A Design Guide for Implementers and Reviewers

Low Impact Development Manual for Michigan

Low Impact Development Manual for Michigan:
A Design Guide for Implementors and Reviewers

SEMCOG 2008

Abstract

Low Impact Development (LID) is the cornerstone of stormwater management with the goal of mimicking a site's presettlement hydrology by using design techniques that infiltrate, filter, store, evaporate, and detain runoff close to its source. Because LID uses a variety of useful techniques for controlling runoff, designs can be customized according to local regulatory and resource protection requirements, as well as site constraints.

This manual provides communities, agencies, builders, developers, and the public with guidance on how to apply LID to new, existing, and redevelopment sites. The manual provides information on integrating LID from the community level down to the site level. It not only outlines technical details of best management practices, but also provides a larger scope of managing stormwater through policy decision, including ordinances, master plans, and watershed plans.

Funding for this project was made available by the Michigan Department of Environmental Quality through a grant from the U. S. Environmental Protection Agency. Preparation of this document may also be financed in part through grants from and in cooperation with the Michigan Department of Transportation with the assistance of the U.S. Department of Transportation's Federal Highway Administration and Federal Transit Administration; the Michigan Department of Natural Resources with the assistance of the U.S. Environmental Protection Agency; the Michigan State Police Office of Highway Safety Planning; and local membership contributions.

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4. One of five rain gardens in the parking lot of the Macomb County Administration Building, Mt. Clemens, MI; Macomb County Planning and Economic Development.

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5. System of bioretention areas designed to intercept parking lot runoff in Grand Rapids, MI; Fishbeck, Thompson, Carr & Huber.

Acknowledgements

The development of a thorough manual on low impact development requires insight and expertise from a number of perspectives. The successful development of this manual would not have been possible without major contributions from a number of individuals. We would like to specifically thank the following individuals for their technical review of the manual.

Janis Bobrin, Washtenaw County Drain Commissioner's Office
Andy Bowman, Grand Valley Metro Council
Thomas Cahill, Cahill Associates
Dana Calhoun, Hubbell, Roth & Clark, Inc.
Don Carpenter, Lawrence Technological University
Ron Cavallaro, Orchard, Hiltz & McCliment
Brian Cenci, Fitzgerald Henne and Associates, Inc.
Dan Christian, Tetra Tech
Marcy Colclough, Southwest Michigan Planning Commission
Tim Cullen, University of Michigan
Keith Depp, City of Rochester Hills
Scott Dierks, JFNew
Donna DiNinno, UNI-Group USA
Dave Drullinger, Michigan Department of Environmental Quality
Tiffany Eichorst, Calhoun County Road Commission
Sally Elmiger, Carlisle/Wortman Associates
Shannan Gibb-Randall, InSite Design Studio, Inc.
Jerry Hancock, City of Ann Arbor
Aaron Harris, Michigan Concrete Association
Mark Heiber, Harley Ellis Devereaux
Chuck Hersey, SEMCOG
Steve Holden, Michigan Department of Environmental Quality
Wesley R. Horner, Cahill Associates
Dan Hula, Hula Engineering
Nina Ignaczak, Oakland County Planning and Economic Development Services
Kelly Karll, Environmental Consulting & Technology, Inc.

Shawn Keenan, City of Auburn Hills
Andrea Kevrick, InSite Design Studio, Inc.
Ron Kinney, Road Commission for Oakland County
Christine Kosmowski, City of Battle Creek
Randy Lemoine, City of Grand Rapids/Symbiotic Ventures
Lisa Lenfesty, Environmental Consulting & Technology, Inc.
Brian Majka, JFNew
Amy Mangus, SEMCOG
Royce Maniko, Monroe County Planning Commission
Charles Mills, Asphalt Association of Michigan
Jennifer Muladore, Huron Pines Conservation District
Patty O'Donnell, Northwest Michigan Council of Governments
Noel Mullett, Wayne County Department of Environment
Kristen O. Jurs, St. Clair County Health Department
Todd Pascoe, Atwell Hicks
Andy Potts, Cahill Associates
Evan Pratt, Orchard, Hiltz & McCliment
Angela Riess, SEMCOG
Ralph Reznick, Michigan Department of Environmental Quality
Judy Ruszkowski, Michigan Department of Transportation
Gerard Santoro, Macomb County Planning and Economic Development Department
Mark St. Charles, Green Oak Township
Claire Schwartz, Fishbeck, Thompson, Carr & Huber, Inc.
Lynne Seymour, Macomb County Public Works Office
Susan Stefanski, SEMCOG
Charles Taylor, Advanced Pavement Technology
Dennis Wojcik, Washtenaw County Drain Commissioner's Office

We also extend our gratitude to those individuals who provided pictures and case study information for the manual. We have sourced each image with the appropriate company/organization's name. Where no source is given, the image or schematic is a SEMCOG or Cahill Associates graphic.

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Chapter 1

Introduction

Michigan is the Great Lakes State and home to thousands of inland lakes and streams. Residents and visitors alike rely on Michigan's abundant water resources to provide clean, safe drinking water and for a vast array of recreational activities. In addition, Michigan's economic prosperity is dependent on the availability and health of our water resources.

Due to the numerous ways we use our water, it is imperative for us to protect and restore our water resources. To achieve this goal, actively managing stormwater runoff is essential. Stormwater runoff contributes to a variety of impairments to our water resources. This includes polluting our waterways as well as channelizing streambanks and ruining the habitat that animals and plants need to survive.

A view of the Lake Michigan shoreline near Manistee

Low Impact Development (LID) is the cornerstone of stormwater management. LID uses the basic principle that is modeled after nature: manage rainfall where it lands. The outcome of LID is mimicking a site's presettlement hydrology by using design techniques that infiltrate, filter, store, evaporate, and detain runoff close to its source. Because LID utilizes a variety of useful techniques for controlling runoff, designs can be customized according to local regulatory and resource protection requirements, as well as site constraints.

LID practices offer additional benefits. They can be integrated into the existing infrastructure and are often more cost effective and aesthetically pleasing than traditional, structural stormwater conveyance systems.

Michigan's Water Resources

- Michigan has more fresh water coastline than any other state with 3,126 miles of Great Lakes shoreline.
- Michigan has more than 11,000 inland lakes and more than 36,000 miles of streams.
- You are never more than six miles from a stream or lake.
- Anywhere in Michigan, you are within 85 miles of one of the Great Lakes.
- Michigan ranks fifth in the nation in the number of licensed anglers who contribute $2 billion annually to the economy.
- Michigan ranks third in the nation for the number of registered boats. Recreational boating contributes $2 billion annually to the economy.

Source: State of Michigan

Why this manual was created

This manual provides communities, agencies, builders, developers, and the public with guidance on how to apply LID to new, existing, and redevelopment sites. The manual provides information on integrating LID from the community level down to the site level. It not only contains technical details of best management practices, but also provides a larger scope for managing stormwater through policy decision, including ordinances, master plans, and watershed plans.

This manual is intended to facilitate broad application of LID techniques throughout Michigan. The level of application of LID practices will vary from place to place. Stakeholders can use this manual as technical guidance for how to design, construct, and maintain a specific LID measure (e.g., how to design a rain garden). Others may use the manual as a reference for requiring application of LID in an ordinance to achieve a prescribed standard, such as assuring that the site is designed to mimic presettlement hydrology.

How this manual is organized

This manual is designed to provide the guidance necessary to promote the use of LID throughout Michigan. It is organized into ten chapters with related appendices and checklists.

Chapter 1: Introduction provides information on LID, identifies affected stakeholders, and provides guidance on how to use this manual.

Chapter 2: Stormwater Management in Michigan: Why LID? Describes the overall hydrologic cycle and water quality problems related to stormwater. It also describes in more detail the definition of LID, benefits, and relationships to other environmental programs.

Chapter 3: LID in Michigan summarizes Michigan data for the key determinants and variables that are used in LID design. Included with the descriptions of these determinants and variables are resources for obtaining data.

Chapter 4: Integrating LID at the Community Level discusses ways to effectively incorporate LID into the appropriate elements of a master plan, ordinances, and local municipal programs.

Michigan has more than 36,000 miles of streams that provide numerous recreational opportunities, including kayaking on the Clinton River through downtown Mt. Clemens.

Source: Macomb County Planning and Economic Development

Chapter 5: Incorporating LID into the Site Design Process describes 9 LID-specific steps to consider during the existing site plan review process. It emphasizes the importance of total site design where developers integrate stormwater management at the beginning of the process.

Chapter 6: Nonstructural Best Management Practices describes specific practices that prevent stormwater runoff by integrating planning and site design techniques that preserve natural systems and hydrologic functions, and protects open spaces, wetlands, and stream corridors on a site.

Chapter 7: Structural Best Management Practices describes specific structural practices, their stormwater functions, and design requirements. It provides design guidance for users to determine what structural BMPs to incorporate into a site.

Chapter 8: Special Areas provides detailed information for LID applications in settings where a diverse mix of physical and land use conditions must be confronted, such as contaminated brownfield sites, transportation corridors, and wellhead protection areas.

Chapter 9: Recommended Design Criteria and Methodology discusses the recommended design criteria to consider when designing and constructing BMPs for low impact development.

Chapter 10: Michigan Case Studies highlights numerous successful LID examples throughout Michigan.

Appendices: Includes all of the supplemental information and additional resources that users can access for more LID information. It also includes a model stormwater ordinance that integrates LID techniques.

LID techniques can also be implemented in special areas such as this rain garden along a road in Grayling.

Source: Huron Pines Conservation District

How to use this manual

There are numerous organizations, industries, communities, professionals, and individuals who have an interest in designing and implementing low impact development practices in Michigan. To proactively manage stormwater and protect water quality, it will take the support of all stakeholders involved to successfully communicate, coordinate, and to put LID methods into practice. Although the entire manual is of use to everyone involved in this process, the chapters that may be of the most interest to a given stakeholder are identified in the descriptions below.

Elected officials

Role in LID: Elected officials play an important role by deciding on the extent to which LID will be implemented in their community. Elected officials set the policy. In addition, municipal boards and councils can choose to require the use of LID practices through appropriate ordinances and procedures for a given community. Elected officials need to know that LID is practical, fiscally feasible, and that performance measures can be achieved.

How to use the manual: Elected officials can use Chapters 1 and 2 to learn the LID basics and Chapter 4 to learn the integrated process of LID that includes community planning, site planning, and gaining support for LID.

Towar Rain Gardens, City of East Lansing, MI
Source: Fitzgerald Henne and Associates, Inc.

This LID development at Western Michigan University offers additional benefits such as providing habitat, recreational trails, and improved quality of life.
Source: Fishbeck, Thompson, Carr & Huber, Inc.

Planning Commissions

Role in LID: Planning commissioners have numerous opportunities to encourage implementation of LID in their community. First, the planning commission typically updates and adopts the community's master plan. Incorporating LID into the master plan would be an important step in implementing LID in the community.

The planning commission also reviews new development proposals and proposes language for zoning ordinances. The commission can ensure that zoning and development ordinances allow the use of LID techniques, write LID requirements into ordinances as appropriate for their community, and encourage developers to use LID concepts.

How to use the manual: Like elected officials, the planning commission can use Chapters 1 and 2 to learn the LID basics. In addition, as reviewers of site plans in the community, planning commissioners should be familiar with Chapters 4 and 5 for help with including LID techniques in master plans and for review of site plans. Depending on the level of review by the commission, planning commissioners may need to be familiar with specific design criteria found in Chapters 6 and 7.

Staff Planners/Planning Consultants

Role in LID: Staff planners and/or planning consultants have multiple avenues for encouraging LID implementation in their community. Often it is the staff personnel that meet early on with the development community to discuss a new development. The staff person could share the community's interest in using LID with the developer during these early meetings. Additionally, staff and planning consultants can be supportive when a developer submits a plan for a LID project.

The staff planner/planning consultant also reviews and comments on the site plan prior to review by the planning commission. Finally, staff planners and/or planning consultants play another role in LID by educating local communities (e.g., planning commission, elected officials) about the opportunity to implement LID in their community.

How to use the manual: Staff planners and planning consultants who are not familiar with LID could benefit from Chapters 1 and 2 to review the LID basics. The most beneficial part of the manual for these stakeholders will be the technical chapters on site planning, green infrastructure, and the process of selecting BMPs (Chapters 5, 6, and 7). They will also want to make use of the individual fact sheets, pull outs, pictures, and graphics that are available in the technical sections of this manual.

Local, County, and State Engineers/ Engineering Consultants/Developers/ Landscape Architects

Role in LID: These stakeholders are either designers of site development or reviewers of the design for some public agency. These stakeholders must be the most familiar with the detailed design methods in the manual.

Beech Park Bioretention Area, Troy, MI
Source: City of Troy

Additionally, municipal and agency engineers or consultants often advise the commissions, boards, or agency management they work for on appropriate design criteria to use in ordinances, standards, and procedures. The design portions of this manual will provide specific design criteria that these stakeholders can adapt and recommend as appropriate to requests from the communities they represent.

How to use the manual: These stakeholders are the most technical stakeholders and will routinely use the technical design standards section of the manual (Chapters 5, 6, 7, and 9). This manual provides design criteria that assists incorporating LID techniques into a site design as well as the basis for reviewers to evaluate LID techniques submitted to them.

Local Public Works/Drain Commission/ Road Commission/Michigan Department of Transportation

Role in LID: These stakeholders are responsible for designing, implementing, and maintaining roads and drains. Road and drain projects represent a major opportunity for implementing LID in Michigan.

How to use the manual: The detailed design criteria in Chapters 6, 7, 8, and 9 are adaptable for use in Michigan's transportation and drainage networks.

Citizens/Business Owners/Watershed and Environmental Organizations Regional Organizations/Other LID Proponents

Role in LID: These are stakeholders that may desire to implement LID practices on sites that they own or have influence over. In some cases, organizations may wish to promote the benefits of LID to interested individuals, groups, and communities.

How to use the manual: Chapters 6, 7, and 9 will be the most useful to those wishing to implement LID practices. Chapters 1, 2, 3, and 10 will be useful to those promoting LID implementation.

Feedback on the manual

Feedback from users is integral in identifying the effectiveness of the manual as well as providing future updates to keep the manual as accurate and relevant as possible. Please submit comments or suggestions to infocenter@semcog.org. For additional copies, this manual is available online as a PDF in color at semcog.org.

Chapter 2

Stormwater Management in Michigan: Why LID?

Clean water resources are essential to the economic vitality of Michigan. Proper stormwater management is an essential component of water quality protection. Low impact development is a cornerstone of stormwater management and thus is the pathway to protecting water resources and enabling economic growth.

