTS SHALL BE PERFORMED FOR EVERY 500 CUBIC YARDS OF PLANTING SOIL, WITH THE EXCEPTION OF PH AND ORGANIC CONTENT TESTS, WHICH ARE REQUIRED ONLY ONCE PER RAIN GARDEN AREA.

LEGEND

- FLOW ARROWS
- INFILTRATION ARROWS
- CURB TURNOUT / CONCRETE FLUME
- 4" PERFORATED UNDERDRAIN – RAIN GARDENS AND LINEAR DETENTION
- TYPICAL STORMWATER OUTLET STRUCTURE, PIPE AND END SECTION
- TYPICAL ROOF STORMWATER PIPE AND END SECTION INTO RAIN GARDEN OR LINEAR DETENTION
- PROPERTY BOUNDARY / RIGHT-OF-WAY
- BUILDING SETBACK / REQUIRED YARD

DRAWING NUMBER
C.5a
SHEET 5 OF 6

PROJECT NUMBER
01.0026.A.1

GREEN INFRASTRUCTURE
SITE EXAMLPES

LID LAYOUT
RAIN GARDEN #6 PROFILE & SECTION

DWN BY: EEK
CHKD. BY: JTB
SCALE: NA
DATE: NOVEMBER 2008

CITY OF INDIANAPOLIS
AMEC EARTH & ENVIRONMENTAL
INDIANAPOLIS, INDIANA

WILLIAMS CREEK CONSULTING, INC.
919 NORTH EAST STREET
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Appendix C

Cost Differential Illustration

The following cost estimate is based upon variables which most likely would represent large discrepancies between strategies and easiest to quantify in this theoretical context. Due to the theoretical pre-development topography at the site, mass earthwork is not included; only the excavation necessary to build the BMPs was considered valid.

These computed differentials are minimized with the small site considered. As site area increases, earthwork and pipe cost differentials can be expected to increase geometrically. Pipe cost per acre increase as larger pipes would be required moving towards the downstream end. Assuming a flat site, earthwork cost per acre increase as more fill per acre is required moving towards the upstream end of the drainage system.

Generally, a low impact development strategy will, by definition, propose less change to the existing topography while conventional strategies require it for pipe slope and cover. For the distributed storage strategy, a green roof was not specified. The storage in the rain gardens and linear swales was adequate to meet allowable outfall rates. Despite operating cost savings, green roofs are generally require larger capital investment per cubic foot of storage than the BMPs specified. Had a greater density been sought by the Owner, a green roof may have been necessary. Generally, there will be a critical density at which point stormwater storage becomes much more expensive. The Engineer should advise the Owner to weigh profit rather than revenue against construction cost associated with increased density developments.

The totals that follow basically weigh the cost of pipe conveyance versus a system that uses BMPs to convey stormwater.

CONVENTIONAL INFRASTRUCTURE DIFFERENTIAL

ITEMS CONSIDERED					
PIPES					
SIZES	LENGTH (LF)		COST/LF		TOTAL
4" (UNDERDRAIN)	0	$	4.00	$	-
12"	190	$	35.00	$	6,650.00
15"	334	$	35.50	$	11,857.00
18"		$	36.50	$	-
21"	413	$	38.00	$	15,694.00
Total Pipe cost				$	34,201.00
STRUCTURES					
SIZE	QUANTITY		COST/STR		TOTAL
4' Diameter Manhole Basins complete	6	$	1,500.00	$	9,000.00
UNDERGROUND STORAGE					
	QUANTITY (AC-FT)		COST/AC-FT		TOTAL
Stormtech Chambers	0.386	$	250,000.00	$	96,500.00
WET POND EXCAVATION					
	QUANTITY (CYD.)		COST/YARD		TOTAL
	18069	$	5.00	$	90,345.00
PLANTING					
TURF GRASS SEED					
	QUANTITY (SQ.FT)		COST/SQ.FT.		TOTAL
	192535	$	0.04	$	7,701.41
TOTAL DIFFERENTIAL ESTIMATE				$	237,747.41

DISTRIBUTED STORAGE INFRASTRUCTURE DIFFERENTIAL

ITEMS CONSIDERED					
PIPES					
SIZES	LENGTH (LF)		COST/LF		TOTAL
4" (UNDERDRAIN)	1050	$	4.00	$	4,200.00
12"	390	$	35.00	$	13,650.00
15"	0	$	35.50	$	-
18"	0	$	36.50	$	-
21"	0	$	38.00	$	-
Total Pipe cost				$	17,850.00
STRUCTURES					
SIZE	QUANTITY		COST/STR		TOTAL
32" Agridrain Raingarden outlets Comple	4	$	950.00	$	3,800.00
BMP EXCAVATION					
	QUANTITY (CYD.)		COST/YARD		TOTAL
	13086	$	5.00	$	65,430.00
RAINGARDEN RETAIN WALLS					
	QUANTITY (SF)		COST/SF		TOTAL
	72	$	15.00	$	1,080.00
PLANTING					
BMP 2' ENGINEERED BACKFILL					
	QUANTITY (CYD.)		COST/YARD		TOTAL
	341	$	60.00	$	20,444.44
LIVE PLUG MATERIAL 3' O.C.					
	QUANTITY (SQ.FT)		COST/SQ.FT.		TOTAL
	667	$	4.00	$	2,666.67
TOTAL DIFFERENTIAL ESTIMATE				$	111,271.11

Appendix D

Green Roof Evaluation

Curve Number Reductions for Green Roofs

This Appendix serves to lend guidance to Engineers in order to account for the hydrologic analysis of green roofs. Simply looking up curve numbers for green roofs generally yields a wide variety of curve numbers which may or may not respect the specific characteristics of the roof. There are methods to calculate the behavior of the roof based upon the specific design. The first would be to model the roof with a curve number of 98 which discharges to a "pond" with a stage-storage relationship respective of the porosity of the material specified for planting and outletting as designed. The second method is to utilize SCS methods to assign an adjusted curve number to the green roof. The NRCS provides equations for this. The equations basically subtract the roof top storage from the expected runoff volume. Then the curve number that would produce the new runoff volume is assigned to the roof. The methods below can also be used beyond the green roof analysis as a tool to project how much distributed storage would be necessary per acre to yield a desired reduced curve number. This can be particularly useful in regions which regulate runoff *volume*.

SCS hydrologic methods calculate storm runoff volumes using rainfall, initial abstraction, potential retention based on land use and soil type, and retained rainfall volume. These relationships can be expressed in the SCS equations:

$$Q = (P - 0.2S)^2 / (P + 0.8S)$$

$$S = 1000/CN - 10$$

Where;
Q = runoff volume in inches
P = design storm rainfall volume in inches
S = potential maximum retention and initial abstraction
CN = runoff curve number based on land use and soil type

<u>Step 1 is the calculation of additional storage specified as part of the green roof:</u>

Assuming a 4" depth planting soil with a void ratio of 0.3 would allow 0.099 cu-ft per sq-ft of green roof.
Define Storage Depth, S_d = 0.099 ft.

<u>Step 2 is the calculation of runoff depth without the green roof:</u>

$$Q_d = (P - Ia)^2 / (P - Ia) + 1000/CN - 10$$

Where;
Q_d = Default runoff depth
Ia = Initial abstraction (0.2S)
CN = Default curve number

Therefore:
$Q_d = (6.00 - 0.04)^2 / (6.00 - 0.04) + 1000/98 - 10$
Q_d = 5.76 in.

<u>Step 3 is the calculation of the revised runoff volume given the green roof:</u>

$Q_g = Q_d - S_d*12$
Q_g = 4.57 in.

<u>Step 4 is the back calculation of reduced curve number:</u>

$RCN = 200 / \{(P + 2* Q_g +2) – (5* Q_g *P + 4* Q_g^{2})^{1/2}$

RCN = 88

Once a spreadsheet is created, the designer can quickly calculate how much distributed storage would be required to, for example, maintain the pre-development curve number.

Other depths of green roofs would produce the reduced curve numbers in Table 1. The designer could also design the media depth and engineer the void ratio to account for the water quality volume, if desired.

Table 1

Media Depth		Void Ratio	Default CN	RCN
4	in.	0.3	98	88
6	in.	0.3	98	82
9	in.	0.3	98	73
12	in.	0.3	98	63

Details of the use and derivation of the above equations can be found in Technical Reference 55. The above results reflect the assumption that runoff is effectively removed from the storm.

Appendix E

Stormwater BMP Inspection Fee Calculation

The City of Indianapolis via Section 103.04 in the Draft Stormwater Manual provides for drainage fees. This includes inspection fees for City inspection of BMPs. Example sites are discussed in order to aide Applicants in the filing of appropriate fees. These examples even include a scenario with 6 raingardens throughout a ¾ acre parking lot and classify this as a single BMP for the calculation of fees. However, more guidance may be warranted. It is currently unclear how many raingardens, or how large of a parking lot can be classified as a single BMP. Also, it is intuitive to presume that not all BMPs are equally easy to inspect; i.e. a catch basin insert which requires inspection beneath the pavement seems more difficult to inspect than wet ponds.

Based upon Section 103.04, the following represents the presumption of applicable inspection fees for both the Conventional and Distributed Storage Alternatives. For the Distributed Storage Alternative, the raingardens were grouped according to common outlet point. For example, raingardens 1 - 3 all discharge to the north swale and are counted as a single BMP while raingardens 4 – 9 all discharge to the south swale and are counted as a single BMP:

Conventional:

Number of BMPs		1	
First three years LS	$	705.00	per BMP
Annual inspection	$	235.00	per BMP
additional inspections	$	235.00	per hour
capital cost	$	705.00	
operating cost	$	235.00	

Distributed Storage:

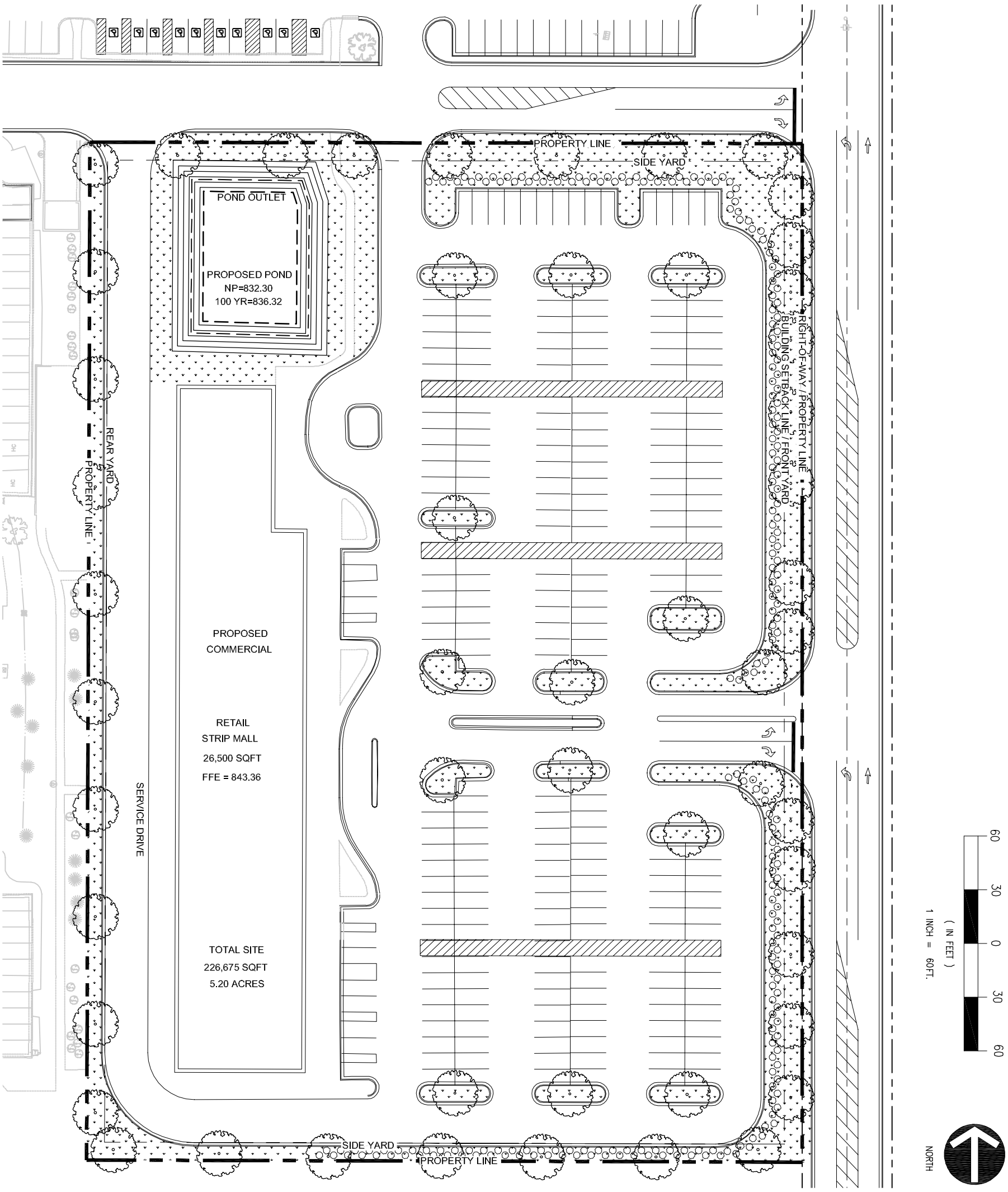
Number of BMPs		5	
First three years LS	$	705.00	per BMP
Annual inspection	$	235.00	per BMP
additional inspections	$	235.00	per hour
capital cost	$ 3,525.00		
operating cost	$ 1,175.00		

The results above indicate that the inspection fees mandated by the City represent an additional cost to Owner should the distributed storage approach be selected. The design life of the facility is too hypothetical to analyze the payback period for the capital cost. However, a typical lease rate for the 26,500 square foot facility could likely be between $10 and $15 per square foot. The operating cost differential above is $940 per year. Therefore, the increased aethstetic appeal of the distributed storage alternative would need to merit an additional $ 0.04 per square foot on the lease rate in order to discount for the apparent increased cost of inspection.

Inspection and maintenance of BMPs is most directly related to the amount of suspended solids accrued within them. Suspended solids generally originate from stormwater flow off impervious surfaces. Therefore, as the City moves toward more distributed storage and source control alternatives, it may become more equitable and easier to quantify inspection fees based upon impervious surface acreage, rather than “number of BMPs”.