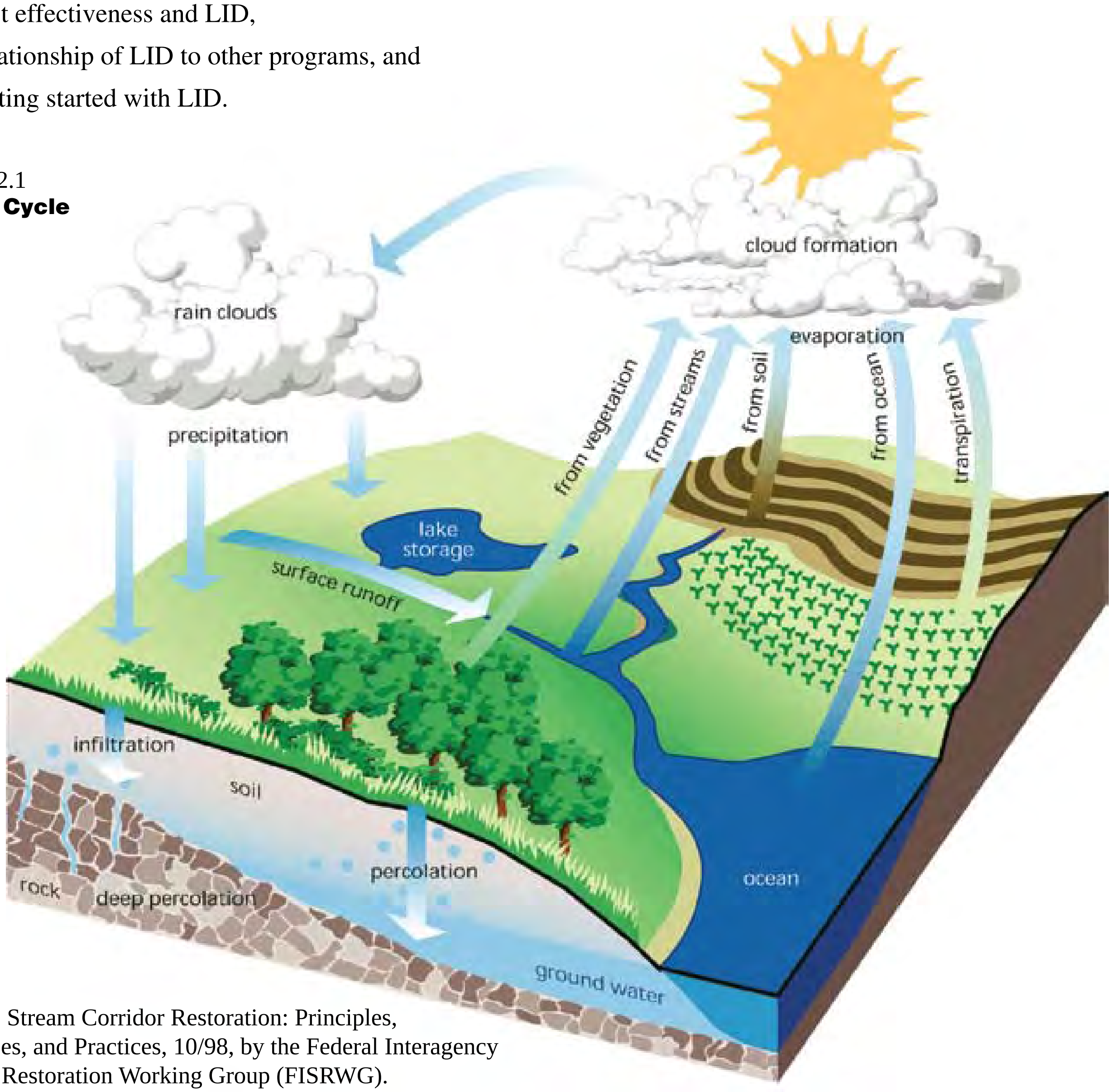
This chapter discusses:

- The importance of the water cycle,
- The impacts of stormwater runoff,
- An overview of what LID is and how it works,
- Benefits of implementing LID,
- Cost effectiveness and LID,
- Relationship of LID to other programs, and
- Getting started with LID.

The importance of the water cycle

A key component of protecting water resources is keeping the water cycle in balance. The movement of rainfall from the atmosphere to the land and then back to the atmosphere — the water (hydrologic) cycle — is a naturally continuous process essential to human and virtually all other forms of life (Figure 2.1). This balanced water cycle of precipitation, evapotranspiration, infiltration, groundwater recharge, and stream base flow sustains Michigan's vast but fragile water resources.

Figure 2.1
Water Cycle



Source: Stream Corridor Restoration: Principles, Processes, and Practices, 10/98, by the Federal Interagency Stream Restoration Working Group (FISRWG).

In a natural woodland or meadow in Michigan, most of the annual rainfall soaks into (infiltrates) the soil mantle. Over half of the annual rainfall returns to the atmosphere through evapotranspiration. Surface vegetation, especially trees, transpire water to the atmosphere with seasonal variations.

Water that continues to percolate downward through the soil reaches the water table and moves slowly down-gradient under the influence of gravity, ultimately providing baseflow for streams and rivers, lakes, and wetlands. On an annual basis, under natural conditions, only a small portion of annual rainfall results in immediate stormwater runoff (Figure 2.2). Although the total amount of rainfall varies in different regions of the state (see Chapter 3), the basic relationships of the water cycle are relatively constant.

Conventional land development changes the land surface and impacts the water cycle (Figure 2.3). Altering one component of the water cycle invariably causes changes in other elements of the cycle. Impervious surfaces, such as roads, buildings, and parking areas, prevent rainfall from soaking into the soil and significantly increase the amount of rainfall that runs off. Additionally, research shows that soil compaction resulting from land development produces far more runoff than the presettlement soil conditions. As natural vegetation systems are removed, the amount of evapotranspiration decreases. As impervious areas increase, runoff increases, and the amount of groundwater recharge decreases.

These changes in the water cycle have a dramatic effect on our water resources. As impervious and disturbed or compacted pervious surfaces increase and runoff volumes increase, stream channels erode, substrate in the river bottom is impacted, habitat is lost or reduced, and populations of fish and other aquatic species decline. Reduced infiltration and groundwater recharge results in lowered water tables and reduced stream baseflow, generally worsening low flow conditions in streams during dry periods.

The Impacts of stormwater runoff

Stormwater runoff is rainfall or snowmelt that runs off the land and is released into rivers and lakes. Problems related to stormwater runoff are most evident in areas where urbanization has occurred. As mentioned above, the change in the water cycle has a dramatic effect on our water resources. This impact is based on both the quantity and quality of stormwater runoff reaching our rivers and lakes.

The impacts of stormwater runoff are well documented in Michigan and throughout the country. They include:

- **Increased flooding and property damage.** Increased impervious surfaces decrease the amount of rainwater that can naturally infiltrate into the soil and increase the volume and rate of stormwater runoff. These changes lead to more frequent and severe flooding and potential damage to public and private property.

Figure 2.2
Approximate annual water cycle for an undeveloped acre in Michigan

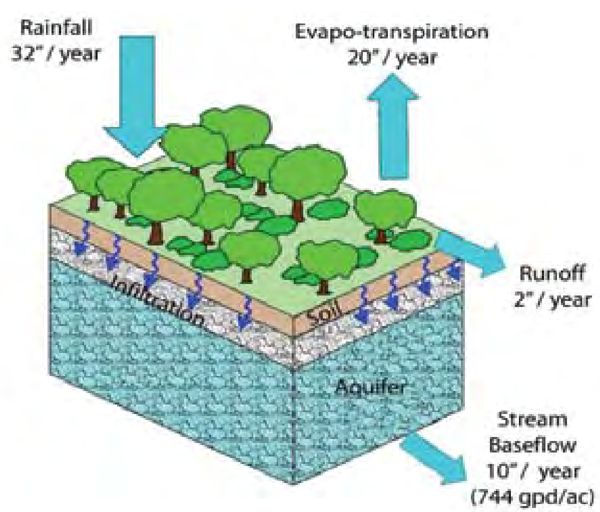
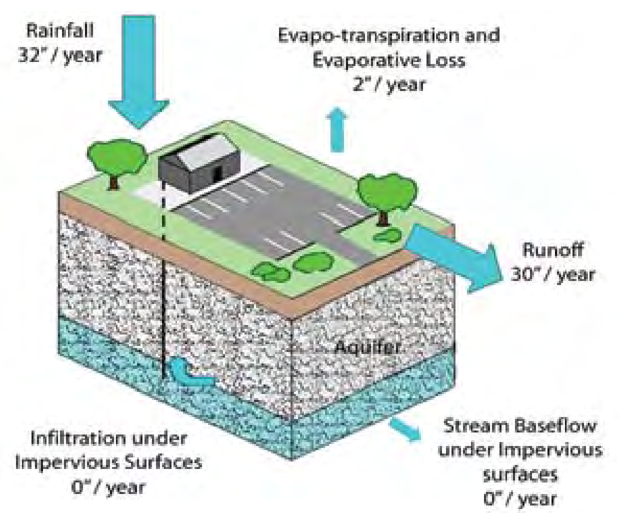


Figure 2.3
Representative altered water cycle under the impervious parking lot



- **Degradation of the stream channel**. One result of runoff can be more water moving at higher velocities through stream channels. This condition is called "flashy flows" and happens at increased frequency as an area is developed. As a result, both the streambank and stream bed are eroded more frequently. This can result in widening and deepening the channel, as well as a decline in stream substrate quality, and degradation of habitat.

Streambank erosion and degraded habitat
Source: Wayne County Department of Environment

- **Less groundwater recharge and dry weather flow**. As impervious surfaces increase, the infiltration of stormwater to replenish groundwater decreases. Groundwater is important because many people rely on groundwater for their drinking water supply. In addition, the groundwater "feeds" rivers and lakes especially during the dry season to ensure a steady flow. When the groundwater recharge decreases, the amount of dry weather flow decreases, negatively impacting aquatic life and recreational opportunities.
- **Impaired water quality**. Impervious surfaces accumulate pollutants that are absorbed by stormwater runoff and carried to lakes and streams. Examples of these pollutants include:
  - Hydrocarbons and trace metals from vehicles,
  - Suspended solids from erosive stream banks and construction sites,
  - Chlorides from road salt,
  - Nutrients from fertilizer and grass clippings and leaves left on streets and sidewalks, and
  - Bacteria from pet waste, goose droppings, and other wildlife.
- **Increased water temperature**. Impervious surfaces are warmed by the sun. Runoff from these warmed surfaces increase the temperature of water entering our rivers and lakes. This can adversely impact aquatic life that requires cold water conditions (e.g., trout).
- **Loss of habitat**. The decline in habitat due primarily to the erosive flows and the increased water temperature will negatively impact the diversity and amount of fish and aquatic insects.
- **Decreased recreational opportunities**. Stormwater runoff can negatively impact water resources in many different ways (e.g., decreased water quality, increased temperature, and decreased habitat). The result is diminished recreational and economic opportunities for communities throughout the state.

Stormwater solutions — Low Impact Development

What is LID?

From a stormwater management perspective, low impact development (LID) is the application of techniques that emulate the natural water cycle described in the previous section LID uses a basic principle modeled after nature: manage rainfall by using design techniques that infiltrate, filter, store, evaporate, and detain runoff close to its source.

Techniques are based on the premise that stormwater is a resource, not a waste to be quickly transported and disposed. Instead of conveying and managing/treating stormwater in large, costly, end-of-pipe facilities located often at the bottom of drainage areas, LID addresses stormwater through small, cost-effective landscape features often located at the lot level.

Native plantings at East Grand Rapids, MI Community Center

Almost all components of the urban environment have the potential to serve as elements of an integrated stormwater management system. This includes open space, as well as rooftops, streetscapes, parking lots, sidewalks, and medians. LID is a versatile approach that can be applied equally well to new development, urban redevelopment, and in limited space applications such as along transportation corridors.

How does LID work?

LID strives to replicate virtually all components of the natural water cycle by:

- Minimizing total runoff volume,
- Controlling peak rate of runoff,
- Maximizing infiltration and groundwater recharge,
- Maintaining stream baseflow,
- Maximizing evapotranspiration, and
- Protecting water quality.

Stormwater management historically focused on managing the flood effects from larger storms. Exclusive reliance on peak rate control prevents flooding, but doesn't protect streams and water quality. Thorough stormwater management should target infrequent large storms, as well as the much more frequent, smaller storms.

With the change in land surface generated by land development, not only does the peak rate of runoff increase, but the *total volume* of runoff also often dramatically increases. LID focuses on both peak rates and total volumes of runoff. LID application techniques are designed to hold constant peak rates of runoff for larger storms and prevent runoff volume increases for the much more frequent, smaller storms. Thus, the natural flow pattern is kept in better balance, avoiding many of the adverse impacts associated with stormwater runoff.

LID focuses on the following stormwater outcomes, described in more detail in Chapter 9:

- Preventing flooding,
- Protecting the stream channel,
- Improving and protecting water quality, and
- Recharging groundwater.

Chapter 9 describes recommended criteria that communities and/or developers may use at the site level to implement LID designs. This may also be used at the community level to develop standards to ensure that development meets the outcomes listed above.

Infiltration practices often associated with LID provide enhanced water quality benefit compared to many other BMPs. Percent of pollutant removal for various LID practices is shown in the table below.

Table 2.1
Pollutant Removal Table (in percentages)

Pollutant	Infiltration Practices	Stormwater Wetlands	Stormwater Ponds Wet	Filtering Practices	Water Quality Swales	Stormwater Dry Ponds
Total Phosphorus	70	49	51	59	34	19
Soluble Phosphorus	85	35	66	3	38	-6
Total Nitrogen	51	30	33	38	84	25
Nitrate	82	67	43	-14	31	4
Copper	N/A	40	57	49	51	26
Zinc	99	44	66	88	71	26
TSS	95	76	80	86	81	47

Source: "National Pollutant Removal Performance Database for Stormwater Treatment practices" Center for Watershed Protection, June 2000.

Principles of LID

Successful application of LID is maximized when it is viewed in the context of the larger design process. This process is reflected in a set of principles used to guide development of this manual.

- Plan first,
- Prevent. Then mitigate,
- Minimize disturbance,
- Manage stormwater as a resource — not a waste,
- Mimic the natural water cycle,
- Disconnect. Decentralize. Distribute,
- Integrate natural systems,
- Maximize the multiple benefits of LID,
- Use LID everywhere, and
- Make maintenance a priority.

Plan first. To minimize stormwater impacts and optimize the benefits of LID, stormwater management and LID should be integrated into the community planning and zoning process.

Prevent. Then mitigate. A primary goal of LID is preventing stormwater runoff by incorporating nonstructural practices into the site development process. This can include preserving natural features, clustering development, and minimizing impervious surfaces. Once prevention as a design strategy is maximized, then the site design — using structural BMPs — can be prepared.

Minimize disturbance. Limiting the disturbance of a site reduces the amount of stormwater runoff control needed to maintain the natural hydrology.

Manage stormwater as a resource — not a waste. Approaching LID as part of a larger design process enables us to move away from the conventional concept of runoff as a disposal problem (and disposed of as rapidly as possible) to understanding that stormwater is a resource for groundwater recharge, stream base flow, lake and wetland health, water supply, and recreation.

Mimic the natural water cycle. Stormwater management using LID includes mimicking the water cycle through careful control of peak rates as well as the volume of runoff and groundwater recharge, while protecting water quality. LID reflects an appreciation for management of both the largest storms, as well as the much more frequent, smaller storms.

Disconnect. Decentralize. Distribute. An important element of LID is directing runoff to BMPs as close to the generation point as possible in patterns that are decentralized and broadly distributed across the site.

Integrate natural systems. LID includes careful inventorying and protecting of a site's natural resources that can be integrated into the stormwater management design. The result is a natural or "green infrastructure" that not only provides water quality benefits, but greatly improves appearance by minimizing infrastructure.

Maximize the multiple benefits of LID. LID provides numerous stormwater management benefits, but also contributes to other environmental, social, and economic benefits. In considering the extent of the application of LID, communities need to consider these other benefits.

Use LID everywhere. LID can work on redevelopment, as well as new development sites. In fact, LID can be used on sites that might not traditionally consider LID techniques, such as in combined sewer systems, along transportation corridors, and on brownfield sites. Broad application of LID techniques improves the likelihood that the desired outcome of water resource protection and restoration will be achieved.

Make maintenance a priority. The best LID designs lose value without commitment to maintenance. An important component of selecting a LID technique is understanding the maintenance needs and institutionalizing a maintenance program. Selection of optimal LID BMPs should be coordinated with both the nature of the proposed land use/building program and the owners/operators of the proposed use for implementation of future maintenance activities.