Appendix F

Landscape plan



LEGEND

- REQUIRED DECIDUOUS TREE
- REQUIRED SHRUB
- TURF GRASS – IRRIGATION REQUIRED
- PEDESTRIAN CROSSING
- PROPERTY BOUNDARY / RIGHT-OF-WAY
- BUILDING SETBACK / REQUIRED YARD

LANDSCAPE REQUIREMENTS

FRONT YARD (570')
1. TREES (40' O.C.)
   15 DECIDUOUS TREES REQUIRED
   15 DECIDUOUS TREES PROVIDED
2. SCREENING (500' PARKING – 4' O.C.)
   125 SHRUBS REQUIRED
   125 SHRUBS PROVIDED

SIDE YARD – NORTH (400')
1. TREES (60' O.C.)
   7 DECIDUOUS TREES REQUIRED
   7 DECIDUOUS TREES PROVIDED
2. SCREENING (190' PARKING – 4' O.C.)
   48 SHRUBS REQUIRED
   48 SHRUBS PROVIDED

SIDE YARD – SOUTH (400')
1. TREES (60' O.C.)
   7 DECIDUOUS TREES REQUIRED
   7 DECIDUOUS TREES PROVIDED
2. SCREENING (237' PARKING – 4' O.C.)
   60 SHRUBS REQUIRED
   60 SHRUBS PROVIDED

REAR YARD (570')
1. TREES (60' O.C.)
   10 DECIDUOUS TREES REQUIRED
   10 DECIDUOUS TREES PROVIDED

INTERIOR PARKING LOT (247 PARKING SPACES)
1. ISLAND AREA (15 SQFT/PARKING SPACE)
   3,705 SQFT REQUIRED
   4,440 SQFT PROVIDED
2. TREES (1 TREE/20 PARKING SPACES)
   13 DECIDUOUS TREES REQUIRED
   13 DECIDUOUS TREES PROVIDED

DRAWING NUMBER
C.1a
SHEET 1a OF 4

PROJECT NUMBER
01.0026.A.1

GREEN INFRASTRUCTURE
SITE EXAMLPES

CONVENTIONAL LAYOUT
LANDSCAPE PLAN

DWN BY: EEK
CHKD. BY: JTB
SCALE: 60
DATE: AUGUST 2008

CITY OF INDIANAPOLIS
AMEC EARTH & ENVIRONMENTAL
INDIANAPOLIS, INDIANA

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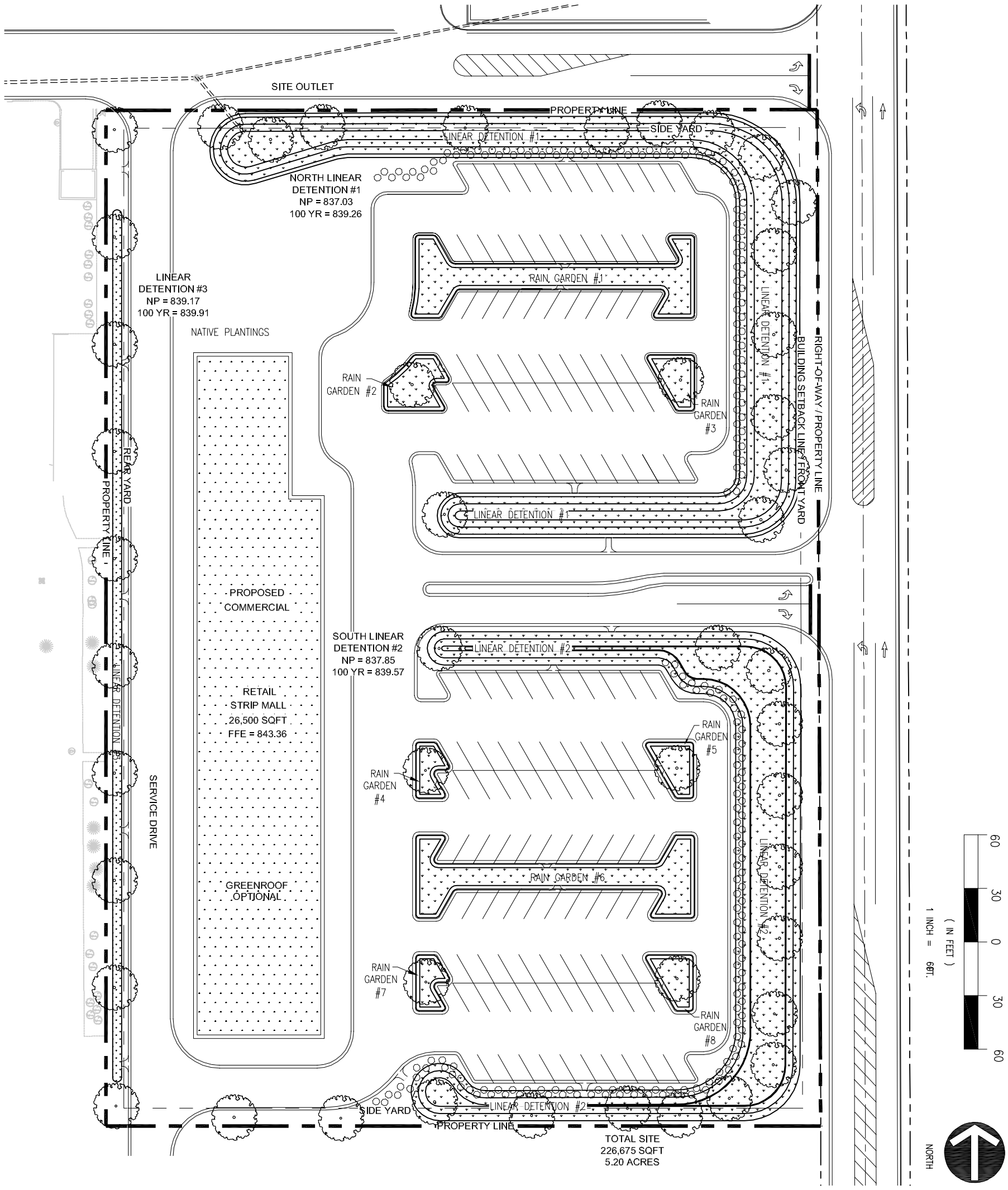
INDIANAPOLIS, INDIANA 46202
Ph: (317) 423-0690 Fax: (317) 423-0696



LEGEND

- REQUIRED DECIDUOUS TREE
- REQUIRED SHRUB
- WET MESIC NATIVE SEED/PLUG MIX – NO IRRIGATION REQUIRED
- OPTIONAL GREEN ROOF
- PROPERTY BOUNDARY / RIGHT-OF-WAY
- BUILDING SETBACK / REQUIRED YARD

LANDSCAPE REQUIREMENTS

FRONT YARD (570')
1. TREES (40' O.C.)
   15 DECIDUOUS TREES REQUIRED
   15 DECIDUOUS TREES PROVIDED
2. SCREENING (414' PARKING – 4' O.C.)
   104 SHRUBS REQUIRED
   116 SHRUBS PROVIDED

SIDE YARD – NORTH (400')
1. TREES (60' O.C.)
   7 DECIDUOUS TREES REQUIRED
   7 DECIDUOUS TREES PROVIDED
2. SCREENING (178' PARKING – 4' O.C.)
   45 SHRUBS REQUIRED
   46 SHRUBS PROVIDED

SIDE YARD – SOUTH (400')
1. TREES (60' O.C.)
   7 DECIDUOUS TREES REQUIRED
   7 DECIDUOUS TREES PROVIDED
2. SCREENING (178' PARKING – 4' O.C.)
   45 SHRUBS REQUIRED
   50 SHRUBS PROVIDED

REAR YARD (570')
1. TREES (60' O.C.)
   10 DECIDUOUS TREES REQUIRED
   10 DECIDUOUS TREES PROVIDED

INTERIOR PARKING LOT (150 PARKING SPACES)
1. ISLAND AREA (15 SQFT/PARKING SPACE)
   2,250 SQFT REQUIRED
   9,852 SQFT PROVIDED
2. TREES (1 TREE/20 PARKING SPACES)
   8 DECIDUOUS TREES REQUIRED
   8 DECIDUOUS TREES PROVIDED

DRAWING NUMBER
C.2a
SHEET 2a OF 4

PROJECT NUMBER
01.0026.A.1

GREEN INFRASTRUCTURE
SITE EXAMLPES

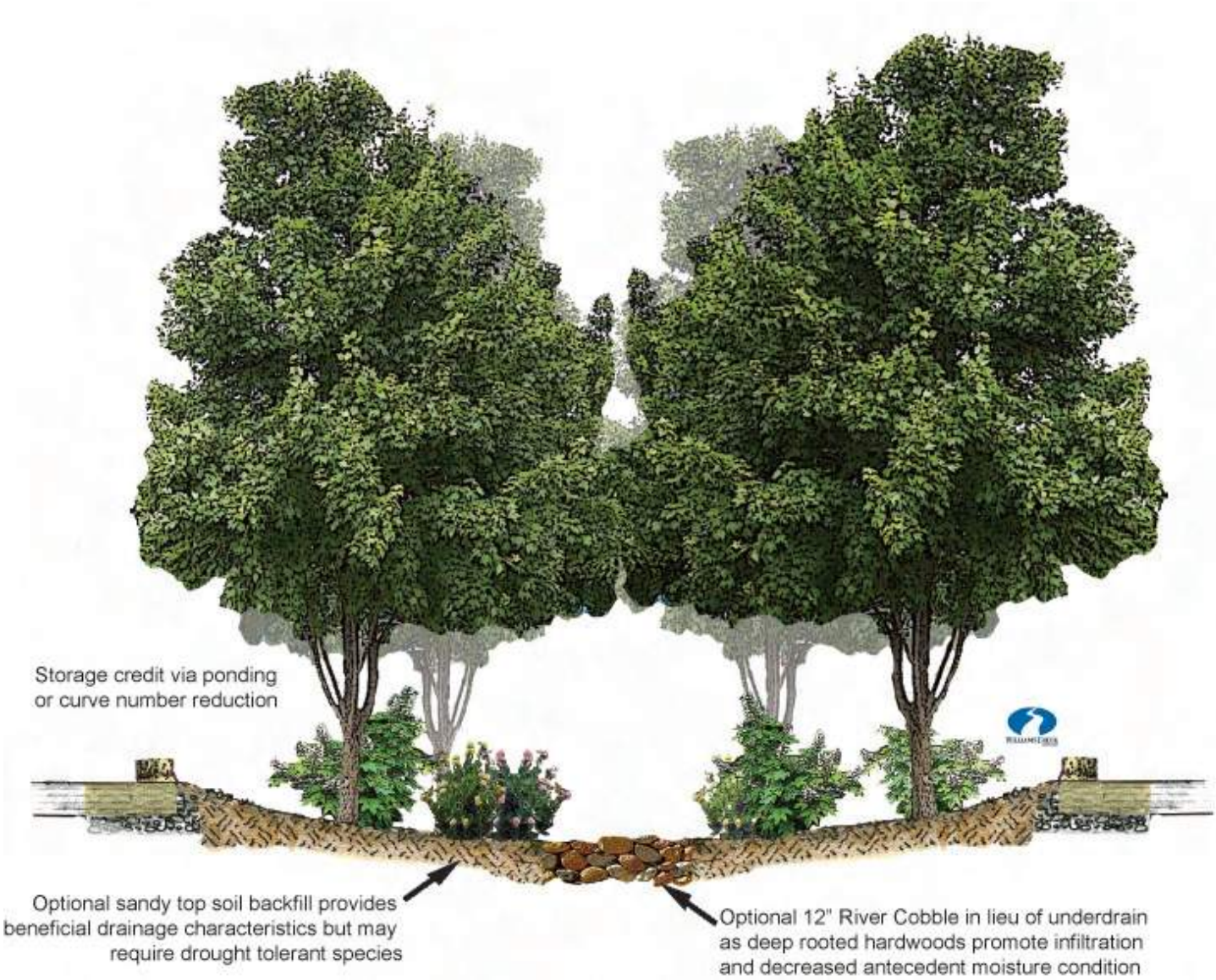
LID LAYOUT
LANDSCAPE PLAN

DWN BY: EEK
CHKD. BY: JTB
SCALE: 60
DATE: AUGUST 2008

CITY OF INDIANAPOLIS
AMEC EARTH & ENVIRONMENTAL
INDIANAPOLIS, INDIANA

WILLIAMS CREEK CONSULTING, INC.
919 NORTH EAST STREET
INDIANAPOLIS, INDIANA 46202
Ph: (317) 423-0690 Fax: (317) 423-0696

LID CONCEPTUAL DESIGN



SECTION OF RAINGARDEN ISLANDS

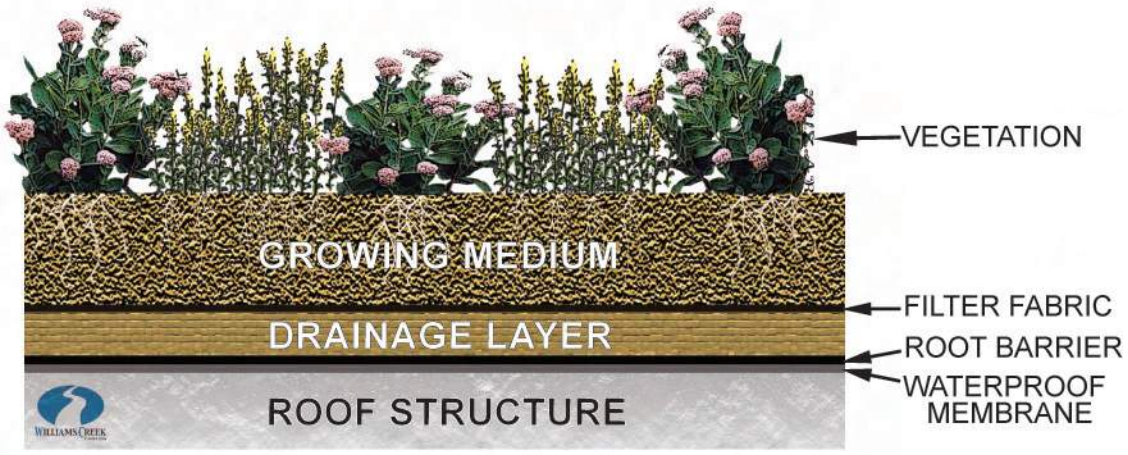
SECTION OF SWALE WITH NATIVE VEGETATION

Note: Native plantings may have low post-established maintenance requirements, such as only 1-2 mowings annually. Mowing creates continual grass clipping discharges (TSS). Clippings are not discharged with native plantings at conventional rates due to reduced mowing needs.

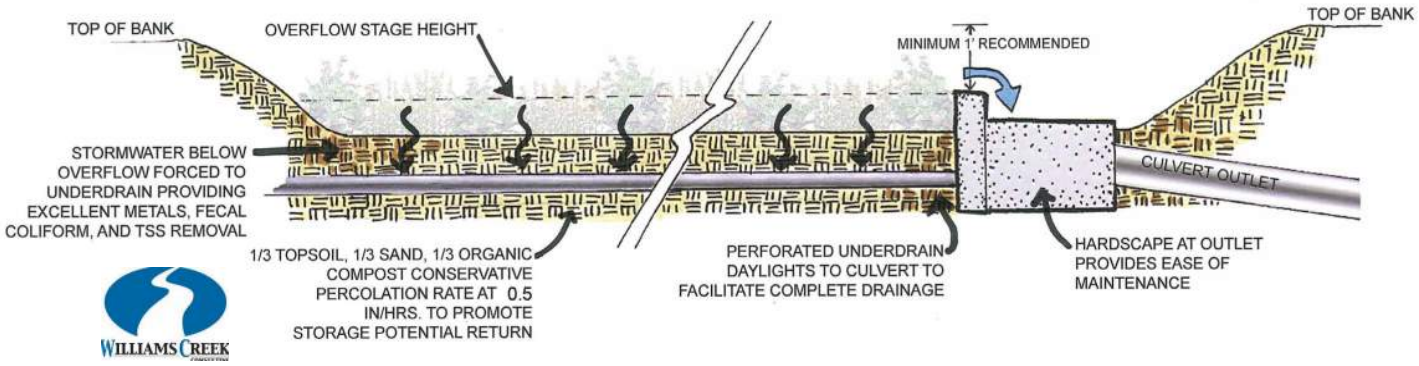
WET AND/OR DRY POND EDGE OPTIONS- CONVENTIONAL TURF EDGE

WET AND/OR DRY POND EDGE OPTIONS- NATIVE FORB AND GRASS EDGE

SECTION OF BASIN WITH NATIVE VEGETATION

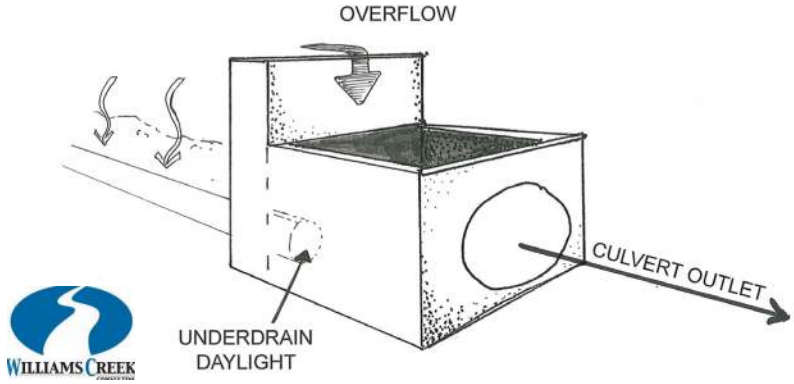


GREEN ROOF SECTION WITH TYPICAL LAYERS

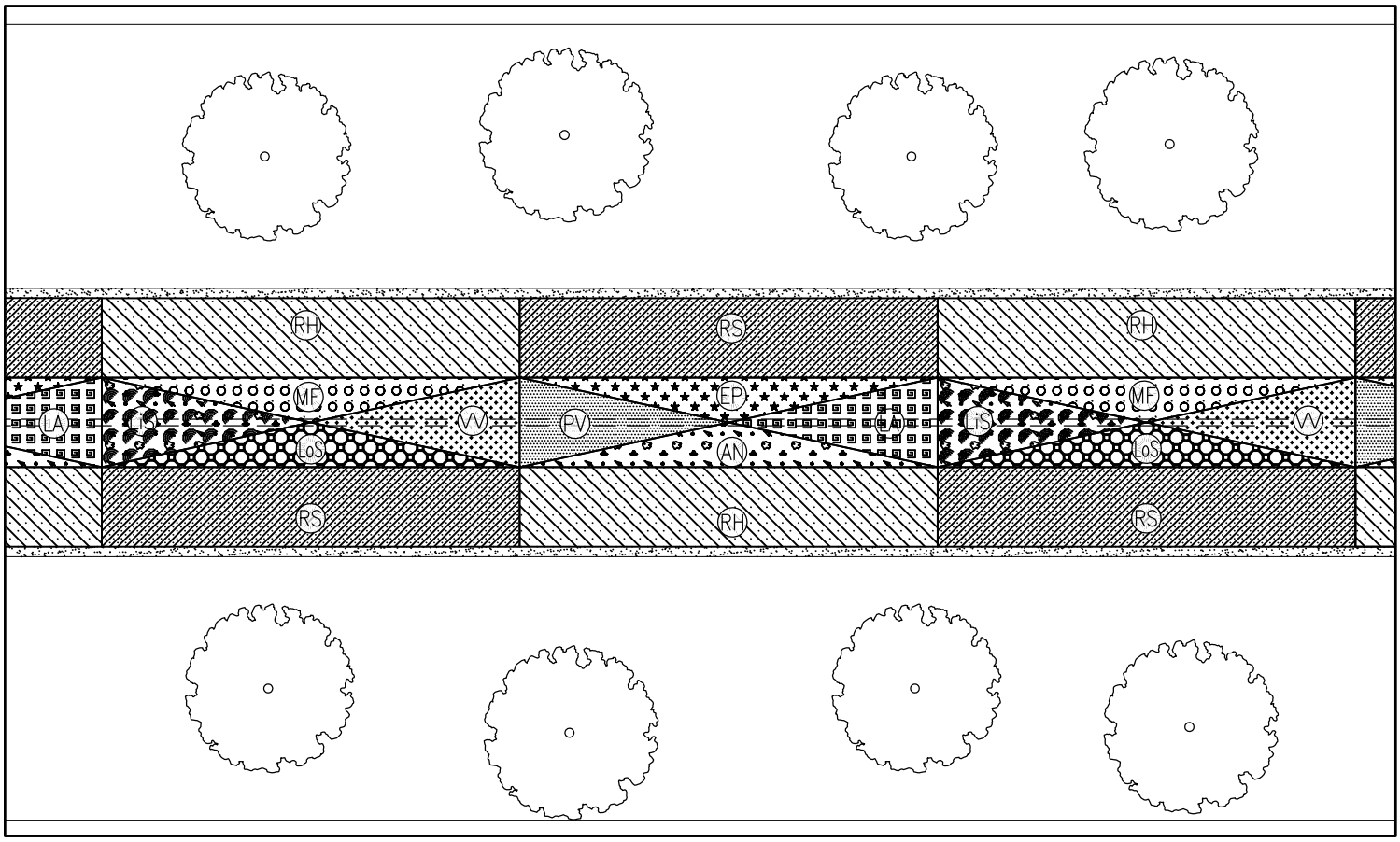


TYPICAL LINEAR SWALE OUTLET DIAGRAM
PROFILE VIEW

NTS



TYPICAL LINEAR SWALE HARDSCAPE OUTLET
BASIC DETAIL VIEW



NATIVE PLANT RAINGARDEN PLUG MIX		
TYPE OF PLUGS - FORBS		
LATIN NAME	COMMON NAME	LABEL
Aster novae-angliae	New England Aster	AN
Echinacea purpurea	Purple Coneflower	EP
Liatris spicata	Dense Blazing Star	LiS
Liatris aspera	Rough Blazing Star	LA
Lobelia siphilitica	Great Lobelia	LoS
Monarda fistulosa	Bergamot	MF
Physotegia virginiana	Obedient Plant-White	PV
Rudbeckia hirta	Black-Eyed Susan	RH
Rudbeckia subtomentosa	Sweet Black-Eyed Susan	RS
Veronicastrum virginicum	Culver's Root	VV
TOTAL PLUGS		

LEGEND

- FLOWLINE
- ANCHOR WALL HIGHLAND STONE
- ASTER NOVAE-ANGLIAE
- ECHINACEA PURPUREA
- LIATRIS SPICATA
- LIATRIS ASPERA
- LOBELIA SIPHILITICA
- MONARDA FISTULOSA
- PHYSOTEGIA VIRGINIANA
- RUDBECKIA HIRTA
- RUDBECKIA SUBTOMENTOSA
- VERONICASTRUM VIRGINICUM
- XX FORB SPECIES CALL OUT

PLANTING PLAN EXAMPLE UTILIZING NATIVES IN A FORMALIZED PATTERN

Attachment 1: Guidelines for Subsuface Investigation and Infiltration Testing

1.0 Introduction

The guidelines for subsurface investigation and infiltration testing include: evaluation criteria, evaluation process, and soil infiltration protocol to follow when designing infiltration Best Mangement Practices (BMPs). Infiltration BMPs are storm water management practices aimed at infiltrating some fraction of storm water runoff from developed surfaces into the soil horizon, attempting to replicate the natural hydrologic regime. Infiltration testing should be performed at the location of proposed infiltration BMPs per the guidelines provided in this attachment. Table 1.1 summarizes the infiltration BMP siting requirements for evalutating their suitability. Suitable infiltration BMP sites shall meet or exceed the evaluation criteria presented in Table 1.1

Table 1.1 Evaluation Criteria

Depth to bedrock	> 4 feet from invert of infiltration BMP to bedrock
Depth to water table	> 2 feet from invert of infiltration BMP to seasonal high water table
Infiltration rate	> 0.5 in/hr (infiltration rate of native soil at invert of infiltration BMP)
Hotspot	No infiltration BMPs allowed at Hotspots (See Section 2.0)

Infiltration BMPs may not be suited for every site. For example, sites with soil and groundwater contamination are not suited for infiltration BMPs. More examples of Hotspots where infiltration BMPs are not suited are provided in Section 2 of this document. If your site is suitable for infiltration BMPs collecting reliable in situ infiltration rates is critical for design. Section 3 provides accepted methodology to use when collecting infiltration rates for your site and reporting requirements. The guidelines are described in detail in this document.

Safety

As with all field work and testing, attention to all applicable Occupational Safety and Health Administration (OSHA) regulations and local guidelines related to earthwork and excavation is required. Digging and excavation should never be conducted without adequate notification through the Indiana Underground Plant Protection Service (IUPPS www.iupps.org or call 811). Excavations should never be left unsecured and unmarked, and all applicable authorities should be notified prior to any work.

2.0 Hotspot Investigation Procedures

Justification: This policy is intended to encourage infiltration on most sites while addressing potential contamination of groundwater and surface water caused by infiltration on sites with contaminated soils.

Required Steps:

Step 1: Determine the prior land use at the site to be developed, and review any data on soil or groundwater quality.

- For larger development sites, a formal Phase I site assessment is often required by the lender in order to determine if any environmental hazard exists on the site. A determination of prior land use is part of this assessment.

- On sites where a formal Phase I is not conducted, methods to determine prior land use may include a title search, aerial photographs, soil surveys, topographic maps, city and state regulatory databases, and a review of state and local records.

Step 2: Determine the potential for contamination based on available data and prior land use.

- The following land uses are considered to have a potential for contaminated soil which may adversely affect the quality of groundwater discharging to surface water. Infiltration is prohibited on these sites unless the applicant can show that there is no potential for contaminant migration due to infiltration.

  - Sites designated as CERCLA (Superfund) sites
  - Auto recycler facilities and junk yards
  - Commercial laundry and dry cleaning
  - Commercial nurseries
  - Vehicle fueling stations, service and maintenance areas
  - Toxic chemical manufacturing and storage
  - Petroleum storage and refining
  - Public works storage areas
  - Airports and deicing facilities, railroads and rail yards, marinas and ports

- Heavy manufacturing and power generation
- Metal production, plating and engraving operations
- Landfills and hazardous waste material disposal
- Sites on subsurface material such as fly ash known to contain mobile heavy metals and toxins

Step 3: For sites that do not qualify as hotspots, proceed with design of infiltration BMP facilities. For hotspots, proceed with design of water quality treatment facilities.

Reference: *http://www.phillyriverinfo.org/WICLibrary/Appendices%20A-C.pdf*

3.0 Subsurface Investigation and Soil Infiltration Testing

Subsurface investigation and soil infiltration testing is competed to determine the design infiltration rate and ensure adequate distance between the bottom elevation of the infiltration BMP and bedrock and ground water. This section provides the four steps for soil infiltration testing and reporting. It is recommended that soil evaluation and investigation be conducted following development of a concept plan or early in the development of a preliminary plan. Soil evaluation and investigation may be conducted by soil scientists, local health department sanitarians, design engineers, professional geologists, and other qualified professionals and technicians. The storm water designer is *strongly* encouraged to directly observe the testing process to obtain a first-hand understanding of site conditions.

Step 1. Background evaluation

Prior to performing testing and developing a detailed site plan, existing conditions at the site should be inventoried and mapped including, but not limited to:

- Existing mapped soils and USDA Hydrologic Soil Group classifications.
- Existing geology, including depth to bedrock, or other features of note.
- Existing hydrology (topography, slope, drainage patterns, streams, and watershed boundaries).
- Existing and past land use conditions.
- Other natural or man-made features or conditions that may impact design, such as existing nearby structures (buildings, walls), abandoned wells, etc.
- A concept design plan or preliminary layout plan for development including:
    - Preliminary grading plan and areas of cut and fill,
    - Proposed location of development (specifically, location of infiltration BMPs),
    - Location of all former, existing, and proposed onsite wastewater systems, water supply sources and wells,
    - Location of other features of note such as existing utilities and rights-of-way.

Step 2. Soil Boring and Test Pit Observations

In Step 1, the designer should determine the potential location of infiltration BMPs. The approximate location of these BMPs should be on the proposed development plan and serve as the basis for the location and number of tests to be performed onsite. The tests performed can be

test pits or soil borings. Information to aid the initial site planning is listed below. Test pit and soil boring stakes should be left in the field to identify where site investigation were performed. These are being completed to ensure adequate distance between the bottom eleveation of the infiltration BMP and the bedrock and groundwater. Table 3.1 provides guidelines for the location and quantity of test pits and soil borings.

Table 3.1 Infiltration BMP Area Investigation Guidelines

Test	Test Pit or Soil Boring
Quantity	< 1,000 ft^2 = 2 tests 1,000 – 10,000 ft^2 = 4 tests > 10,000 ft^2 = 4 tests + 1 test for every additional 5,000 ft^2
Location	Proposed infiltration area
Depth	Excavate test pit or penetrate each standard soil boring to a depth at least 4 feet below the bottom of the propsed infiltration area.

Boring Log Preliminary Evaluation

The boring log should be continued to a depth adequate to show separation between the bottom of the infiltration BMP and the seasonal high groundwater level. (The boring depth will vary, based on BMP depth.)