Benefits of implementing LID

Implementing LID offers numerous benefits to communities, developers, and the public that extend well beyond water quality protection. Here are some examples:

Communities, agencies, and the public

- Reduces municipal infrastructure and utility maintenance costs (e.g., streets, curbs, gutters, storm sewers).
- Increases energy and cost savings for heating, cooling, and irrigation.
- Reduces flooding and streambank erosion.
- Replenishes groundwater drinking supply.
- Assists in meeting regulatory obligations.
- Serves multiple purposes (e.g., traffic calming, greenways).
- Brings neighborhoods together in maintaining LID.
- Increases recreational opportunities.
- Provides environmental education opportunities.
- Improves quality of life for residents.
- Protects community character/aesthetics.
- Protects and enhances sensitive habitat.
- Restores/protects fisheries and other aquatic life.
- Reduces salt usage and snow removal on paved surfaces.

Developers

- Reduces land clearing and grading costs.
- Potentially reduces infrastructure costs (e.g., streets, curb, gutters).
- Reduces stormwater management construction costs.
- Increases marketability leading to faster sales.
- Potentially increases lot yields/amount of developable land.
- Assists in meeting LEED (Leadership in Energy and Environmental Design) Certification requirements.
- Appealing development consistent with the public's desire for environmental responsibility.

Environmental

- Protects/restores the water quality of rivers and lakes.
- Protects stream channels.
- Reduces energy consumption.
- Improves air quality.
- Preserves ecological and biological systems.
- Reduces impacts to terrestrial and aquatic plants and animals.
- Preserves trees and natural vegetation.
- Maintains consistent dry weather flow (baseflow) through groundwater recharge.
- Enhances carbon sequestration through preservation and planting of vegetation.

Recreation in Glen Haven, MI

Michigan inland lakeshore on Horseshoe Lake, Northfield Township, MI

Cost effectiveness and LID

A variety of sources are now available documenting the cost effectiveness — even cost reductions — which can be achieved through the application of LID practices. The U.S. Environmental Protection Agency (EPA) released *Reducing Stormwater Costs Through Low Impact Development (LID) Strategies and Practices*, reporting on cost comparisons for 17 different case studies across the country. EPA results demonstrate the positive cost advantages of LID practices, when compared with traditional development patterns using conventional stormwater management techniques.

Based on this recent work, EPA concludes that, in the majority of cases, significant cost savings resulted from reduced site grading and preparation, less stormwater infrastructure, reduced site paving, and modified landscaping. Total capital cost savings ranged from 15 to 80 percent when using LID methods. Furthermore, these results are likely to conservatively undercount LID benefits. In all cases, there were benefits that this EPA study did not monetize or factor into each project's bottom line. These benefits include:

- Improved aesthetics,
- Expanded recreational opportunities,
- Increased property values due to the desirability of the lots and their proximity to open space,
- Increased total number of units developed,
- Increased marketing potential, and
- Faster sales.

Traverse City, MI, Marina

Using LID to meet regulatory requirements

LID practices can be used to meet a variety of state and federal permit programs. These range from the National Pollutant Discharge Elimination System (NPDES) Phase I and Phase II stormwater requirements, to combined sewer overflow (CSO) and sanitary sewer overflow (SSO) requirements. For example, many Michigan municipalities are plagued with CSO problems as well as SSOs caused by excessive inflow of stormwater and groundwater into the sanitary sewer system. Communities can integrate LID practices, such as a residential rain barrel program and downspout disconnection to their overflow control programs to help reduce stormwater inflow into the system, thereby reducing overflows.

Additionally, cost estimates do not include any sort of monetizing of the environmental impacts which are avoided through LID, as well as reductions in long-term operation and maintenance costs, and/or reductions in the life cycle costs of replacing or rehabilitating infrastructure.

Confirming EPA results, a recent report by the Conservation Research Institute for the Illinois Conservation Foundation, *Changing Cost Perceptions: An Analysis of Conservation Development*, 2005, undertook three different types of analyses on this cost issue — a literature review, an analysis of built-site case studies, and a cost analysis of hypothetical conventional versus conservation design templates. In terms of literature review, this study concludes:

- Public infrastructure costs are lower when a development is built within the context of smart growth patterns that conserve land.
- At the site level, significant cost savings can be achieved from clustering, including costs for clearing and grading, stormwater and transportation infrastructure, and utilities.
- Installation costs can be between $4,400 and $8,850 cheaper per acre for natural landscaping than for turf grass approaches.

Table 2.2
Summary of Cost Comparisons Between Conventional and LID Approaches

Project	Conventional Development Cost	LID Cost	Cost Difference	Percent Difference
2nd Avenue SEA Street	$868,803	$651,548	$217,255	25%
Auburn Hills	$2,360,385	$1,598,989	$761,396	32%
Bellingham City Hall	$27,600	$5,600	$22,000	80%
Bellingham Bloedel Donovan Park	$52,800	$12,800	$40,000	76%
Gap Creek	$4,620,600	$3,942,100	$678,500	15%
Garden Valley	$324,400	$260,700	$63,700	20%
Laurel Springs	$1,654,021	$1,149,552	$504,469	30%
Mill Creek[a]	$12,510	$9,099	$3,411	27%
Pairie Glen	$1,004,848	$599,536	$405,312	40%
Somerset	$2,456,843	$1,671,461	$785,382	32%
Tellabs Corporate Campus	$3,162,160	$2,700,650	$461,510	15%

[a] Mill Creek costs are reported on a per-lot basis.

Source: *Low Impact Development (LID) Strategies and Practices*, USEPA, 2007

- Maintenance cost savings range between $3,950 and $4,583 per acre, per year over 10 years for native landscaping approaches over turf grass approaches.
- While conventional paving materials are less expensive than conservation alternatives, porous materials can help total development costs go down, sometimes as much as 30 percent by reducing conveyance and detention needs.
- Swale conveyance is cheaper than pipe systems.
- Costs of retention or detention cannot be examined in isolation, but must instead be analyzed in combination with conveyance costs, at which point conservation methods generally have a cost advantage.
- Green roofs are currently more expensive to install than standard roofs, yet costs are highly variable and decreasing. Green roofs also have significant cost advantages when looking at life cycle costs (e.g., building, heating, and cooling costs).

Principles of Smart Growth

- Create a range of housing opportunities and choices.
- Create walkable neighborhoods.
- Encourage community and stakeholder collaboration.
- Foster distinctive, attractive communities with a strong sense of place.
- Make development decisions predictable, fair, and cost effective.
- Mix land uses.
- Preserve open space, farmland, natural beauty, and critical environmental areas.
- Provide a variety of transportation choices.
- Strengthen and direct development towards existing communities.
- Take advantage of compact building design.

Source: Smart Growth Network

Relationship of LID to other programs

LID is compatible with the principles of smart growth and the requirements of the U.S. Green Building Council's LEED program because LID offers prevention and mitigation benefits that make land development much more sustainable.

LID and Smart Growth

LID is often seen as a site specific stormwater management practice, while smart growth is often a broader vision held at a community, county, or regional level. However, as noted in Chapter 4, an important first step in LID is incorporating LID at the community level.

There are direct connections between LID and smart growth. For example, principles relating to compact building design and preserving natural features directly relate to nonstructural LID BMPs listed in Chapter 6. Upon further evaluation, LID is also consistent with the larger concepts of stakeholder collaboration; fostering communities with a strong sense of place; and implementing fair, predictable, and cost effective development decisions.

LID and LEED

The Leadership in Energy and Environmental Design (LEED) certification encourages and accelerates global adoption of sustainable green building and development practices by creating and implementing widely understood and accepted tools and performance criteria. LEED has developed rating systems for a myriad of development scenarios, including new construction, existing buildings, commercial interiors, core and shell, schools, retail, healthcare, homes, and neighborhood development.

As with Smart Growth, there are significant connections between LID and LEED certification. In fact, LID practices are integrated into each of the LEED rating systems.

The United States Green Building Council (USGBC), the Congress for New Urbanism and the National Resources Defense Council are currently working on a new rating system called LEED for Neighborhood Development (LEED-ND). The strongest connection between the LEED system and LID will be through LEED-ND certification. LEED-ND is part of the natural evolution of the green building movement, expanding sustainability standards to the scale of the neighborhood. While current green building standards focus on buildings in isolation, LEED-ND will bring emphasis to the elements that determine a development's relationship with its neighborhood, region, and landscape. LEED-ND sets standards in four categories that pinpoint essential neighborhood characteristics:

- Complete, compact, and connected neighborhoods,
- Location efficiency,
- Resource efficiency, and
- Environmental preservation.

Currently, the LEED-ND system is being piloted by the USGBC. The post-pilot version of the rating system, which will be available to the public, is expected to launch in 2009 (See LEED-ND criteria pullout).

Fairmount Square LEED Certification

Fairmount Square is a 4-acre infill site that uses rainwater capture, porous pavement, and rain gardens to manage its stormwater. The project is also seeking various LEED credits for new construction.

The building was designed with a focus of structural longevity and durability, energy efficiency, and a high quality indoor environment. Key site features include: better insulated concrete framing and roofing material and the use of low off-gassing interior materials such as carpet, paints, caulks, and adhesives. The project also takes advantage of existing infrastructure by being close to transit lines and other community features within walking distance to the site.

Fairmount Square, Grand Rapids, MI

Source: Fishbeck, Thompson, Carr & Huber, Inc.

Getting started with LID

LID can be implemented by many different groups, including communities, counties, developers, agencies, or individuals. Implementing LID can take many forms. For some, implementation might be encouraged on a voluntary basis during the site plan review process. For others, LID might become an expected application at each site and be institutionalized in an ordinance or through multiple ordinances.

A key first step is for different institutions within a local government to discuss the pros and cons of various approaches to LID. These stakeholders might include mayors/supervisors, councils/trustees, planning commissions, public works department, etc. The outcome of these discussions will be action steps toward instituting LID at the desired scale on a community basis.

City of Wixom, MI Habitat Park
Source: Hubbell, Roth & Clark, Inc.

LEED-ND Criteria

Smart Location and Linkage (SLL)

SLL Prerequisite 3: Imperiled species and ecological communities

SLL Prerequisite 4: Wetland and water body conservation

SLL Prerequisite 6: Floodplain avoidance

SLL Credit 8: Steep slope protection

SLL Credit 9: Site design for habitat or wetland conservation

SLL Credit 10: Restoration of habitat or wetlands

SLL Credit 11: Conservation management of habitat or wetlands

Neighborhood pattern and design (NPD)

NPD Prerequisite 1: Open community

NPD Prerequisite 2: Compact development

NPD Credit 1: Compact development

Green construction and technology (GCT)

GCT Prerequisite 1: Construction activity pollution prevention

GCT Credit 3: Reduced water use

GCT Credit 6: Minimize site disturbance through site design

GCT Credit 7: Minimize site disturbance during construction

GCT Credit 9: Stormwater management

GCT Credit 10: Heat island reduction

References

Center for Watershed Protection. www.cwp.org

Conservation Research Institute. *Changing Cost Perceptions: An Analysis of Conservation Development*, 2005. www.nbwctp.org/resources/CD/Changing_Cost_Perceptions.pdf

Smart Growth Network. www.smartgrowth.org

U.S. Environmental Protection Agency. *Reducing Stormwater Costs Through Low Impact Development (LID) Strategies and Practices*, December 2007. www.epa.gov/sites/production/files/2015-10/documents/2008_01_02_nps_lid_costs07uments_reducingstormwatercosts-2.pdf

U.S. Green Building Council. LEED Rating System. www.usgbc.org/leed

Chapter 3

LID in Michigan: The Key Determinants

This chapter summarizes Michigan data for the key determinants and variables that are used in LID design. Included with the descriptions of these determinants and variables are resources for obtaining data. The figures, tables, data, etc., included in this chapter are for illustrative purposes only and should not be used for design. Wherever possible, design should be based on site specific information gathered by field investigation or other local data sources. This chapter discusses:

- Michigan climate, including rainfall, snowfall, and soil freezing,
- Geology and soil groups,
- Plant resources, and
- Sensitive areas, including wetlands, wellhead protection areas, and sensitive and impaired waters.

The State of Michigan is a land of contrasts and broad continuums. Driven by climate changes, vast ancient inland seas and mile-high glaciers expanded and contracted over the Michigan landscape. These movements left behind and sculpted geological material overlying mineral deposits across the state and contributed to the emergence of a variety of watersheds with a wide range of characteristics. For example, soils in Michigan range from heavy clay, such as ancient lake sediments on the eastern side of the state, to the very well-draining sands of the northern half of the Lower Peninsula. This may lead practitioners to think that a single development strategy – minimizing hydrologic impacts – would be difficult to implement and standardize. However, LID works across many continuums precisely because the benchmark is always local and calibrated to the local hydrologic conditions.

This manual was prepared for use throughout Michigan. In design, LID is structured to maximize the use of natural features to mimic presettlement hydrology. In application, LID must be site specific. The site specific considerations highlighted in this chapter provide a preview of what to include in a local LID program. The generalized data in this chapter are provided for illustrative purposes. This should be substituted with the best available local data.

Climate

Climate drives site hydrology. Michigan's unique location, bordering four Great Lakes, moderates and exacerbates climate conditions. The lakes can moderate temperature extremes but can also significantly change precipitation patterns. For instance, lake effect precipitation results in the highest annual precipitation totals on the southwestern side of the state. Precipitation in the form of rainfall and snowmelt, and issues relating to freeze/thaw are key determinants that must be considered when using LID techniques.

Rainfall

A common goal in applying LID is to keep as much stormwater on a site as possible. Therefore, design is closely related to rainfall patterns in a particular area. The average annual rainfall in Michigan ranges from less than 28 inches to more than 38 inches per year (Figure 3.1). Annual rainfall varies from the wetter southwest to the drier north and east. But, storm frequency data show some consistency across the state. For example, the two-year frequency, 24-hour duration storm only varies by region from 2.09 to 2.42 inches (Table 3.1). (Storm frequency is based on the statistical probability of a storm occurring in a given year. That is, a 10-year, 24-hour storm has a 10 percent chance of occurring in any single year; a 50-year storm has a two percent chance; and a 100-year storm, a one percent chance).