Boring logs may be used as a guide during preliminary evaluation of the feasibility of infiltration BMPs. The logs cannot be used in lieu of post-construction testing or as an infiltration test to establish a design infiltration rate. The submittal for each boring log must include an associated soil classification consistent with ASTM D2488-00, Standard Practice for Classification for Description and Identification of Soils (Visual-Manual Procedure). The submittal should also include any additional pertinent subsurface information, such as soil moisture conditions, depth and description of undocumented or engineered fill, soil color and mottling conditions, soil stiffness or density, and approximate depth of contact between soil types.

Boring logs may be used to characterize the soils for a proposed facility as long as the log follows ASTM D2488-00, is performed by a qualified professional (Professional Engineer, Registered Geologist, or Certified Engineering Geologist), and demonstrates the potential for infiltration. Logs from outside the immediate vicinity of the proposed facility may be used if the qualified professional can determine that the soil strata are consistent between the proposed facility and the borehole.

Test Pits

A test pit allows visual observation of the soil horizons and overall soil conditions both horizontally and vertically in that portion of the site. A test pit consists of a backhoe-excavated trench. The trench should be benched at a depth of 2-3 feet for access and/or infiltration testing. At each test pit, the following conditions are to be noted and described. Depth measurements should be described as depth below the ground surface:

- Soil horizons (upper and lower boundary),
- Soil texture, structure, and color for each horizon,
- Color patterns (mottling) and observed depth,
- Depth to water table,
- Depth to bedrock,
- Observance of pores or roots (size, depth),
- Estimated type and percent coarse fragments,
- Hardpan or limiting layers,
- Strike and dip of horizons (especially lateral direction of flow at limiting layers), and
- Additional comments or observations.

At the designer's discretion, soil samples may be collected at various horizons for additional analysis. Following testing, the test pits should be refilled with the original soil and the topsoil replaced. A test pit should ***never*** be accessed if soil conditions are unsuitable or unstable for safe entry, or if site constraints preclude entry. OSHA regulations should always be observed.

It is important that the test pit provide information related to conditions at the bottom of the proposed infiltration BMP. If the BMP depth will be greater than 90 inches below existing grade, deeper excavation of the test pit will be required. The designer is cautioned regarding the proposal of systems that are significantly deeper than the existing topography, as the suitability for infiltration is likely to decrease. The design engineer is encouraged to consider reducing grading and earthwork as needed to reduce site disturbance and provide greater opportunity for storm water management.

The recommendations in Table 3.1 are guidelines. Additional tests should be conducted if local conditions indicate significant variability in soil types, geology, water table levels, depth and type of bedrock, topography, etc. Similarly, uniform site conditions may indicate that fewer test pits are required. Excessive testing and disturbance of the site prior to construction is not recommended.

Step 3. Infiltration Tests for Acquiring Design Infiltration Rate

A variety of field tests exists for determining the infiltration capacity of a soil. Laboratory tests are not recommended, as a homogeneous laboratory sample does not represent field conditions. Infiltration tests should be conducted in the field. Infiltration tests should not be conducted in the rain, within 24 hours of significant rainfall events (> 0.5 inches), or when the temperature is below freezing. Based on observed field conditions, the designer may elect to modify the

proposed bottom elevation of a BMP. Personnel conducting infiltration tests should be prepared to adjust test locations and depths depending on observed conditions.

Table 3.2 Infiltration Testing Guidelines

Test	Infiltration
Quantity	< 1,000 ft^2 = 2 tests 1,000 – 10,000 ft^2 = 4 tests > 10,000 ft^2 = 4 tests + 1 test for every additional 5,000 ft^2
Location	Proposed infiltration area. May be performed performed within an open test pit or a standard soil boring.
Depth	4 feet below the bottom of the propsed infiltration area.

Methodologies discussed in this protocol include:

- Double-ring infiltrometer tests
- Percolation tests

There are differences between the two methods. A double-ring infiltrometer test estimates the vertical movement of water through the bottom of the test area. The outer ring helps to reduce the lateral movement of water in the soil from the inner ring. A percolation test allows water movement through both the bottom and sides of the test area. For this reason, the measured rate of water level drop in a percolation test must be adjusted to represent the discharge that is occurring on both the bottom and sides of the percolation test hole. Other testing methodologies and standards that are available but not discussed in detail in this protocol include (but are not limited to):

• Constant head double-ring infiltrometer.

• Testing as described in the *Maryland Storm water Manual*, Appendix D.1, using five-inch diameter casing.

• ASTM 2003 Volume 4.08, Soil and Rock (I): Designation D 3385-03, Standard Test Method for Infiltration Rate of Soils in Field Using a Double-Ring Infiltrometer.

• ASTM 2002 Volume 4.09, Soil and Rock (II): Designation D 5093-90, Standard Test Method for Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer with a Sealed-Inner Ring.

• Guelph permeameter.

• Constant head permeameter (Amoozemeter).

Methodology for double-ring infiltrometer field test

A double-ring infiltrometer consists of two concentric metal rings. The rings are driven into the ground and filled with water. The outer ring helps to prevent divergent flow. The drop-in water level or volume in the inner ring is used to calculate an infiltration rate. The infiltration rate is the amount of water per surface area and time unit which penetrates the soils. The diameter of the inner ring should be approximately 50-70 percent of the diameter of the outer ring, with a minimum inner ring size of four inches. Double-ring infiltrometer testing equipment designed specifically for that purpose may be purchased. However, field testing for storm water BMP design may also be conducted with readily available materials. Equipment for double-ring infiltrometer test include: Two concentric cylinder rings six inches or greater in height. Inner ring diameter equal to 50-70 percent of outer ring diameter (i.e., an eight-inch ring and a 12-inch ring). Material typically available at a hardware store may be acceptable.

- Water supply,
- Stopwatch or timer,
- Ruler or metal measuring tape,
- Flat wooden board for driving cylinders uniformly into soil,
- Rubber mallet, and
- Log sheets for recording data.

Procedure for double-ring infiltrometer test

1.) Prepare level testing area.

2.) Place outer ring in place; place flat board on ring and drive ring into soil to a minimum depth of two inches.

3.) Place inner ring in center of outer ring; place flat board on ring and drive ring into soil a minimum of two inches. The bottom rim of both rings should be at the same level.

4.) The test area should be presoaked immediately prior to testing. Fill both rings with water to water level indicator mark or rim at 30-minute intervals for one hour. The minimum water depth should be four inches. The drop in the water level during the last 30 minutes of the presoaking period should be applied to the following standard to determine the time interval between readings:

° If water level drop is two inches or more, use 10-minute measurement intervals.

° If water level drop is less than two inches, use 30-minute measurement intervals.

• Obtain a reading of the drop in water level in the center ring at appropriate time intervals. After each reading, refill both rings to water level indicator mark or rim. Measurement to the water level in the center ring should be made from a fixed reference

point and should continue at the interval determined until a minimum of eight readings are completed or until a stabilized rate of drop is obtained, whichever occurs first. A stabilized rate of drop means a difference of ¼ inch or less of drop between the highest and lowest readings of four consecutive readings.

• The drop that occurs in the center ring during the final period or the average stabilized rate, expressed as inches per hour, should represent the infiltration rate for that test location.

Methodology for percolation test

Equipment for percolation test:

• Post hole digger or auger,

• Water supply,

• Stopwatch or timer,

• Ruler or metal measuring tape,

• Log sheets for recording data,

• Knife blade or sharp-pointed instrument (for soil scarification),

• Course sand or fine gravel, and

• Object for fixed-reference point during measurement (nail, toothpick, etc.).

Procedure for percolation test

This percolation test methodology is based largely on the criteria for onsite sewage investigation of soils. A 24-hour pre-soak is generally not required as infiltration systems, unlike wastewater systems, will not be continuously saturated.

1. Prepare level testing area.

2. Prepare hole having a uniform diameter of 6-10 inches and a depth of 8-12 inches. The bottom and sides of the hole should be scarified with a knife blade or sharp-pointed instrument to completely remove any smeared soil surfaces and to provide a natural soil interface into which water may percolate. Loose material should be removed from the hole.

3. (Optional) Two inches of coarse sand or fine gravel may be placed in the bottom of the hole to protect the soil from scouring and clogging of the pores.

4. Test holes should be presoaked immediately prior to testing. Water should be placed in the hole to a minimum depth of six inches over the bottom and readjusted every 30 minutes for one hour.

• The drop in the water level during the last 30 minutes of the final presoaking period should be applied to the following standard to determine the time interval between readings for each percolation hole:

° If water remains in the hole, the interval for readings during the percolation test should be 30 minutes.

° If no water remains in the hole, the interval for readings during the percolation test may be reduced to 10 minutes.

• After the final presoaking period, water in the hole should again be adjusted to a minimum depth of six inches and readjusted when necessary after each reading. A nail or marker should be placed at a fixed reference point to indicate the water refill level. The water level depth and hole diameter should be recorded.

• Measurement to the water level in the individual percolation holes should be made from a fixed reference point and should continue at the interval determined from the previous step for each individual percolation hole until a minimum of eight readings are completed or until a stabilized rate of drop is obtained, whichever occurs first. A stabilized rate of drop means a difference of ¼ inch or less of drop between the highest and lowest readings of four consecutive readings.

• The drop that occurs in the percolation hole during the final period, expressed as inches per hour, should represent the percolation rate for that test location.

• The average measured rate must be adjusted to account for the discharge of water from both the sides and bottom of the hole and to develop a representative infiltration rate. The average/ final percolation rate should be adjusted for each percolation test according to the following formula:

Infiltration Rate = (Percolation Rate)/(Reduction Factor) Where the Reduction Factor is given by**:

$$R_f = (2d_1 - \Delta d)/DIA + 1$$

With:
d_1 = Initial Water Depth (in.)
Δd = Average/Final Water Level Drop (in.)
DIA = Diameter of the Percolation Hole (in.)

The percolation rate is simply divided by the reduction factor as calculated above or shown in Table 3.3 below to yield the representative infiltration rate. In most cases, the reduction factor varies from about two to four depending on the percolation hole dimensions and water level drop – wider and shallower tests have lower reduction factors because proportionately less water exfiltrates through the sides.
*** The area reduction factor accounts for the exfiltration occurring through the sides of percolation hole. It assumes that the percolation rate is affected by the depth of water in the hole and that the percolating surface of the hole is in uniform soil. If there are significant problems with either of these assumptions then there adjustments may be necessary.*

Table 3.3 Sample Percolation Rate Adjustments

Perc. Hole Diameter (in.)	Initial Water Depth, D_1 (in.)	Ave./Final Water Level Drop, Δd (in.)	Reduction Factor, R_f
6	6	0.1	3
		0.5	2.9
		2.5	2.6
	8	0.1	3.7
		0.5	3.6
		2.5	3.3
	10	0.1	4.3
		0.5	4.3
		2.5	3.9
8	6	0.1	2.5
		0.5	2.4
		2.5	2.2
	8	0.1	3
		0.5	2.9
		2.5	2.7
	10	0.1	3.5
		0.5	3.4
		2.5	3.2
10	6	0.1	2.2
		0.5	2.2
		2.5	2
	8	0.1	2.6
		0.5	2.6
		2.5	2.4
	10	0.1	3
		0.5	3
		2.5	2.8

Additional Potential Testing – Bulk Density

Bulk density tests measure the level of compaction of a soil, which is an indicator of a soil's ability to absorb rainfall. Developed and urbanized sites often have very high bulk densities and, therefore, possess limited ability to absorb rainfall (and have high rates of storm water runoff). Vegetative and soil improvement programs can lower the soil bulk density and improve the site's ability to absorb rainfall and reduce runoff.

Applicability of Testing Results

Infiltration test results acquired using the above methods are used to determine if infiltration BMPs are suitable at a site, as well as to obtain the required data for infiltration BMP design. Even with appropriate infiltration rates, sites may be unsuitable for infiltration BMPs due to proposed grade changes (excessive cut or fill), lack of suitable areas, size constraints, or hotspots. With lower infiltration rates, the use of underdrains, treatment trains, or overflows may make the practice more suitable. Recommended infiltration rates and drain down times for infiltration practices are included in the cited attachment for each practice per Table 3.4.

Table 3.4 Drawdown Time

Infiltration BMP	Maximum Drawdown Time	Attachment
Permeable Pavement	72 hours	3
Bioinfiltration, Bioretention, Rain Garden	48 hours	5
Swale	48 hours	6
Subsurface Infiltration	72 hours	1
Infiltration Pond	48 hours	

Step 4. Soil Infiltration Report

At the conclusion of soil infiltration testing a Soil Infiltration Report should be prepared and filed with the site design documents. The Soil Infiltration Report should contain the following information:

1. Scope of investigation,
2. General description of the proposed development for which the exploration has been conducted,
3. Geologic conditions of the site,
4. Drainage facilities at the site,
5. Details of boring,
6. Description of subsoil conditions as determined from the soil and rock samples collected,
7. Groundwater table as observed from the boreholes,
8. Details on recommendations and alternatives,
9. Any anticipated construction problems, and
10. Limitations of the investigation.

The following graphic presentation also should be attached to the Soil Infiltration Report:

1. Site location map,
2. Location of boring and/or test pits with respect to the proposed development,
3. Boring logs,
4. Laboratory test results, and
5. Other special presentations.

References

Philadephia Water Department. Philadelphia Storm Water Management Guidance Manual version 2.0 Appendices A-C. April 2011

Southeast Michigan Council of Governments (SEMCOG). Appendix E Soil Infiltration Testing Protocol. Low Impact Development Manual for Michigan. 2008

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Fritton, D.D., T.T. Ratvasky, and G. W. Peterson. 1986. Determination of saturated hydraulic conductivity from soil percolation test results. Soil Sci. Soc. Am. J. 50:273-276.

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Attachment 2: Green Roof Design Guidelines

A green roof (vegetated roof/eco roof/roof garden) is a system consisting of waterproofing material, growing medium and vegetation. A green roof can be used in place of a traditional roof as a way to limit impervious site area and reduce storm water runoff. The green roof design should attempt to mimic pre-developed site hydrology, reducing post-developed peak runoff rates to near pre-developed rates. Green roofs also help mitigate runoff temperatures by keeping roofs cool and retaining much of the runoff from typical storm events. Although many green roofs consist of lightweight growing medium and low-growing succulent vegetation, other more heavily planted systems are possible; in either case the design should be self-sustaining.

There are three basic types of green roofs. An extensive green roof system is 6 inches or less in depth, and has a water saturation weight of 10-35 lbs/ft². It usually has limited accessibility and is planted with drought-tolerant succulent plants and grasses. A semi-intensive green roof contains material 25% above or below 6 inches. It may be partially accessible, has a water saturation weight of up to 50 lbs/ft² and has potential for greater plant diversity than an extensive roof. An intensive green roof is deeper than 6 inches and typically has a water saturation weight between 50-300 lbs/ft². These roofs are usually accessible to others besides maintenance and allow for great plant diversity. Each green roof project is unique, given the purpose of the building, its architecture and the preferences of its owner and end user. Since guidelines are constantly being upgraded and approved, the engineer is responsible for verifying that the design materials meet all current standards at the time of design. Green roof systems are typically comprised of the same components:

- Plant material
- Growing medium
- Filter fabric
- Drainage layer
- Insulation (optional)
- Waterproof membrane/root barrier
- Roof structure
- **Modular systems contain most or all of the above components are an alternative material.**

Table 1. Recommended Design Procedure
Early communication between design team (developer, civil engineer, structural engineer, architect, landscape architect, planner, roofer, etc.) is important.
Investigate feasibility of the installation of a green roof. A structural engineer should verify that the roof will support the weight of the green roof system.
Determine the portion of roof that will have a green roof. Typically 10% or less of the green roof is composed of non-vegetated components such as gravel and pavers.

Extensive green roofs that have an engineered growing medium of at least 3 inches thick can be permitted as a water quality volume reduction equal to the area of the green roof.
Green roofs are not considered impervious surfaces when determining storm water management requirements, but they are not zero discharge systems. The roof drainage system and the remainder of the site drainage system must safely convey roof runoff.
Develop a planting plan based on the thickness of planting media.
Complete construction plans and specifications.
If using a modular system, verify media thickness, thickness of plant media, appropriate placement of system and other design criteria before calculating the amount of runoff that will be retained.

Design Guidelines

The use of green roofs provides a quantitative benefit for both water quantity and quality management. The following paragraphs discuss the details of how a green roof affects the design, runoff quantity and quality.

Installing a green roof alters the surface response to rainfall with respect to runoff. A green roof will have a significant increase in storage capability when compared to a standard roof with little or no storage capability. The initial rainfall striking the soil of a green roof is absorbed until the soil is saturated.

The capacity of a green roof to absorb runoff is governed by planting media thickness, roof slope or "pitch", and rainfall depth. Consequently, runoff from and curve numbers (CN's) applied to a green roof may vary for the one (1), two (2), 10, and 100-year design storm events depending on individual design characteristics. To simplify the design and approval process, the City of Indianapolis has adopted a method where the post development CN used for green roofs when computing the hydrologic computations is adjusted by the average depth of the green roof soil. In general, the CN of a roof (98) may be reduced by 2 for each inch of planting soil. The following table provides sample soil depth and CN values.

Roof Thickness (in)	Curve Number (CN)
1	96
2	94
3	92
4	90
5	88
6	86

The use of these reduced curve numbers will account for reduced runoff from a green roof when the post-developed runoff rates are compared to the pre-developed runoff rates. Runoff depth is computed using the NRCS CN method. Retention, S, is a function of: land use, interception, infiltration, depression storage, and antecedent moisture. S has an empirical relationship with

CN. Curve number, CN, is an index that reflects land use, hydrologic soil group, and treatment class.

$$S = \frac{1000}{CN} - 10$$

Runoff depth, Q, for a given rainfall depth, P in inches reflect volumes and are referred to as volumes because the depths occur over the entire area.

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}$$

A design example utilizing the NRCS CN method for calculating runoff depth is provided in the Green Roof Design Example within this attachment.

Construction of a green roof in place of a standard impervious roof will also positively impact water quality design. When using the equation in Chapter 700, Section 701.04 of the City of Indianapolis Storm Water Design & Construction Specifications Manual to compute the water quality volume, the percent impervious, I, (Rv = (0.05 +0.009(I)) is reduced and the water quality volume as well. If the water quality flow rate (WQr) is calculated using the equation in City of Indianapolis Approved Storm water Quality Unit (SQU) Selection Guide, the impervious area is reduced by the area of the green roof, reducing the water quality treatment rate and the subsequent size of the water quality unit required.

Below are the Design Calculations and Design Checklists spreadsheets.

Green Roof Design Calculations				
Section 1. Existing Roof Runoff				
1	Existing Roof Area	A	14803	sq-ft
2	Curve Number	CN	98	
3	Retention	S	0.20	
4	Rainfall Depth	P	1	in
5	Runoff Depth	Q	0.79	in
6	Runoff Voume	V	0.022	acre-ft
Section 2. Proposed Green Roof Runoff				
7	Green Roof Area	A	14803	sq-ft
8	Green Roof Soil Depth	d	6	in
9	Green Roof Curve Number	CN_{GR}	86	
10	Retention	S	1.63	
11	Rainfall Depth	P	1	in
12	Runoff Depth	Q	0.20	in
13	Runoff Volume	V	0.006	acre-ft
Section 3. Proposed Green Roof Storage				
14	Green Roof Area	A	14803	sq-ft
15	Rainfall Depth	P	1	in
16	Green Roof Soil Depth	d	6	in
18	Soil Dry Weight	W_{dry}	60	lbs/ft^3
19	Soil Saturated Weight	W_{sat}	90	lbs/ft^3
20	Runoff Retained	$V_{storage}$	1.80	gal/ft^2
			0.082	acre-ft

Green Roof Design Checklist				
Section 1. Engineering/Drainage Report Requirements				
1	Storage Volume Calculations	Y/N		
2	Emergency Overflow Calculations	Y/N		
3	Water Quality Volume Calculations	Y/N		
4	Water Quantity Volume Calculations	Y/N		
5	Structural Engineers Certification (for Retrofits)	Y/N		
Section 2. Plan Requirements				
6	Soil Depth	Y/N		
7	Impermeable Membrane	Y/N		
8	Filter Fabric	Y/N		
9	Soil Specifications	Y/N		
10	Drainage Layer	Y/N		
11	Plant Specifications	Y/N		
12	Filter Fabric	Y/N		
Section 3. O & M Manual Requirements				
13	Tabular Inspection Schedule	Y/N		
14	Site Diagram with Green Roof Area	Y/N		
15	Inspections Checklist	Y/N		
16	Startup Maintenance	Y/N		
17	Fertilizer Guidance	Y/N		
18	Plant Coverage Minimum Requirement (90%)	Y/N		
19	Emergency Overflow System Inspection	Y/N		
20	Wind and Rain Erosion Inspection	Y/N		
21	Weeding	Y/N		

Green Roof Design Example:

This design example walks through the use of the Green Roof Design Guidelines contained in the Indianapolis Green Supplemental Document. This design example will illustrate the benefits of a green roof for reducing the runoff CN and providing water quantity benefits.

Collect Existing/Proposed Site Information

Existing Conditions:
Drainage Area = 1.26 acres
Roof/Parking Lot CN = 98
Lawn CN = 74
Pre-Development CN = 89
Percent Impervious = 63%

Proposed Conditions:
Drainage Area = 1.26 acres
Parking Lot CN = 98
Roof CN = 86
Lawn CN = 74
Post-Development CN = 86
Percent Impervious = 36%
Green Roof Type = Extensive
Planting Depth = 6 inches

Calculate Site Runoff

To illustrate the benefits of the green roof, existing and proposed site runoff should be compared. Refer to the Green Roof Design Guidelines for a description of the NRCS Curve Number method for calculating runoff and water quality benefits green roofs can provide.

Existing Site Runoff:

Land Use	CN	Area (sq-ft)
Roof	98	14803
Parking Lot	98	19588
Lawn	74	20495

Calculate Area Weighted CN:

$$CN = \frac{CN_1(A_1) + CN_2(A_2) + CN_3(A_3)}{A_1 + A_2 + A_3} = 89$$

Calculate S:

$$S = \frac{1000}{89} - 10 = 1.24$$

Calculate Q (P = 1 inch):

$$Q = \frac{[1'' - 0.2(1.24)]^2}{1'' + 0.8(1.24)} = 0.28''$$

Proposed Site Runoff:

Land Use	CN	Area (sq-ft)
Roof	86	14803
Parking Lot	98	19588
Lawn	74	20495

Calculate Area Weighted CN:

$$CN = \frac{CN_1(A_1) + CN_2(A_2) + CN_3(A_3)}{A_1 + A_2 + A_3} = 86$$

Calculate S:

$$S = \frac{1000}{86} - 10 = 1.63$$

Calculate Q (P = 1 inch):

$$Q = \frac{[1'' - 0.2(1.63)]^2}{1'' + 0.8(1.63)} = 0.20''$$

Calculate Runoff Retained in Green Roof

Installing a green roof alters the surface response to rainfall with respect to runoff. A green roof will have a significant increase in storage capability when compared to a standard roof. Estimates of the planting soils storage capacity are important values when calculating the runoff that can be expected to be absorbed. The dry soil weight and saturated soil weight values should be verified by members of the design team involved with planting soil specification. The design table provided in the Green Roof Design Guidelines is utilized in this example.

Section 3. Proposed Green Roof Storage				
14	Green Roof Area	A	14803	sq-ft
15	Rainfall Depth	P	1	in
16	Green Roof Soil Depth	d	6	in
18	Soil Dry Weight	W_{dry}	60	lbs/ft^3
19	Soil Saturated Weight	W_{sat}	90	lbs/ft^3
20	Runoff Retained	$V_{storage}$	1.80	gal/ft^2
			0.082	acre-ft

Water Quality Calculations

$WQ_v = (P)(R_v)(A)/12$

where:

WQ_v = water quality volume (acre-feet)
P = 1 inch of rainfall
R_v = 0.05+0.009(I) where I is the percent impervious cover
A = area in acres

Existing Site:

A = 1.26 acres
Impervious Area = 0.79 acres
I = 63 %
R_v = 0.05+0.009(64) = 0.617

WQ_v= (1)(0.617)(1.26)/12 = **0.065 acre-ft**

Proposed Site:

A = 1.26 acres
Impervious Area = 0.45 acres
I = 36 %
R_v = 0.05+0.009(36) = 0.374

WQ_v= (1)(0.374)(1.26)/12 = **0.039 acre-ft**

Attachment 3: Permeable Pavement System Design Guidelines

Design of permeable pavement systems is critical if they are to function properly and efficiently. The area and shape are dependent on the site design, and selection of the surface material is dependent on intended site uses and desired appearance. The depth of the stone base can be adjusted depending on the management objectives, total drainage area, traffic load, and soil characteristics. The following design procedures are general guidelines that designers can follow.

Siting for Permeable Pavements

Permeable pavements are not suited for every site. Site evaluation is critical for the success of permeable pavement. For optimal performance locate systems on well-drained permeable soils. A geotechnical report/analysis is required whenever permeable pavement is used. It is the designer's responsibility to collect adequate information to ensure the system functions properly. Permeable pavements should not be used until the site has met the minimum standards required for their use. Infiltration guidelines are outlined in **Attachment 1**.

Table 1. Minimum Siting Requirements
Field verify soil infiltration rates according to requirements outlined in **Attachment 1.**
High ground water table depth to bottom of stone storage layer must be 2 feet or greater.
Land surrounding and draining to the permeable pavement does not exceed 20% slope.
Minimum setback of 100 feet from wells used to supply drinking water or as required by local agency. Not recommended for use in well-head protection zones.
Minimum setback of 10 feet from down-gradient of building foundations or as required by building code.

Design Guidelines

Permeable pavements infiltrate runoff through the permeable surface into the gravel subbase. Water is stored in the gravel subbase until it infiltrates the underlying soil or is carried away by an underdrain. Using infiltration area and the saturated vertical infiltration rate of the native soil, estimate how long the surface ponding and soil storage will take to drain. Adjust subbase depth or surface area until minimum design requirements are met. The gravel base and subbase must be designed in accordance with the expected traffic loads and required storage per the Storm Water Design and Construction Specifications Manual. Underdrains placed at the top of the aggregate bed can serve to minimize or prevent standing water in the structural surface. Underdrains must be designed to minimize chance of clogging and must meet release rate requirements. Underdrains can be set above subbase invert elevations to allow for detention storage. See Permeable Pavement Design Checklist and example design within this attachment for calculating permeable pavement system performance.

Table 2. Minimum Design Requirements
Determine Water Quality and Quantity requirements on the site. See City of Indianapolis Storm Water Design & Construction Specifications Manual.
Assume a void ratio of approximately 40% for #8 washed stone.
Design system with a level bottom; use a terraced system on slopes. Provide a positive slope for the bottom if the underlying soils have a high clay content or low permeability in general.
Maximum drain down time for the entire storage volume is 72 hours. Engineer may choose a shorter time based on site conditions and owner preference.
Storage volume must not occur within porous structural surface, but must be entirely contained within stone subbase.
Per City of Indianapolis requirements, at least one underdrain shall be used for all porous pavement systems. Additional underdrains may be required based on layout and individual site conditions.

Table 3. Permeable Pavement System Design Checklist				
Section 1. Permeable Pavement Siting				
1	Slope of surrounding drainage area < 20%	Y/N	Y	
2	Setback from well (must be > 100 ft)		120	ft
3	Setback from buildings (must be > 10 ft)		12	ft
4	Geotechnical investigation complete	Y/N	Y	
5	Infiltration rate of native soils	i	0.55	in/hr
6	Seasonal high ground water table elevation	$ELEV_{GW}$	399	ft
Section 2. Permeable Pavement Sizing				
7	Volume of runoff from design storm	V	1	acre-ft
8	Elevation of bottom of gravel subbase	$ELEV_{base}$	406	ft
9	Maximum depth of gravel subbase	D	3	ft
10	Dimensions of permeable pavement	L	300	ft
		W	100	ft
		A	30000	ft^2
11	Gravel subbase porosity	p	40	%
12	Estimated storage volume of permeable pavement	V_{BMP}	0.826446	acre-ft
Section 3. Permeable Pavement Performance*				
13	Drain down time w/ underdrain		48	hrs
14	Drain down time w/ underdrain and over drain		36	hrs

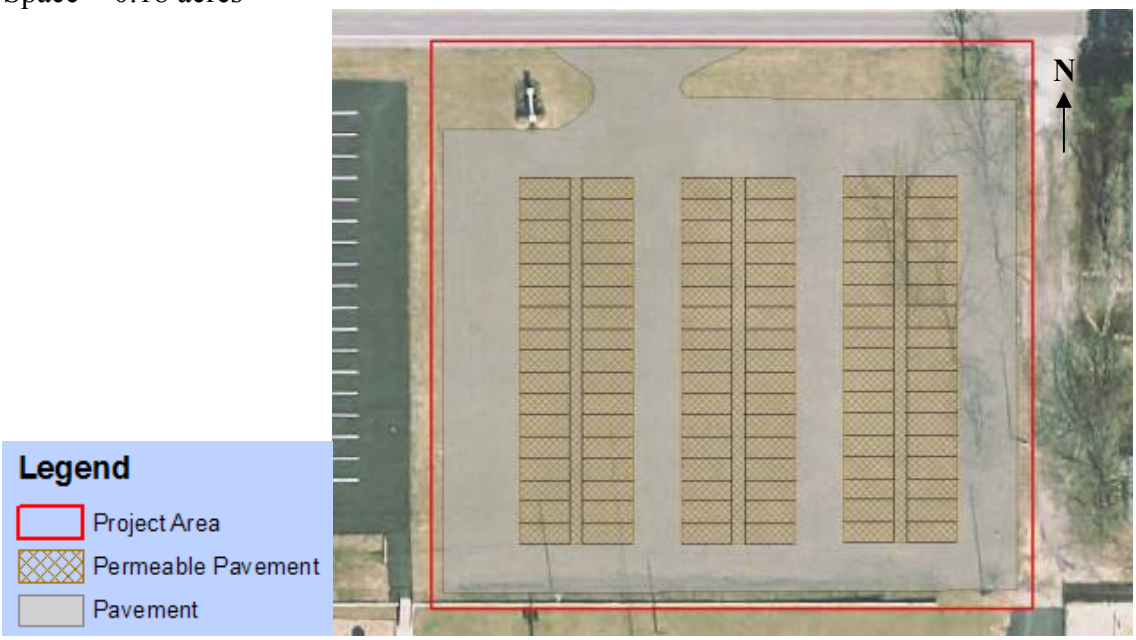
Permeable Pavement System Design Example:

This design example walks through the use of the Permeable Pavement Design Guidelines contained in the Indianapolis Green Supplemental Document.