Table 3.1
Rainfall Event Totals of 24-Hour Duration in Michigan

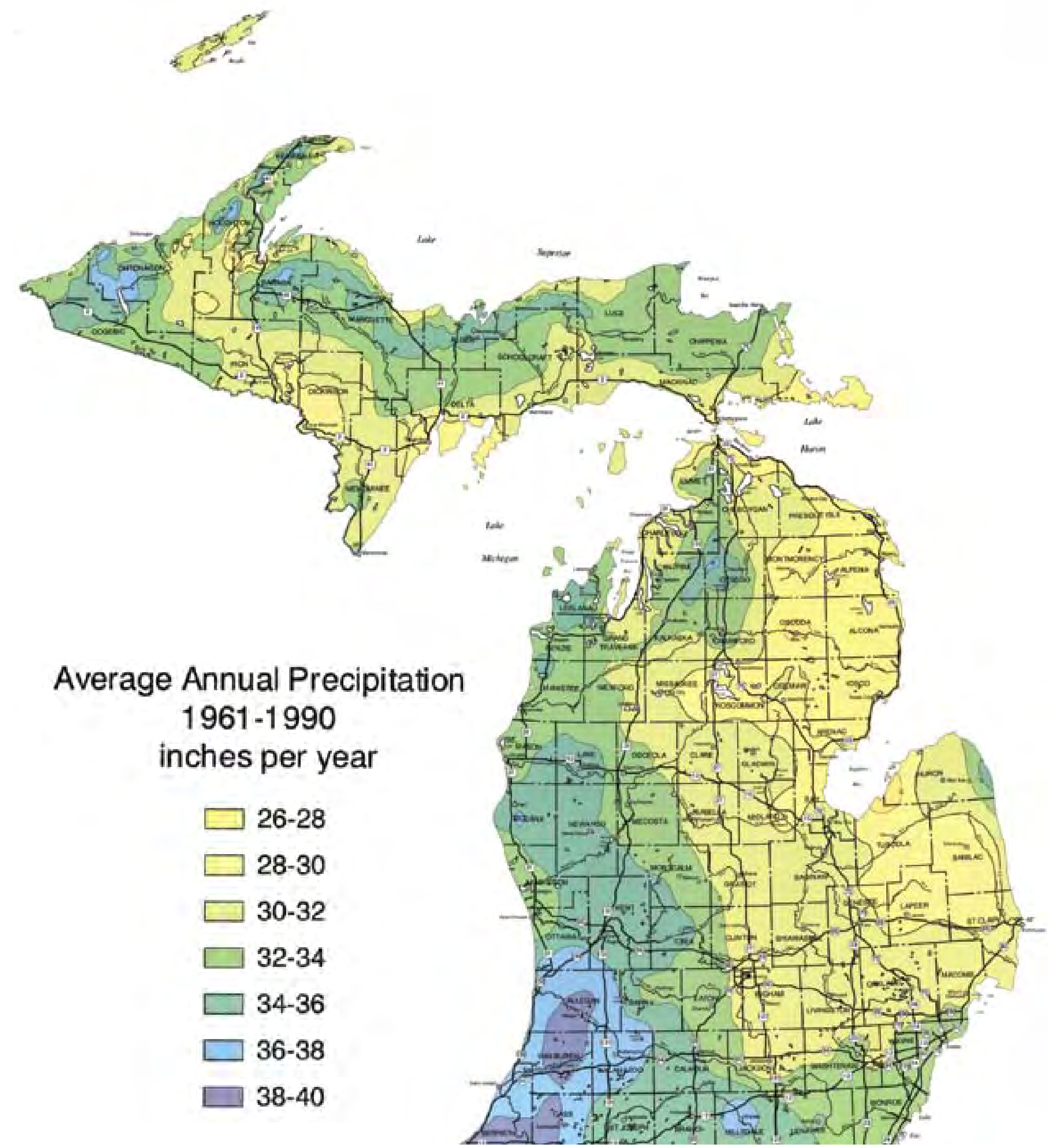
Region of Michigan (numbers refer to the sections of Michigan in Huff and Angel)	1-year Storm (in.)	2-year Storm (in.)	10-year Storm (in.)	50-year Storm (in.)	100-year Storm (in.)
Southwest Lower (8)	1.95	2.37	3.52	5.27	6.15
South-Central Lower (9)	2.03	2.42	3.43	4.63	5.20
Southeast Lower (10)	1.87	2.26	3.13	3.98	4.36
Northwest Lower Peninsula (3)	1.62	2.09	3.21	4.47	5.08
West Upper Peninsula (2)	1.95	2.39	3.48	4.73	5.32

Source: Huff and Angel, 1992. Rainfall Frequency Atlas of the Midwest

Precipitation also varies slightly by season — the wettest seasons being summer (averaging 30 percent of the total annual precipitation) and fall (28.6 percent), followed by spring (24 percent) and winter (17.4 percent). (Huff and Angel, 1992) This seasonal variation is even more dramatic in terms of the largest one-day storms; only 2.3 percent of these large storms occurred in winter, while 44.2 percent fell in fall and 39.5 percent in summer. (Huff and Angel, 1992)

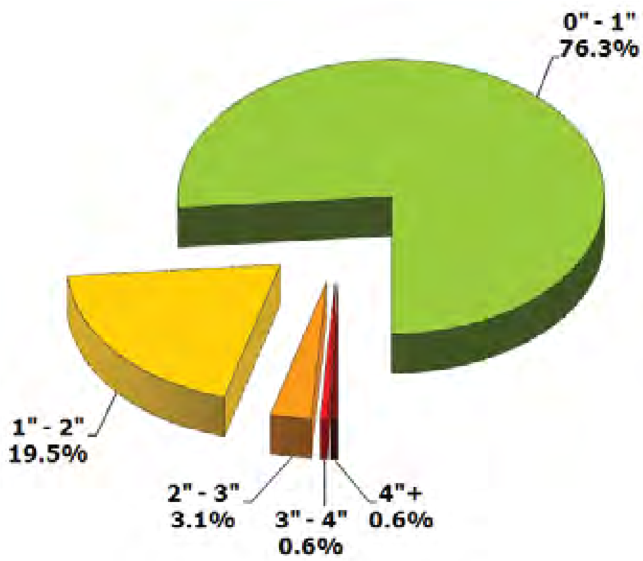
Although large storms are critical in terms of flooding, most rainfall in Michigan actually occurs in relatively small storm events, as indicated in Figure 3.2. Approximately three-quarters of the average annual rainfall throughout the state occurs in storms of one inch or less (76.3 percent calculated for Lansing). About 95 percent of the average annual rainfall occurs in storms of two inches or less, and over 98 percent of average annual rainfall occurs in storms of three inches or less. As discussed above, the two-year frequency rainfall is approximately 2-2.5 inches.

Figure 3.1
Average Annual Precipitation in Michigan



Source: NRCS National Cartography and Geospatial Center

Figure 3.2
Rainfall Distribution by Storm Size for Lansing, Michigan based on Daily Precipitation Values from 1948 to 2007



When stormwater management only addresses large events (two-year storms and greater), much of the actual rainfall and runoff are not properly managed (as much as 95 percent of the annual rainfall). Therefore, managing smaller storms that comprise the vast majority of the annual rainfall in Michigan is critical.

Rainfall frequency data, for application in stormwater calculations, can be found in Chapter 9.

Resources:

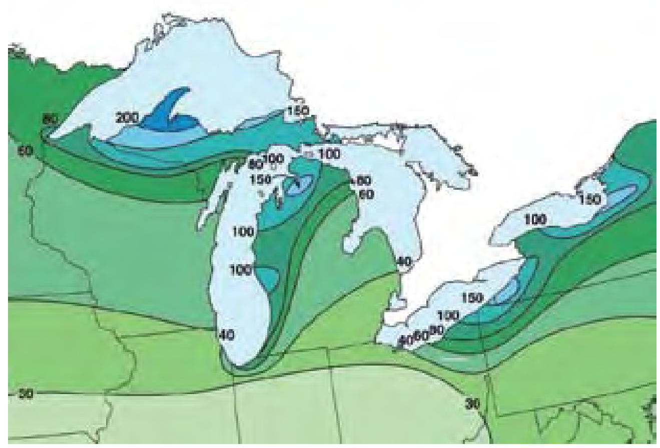
1. The most frequently used rainfall data has been compiled by Huff, F.A. and Angel, J.R. See: Rainfall Frequency Atlas of the Midwest, 1992. Bulletin 71 Midwestern Climate Center and Illinois State Water Survey. MCC Research Report 92-03. Available for free download at: http://www.sws.uiuc.edu/pubdoc/B/ISWSB-71.pdf
2. Long-term daily and monthly precipitation data for about 25 stations throughout Michigan is available free from the United States Historical Climatology Network (USHCN) at: http://cdiac.ornl.gov/epubs/ndp/ushcn/ushcn_map_interface.html

Snow and soil freezing

Snowfall and soil freezing are both important considerations when applying LID practices in Michigan. This is due to numerous issues including storage of large quantities of snow and the impact of freezing on the functioning of the BMP. (Chapter 7 details these considerations and provides solutions for Michigan). The degree to which these factors drive LID design will vary significantly in different parts of the state.

When selecting and designing a BMP, local information on snowfall is important. Annual snowfall in Michigan increases from southeast to northwest, with an average of 30 inches near Lake Erie, an average of 100-150 inches in the northern Lower Peninsula, and an average of 200 inches in the northern Upper Peninsula (Figure 3.3). In the Lower Peninsula, a lake effect snowbelt extends 10-80 km inland from the shore of Lake Michigan (Thomas 1964, cited in Isard and Schaetzl, 1998).

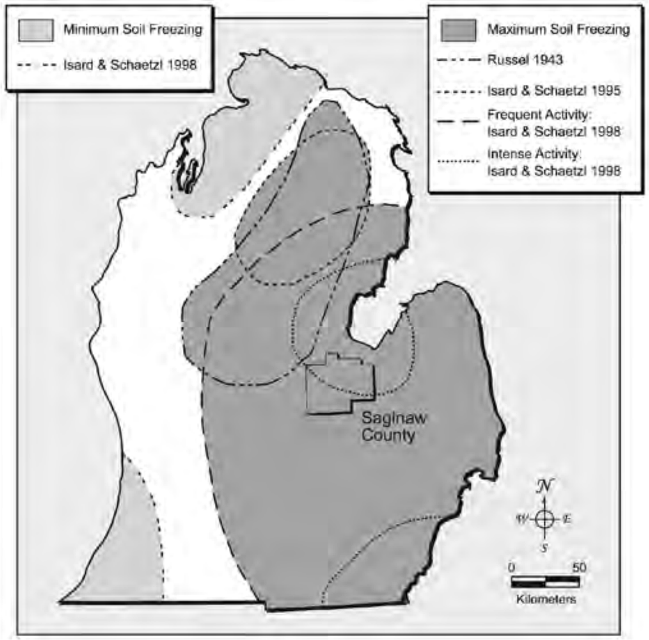
Figure 3.3
Average Annual Snowfall in Inches (1971 – 2000)



Source: Weather Michigan: (http://www.weathermichigan.com)

Local soil freezing information is another important consideration for LID design. This is because ice in soil pores block water infiltration and cause runoff of snowmelt or rain from infiltration BMPs. There are design considerations, such as the use of compost or mulch that insulate infiltration BMP soils (refer to Chapter 7). A thick, persistent snowpack also insulates soil from below-freezing air temperatures. In the snowbelt regions, soil freezing is less frequent, and in some years nonexistent, compared to areas with little or no persistent snow cover throughout the winter (Figure 3.4). On average, the snowbelt regions experience less than two freeze-thaw cycles per year. In contrast, the eastern and southeastern portions of the Lower Peninsula usually

Figure 3.4
Soil Freezing in Lower Michigan



Source: Schaetzl and Tomczak, 2002

experience three to five freeze-thaw cycles per year and the soil may freeze to a depth of five centimeters or more even in warm winters (Isard and Schaetzl, 1998).

Resources:

1. Snowfall and snow cover data are available at: http://www.ncdc.noaa.gov/snow-and-ice/recent-snow/.
2. Soil temperature data for the past two months at a limited number of locations can be found at: https://mawn.geo.msu.edu/.

Earth resources

Geology/Soils

Because many LID techniques rely on infiltrating rain water and runoff, it is essential to consider the soil properties and underlying geology that control the balance between infiltration, runoff, and groundwater elevations. Soil type and texture class determine the rate of infiltration, the amount of water stored in the soil pores, and the relative effort required by evaporation or plant roots to draw water back up against gravity.

Depth to groundwater and depth to bedrock are important considerations in BMP design and can constrain design of infiltration BMPs. Although rare in Michigan, karst formations present another potential constraint to infiltration BMPs. Karst is a carbonate-based bedrock, such as limestone or dolomite, that is highly soluble. Increasing infiltration into karst formations can hasten the dissolution of rock and potentially lead to subsurface voids and sinkholes.

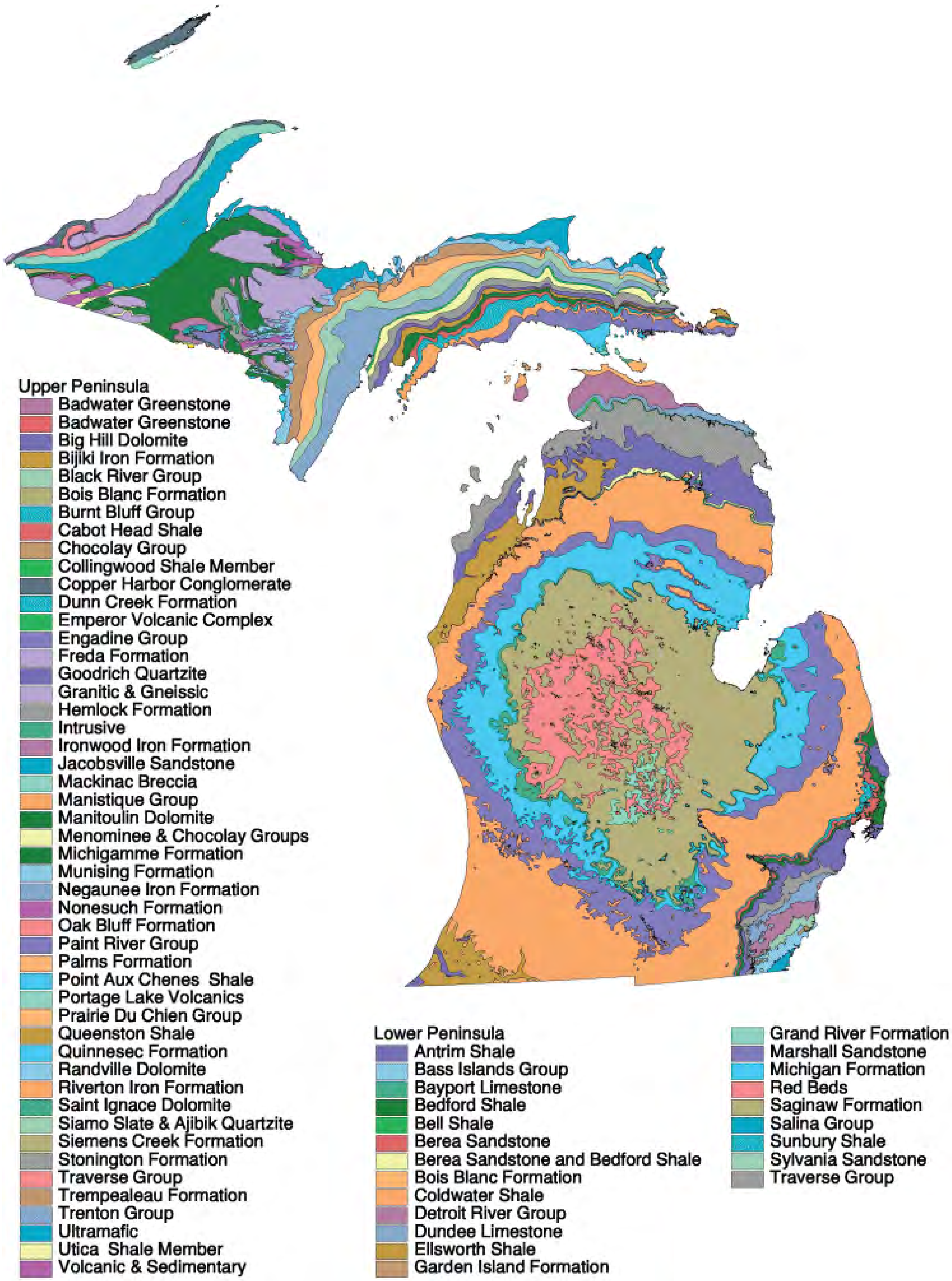
Soils in Michigan are somewhat unique. In most areas of the world, bedrock is weathered to produce soils. However, in Michigan, glacial deposits have buried the bedrock in most areas. This makes the surface geology different in origin and composition than the underlying bedrock geology (Figure 3.5).

In Michigan, ancient bedrock materials are covered with 200-300 feet of glacial deposits, and in some places 1,200 feet of deposits (Kelley, 1960). In general, the surface geology shifts from clay in the southeast Lake Erie region to sands in the north and west (Figure 3.6).

Successfully implementing LID requires balancing the interdependent variables that affect site hydrology. Soils are a key aspect of hydrology that exemplifies this balancing act. Except for a few areas in Michigan where bedrock is exposed in outcrops or erosion of glacial deposits, it is the surface geology that determines soil properties.