Collect Existing/Proposed Site Information

Existing Conditions:
Drainage Area = 1.08 acres
Type A Hydrologic Soils
Infiltration Rate = 0.5 in/hr

Proposed Conditions:
Parking Lot / Driveways = 0.51 acres
Pervious Pavement Area = 0.39 acres
Open Space = 0.18 acres



Permeable Pavement Design Checklist
Complete Section 1 and 2 of the Permeable Pavement Design Checklist with data from the geotechnical analysis and proposed design.

Permeable Pavement Design Checklist				
Section 1. Permeable Pavement Siting				
1	Slope of surrounding drainage area < 20%	Y/N	Y	
2	Setback from well (must be > 100 ft)		120	ft
3	Setback from buildings (must be > 10 ft)		12	ft
4	Geotechnical investigation complete	Y/N	Y	
5	Infiltration rate of native soils	i	0.5	in/hr
6	Seasonal high ground water table elevation	$ELEV_{GW}$	399	ft

Section 2. Permeable Pavement System Sizing				
7	Volume of runoff from design storm	V	0.27	acre-ft
8	Elevatlion of bottom of gravel subbase	$ELEV_{base}$	406	ft
9	Maximum depth of gravel subbase	D	3	ft
10	Dimensions of permeable pavement	L	136	ft
		W	126	ft
		A	17136	ft^2
11	Gravel subbase porosity	p	40	%
12	Estimated maximum storage volume of permeable pavement	V_{BMP}	0.472	acre-ft

Detention Storage Requirements

To be most effective and economically viable for a project, permeable pavement should be designed as a detention system. The outlet control will be the under drain and/or the infiltration rate of the underlying soil. Refer to *Chapter 700 Storm water Quality* of the Storm Water Design & Construction Specifications Manual to determine the storage volume required.

Drainage Area (A) = 1.08 acres

Required Storage Volume Determined per Section 4.3.2.1

Required Storage Volume, $S(t_d)$ = 1.08 * 3" * 1'/12" = **0.27 acre-ft**

Calculate Permeable Pavement Dimensions based on Detention Storage Requirements

Section 1. Permeable Pavement System				
1	Dimensions of permeable pavement	L	136	ft
		W	126	ft
		A_{BMP}	17136	ft^2
2	Depth of gravel subbase	D	2	ft
3	Gravel subbase porosity	p	40	%
4	Infiltration rate of native soils	i	0.5	in/hr
5	Storage Volume	S	0.315	acre-ft
6	Underdrain Diameter	d_u	0	in
7	Overdrain Diameter	d_o	0	in

Drain Down Time Requirements
The maximum drain down time for the entire storage volume is 72 hours. 1.) Finalize dimensions and depth of permeable pavement system. 2.) Compute volume of water that can infiltrate the soil in 72 hours.

Infiltration Rate = 0.5 in/hr
Permeable Pavement Area = 17136 ft^2
Porosity = 40%
Permeable Pavement Infiltration Area = 17136 ft^2 * 0.40 = 6854 ft^2
Time to Drain – 72 hrs

Calculate the volume of water infiltrating through the bottom of the permeable pavement system.

0.5 in/hr * 1ft/12in * 6854 ft^2 * 72 hrs * 1acre/43560 ft^2 = **0.47 acre-ft**

Maximum storage for the permeable pavement system is 0.315 acre-ft. The volume that can be infiltrated in 72 hours is equal to or exceeds the maximum volume of runoff the system can contain. The permeable pavement system can drain down the entire storage volume in less than or equal to 72 hours through infiltration into underlying soils.

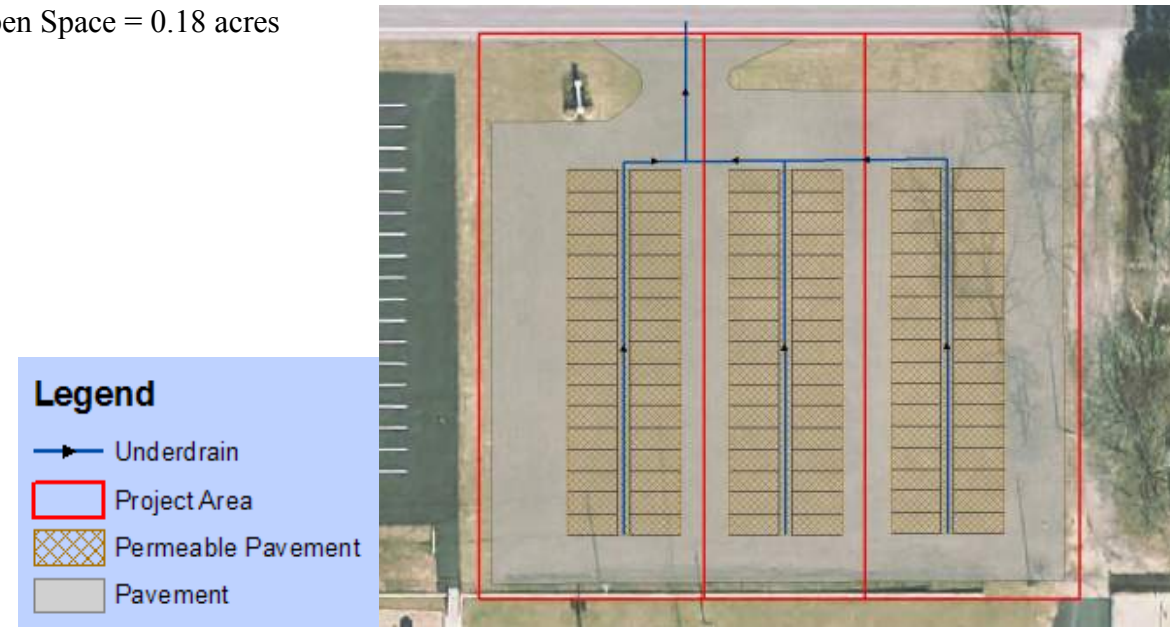
Permeable Pavement System with Underdrain Design Example:

This design example walks through the use of the Permeable Pavement Design Guidelines contained in the Indianapolis Green Supplemental Document.

Collect Existing/Proposed Site Information

Existing Conditions:
Drainage Area = 1.08 acres
Type D Hydrologic Soils
Infiltration Rate = 0.02 in/hr

Proposed Conditions:
Parking Lot / Driveways = 0.51 acres
Pervious Pavement Area = 0.39 acres
Open Space = 0.18 acres



Permeable Pavement System Design Checklist
Complete Section 1 and 2 of the Permeable Pavement Design Checklist with data from the geotechnical analysis and proposed design.

Permeable Pavement Design Checklist				
Section 1. Permeable Pavement Siting				
1	Slope of surrounding drainage area < 20%	Y/N	Y	
2	Setback from well (must be > 100 ft)		120	ft
3	Setback from buildings (must be > 10 ft)		12	ft
4	Geotechnical investigation complete	Y/N	Y	
5	Infiltration rate of native soils	i	0.7	in/hr
6	Seasonal high ground water table elevation	$ELEV_{GW}$	399	ft
Section 2. Permeable Pavement Sizing				
7	Volume of runoff from design storm	V	0.27	acre-ft
8	Elevatlion of bottom of gravel subbase	$ELEV_{base}$	406	ft
9	Maximum depth of gravel subbase	D	3	ft
10	Dimensions of permeable pavement	L	136	ft
		W	126	ft
		A	17136	ft^2
11	Gravel subbase porosity	p	40	%
12	Estimated maximum storage volume of permeable pavement	V_{BMP}	0.472	acre-ft

Detention Storage Requirements
To be most effective and economically viable for a project, permeable pavement should be designed as a detention system. The outlet control will be the under drain and/or the infiltration rate of the underlying soil. Refer to *Chapter 700 Storm water Quality* of the Storm Water Design & Construction Specifications Manual to determine the storage volume required.

Drainage Area (A) = 1.08 acres

Required Storage Volume Determined per Section 4.3.2.1

Required Storage Volume, $S(t_d)$ = 1.08 * 3” * 1’/12” = **0.27 acre-ft**

Calculate Permeable Pavement Dimensions based on Detention Storage Requirements

Section 1. Permeable Pavement System				
1	Dimensions of permeable pavement	L	136	ft
		W	126	ft
		A_{BMP}	17136	ft^2
2	Depth of gravel subbase	D	2	ft
3	Gravel subbase porosity	p	40	%
4	Infiltration rate of native soils	i	0.02	in/hr
5	Storage Volume	S	0.315	acre-ft
6	Underdrain Diameter	d_u	0	in
7	Overdrain Diameter	d_o	0	in

Drain Down Time Requirements
The maximum drain down time for the entire storage volume is 72 hours. 1.) Finalize dimensions and depth of permeable pavement system. 2.) Compute volume of water that can infiltrate the soil in 72 hours with.

Infiltration Rate = 0.02 in/hr (not including underdrain)
Permeable Pavement Area = 17136 ft^2
Porosity = 40%
Permeable Pavement Infiltration Area = 17136 ft^2 * 0.40 = 6854 ft^2
Time to Drain – 4872 hrs

Calculate volume of water infiltrating through the bottom of the permeable pavement system.

0.02 in/hr * 1ft/12in * 6854 ft^2 * 72 hrs * 1acre/43560 ft^2 = **0.0189 acre-ft**

Maximum storage for the permeable pavement system is 0.315 acre-ft. The volume that can be infiltrated in 72 hours is less than maximum volume of runoff system can contain. Without an under drain this system will not meet 72 hour drain down requirement.

Design Underdrain for Permeable Pavement System
The permeable pavement system should be designed as detention storage. Detention storage designs require an outlet to rate flow through the system. The design must illustrate the drain down time of the permeable pavement system is less than 72 hours.

<u>Two Options:</u>

1.) A model calculating the depth of the permeable pavement system with flow being routed through the underdrain and overdrain (both modeled as orifices), and infiltration. The figure below illustrates the drain down time of the permeable pavement system.

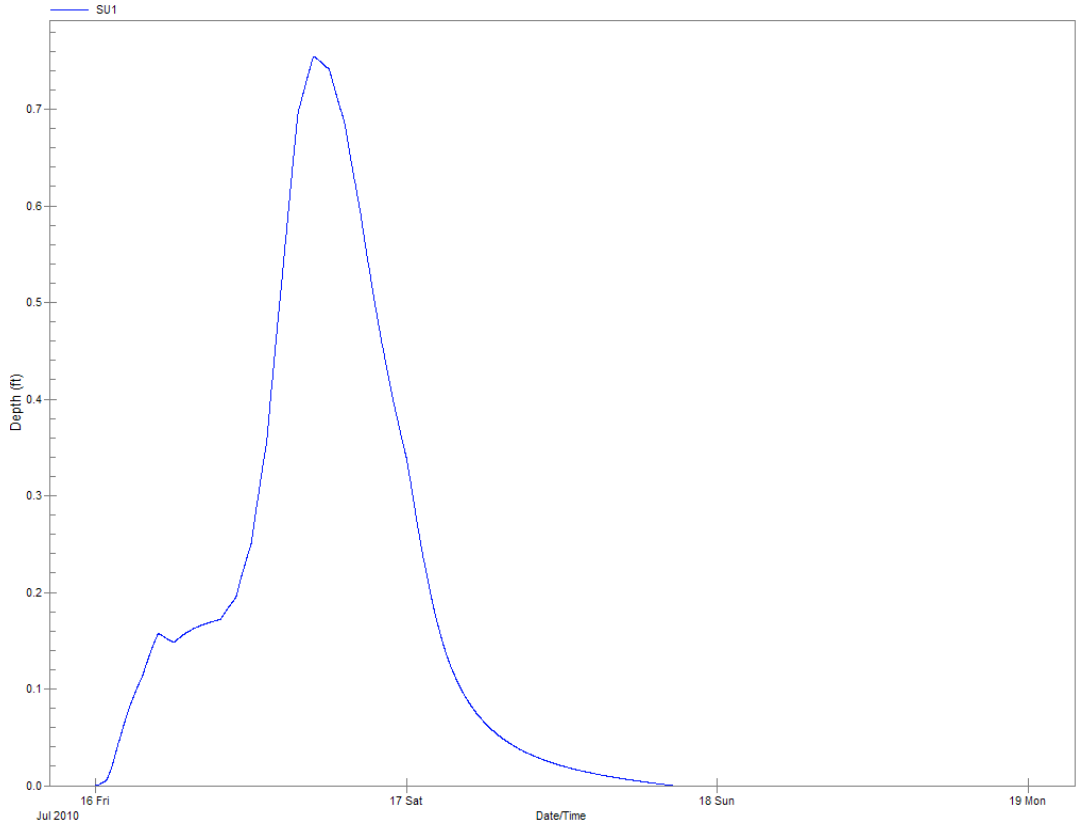


Figure 1. Graph of Depth vs Time for Permeable Pavement System

2.) Develop a rating curve with an underdrain, overdrain, and infiltration rate. Route runoff through the permeable pavement system as if it were a detention pond.

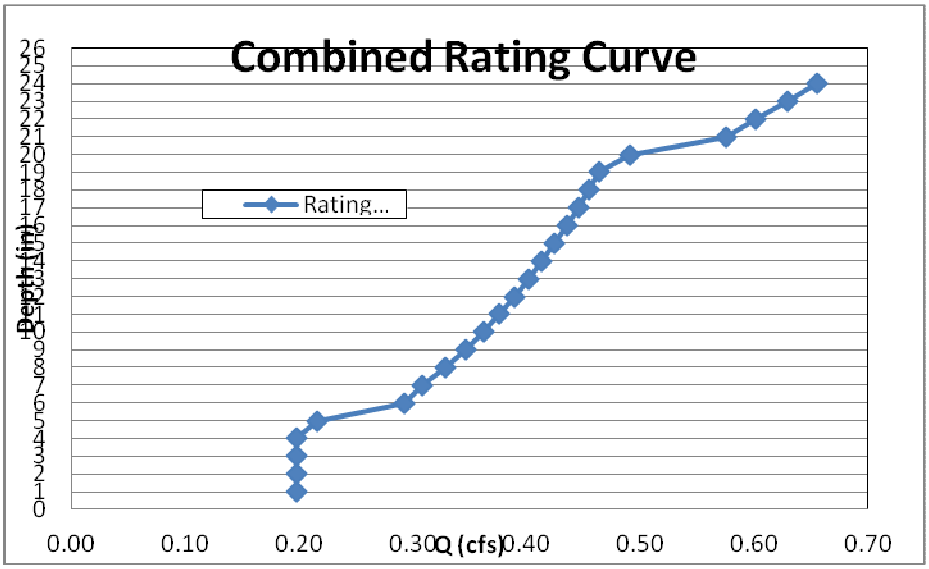


Figure 2. Combined Rating Curve for Permeable Pavement System

Table 3. Example of Rating Curve Calculations

Underdrain		
d_u	3	in
Depth	3	in
E	4.5	in
C	0.6	

Overdrain		
d_o	3	in
Depth	18	in
E	19.5	in
C	0.6	

Depth in	Underdrain Head in	Flow cfs	Overdrain Head in	Flow cfs	Infiltration Flow cfs	Total Flow cfs
1	0	0.000	0	0.000	0.198	0.20
2	0	0.000	0	0.000	0.198	0.20
3	0	0.000	0	0.000	0.198	0.20
4	0	0.000	0	0.000	0.198	0.20
5	1	0.018	0	0.000	0.198	0.22
6	2	0.094	0	0.000	0.198	0.29
7	3	0.110	0	0.000	0.198	0.31
8	4	0.131	0	0.000	0.198	0.33
9	5	0.148	0	0.000	0.198	0.35
10	6	0.164	0	0.000	0.198	0.36
11	7	0.178	0	0.000	0.198	0.38
12	8	0.191	0	0.000	0.198	0.39
13	9	0.204	0	0.000	0.198	0.40
14	10	0.215	0	0.000	0.198	0.41
15	11	0.226	0	0.000	0.198	0.42
16	12	0.237	0	0.000	0.198	0.44
17	13	0.247	0	0.000	0.198	0.45
18	14	0.257	0	0.000	0.198	0.45
19	15	0.266	0	0.000	0.198	0.46
20	16	0.275	1	0.018	0.198	0.49
21	17	0.284	2	0.094	0.198	0.58
22	18	0.292	3	0.110	0.198	0.60
23	19	0.300	4	0.131	0.198	0.63
24	20	0.308	5	0.148	0.198	0.65

Attachment 4: Rain Water Harvesting Design Guidelines

Rain barrels, cisterns, and storage tanks are structures designed to intercept and store runoff from rooftops. Rain barrels are used on a small scale while cisterns and tanks may be larger. These systems may be above or below ground, and they may drain by gravity or be pumped. Stored water may be slowly released to a pervious area, used for irrigation, or plumbed into buildings per code for use inside. These techniques only serve as an effective storm water control if the stored water is emptied between most storms, freeing up storage volume for the next storm.

Siting for Rain Barrel, Cistern and Storage Tanks

Rain Barrel: The most common use of rain barrels is connection of one roof leader (downspout) to a single barrel on a residential property. Stored water can provide irrigation for a garden or can be released slowly to a lawn. Barrels can either be purchased or can be built by the homeowner. They are ideal for gardeners and concerned citizens who want to manage storm water without a large initial investment. They are also an easy retrofit. A design professional and storm water design calculations are typically not needed. The labor and installation can generally be performed by the property owner or handyman. The materials necessary are generally low cost and can be found at local retail hardware or plumbing supply stores.

Cistern/Storage Tank: Surface tanks may be larger than rain barrels but serve the same function. They can be integrated into sites where a significant water need exists or rain harvesting and reuse is desired. They may drain by gravity or be pumped. These typically need design professional assistance for more complex water collection and delivery system design. Typically need to be installed to local code by a certified and bonded plumbing or construction contractor.

Table 1. Minimum Design Elements
Storage devices designed to capture small, frequency storm events with opportunity for larger storm volume capture.
Storage techniques may include rain barrels, underground concrete or prefabricated tanks, above ground vertical storm volume capture.
Systems must provide for storage, overflow or bypass of large storm events per City of Indianapolis Storm Water Design & Construction Specifications Manual.
Placement of storage elements higher than areas where water will be reused may reduce or eliminate pumping needs.
For effective storm water control, water must be used or discharge before the next storm event.
Most effective when designed to meet a specific water need for reuse.

Table 2. Suggested Storage Design Values	
Rain Barrel	50-150 gallons
Cistern	500-7,000 gallons
Larger Above Ground Tank	3,000-12,000 gallons

Design Guidelines

Identify opportunities and areas where water can be reused for irrigation, released to an infiltration area, or meet indoor use needs. Estimate the rate at which water can be reused. If the process of reuse is proposed to meet the Water Quality requirement, check the local storm water design codes and ordinances. For irrigation or garden use, determine the water needs of the plants; an assumption of 1 inch per week over the soil area may be used for approximate results. Identify potential infiltration areas where water may be discharged to at a slow rate. The most important variable in designing a rain barrel, cistern, or storage tank it estimating the storage needed. A rough estimate may be obtained by performing a weekly water balance of rainfall and water reuse. To ensure the rain barrel has adequate storage a Design Professional should perform calculations to verify the rain barrel overflow has enough capacity. Depending on the complexity of system and/or intended reuse options, a Design Professional may need to be contracted to perform more rigorous analysis in order to best meet water demand needs.

Table 3. Rain Barrel, Cistern, and Storage Tank Design Guidelines
Identify roof leaders where rain barrels, cistern, or storage tank will be installed.
Consider elevating the barrel by placing it on a stable platform to increase water pressure at ground level.
If emptying the barrel manually, develop a plan so that it is partially or completely emptied on average every 3 to 4 days.
Position the overflow hose to discharge larger storms. The overflow should be discharged to an area protected from erosion. At a minimum, direct the overflow to the same location as the roof leader before placing the storage tank.
Cisterns and larger storage tanks should be designed to local codes and ordinances, preparing complete construction plans and specifications.

The spreadsheet below illustrates a method for designing the rain barrel for residential use. Cisterns and storage tanks vary by manufacturer and design. The Design Professional must provide documentation proving the cistern or storage tank will provide adequate storage for runoff from roof area.

Section 1. Rain Barrel, Cistern, and Storage Tank Hydraulics				
1	Dimensions of Roof Draining to Barrel	L	81	ft
		W	63	ft
		A_{BMP}	5103	ft^2
2	Depth of Precipitation	P	2	in
3	Volume of Runoff from Roof	V	850.5	ft^3
			113.7	gal
4	Storage Volume of Barrel Receiving Runoff	V_{barrel}	200	gal
6	Outlet	d_{out}	2	in
7	Overflow	d_o	3	in

Outlet		
d_{out}	2	in
Depth	3	in
E	4	in
C	0.65	

Overflow		
d_o	3	in
Depth	36	in
E	37.5	in
C	0.65	

Depth in	Outlet Head in	Flow cfs	Overflow Head in	Flow cfs	Total Flow cfs
1	0	0.00	0	0.000	0.000
2	0	0.00	0	0.000	0.000
3	0	0.00	0	0.000	0.000
4	0	0.00	0	0.000	0.000
5	1	1.51	0	0.000	1.506
6	2	2.13	0	0.000	2.130
7	3	2.61	0	0.000	2.608
8	4	3.01	0	0.000	3.012
9	5	3.37	0	0.000	3.367
10	6	3.69	0	0.000	3.688
11	7	3.98	0	0.000	3.984
12	8	4.26	0	0.000	4.259
13	9	4.52	0	0.000	4.517
14	10	4.76	0	0.000	4.762
15	11	4.99	0	0.000	4.994
16	12	5.22	0	0.000	5.216
17	13	5.43	0	0.000	5.429

Rain Barrel Design Example:

This design example walks through the use of the Rain Barrel Design Guidelines contained in the Indianapolis Green Supplemental Document.

Collect Existing/Proposed Site Information

Existing Conditions:
Roof Area = 1596 sq-ft

Proposed Conditions:
No. of Rain Barrels = 3
Roof Area 1 = 726.25 sq-ft
Roof Area 2 = 606.29 sq-ft
Roof Area 3 = 263.42 sq-ft
Precipitation Depth = 6 inches

Rain Barrel Design Checklist

Storage Requirements

To be most effective and economically viable for a project, the design must identify which roof leaders can drain to the rain barrel and the area of the roof draining to each leader. This example will only include calculations for one rain barrel. The spreadsheet and methodology can be utilized for the other two rain barrels in this example.

Section 1. Rain Barrel, Cistern, and Storage Tank Hydraulics				
1	Dimensions of Roof Draining to Barrel	L	41.5	ft
		W	17.5	ft
		A_{BMP}	726.25	ft^2
2	Depth of Precipitation	P	6	in
3	Volume of Runoff from Roof	V	363.125	ft^3
			48.5	gal
4	Storage Volume of Barrel Receiving Runoff	V_{barrel}	55	gal
6	Outlet	d_{out}	2	in
7	Overflow	d_o	3	in

Outlet		
d_{out}	2	in
Depth	3	in
E	4	in
C	0.65	

Overflow		
d_o	3	in
Depth	29	in
E	30.5	in
C	0.65	

Depth in	Outlet Head in	Flow cfs	Overflow Head in	Flow cfs	Total Flow cfs
1	0	0.00	0	0.000	0.000
2	0	0.00	0	0.000	0.000
3	0	0.00	0	0.000	0.000
4	0	0.00	0	0.000	0.000
5	1	1.51	0	0.000	1.506
6	2	2.13	0	0.000	2.130
7	3	2.61	0	0.000	2.608
8	4	3.01	0	0.000	3.012
9	5	3.37	0	0.000	3.367

10	6	3.69	0	0.000	3.688
11	7	3.98	0	0.000	3.984
12	8	4.26	0	0.000	4.259
13	9	4.52	0	0.000	4.517
14	10	4.76	0	0.000	4.762
15	11	4.99	0	0.000	4.994
16	12	5.22	0	0.000	5.216
17	13	5.43	0	0.000	5.429
18	14	5.63	0	0.000	5.634
19	15	5.83	0	0.000	5.832
20	16	6.02	0	0.000	6.023
21	17	6.21	0	0.000	6.209
22	18	6.39	0	0.000	6.389
23	19	6.56	0	0.000	6.564
24	20	6.73	0	0.000	6.734
25	21	6.90	0	0.000	6.900
26	22	7.06	0	0.000	7.063
27	23	7.22	0	0.000	7.222
28	24	7.38	0	0.000	7.377
29	25	7.53	0	0.000	7.529
30	26	7.68	0	0.000	7.678
31	27	7.82	1	1.065	8.889
32	28	7.97	2	1.844	9.812
33	29	8.11	3	2.381	10.490
34	30	8.25	4	2.817	11.065
35	31	8.38	5	3.194	11.578

To ensure the rain barrel has adequate storage a Design Professional should perform calculations to verify the rain barrel overflow has enough capacity. Depending on the complexity of system and/or intended reuse options, a Design Professional may need to be contracted to perform more rigorous analysis in order to best meet water demand needs.

Attachment 5: Bioretention Design Guidelines

Design of bioretention systems is somewhat flexible. The area, depth, and shape of the system can be varied to accommodate site conditions and constraints. The following design procedures are general guidelines that designers can follow. Bioretention areas should be feasible on site and sized for expected runoff volume. The following general guidelines can assist the designer in evaluating bioretention site applicability.

- Facilities can be placed close to the source of run-off generation.
- The site permits the distributed bioretention facilities.
- Available room for installation including setback requirements.
- Suitable soils availability and following infiltration guidelines (**Attachment 1**).

Table 1. Minimum Siting Requirements
Field verify soil infiltration rates.
High ground water table depth to bottom of stone storage layer must be 2 feet or greater.
Land surrounding and draining to the bioretention does not exceed 20% slope.
Minimum setback of 100 feet from wells used to supply drinking water or as required by local agency. Not recommended for use in well-head protection zones.
Minimum setback of 10 feet from down-gradient of building foundations or as required by building code.

Bioretention areas are suitable for many types and sizes of development. To size/design a bioretention facility, the designer has to first determine the intended purpose of the bioretention. For example, what are the site requirements for water quality and quantity control? An example calculation for a 1.1 acre site is provided in the **Bioretention Design Example, within this attachment**.

Table 2. Minimum Design Requirements
Determine Water Quality and Quantity requirements on the site. See City of Indianapolis Storm Water Design & Constructon Specifications Manual.
Typical ponding depth of 6-18 inches (maximum 24 inches).
Minimum soil depth of 18 inches.
Estimate drain down time of bioretention system. The maximum drain down time for surface water storage is 48 hours.
Include an underdrain if necessary to meet drain down requirements.

Provisions shall be made for overflow during large storm events. An overflow weir or storm water inlet may be required, on a case-by-case basis, depending on flow volume and site conditions. Size should be determined by the 10 year storm with the overflow away from the building.
Choose native plants, trees, and mulch appropriate for site.