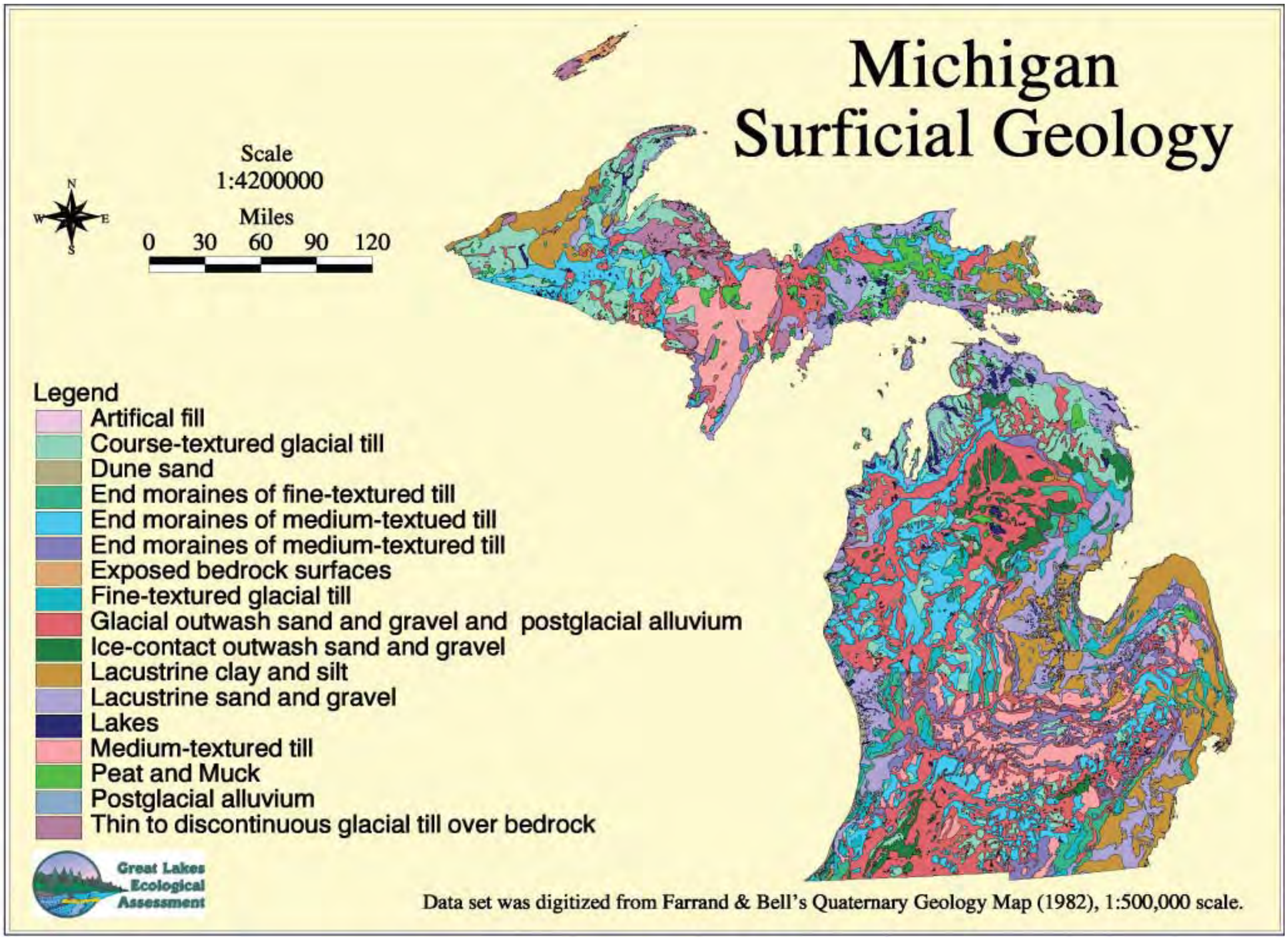
For LID, a soil's infiltration capacity should be understood in relation to the soil's capacity to filter/remove pollutants before reaching groundwater. Clays have very low infiltration rates but tend to have the highest capacity for removing pollutants. On the other hand, sands have high infiltration rates, but tend to have low capacities for removing pollutants. Organic-rich soils tend to have high infiltration rates, but are often found in high groundwater locations. Organic-rich soils also tend to have high capacities for pollutant removal.

Figure 3.5
Michigan Bedrock Geology



Source: US Forest Service, Great Lakes Ecological Assessment, (http://www.ncrs.fs.fed.us/gla/)

Figure 3.6
Michigan Surficial Geology



Source: US Forest Service, Great Lakes Ecological Assessment, (http://www.ncrs.fs.fed.us/gla/)

Soil groups

Soils can be grouped and classified in a number of ways, including by:

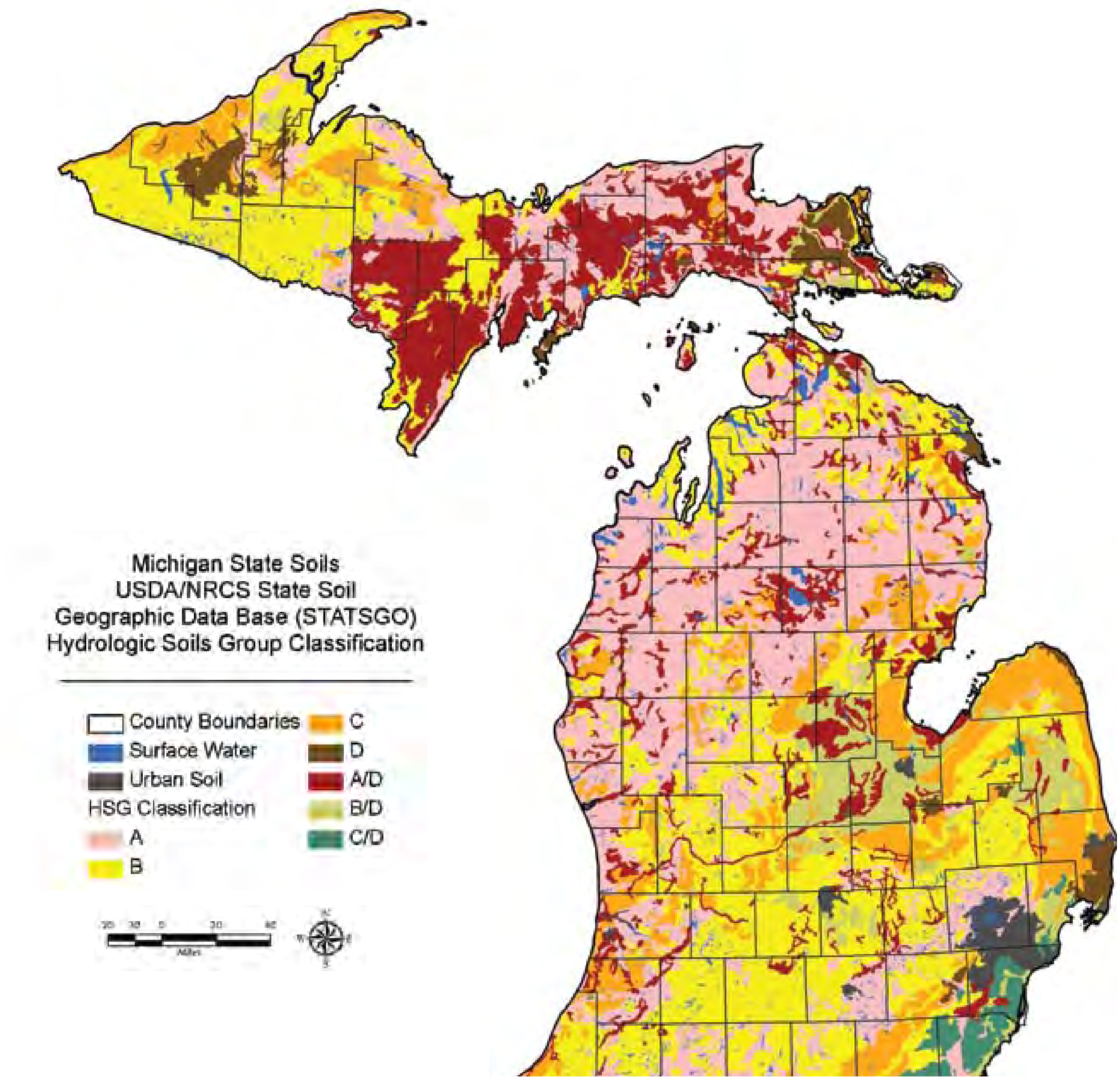
- Soil orders (soil origin and properties),
- Texture class (silt, clay, loam, etc.),
- Engineering properties (bearing strength, internal cohesion, angle or repose, etc.),
- Chemical properties (acidity, cation exchange capacity), and
- Hydrologic properties (well-drained, poorly drained).

The Natural Resources Conservation Service (NRCS) has developed electronic maps of almost all soils in Michigan (refer to: http://websoilsurvey.nrcs.usda.gov/app/). NRCS delineates soils by series; these soils series and names are locally specific. NRCS has associated the series names and soil properties in this spatial, electronic database.

Although soil series names are different in counties across the state, many soil series are quite similar with respect to drainage. Soil series are assigned a Hydrologic Soil Group (HSG) rating, A-D, which describes the physical drainage and textural properties of each soil type and is useful for stormwater, wastewater, and other applications (Figure 3.7). This HSG rating usually is based on a range of permeability, as well as certain physical constraints such as soil texture, depth to bedrock, and seasonal high water table (SHWT) and are defined in Table 3.2.

All soils are permeable and drain to some degree unless they are saturated by hydrologic conditions, such as hydric soils in a wetland. The wetter D soils have little or no infiltration potential during rainfall and produce much greater surface runoff with seasonal variability.

Figure 3.7
Hydrologic Soils Group Classification



Source: United States Department of Agriculture, Natural Resources Conservation Service

Table 3.2
Hydrologic Soil Groups

Soil Group	Soil Type	Drainage Capacity
A	sand, loamy sand, sandy loam	very well drained and highly permeable
B	silt loam, loam	good
C	sandy clay loam	fair
D	clay loam, silty clay loam, sandy clay, silty clay, clay	poorly drained and generally situated in a valley bottom or floodplain

Most soils in Michigan are classified with a HSG rating of A or B, both usually being very good for applying many stormwater management systems, as well as onsite septic systems and other infiltration applications. State Soil Geographic Database (STATSGO) data for Michigan indicates that:

- 29 percent of soils are classified as A,
- 32 percent as B,
- 13 percent as C, and
- Three percent as D, along with some mixed (A/D, B/D) classifications (Figure 3.8).

It should be noted that the permeability ranges listed for the HSG ratings are based on the minimum rate of infiltration obtained for bare soil after prolonged wetting (USDA SCS,1986). Vegetative cover increases these rates three to seven times (Lindsey et. al., 1992).

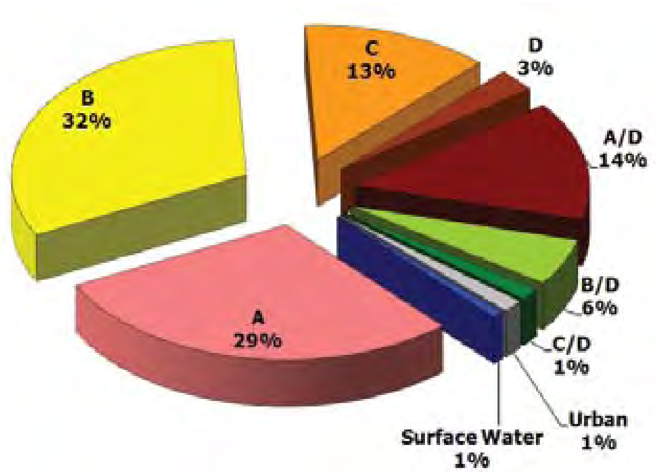
It is important to also understand the infiltration capacity of soils below the near-surface (approximately top 12 inches) to adequately characterize a soil's infiltration capacity because deeper soils may be more limiting to infiltration than surface soils.

County soil surveys may be used as a preliminary source for soil column characterization. However, it is recommended that site specific soil testing be done before final design and implementation of LID projects in order to confirm soil characterization and infiltration capacity (Appendix E).

Resources:

1. Soil survey data are available online from NRCS Soil Surveys at: http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Figure 3.8
Distribution of Hydrologic Soil Groupings (HSGs) in Michigan



Pollutant removal by soils

Many factors influence a soil's pollutant removal capacity. Factors that influence pollutant removal include infiltrated water quality, and soil characteristics such as age, pH, particle size, mineral content, organic matter content, oxidation-reduction potential (redox), as well as the soil flora and fauna at the surface and in the subsurface. To simplify, this manual limits discussion to a few key factors that are reasonable surrogates for estimating pollutant removal through soils — soil organic matter content and cation exchange capacity (CEC).

Soil provides the medium for decomposition of all organic material generated on the land surface. Soil is the habitat for a vast spectrum of micro- and macro-organisms that form a natural recycling system. The rhizosphere (the rooting zone) includes: roots, viruses, bacteria, fungi, algae, protozoa, mites, nematodes, worms, ants, maggots, other insects and insect larvae (grubs), earthworms, and rodents.

Processed nutrients in the rhizosphere are, in turn, used by the vegetative systems that develop on the soil mantle. When precipitation is infiltrated, it transports pollutants from the surface into this soil treatment system, which effectively and efficiently breaks down most nonpoint source pollutants (biologically), removes them from the stormwater by cation exchange (chemically), and/or physically filters them through soil particles.

One important measure of chemical pollutant removal potential is the CEC which is closely related to the organic content in the soil. Soils with a CEC of 10 milli-equivalents per 100 grams of soil are very efficient as a treatment medium, and offer the best opportunity to reduce or completely remove most common pollutants, such as phosphorus, metals, and hydrocarbons. Pollutants that are dissolved in stormwater, such as nitrate, are the exception. Nitrates typically move with the infiltrating rainfall and do not undergo significant reduction or transformation, unless an anaerobic environment with the right class of microganisms is encountered.

There are seven soil orders in Michigan with varying CECs (Figure 3.9). The typical CEC ranges of these soil orders are summarized in Table 3.3. Two soil orders that have relatively high CECs in Michigan are Mollisols and Histosols. Mollisols are young soils formed in grassland regions, and have high organic content derived from long-term additions from plant roots. Mollisols are common in the southeastern portion of the Lower Peninsula and sporadic throughout the remainder of the Lower Peninsula. Histosols, or peat-derived soils, have very high organic matter content and also have high CEC. Histosols are common in the eastern Upper Peninsula, and present sporadically in the Lower Peninsula.

Figure 3.9
Dominant Soil Orders of Michigan

Source Michigan State University Center for Remote Sensing and Geographic Sciences (http://www.rsgis.msu.edu)

Table 3.3
Representative Cation Exchange Capacities in Surface Soils

Soil Order	CEC $mol_c\ kg^{-1}$
Alfisols	0.12 ± 0.08
Aridisols	0.16 ± 0.05
Entisols	1.4 ± 0.3
Inceptisols	0.19 ± 0.17
Mollisols	0.22 ± 0.10
Oxisols	0.05 ± 0.03
Spodosols	0.11 ± 0.05
Ultisols	0.06 ± 0.06
Vertisols	0.37 ± 0.08

Source: Sposito, 1989. *The Chemistry of Soils*.

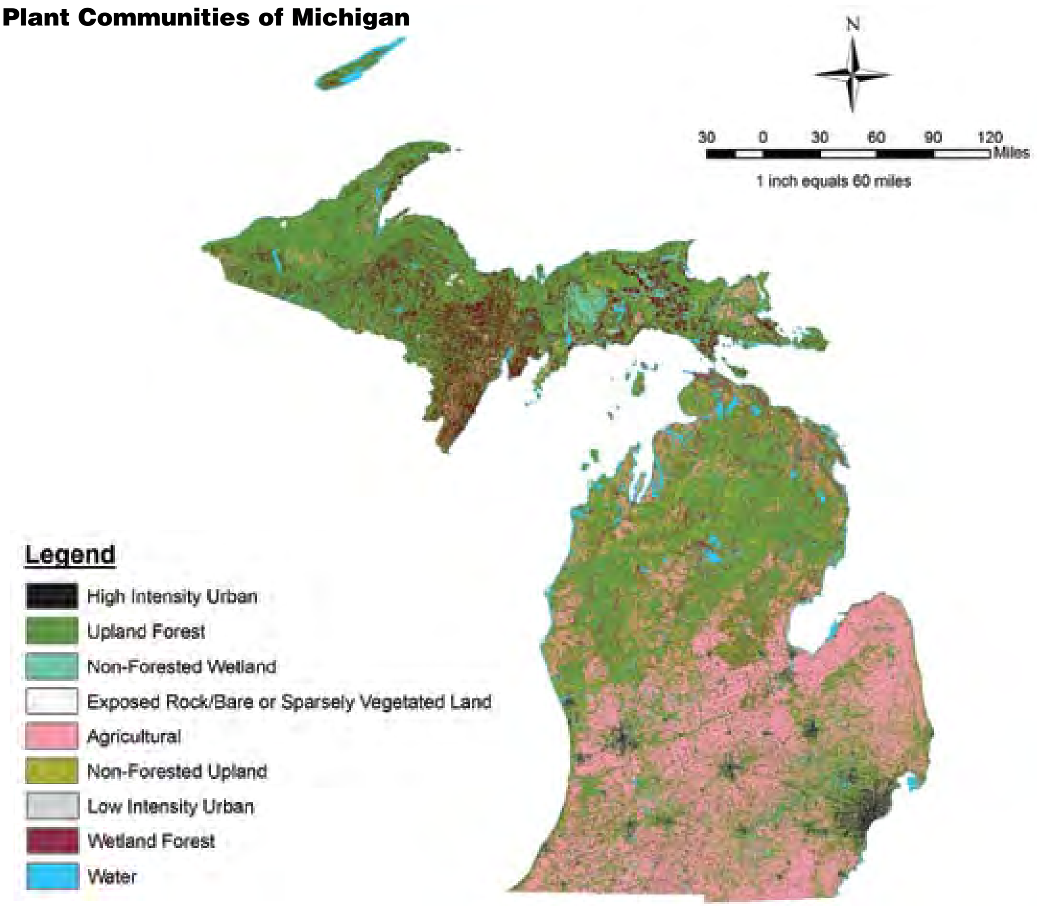
Biotic resources

The biotic resources of Michigan span a vast array of flora and fauna. These organisms impact the effectiveness of stormwater management programs and are impacted by the programs set in place. LID involves capitalizing on the unique opportunities afforded by natural systems to a more significant extent than conventional stormwater management. In turn, LID attempts to reduce impacts on natural systems beyond the capacities of conventional development.

Successfully applying LID involves shifting our approach from design by reshaping the environment to design by developing land in ways that take advantage of natural processes. Clearly, minimizing impervious surfaces, a key LID nonstructural BMP (Chapter 6), maximizes the preservation of natural features. On developed land, many LID BMPs emulate the process of natural soils, flora, and fauna. The entire plant sphere, from the tree canopy to the understory, shrubs and herbaceous shoots, plant litter, and the rhizosphere is actively engaged in water recycling. Along each step of the way, plants work to capture, store, and reuse precipitation. LID BMPs capitalize on this natural water conservation and reuse cycle.

In addition to the stormwater management benefits, plant communities provide food, shelter, and habitat for wildlife species in Michigan, including mammals, birds, reptiles, amphibians, and insects.

Figure 3.10
Current Plant Communities of Michigan



Preserving natural communities

A key concept of LID is preserving natural areas through various land design options (Chapter 6, Nonstructural BMPs). During site design, it is critical to systematically consider the present land cover, as well as the quality of the existing ecological and plant communities in order to determine if and how these communities should be preserved through LID.

The Floristic Quality Assessment (MI DNR, 2001) is a method for evaluating the quality of existing ecological and plant communities. The FQA provides a consistent and repeatable method for evaluating plant quality and biodiversity. Floristic quality is assumed to be an implicit indicator of biological health and natural feature significance. High floristic quality scores indicate that local conditions, including hydrology and water quality, are still functioning in a range that supports native vegetation. Figure 3.10 provides a graphic summary of current plant communities throughout Michigan.

Using native plants for revegetation

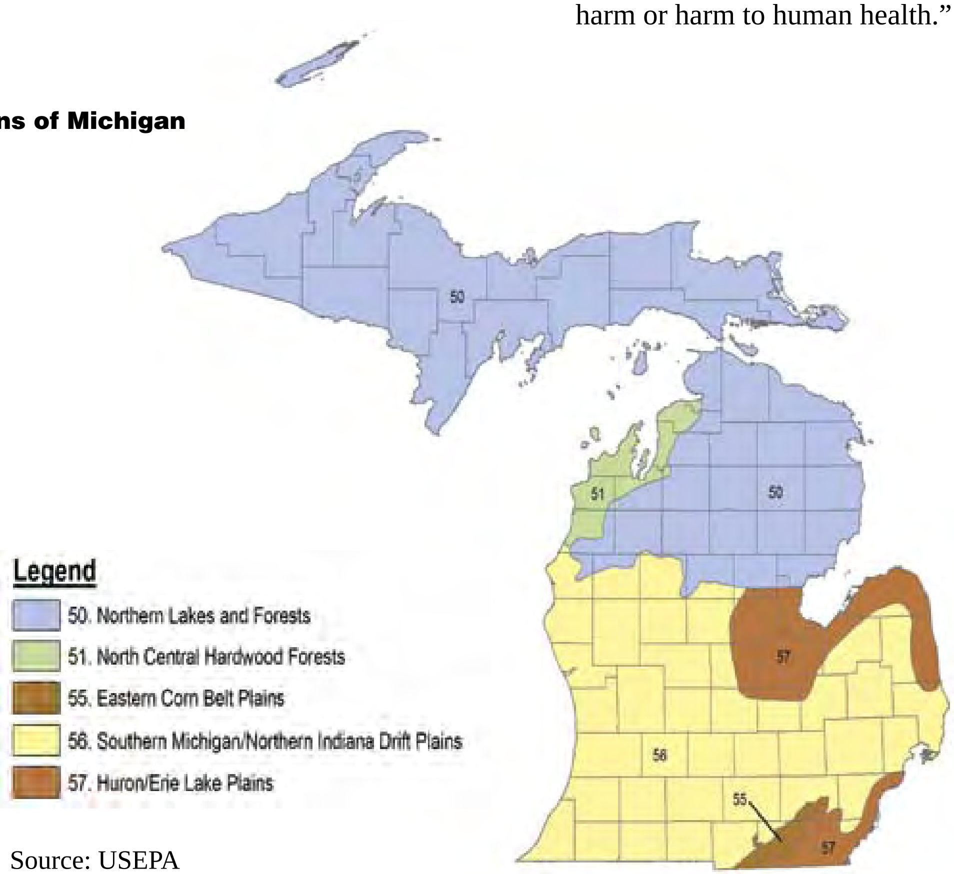
LID BMPs usually include using native plants because of the multiple benefits they provide. (For the purposes of this manual, native plants are defined as those occurring in a given ecoregion prior to European settlement). Native plants offer many advantages over non-natives, while still providing beneficial services such as increased infiltration rates, nutrient removal from stormwater, and carbon sequestration in their roots. Native plants are typically drought and disease tolerant, require little maintenance once established, and help restore plant diversity and soil stability. Native plants also attract a diverse abundance of wildlife including butterflies, songbirds, and beneficial insects, such as honey bees.

Native plants help create a self-sustaining natural habitat. Plant selection criteria should be based on an ecoregion (Figure 3.11) to ensure that plants can survive and flourish in specific climatic and environmental conditions. Recommended commercially available native plant lists by ecoregion and by BMP are provided in Appendix C (Recommended BMP Plant Lists).

Exotic and invasive plant species

In addition to native species, approximately 800 non-native plants have been introduced into the wild flora of Michigan. Of these introduced species, a small percentage has become invasive. The Michigan Invasive Plant Council (MIPC, www.invasiveplantsmi.org) defines an invasive species as “an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health.”

Figure 3.11
Ecoregions of Michigan



Source: USEPA

There is currently no single broadly accepted list of invasive species in Michigan. However, MIPC is currently evaluating species based on several scientific criteria in order to produce a recommended list of species identified as invasive. The Michigan Natural Features Inventory also has produced a series of fact sheets on selected invasive species (see *Resources*). Species that are generally accepted as invasive typically include:

- Spotted knapweed (*Centaurea maculosa*),
- Purple loosestrife (*Lythrum salicaria*),
- Common reed (*Phragmities australis*),
- Garlic mustard (*Alliaria petiolata*), and
- Honeysuckle species (*Lonicera spp.*).

When designing a LID technique, it's imperative to use plants that are not invasive, preferably using plants that are native to Michigan. That's because invasive species can affect the LID practice by altering the natural community's hydrologic processes. By affecting soil and vegetative structure, invasive species have the ability to increase erosion, decrease infiltration, and decrease water filtration. For instance, garlic mustard, a biennial herb, will often inhibit tree regeneration along woodland edges. Fewer trees will lead to less rainfall interception and lower amounts of organic matter in the forest soil, thus reducing a soil's ability to infiltrate and treat stormwater.

In addition, many of the nonstructural BMPs include preservation of natural areas. It's important to note that the quality of the natural area (not just quantity of the natural area) also should be assessed. For example, in preserving a riparian area, an inventory of potential invasive species and a management program should be put in place.

Resources:

1. Michigan Natural Features Inventory fact sheets can be found online at: http://mnfi.anr.msu.edu/
2. Michigan Department of Natural Resources Floristic Quality Assessment. Refer to http://www.michigandnr.com/publications/pdfs/HuntingWildlifeHabitat/FQA_text.pdf

Sensitive areas

When implementing LID in Michigan, it is vitally important to understand the connection of the site to such sensitive areas as wetlands, high quality waters, wellhead protection areas, and impaired waterways. Each one of these sensitive areas may require adjustment in the LID design to ensure protection of these resources. Additional information on some of these topics can be found in Chapter 8, Implementing LID in Special Areas.

Wetlands

In Michigan, approximately 3-5 million of the original 11 million acres of wetlands remain; the 100,000 acres of coastal wetlands that remain represent only one-quarter of presettlement cover (Mitsch and Gosselink, 1993). Wetlands are delineated based on soil properties, hydrologic regime, and vegetation. LID provides an opportunity in Michigan to help sustain hydrology and water quality in wetlands. For instance, floristic quality and ecological function are largely driven by water quality and the amount of time the species is saturated with water.

Before changes in land use occurred, many wetlands were fed mostly by groundwater. With land development and artificial drainage, additional surface runoff is channeled to wetlands. The additional surface runoff can have adverse impacts such as raising inundation depths, duration of high water, and degrading water quality. Higher water depths maintained for longer periods of time, either in combination with degraded water quality or alone, can significantly alter native wetland plant populations. This is a problem that has transformed many of Michigan's emergent wetlands from areas of diverse vegetation with a high level of habitat value to flow-through cattail or phragmites ponds.

Wetlands provide important value and service, including water storage, water quality improvement, and habitat for aquatic fauna and birds. Wetlands produce more wildlife and plants than any other Michigan habitat type on an area basis (MDNR - Wetlands). For these reasons most wetland systems should not be subjected to significant hydrologic or water quality alterations. Restoring historically lost wetlands and creating new wetlands where they never existed are better alternatives to address stormwater volume and control. The Department of Environemental Quality has developed a GIS-based Landscape Level Wetland Functional Assessment tool identifying prime areas for re-establishing historically lost wetlands. Highly degraded wetlands such as those dominated by invasive species may offer additional alternatives. (see "Utilizing Wetland Restoration and Creation BMPs for Stormwater Volume Control" p. 31).

The State of Michigan assumes responsibility for administering Section 404 of the Clean Water Act by regulating most inland wetlands within the state. The Department of Environmental Quality regulates wetlands under state law provided in Part 303 of the Natural Resources and Environmental Protection Act 1994 PA 451. The state and the U.S. Army Corp of Engineers together regulate wetlands adjacent to the Great lakes and connecting channels. In general, wetlands are regulated by the state if they have a direct surface water connection or are within 500 feet of a lake, pond, river, or stream; if they have a total area greater than 5 acres; or if the state determines that the protection of the wetland is essential to the preservation of the natural resources of the state.

Michigan encourages municipalities to regulate wetlands not falling under the state program. State law (Part 303) authorizes municipalities to regulate smaller wetlands, provided municipalities use the same wetlands definition, regulatory standards, and application process used by MDEQ. Some Michigan municipalities (e.g., Ann Arbor Township) have addressed the value of wetlands in their master plan, developed wetlands inventories, and enacted wetlands ordinances, consistent with this state guidance.

Based on three major attributes (soil properties, hydrologic regime, and vegetation), Michigan's wetlands can be divided into several major categories. Among these classifications are:

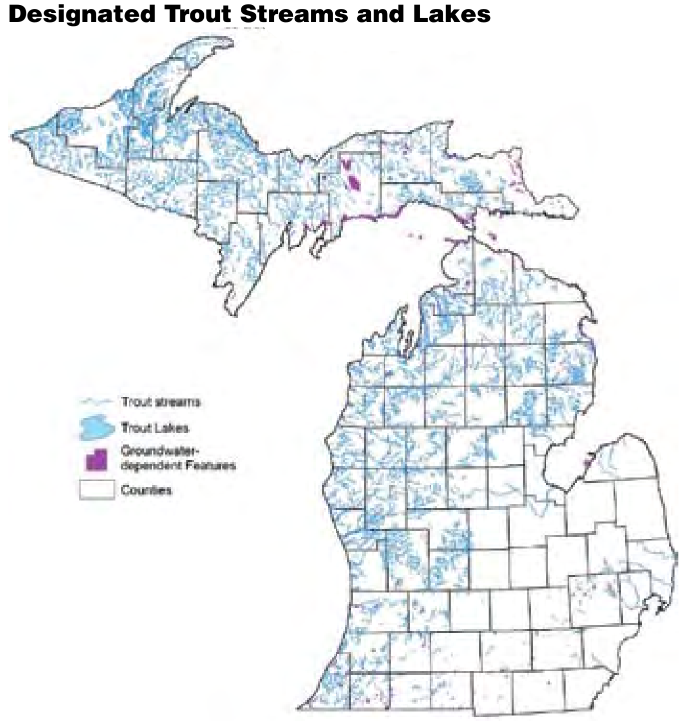
- Bogs,
- Fens,
- Forested wetlands,
- Marshes,
- Shrub carr/thickets, and
- Wet prairies.

Detailed descriptions of Michigan's wetland types were developed by the Michigan Natural Features Inventory. The Michigan Department of Environmental Quality has created county maps that overlay the National Weland Inventory (NWI) data with soils data and MDNR's Michigan Resource Inventory System land cover data. In Southeast Michigan, SEMCOG created maps that overlay NWI data, soils data, and the SEMCOG 2000 land use/ land cover map for their seven-county planning region. Although these resources can be used as an overview, onsite wetland delineations must be performed in accordance with Part 303 for jurisdictional determination.

Resources:

1. Detailed description of wetland types from the Michigan Natural Features Inventory can be found at http://mnfi.anr.msu.edu/
2. MDEQ wetland maps can be viewed at http://www.michigan.gov/cgi/0,4548,7-158-52927_53037_125037_12540_13817_22351-58858--,00.html.
3. SEMCOG's Wetland Indicator Maps are available at http://semcog.org

Figure 3.12
Designated Trout Streams and Lakes



Source: Michigan Groundwater Inventory and Mapping Project, 2005 http://www.egr.msu.edu/igw/GWIM%20 Figure%20Webpage/index.htm

Wellhead protection areas/ public water supply

Wellhead protection areas and public water supply areas are sensitive areas due to the fact that residents rely on groundwater for their drinking water. Therefore, certain LID practices, specifically infiltration practices, need to be assessed carefully in these areas (e.g., during the site plan review process). Typically, appropriately sized infiltration BMPs with a reasonable depth of topsoil (18-24 inches) should provide a high degree of filtering of runoff. However, there may be some combination of site constraints, including high groundwater in a public supply area with rapidly infiltrating soils that may necessitate a higher degree of water quality analysis and design redundancy than typical infiltration BMP designs. Please see Chapter 8 for additional information on the use of infiltration BMPs in public water supply areas.