Table 3. Bioretention Design Checklist

Section 1. Bioretention Siting				
1	Slope of surrounding drainage area < 20%	Y/N		
2	Setback from well (must be > 100 ft)			ft
3	Setback from buildings (must be > 10 ft)			ft
4	Geotechnical investigation complete	Y/N		
5	Infiltration rate of native soils	i		in/hr
6	Seasonal high ground water table elevation	$ELEV_{GW}$		ft
Section 2. Bioretention Sizing				
7	Volume of runoff from design storm	V		acre-ft
8	Bioretention area	A		sq-ft
9	Soil depth (See **Amended Soil Detail** for appropriate soil mix)	d_{soil}		ft
10	Ponding depth	$d_{ponding}$		ft
11	Soil porosity	p		%
12	Estimated maximum storage volume of bioretention	V_{BMP}		acre-ft
Section 3. Bioretention Performance				
13	Drain down time (*infiltration only*)			hrs
14	Drain down time w/ underdrain			hrs
15	Drain down time w/ underdrain and over drain			hrs

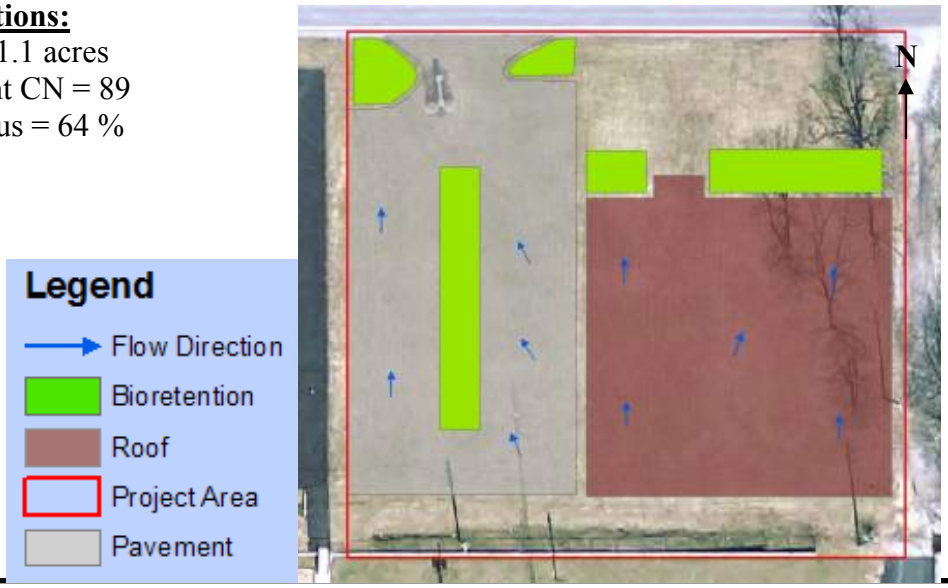
Bioretention/Rain Garden Design Example:

This design example walks through the use of the Bioretention Design Guidelines contained in the Indianapolis Green Supplemental Document. This design example will require the bioretention/rain garden BMPs to account for the water quality volume from the roof top and parking area. Bioretention areas will be designed to disconnect the impervious area, route and treat runoff, and discharge to the storm sewer system.

Collect Existing/Proposed Site Information

Existing Conditions:
Drainage Area = 1.1 acres
Pre-Development CN = 74
Percent Impervious = 0%

Proposed Conditions:
Drainage Area = 1.1 acres
Post-Development CN = 89
Percent Impervious = 64 %



Detention Storage Requirements
Determine the storage required to capture the water quality volume. The water quality volume is the runoff produced from 1 inch of rainfall over the impervious area. The outlet control will be an overflow structure and infiltration.

Water Quality Volume Calculation:

$WQ_v = (P)(R_v)(A)/12$

where:
WQ_v = water quality volume (acre-feet)
P = 1 inch of rainfall
R_v = 0.05+0.009(I) where I is the percent impervious cover
A = area in acres

Example:

A = 1.1 acres
Impervious Area = 0.7 acres
I = 64 %
R_v = 0.05+0.009(64) = 0.626

WQ_v= (1)(0.626)(1.1)/12 = **0.0574 acre-ft**

Assuming a 6" ponded depth, 0.12 acres of bioretention is necessary to capture and treat the water quality volume.

Drain Down Time Requirements
The maximum drain down time for the entire storage volume is 48 hours. Finalize dimensions and depth of bioretention system. Compute volume of water that can infiltrate the amended soil in 48 hours.

Infiltration Rate = 0.5 in/hr
Bioretention Area = 5227 ft^2
Porosity = 30%
Bioretention Infiltration Area = 5227 ft^2 * 0.30 =1568 ft^2
Time to Drain – 48 hrs

Calculate the volume of water infiltrating through the bottom of the bioretention system.
0.5 in/hr * 1ft/12in * 1568 ft^2 *48 hrs * 1acre/43560 ft^2 = **0.0719 acre-ft**

Maximum storage for the bioretention system is 0.0574 acre-ft. The volume that can be infiltrated in 48 hours exceeds maximum volume of runoff the system can contain. The bioretention system can drain down the entire storage volume in less than 48 hours through infiltration into underlying soils.

Attachment 6: Swale Design Guidelines

A swale is a vegetated open channel, planted with a combination of grasses and other herbaceous plants, shrubs, or trees. A traditional swale reduces peak flow at the discharge point by increasing travel time and friction along the flow path. Swales can provide some infiltration and water quality treatment; these functions can be enhanced by incorporating retentive grading, or check dams periodically along the length of the swale. In some situations, such as along roadsides and between properties, a hybrid ditch may be an appropriate type of swale to utilize as an alternative to a conventional ditch. Hybrid ditches typically have a smaller footprint than conventional ditches and can be connected to the storm drain system via a subsurface pipe.

Siting for Swales

Swales are applicable in many urban settings such as parking, commercial and light industrial facilities, roads and highways, and residential developments. For instance, a swale is a practical replacement for roadway median strips and parking lot curb and gutter. Swales can be an effective means of decentralizing storm water management so that primary detention facilities become less necessary.

Table 1. Minimum Siting Requirements
Field verify soil infiltration rates according to **Attachment 1.**
High ground water table depth to bottom of stone storage layer must be 2 feet or greater.
Land surrounding and draining to the swale does not exceed 20% slope.
Minimum setback of 100 feet from wells used to supply drinking water or as required by local agency. Not recommended for use in well-head protection zones.
Minimum setback of 10 feet from down-gradient of building foundations or as required by building code.

Design Guidelines

Swales are landscaped channels that convey storm water and reduce peak flows by increasing travel time and flow resistance. Depending on design and underlying soil permeability, they can effectively reduce runoff volume and improve water quality. Check dams increase these functions by creating ponding areas where settling and infiltration can occur. As the number of check dams increases, a swale may resemble a series of bioinfiltration/bioretention basins while still being designed to convey peak flows. The first ponding area may be designed as a sediment forebay and function as a pretreatment practice for the remainder of the swale or other storm water management facilities. An example calculation for a 1.1 acre site is provided in the **Swale Design Example.**

Table 2. Minimum Design Requirements
Determine Water Quality and Quantity requirements on the site. See City of Indianapolis Storm Water Design & Construction Specifications Manual.
Swales may be trapezoidal or parabolic in shape. Recommended widths and slopes in this table may be used as a general guide for parabolic channels.
Check dams are recommended for most applications to improve infiltration and water quality. Check dams are strongly recommended for swales in which flow in combination with soil, slope, and vegetation may result in erosive conditions and must be designed with a maximum drawdown time of 48 hours.
Bottom Width = 2-8 feet.
Side Slopes = 3-4 horizontal to one vertical recommended.
Check dams evenly spaced, 6-12 inches high.

- Consider an underdrain under any of the following conditions:
    - in areas with separate storm sewers or direct discharge to receiving waters where infiltration is infeasible and the swale is needed only to provide water quality treatment;
    - in areas with combined sewers where sufficient detention or travel time can be designed into the system to meet release rate requirements; or
    - in combination with other storm infrastructure where the system as a whole meets storage and release criteria.
- Estimate the portion of Water Quality and Water Quantity requirements met by the design.
- Using infiltration area and the saturated vertical infiltration rate of the native soil, estimate how long storage behind check dams will take to drain. The maximum drain time for the entire storage volume is 48 hours, but the Designer may choose a shorter time based on site conditions and Owner preference but no shorter than 24 hours. If storage does not drain in the time allowed, adjust channel shape, number of check dams, check dam height, or optional underdrain design. Adjust the design so that performance and drainage time constraints are met concurrently. Infiltration guidelines are outlined in **Attachment 1**.
- Check the capacity of the swale system to perform during the 100 year regulatory event defined in the Storm Water Design & Constuction Specifications Manual. An average ponding depth of 12 inches or less, and a maximum ponding depth of 18 inches is required. If higher stages are anticipated, vegetation should be selected per expected hydrologic conditions. Flow over check dams should be estimated using a weir equation, while underdrain conveyance should be modeled as a series outlet representing (1) infiltration rate over horizontal wetted area to (2) orifice flow at the underdrain daylight.

Ultimately, the level of service provided on the site during large events is a joint decision of the Engineer and Owner based on safety, appearance, and potential property damage.

- Choose soil mix and swale vegetation. A minimum of 6 inches of prepared soil is recommended for the channel bottom and slopes. Provide a detail on the plans sheets including the proposed soil mix (**See Ammended Soil Detail**).
- Check resistance of the swale to erosion. For long term functionality, it is recommended that the swale convey the 2-year, 24-hour design storm without erosion. For water quality purposes, channel velocities during a water quality event should not exceed resuspension velocities (2.5 ft/sec). Adjust soil mix, vegetation, and temporary or permanent stabilization measures as needed.
- Design inlet controls, outlet controls, and pretreatment.
- Check that the design meets all requirements concurrently, and adjust design as needed.
- Complete construction plans and specifications.

Table 3. Swale Design Checklist

Section 1. Swale Siting				
1	Slope of surrounding drainage area < 20%	Y/N		
2	Setback from well (must be > 100 ft)			ft
3	Setback from buildings (must be > 10 ft)			ft
4	Geotechnical investigation complete	Y/N		
5	Infiltration rate of native soils	i		in/hr
6	Seasonal high ground water table elevation	$ELEV_{GW}$		ft
Section 2. Swale Sizing				
7	Volume of runoff from design storm	V		acre-ft
8	Bottom Width	W_{bottom}		ft
9	Side Slopes (z:1)	z		
	Depth	d		ft
10	Check Dams	No.		
		Spacing		ft
11	Slope	S		ft/ft
12	Estimated maximum storage volume of swale	V_{BMP}		acre-ft
Section 3. Swale Performance				
13	Capacity for 100 year event	Y/N		
14	Channel Velocity (for 2 year 24 hour event)	v		ft/s

Swale Design Example:

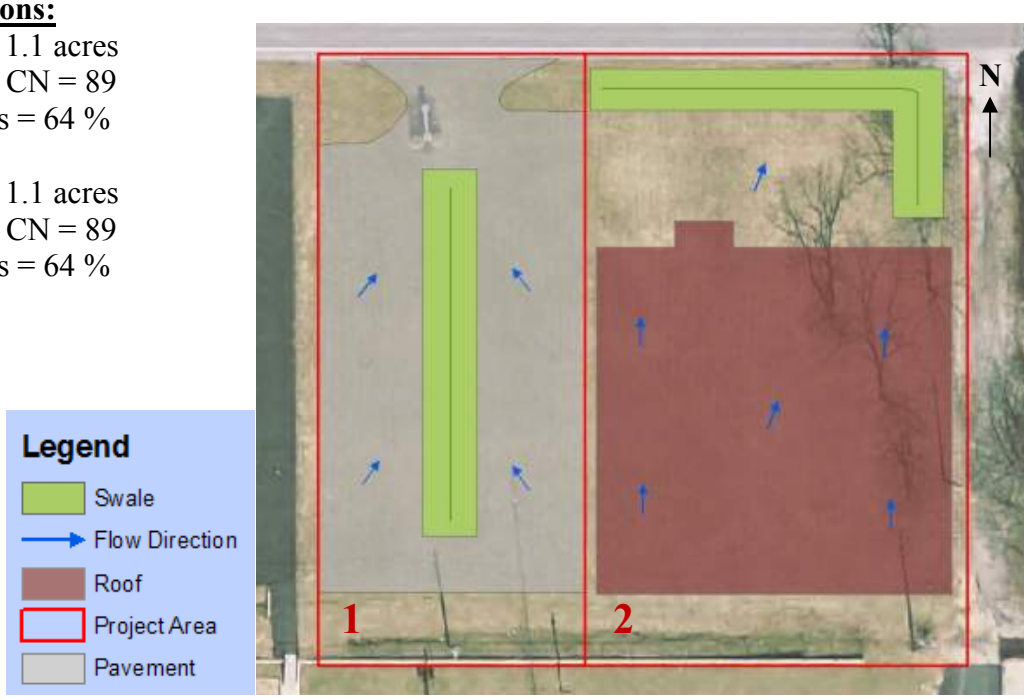
This design example walks through the use of the Swale Design Guidelines contained in the Indianapolis Green Supplemental Document. This design example will require two swales to account for the water quality volume from the roof top and parking area. The swales will be designed to disconnect the impervious area, route and treat runoff, and discharge to the storm sewer system. Infiltration rate should be included in the calculations where check dams are utilized.

Collect Existing/Proposed Site Information

Existing Conditions:
Drainage Area = 1.1 acres
Pre-Development CN = 74
Percent Impervious = 0%
Type A Hydrologic Soils
Infiltration Rate = 0.5 in/hr

Proposed Conditions:
Drainage Area 1 = 1.1 acres
Post-Development CN = 89
Percent Impervious = 64 %

Drainage Area 2 = 1.1 acres
Post-Development CN = 89
Percent Impervious = 64 %



Detention Storage Requirements
Determine the storage required to capture the water quality volume. The water quality volume is the runoff produced from 1 inch of rainfall over the impervious area. The outlet control will be an overflow structure and infiltration.

Water Quality Volume Calculation:

$WQ_v = (P)(R_v)(A)/12$

where:
WQ_v = water quality volume (acre-feet)
P = 1 inch of rainfall
R_v = 0.05+0.009(I) where I is the percent impervious cover
A = area in acres

Example:
A = 1.1 acres
Impervious Area = 0.7 acres
I = 64 %
R_v = 0.05+0.009(64) = 0.626

WQ_v= (1)(0.626)(1.1)/12 = **0.0574 acre-ft**

Assuming check dams result in an average ponded depth of 6", 0.12 acres of swale is necessary to capture and treat the water quality volume.

Drain Down Time Requirements
The maximum drain down time for the entire storage volume is **48 hours**. Finalize dimensions and depth of swale. Compute volume of water that can infiltrate the amended soil in 48 hours.

Infiltration Rate = 0.5 in/hr
Swale Area = 5227 ft^2
Porosity = 30%
Swale Infiltration Area = 5227 ft^2 * 0.30 =1568 ft^2
Time to Drain – 48 hrs

Calculate the volume of water infiltrating through the bottom of the swale.
0.5 in/hr * 1ft/12in * 1568 ft^2 *48 hrs * 1acre/43560 ft^2 = **0.071 acre-ft**

Maximum storage for the swale is 0.0574 acre-ft. The volume that can be infiltrated in 48 hours exceeds maximum volume of runoff the system can contain. The swale can drain down the entire storage volume in less than 48 hours through infiltration into underlying soils.