Figure 3.13
Designated Natural Rivers

Source: MDNR, Michigan's Natural Rivers Program

Well data, wellhead protection areas, and other information can be found at http://www.michigan.gov/deqwhp

Sensitive waters

Michigan has numerous designations highlighting high quality waters. These include: trout streams and lakes (Figure 3.12), natural rivers, federal wild and scenic rivers, and outstanding state resource waters. In addition, waters that are currently designated with water impairments may need special consideration as well.

When incorporating LID practices, special consideration may need to be given to developments that drain to these sensitive water resources. Chapter 8 provides more details on LID implementation in these kinds of areas.

The Michigan Department of Natural Resources has identified trout streams and lakes and classifies them into several categories based on various fishing regulations. These waterbodies are of high quality and LID designs near these areas should be carefully considered to avoid adversely impacting water quality or water temperature.

Resources:

1. Michigan Inland Trout and Salmon Guide: http://www.michigan.gov/dnr/0,4570,7-153-10364_63235-211883--,00.html

The Michigan Natural Rivers Program began with the Natural Rivers Act (1970). This program creates simple zoning criteria that local communities use to design a river protection plan. The purpose and goals of the Natural Rivers Program are consistent with the goals of LID. The Natural Rivers Act aims to minimize direct impacts to the river, banks, and riparian corridor. The communities in the watershed of a designated river work together, across municipal and township boundaries, to create a consistent plan for their waterbody. The program stresses use of natural vegetative buffers in the riparian area, as well as minimum lot widths and setback distances to avoid overcrowding of development on the riverbank (MDNR – Natural Rivers Webpage). Currently, 2,091 miles of river are designated state Natural Rivers in Michigan (Figure 3.13).

The Wild and Scenic Rivers Program is a federal program that designates stream segments on public land or otherwise protected open land as Wild and Scenic Rivers based on scenic, recreational, geologic, fish and wildlife, historic, cultural, and other similar values. The program protects these stream segments by prohibiting dams or other projects that would adversely affect the river values, protecting outstanding natural, cultural, or recreational values; ensuring that water quality is maintained; and requiring creation of a comprehensive river management plan. Where development occurs in the watersheds of Wild and Scenic Rivers, LID would be the building practice most consistent with the goals of the Wild and Scenic Rivers Program. In Michigan, 16 stretches of rivers, comprising 625 miles, including sections of the Pere Marquette, Au Sable, Tahquamenon and Presque Isle Rivers, have been designated under the Wild and Scenic Rivers Program.

Outstanding state resource waters

Where water quality of existing water bodies meets the standards for its designated uses, the water is considered to be high quality. The quality of these waters must be maintained and protected unless relaxing the standards is necessary to accommodate important economic or social development in the area. No lowering of water quality is allowed in waters that are designated Outstanding State Resource Waters (OSRWs). In most cases, LID would be the development practice most consistent with protecting OSRW water quality. However, special provisions for water quality treatment of runoff should be made in areas of highly permeable soils such as sand.

OSRWs include parts of the Carp, Ontonagon, Sturgeon, Tahquamenon, Yellow Dog, and Two-Hearted Rivers; all water bodies in Sleeping Bear Dunes National Lakeshore, Pictured Rocks National Lakeshore and the Isle Royale National Park; and all surface waters of the Lake Superior basin.

Resources:

1. A more complete list of OSRWs can be found in MDEQ's Water Quality Rules. Refer to: http://www.michigan.gov/documents/deq/wrd-rules-part4_521508_7.pdf

Impaired waters

Section 303(d) of the Clean Water Act requires that states assess the quality of their waters and prepare a list of waters that do not meet their designated uses or water quality standards. In Michigan, all waterbodies are required to meet the criteria for the following eight designated uses:

- Agriculture,
- Navigation,
- Warm-Water Fishery,
- Indigenous Aquatic Life and Other Wildlife,
- Partial Body Contact Recreation,
- Total Body Contact Recreation (between May 1 and October 31),
- Public Water Supply, and
- Industrial Water Supply.

There are some waterbodies designated for other uses, such as cold-water fishery. MDEQ publishes the 303(d) list every two years.

Reasons for impairment can include:

- Sediment,
- Nitrogen/ammonia,
- Nuisance plant growth/phosphorus,
- Organic enrichment/low dissolved oxygen,
- Pathogens,
- Mercury,
- Priority organic compounds,
- Flow alterations, and
- Habitat alterations.

Table 3.4
Michigan Rivers and Stream Miles not Supporting Designated Uses Listed by Cause of the Impairment

Cause	Total Miles
Toxic organics	
PCBs in water column	34,754
PCBs in fish tissue	14,844
Dioxin	3,124
PBBs	144
Petroleum hydrocarbons	13
Metals	
Mercury in water column	7,179
Mercury in fish tissue	6,884
Copper	34
Lead	13
Chromium	13
Flow alterations	7,632
Habitat alterations	7,028
Pathogens	1,963
Sedimentation/siltation	1,529
Oxygen depletion	1,136
Nutrients	632
Organic enrichment (sewage)	187
Pesticides	
Chlordane	149
DDT	144
Excess algal growth	106
Impairment unknown	63
Thermal impacts	57
Total suspended solids	47
Oil and grease	37
Unionized ammonia	31
Total dissolved solids	19
Aquatic plants	19
Solids (suspended/bedload)	13

Source: MDEQ, 2008.

Once placed on the 303(d) list, a timeline is put in place for developing a Total Maximum Daily Load (TMDL) for the waterbody. The TMDL rations allowable pollutant load amongst watershed sources. LID practices are an opportunity to help watershed sources achieve TMDLs in impaired waters, both from the perspective of filtering and transforming pollutants, as well as for conserving or restoring (in the case of retrofits) presettlement hydrology.

Resources:

1. The Michigan 303(d) list can be found in the Integrated Water Quality Report, online at http://www.michigan.gov/deq/0,4561,7-135-3313_3686_3728-12711--,00.html

Utilizing Wetland Restoration and Creation BMPs for Stormwater Volume Control

Wetlands improve water quality by filtering out and trapping pollutants like sediments and nutrients in stormwater runoff. Wetlands also store large quantities of water during spring melt and after large rain events reducing the frequency and extent of flooding. This stored water is then released slowly over time to maintain flow in streams and reduce flashiness. Some wetlands are also important for recharging groundwater. Wetlands provide habitat for many species of fish and wildlife while also providing open space and natural beauty. Protection of high quality wetlands involves avoiding the filling of wetlands and minimizing changes to hydrology that will affect wetland quality and function. Re-establishing wetlands where they historically existed, (but don't presently exist), or creating new wetlands (where they never existed) provides an opportunity to provide stormwater quantity control while also increasing wetlands acreage and functions. In rare cases, existing highly degraded wetlands may be used to provide stormwater volume control if the project will also improve other wetland functions. To illustrate this concept, below is suggested language for a city's engineering design manual.

The City discourages the use of existing wetlands for the purposes of providing stormwater quantity control. The City encourages the re-establishment of wetlands where they historically existed, but don't presently exist, or the creation of new wetlands to provide stormwater quantity control and the related functions wetlands provide. The City will only consider approval of use of an existing wetland for stormwater quantity control if all of the following are requirements are satisfied:

A. The wetland must already be highly altered by watershed development and meet certain benchmarks for isolation, high water level fluctuation, low wetland plant richness, dominance of invasive or aggressive plants and altered hydrology.

B. It must be shown that the wetland site does not contain any unique wetland features.

C. An analysis of the pre-developed and post developed water balance for the wetland shows no negative impacts to the existing wetland or adjacent properties. The designer is required to provide the water balance documentation for review. The water balance should include runoff from irrigation.

D. A stormwater management easement shall be provided for the entire wetland. Where portions of the wetland are located on adjacent properties, the developer shall secure all of the required easements.

E. Sufficient pretreatment of the stormwater is provided prior to its discharge to the wetland.

F. A wetland enhancement plan shall be provided. The enhancement plan may include some or all of the following: removal of all or some of the invasive species and restoration with native species; planting of additional trees and shrubs; the creation of open water areas.

G. For wetlands regulated by the Michigan Department of Environmental Quality, a permit from the MDEQ has been obtained for use of the existing wetland for stormwater quantity control.

H. For wetlands regulated by the City, a permit from the City has been obtained for all proposed stormwater discharges and use of the existing wetland for stormwater quantity control.

Source: Environmental Consulting and Technology and the MDEQ Land and Water Management Division.

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*Note: Not all of the above references are cited in this chapter, but are included here for informational purposes.

Chapter 4

Integrating LID at the Community Level

This chapter provides guidance to communities on integrating LID into community plans and regulations and how to make LID a part of the institutional fabric of a community. LID is a new approach to land development that is best accomplished by incorporating LID principles into numerous local government processes, including the master plan, ordinances, and municipal programs.

Integrating LID at the community level provides the community with numerous economic, environmental, and social benefits as outlined in Chapter 2. Overall, LID can help communities meet their land use planning goals of health, safety, and welfare, as well as preserve community character and make desirable places for people to live and work. This chapter provides specific information on:

- Incorporating LID into the master plan,
- Introduction to the LID model stormwater ordinance,
- LID-friendly regulations,
- Using incentives to promote LID,
- LID and community good housekeeping practices, and
- Overcoming challenges: Opportunities for advancing LID in Michigan.

Clinton River near Lake St. Clair, MI

Source: Macomb County Planning and Economic Development

Incorporating LID into the master plan

By design, the master plan sets the course for a community and its residents for the future. It serves as a guide for community leaders in adopting capital improvement plans and annual operating budgets. Also, in Michigan, master plans are the basis for zoning ordinances.

While the master plan is the guide for a community's future, it is also the legal foundation for local land use laws. Therefore, it is important for the community's master plan to acknowledge the importance of LID and stormwater management and relate it to protecting the health, safety, and welfare of its residents. Examples of how using LID techniques can protect health, safety, and welfare include:

- Protection of water quality,
- Reduction of flooding and protection of property, and
- Protection of water features such as lakes, streams, and wetlands so that they can continue to perform the functions that people expect.

In addition to the master plan, there are additional opportunities to integrate LID into other community plans, (e.g., greenways plans, recreation plans, stormwater plans, and watershed management plans).

Master plan goals and policies

The goals and policies for LID and stormwater management should include elements that:

- Protect the land's natural ability to absorb, clean, and store stormwater,
- Minimize impervious surfaces in new construction and redevelopment projects to reduce the amount of runoff and improve infiltration,
- Use Best Management Practices (BMPs) throughout the community to reduce the impacts of stormwater,
- Implement community programs that improve water quality and educate the public about their role in water quality, and
- Link protection of water quality through stormwater management to the protection of residents' health, safety, and welfare.

Following are sample goals and policies that integrate LID practices into the master plan or other community plans.

Goal: Implement stormwater management practices, to protect the health, safety, and welfare of residents from the impacts of stormwater runoff.

Policy: Adopt and/or keep updated regulations to ensure that effective stormwater management techniques are used in new and redevelopment projects within the community.

Policy: Regulate stormwater runoff to provide for the following outcomes:

- Prevent flooding,
- Protect the stream channel,
- Improve and protect water quality, and
- Recharge groundwater.

Goal: Preserve existing natural features that perform stormwater management functions, such as wetlands, riparian vegetation, floodplains, and woodlands, to the greatest extent possible.

Policy: Inventory environmental areas as part of the site plan review process.

Policy: Adopt ordinances to protect environmentally sensitive areas.

Policy: Integrate natural areas, to the greatest extent possible, into the project design during the site plan review process.

Policy: Integrate and coordinate natural area preservation with other community plans such as greenway, recreation, and watershed plans.

Policy: Ensure the long-term sustainability and functioning of natural areas.

Goal: Minimize impervious surfaces in site designs. Minimize the use of enclosed storm sewer systems and eliminate impervious surfaces that are directly connected to surface waters where possible.

Policy: Encourage the use of cluster development, vegetated swales, downspout disconnection, and other practices that reduce impervious surfaces and increase stormwater infiltration.

Goal: Use best management practices to minimize, convey, pretreat, treat, and reduce the volume of stormwater runoff generated by development.

The Saugatuck Center for the Arts specifically included the following educational goal in their policy for redevelopment of the property, "Provide an interpretative opportunity to educate community residents, local schools and patrons regarding stormwater BMPs and the use of native vegetation in applied landscaping."

Source: JFNew

Open Space Development at the Pokagonek Edawat Housing Development in Dowagiac, MI

Source: Pokagon Band of Potowatomi Indians

Policy: Where site conditions allow, use infiltration practices to reduce the volume of stormwater runoff.

Goal: Improve stormwater quality by implementing programs throughout municipal properties and the community that remove pollutants from stormwater and reduces the volume of stormwater.

Policy: Implement programs to reduce the impacts of stormwater from municipally owned or operated properties.

- Use lands owned and maintained by the community as demonstrations for desirable stormwater management practices.
- Implement street maintenance programs for roads owned or operated by the community.
- Work to (or coordinate with the county to) evaluate the amount of salt and/or sand applied to roads, and other paved surfaces, in the winter. Implement procedures to reduce the amount of salt/sand from entering the storm sewer system as much as possible.
- Collect leaves in the fall and compost them for use in community projects.
- Develop and follow building and vehicle maintenance procedures that keep hazardous substances and other pollutants out of storm drainage systems.
- Provide or send employees to training on reducing the impacts of stormwater runoff from municipal properties.

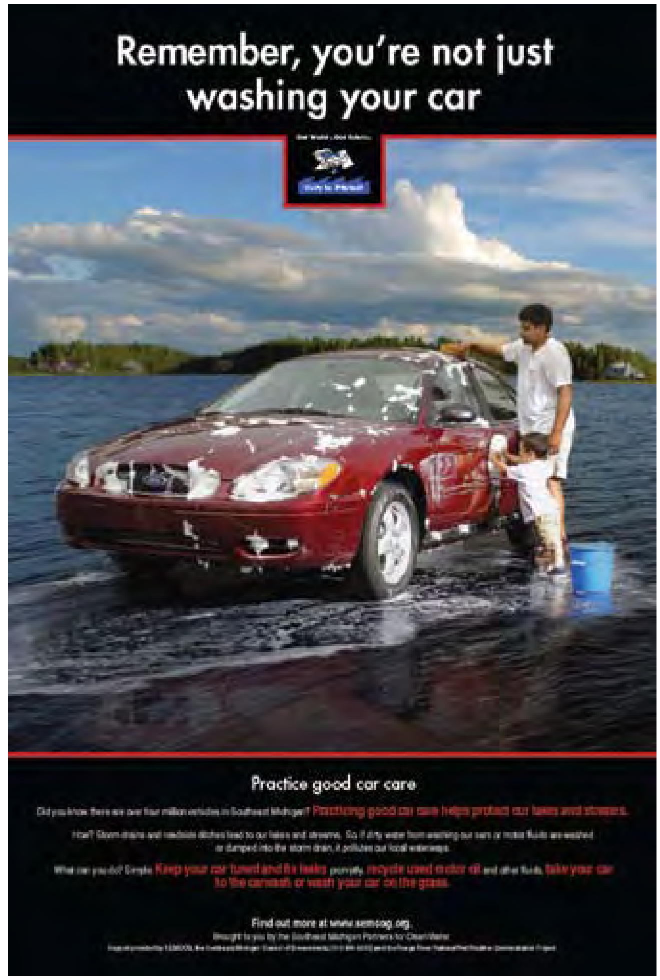
Goal: Educate the public about ecologically safe practices to follow around their homes and businesses.

Policy: Implement and/or publicize community programs that address stormwater issues.

- Initiate/publicize a household hazardous waste clean-up day.
- Distribute educational materials to residents that discuss the impacts of their actions on our water resources.
- Incorporate public education into community-sponsored events.

LID-friendly regulations

Once the master plan has included language supportive of LID, developing ordinances that directly support LID implementation is essential to ensuring community-wide implementation. Equally important is ensuring that existing ordinances are compatible with LID implementation.



Example residential educational campaign.

Model Stormwater Ordinance

Appendix H of this manual provides an example stormwater ordinance that incorporates various elements of LID. The ordinance refers to this manual for such issues as: BMP design, soil testing protocols, and stormwater calculations.

Develop regulations that encourage/require LID techniques

Developing new regulations is one mechanism for implementing LID community-wide. This could include adopting new regulations such as a stormwater ordinance and/or engineering standards.

When considering the adoption of a LID stormwater ordinance, the following items should be discussed within the local community:

- **What is the goal of the ordinance (e.g., protecting water quality, groundwater protection or recharge, channel protection, meeting state stormwater requirements)?**

  Once you determine the goal for implementing an ordinance, you can better determine the specific standards that should be included. For example, the model ordinance includes recommended standards for achieving water quality protection, channel protection, flood control, and groundwater protection. The community can modify the standards in the model ordinance to fit their local needs. Note that Phase I and Phase II stormwater communities are required to have some regulation that addresses water quality and channel protection.

- **What is the coverage area of the ordinance?**

  The community needs to decide the coverage area which could include all developments that undergo site plan review. Another consideration is that Phase I and Phase II stormwater communities must adopt stormwater regulations, and apply for new and redevelopment projects that disturb one acre or more.

- **Are all covered areas treated the same?**

  The community also needs to decide if the standards are going to be applied the same across all covered areas. For example, is redevelopment going to be held to the same standards as new development? Are sensitive areas, (e.g., wellhead protection areas) going to be treated differently in the ordinance? (Additional watershed and site factors that communities may want to review in answering this question can be found in Chapter 5, LID Site Design Process Checklist).

  The model ordinance in this manual identifies specific places where these types of decisions need to be made. It also provides examples as to the different standards that could be used based on different scenarios (e.g., how redevelopment standards could be set up that are slightly different than standards for new or "greenfield" development).

- **Will the community give "credit" for implementing certain BMPs?**

  Another decision a local community needs to make is integrating certain BMPs as credits in the ordinance. Some regulations do allow for additional credits to the developer for soil restoration and native plant revegetation. Chapter 9 provides detail information on the use of stormwater credits.

Black River Riparian Area in City of Bangor, MI
Source: Van Buren Conservation District

- **How will long-term sustainability of the stormwater system be ensured?**

  Local communities will need to decide the mechanism to ensure long-term maintenance of the LID system. This can include maintenance agreements between the homeowners association and the local community. The process for long-term maintenance should be clearly stated in the regulation. Appendix G contains an example maintenance agreement. In addition, the Phase II stormwater permit requires maintenance to be addressed in the regulation.

  The local community may also choose to implement a program at the community level to inspect structural controls at a certain frequency. Appendix F contains example inspection checklists that can be used as guidance.

In addition to developing stormwater regulations, LID implementation could include adopting other ordinances such as wetland, tree preservation, or riparian buffer ordinances. Appendix H provides example ordinances.

Integrating LID into existing regulations

Along with developing specific LID regulations, it's equally important to review current regulations and programs to ensure they are compatible with LID implementation. Following are suggested areas to review:

Parking

- Add to the purpose section that parking standards provide for effective management of stormwater runoff from vehicle areas.
- Require that landscaped areas be sufficiently large to provide stormwater management. Allow for depressed parking islands that can include curb cuts to allow stormwater into the islands. For example, the following sentences could be added if the community requires protective curbs around landscaping. "Curbs separating landscaped areas from parking areas may allow stormwater runoff to pass through them. Curbs may be perforated or have gaps or breaks."
- Allow for native plantings in landscaped areas.
- Include both minimum and maximum parking ratios and aisle standards to avoid construction of excess parking.
- Develop parking standards that reflect average parking needs rather than the possible maximum.
- Allow for shared parking when analysis shows parking needs will be met.
- Allow for multi-level parking.
- Allow for permeable material to be used in overflow parking, sidewalks, patios, etc. Assess if permeable material can be used in the main parking or road area during the site plan process.
- Allow the developer to land-bank parking. (The developer builds parking they believe is initially needed, but leaves enough undeveloped area for additional parking in the future).

Roads

- Design streets for the minimum required paved width needed to support travel lanes; on-street parking (if desired); and emergency, maintenance, and service vehicle access. The widths should be based on traffic volume.
- Reduce the total length of residential streets by examining alternative street layouts to determine the best option for increasing the number of homes per unit length.
- Allow for use of swales, instead of curb and gutter, as part of an integrated LID site design where density, topography, soils, and slope permit. Where feasible, allow curb cuts and swales on existing roadways.
- Incorporate LID-based stormwater infiltration into the center island of cul-de-sacs.

Lot setbacks/Lot width

- Allow for reduced setbacks if the development is part of a cluster development or includes LID techniques.

City of Empire, MI
Minimize impervious surfaces and front set backs.

Construction activity

- Minimize clearing and grading on a site. Consider allowing credits for developments meeting certain criteria. (See Chapter 9).
- Minimize soil compaction, especially on areas that will be used for infiltration and other LID practices. Consider allowing credits for developments meeting certain criteria, which could include soil restoration. (See Chapter 9).

Native vegetation along lake

Many native plants are well over 5-6 feet tall. Landscaping requirements should define what vegetation height requirements apply to so native vegetation can be utilized.

Source: JFNew

Landscaping

- Add reduction of stormwater pollution, temperature, and rate of volume of flow to the purpose section of landscaping/screening.
- Encourage use of native plants in landscaping requirements.
- Prohibit use of non-native, invasive species in landscaping requirements.
- Define the type of vegetation the height requirements apply to (as well as the type of vegetation it does not apply to). For example, remove the height requirement for native plants.
- Set screening criteria that uses vegetation, where appropriate, before walls or berms.

Natural areas/Open space

- Encourage cluster development (i.e., open space subdivisions) as a method for preserving natural areas and reducing impervious surfaces.
- Leave as much open space as possible in its natural condition. This provides stormwater infiltration and reduces maintenance.
- Link open space to existing wetlands, rivers, and other adjacent open space areas. This provides a buffer to these sensitive areas, allows scenic recreational opportunities, provides a wildlife corridor, and could provide a location for nonmotorized transportation opportunities in the community.
- Include requirements to re-establish vegetation in disturbed areas dedicated for open space.

Miscellaneous

- Allow for downspouts to be connected to vegetated areas on the property, not directly to the storm sewer.

Using incentives to promote LID

While some communities may choose to implement a regulatory mechanism, such as a stormwater ordinance requiring the use of LID, other stakeholders may choose to use an incentive program or a combination of regulations and incentives to encourage LID practices. Following are example incentives that could be implemented at various levels of government:

- Allow for a state income tax credit for qualifying LID techniques.
- Offer a bonus such as increased floor area (e.g., floor area ratio) if LID practices are used that accomplish stormwater management goals.

East Hills Center in Grand Rapids, MI

Recognition programs such as the Leadership in Energy and Environmental Design (LEED) certification is one way to encourage LID implementation.

- Accelerate plan reviews for site plans implementing LID techniques.
- Reduce fees charged to the applicant (e.g., plan review fees, utility fees) for site plans implementing LID techniques.
- Offer a density bonus (e.g., allow for an additional lot) to developments that implement LID practices.
- Initiate a recognition program for sites using innovative stormwater management.
- Provide free technical assistance to projects implementing LID techniques.
- Focus grant money on LID implementation such as funding demonstration projects, tours, Web sites, technical assistance, and other educational materials.
- Provide credits on stormwater utility fees to users implementing LID techniques.

LID and community good housekeeping practices

Many LID BMPs operate more effectively and require lower maintenance when pretreatment is provided to remove pollutants (e.g., sediment) that can clog the BMP. Pretreatment devices can include structural BMPs such as filter strips and water quality devices. Local communities can also employ good housekeeping practices that will reduce rehabilitation and replacement costs of stormwater BMPs by preventing or addressing problems early. For example, a street sweeping program will reduce the amount of sediment entering BMPs (e.g., bioretention, porous paving) that can become clogged from sediment deposition.

There is existing information to assist municipal staff and contractors in identifying and employing good housekeeping activities. Detailed fact sheets, training modules, presentations, and posters on individual good housekeeping practices can be downloaded at semcog.org/plans-for-the-region/environment/water/stormwater.

Table 4.1
Community good housekeeping practices

Activity	Impact
Street sweeping	Reduces sediment, nutrients, metals, trash, oil, and toxins
Catch basin cleaning	Reduces sediment, nutrients, metals, trash, oil, and toxins
Managing salt storage	Reduces chlorides
Equipment cleaning and maintenance	Reduces metal, oil, and toxins
Prevent soil erosion	Reduces sediment and nutrients
Proper storage and handling of chemicals and other materials	Reduces sediment, nutrients, metals, oil, grease, and toxins
Stream bank stabilization	Reduces sediment and nutrients, protects riparian vegetation and property
Dumpster maintenance	Reduces sediment, nutrients, bacteria, metals, trash, oil, and toxins
Bridge and road maintenance	Reduces sediment, nutrients, metals, trash, oil, and toxins

Catch basin cleaning in Bloomfield Township, MI

Street sweeping in Bloomfield Township, MI

The importance of street sweeping

For those stakeholders with jurisdiction over streets and parking lots, sweeping is an important good housekeeping practice that will keep your structural BMPs in good working order. When done regularly, street sweeping can remove 50-90 percent of street pollutants. Street sweeping also makes road surfaces less slippery in light rains and improves aesthetics by removing litter and sediment deposits.

Municipalities can choose between various types of street sweepers. The most common street sweepers are mechanical, vacuum filter, and regenerative air. It is important to keep in mind that the type of pollutant, types of surfaces, noise ordinances, and costs all factor into what kind of sweeper is purchased and used. Municipalities often find it useful to have each type of street sweeper in their fleet. Each has its advantages and disadvantages concerning pollutant removal effectiveness, traveling speed, and noise generation.

Material swept off streets often includes sand, salt, leaves, and chemicals. Debris removed from roads is classified as Solid Waste under the Solid Waste Management Act, known as Part 115. To properly dispose of street sweeping material, communities should take sweepings to a landfill. Municipalities should contact the landfill to obtain their individual testing requirements.

To evaluate the effectiveness of a street sweeping program, maintain accurate logs of the number of curb-miles swept and the amount of waste collected. Monthly or yearly intakes (per ton) can be measured per district, road, season, or mile.

Overcoming challenges: Opportunities for advancing LID in Michigan

There are numerous challenges that can occur when implementing LID. These barriers include:

- Number of institutions with jurisdiction over stormwater,
- Restrictive regulations that may not allow for LID techniques (see above section on LID-friendly regulations),
- Resistance from internal sources and/or the community,
- Lack of technical knowledge,
- Lack of resources, and
- Site constraints that may pose challenges to implementing LID (e.g., historical contamination, clay soils).

This section lists some of these challenges, but more importantly provides information on options for overcoming these challenges.

Number of institutions with jurisdiction over stormwater

Challenge: Implementing LID in Michigan can be complicated due to the number of organizations that have some jurisdiction over land use and stormwater decisions in a community. (Table 4.2 provides a summary of entities with stormwater jurisdiction). For example, in a township, the township has authority over land use decisions and can, therefore, implement LID through conservation design techniques, as well as, adopting stormwater regulations. In the same township, the county drain commission has jurisdiction over legally established county drains. The county can have its own set of regulations (e.g., stormwater rules) applying to stormwater discharges to the county drains. Since the county road commission owns many of the roads in a township, they have responsibility over the drainage of their roads. Add into the mix other organizations such as the Michigan Department of Transportation, public school districts, and other public entities and, suddenly, there's a myriad of authorities involved in managing stormwater within the community.

Opportunity: As each of these entities has some jurisdiction over land use, stormwater, or both within the State of Michigan, each has an opportunity to move LID forward within their purview. A major step forward in implementing LID is to develop process options that offer various institutional choices on how to engage in LID in a complementary way. Following are possible processes for moving LID forward in a complementary manner:

Use LID as a mechanism for implementing Michigan's stormwater permit requirements

With over 250 communities in Michigan affected by the Phase II stormwater regulations, linking LID implementation with the Phase II regulations is a natural fit. There are numerous options on who can take the lead on implementing LID to meet Phase II. These include:

- A local community takes the initiative to demonstrate to other Phase II communities that implementing LID is a practical method for meeting the Phase II requirements. The community can then engage the county and other stormwater entities in implementing LID in their jurisdictions.
- County drain commissioners can take the lead for implementing LID in the county. The drain commissioner can develop regulations incorporating LID techniques that meet Phase II requirements. Local communities can then adopt the county standards for their jurisdiction.
- A watershed or subwatershed group, made up of communities, counties, road agencies, and public institutions, develops complementary LID techniques for their watershed/subwatershed.

Use LID as a mechanism for habitat protection, fisheries management, and enhancing recreational opportunities

LID offers the opportunity for those communities and agencies interested in habitat protection, fisheries management, and/or protecting recreational opportunities. For example, focusing on infiltration practices will reduce the thermal load of stormwater runoff to receiving waters, which would positively impact the native fishery.

Incorporate LID into greenways planning

An effective greenways program looks not only at the regional connectivity of green infrastructure, but also at the local connections. It is important for both humans and animals that green infrastructure be connected as much as possible. Using LID techniques such as open space planning, small building envelopes, and natural resource preservation, is one way to ensure this connectivity at a local level.

Macomb Orchard Trail in Macomb County, MI

Source: Macomb County Planning and Economic Development

Partner with state agencies (e.g., MDEQ, DNR, Agriculture) to support LID implementation

State agencies, such as MDEQ, can support LID implementation by providing technical assistance on LID techniques, providing grants and recognition programs, being a LID clearinghouse, and allowing LID techniques in meeting regulatory obligations.

A key starting point is for decision makers at various entities to consider adopting a policy supporting LID.

Resistance from internal sources and or the community

Challenge: Support of the public, elected officials, environmental organizations, etc., is imperative for moving LID forward in a community. Public education and participation are key features of a comprehensive stormwater management program.

Opportunity: There are numerous opportunities to gain support for LID both internally and at the community level.

Educational materials (e.g., signage, Web sites)
Educational materials can be used as a mechanism to inform the public and municipal staff on the benefits of LID and how these techniques can be attractive amenities to the community. Web sites, flyers, signage, and short videos are all means of quickly communicating LID to various audiences.

Demonstration projects and tours
Another way to gain support for LID is to set an example through demonstration projects on visible sites. Providing demonstration sites will show that certain technologies can be successful in Michigan and meet regulatory approval. Providing tours of these demonstration projects is another way to show real-life examples of successful LID implementation.

Public involvement opportunities
Inviting the public to become more involved in LID by participating in a LID project (e.g., planting a demonstration rain garden) is another way to gain support for LID. Not only will residents be more interested in a project that they had a "hand" in, but they will likely speak positively about it with their neighbors. Providing these opportunities also shows municipal staff and elected officials the interest of residents in embracing LID in the community.

Positive public relations/media relations
Working with the media on publicizing LID projects is one way to reach a large number of residents in the community. This again allows residents to see the benefits of LID, but also shows municipal staff and elected officials that this is a priority in the community.

Rain garden and porous asphalt educational signage
Source: City of Battle Creek

Rain garden plantings provide public involvement opportunities

Positive media relations from LID projects
Source: City of Troy

Lack of technical knowledge

Challenge: Both designing and reviewing LID projects require technical knowledge that can be an impediment in moving LID forward in Michigan.

Opportunity: This manual has been developed to assist both the designer and reviewer in the technical aspects of LID implementation. In addition, the manual contains a designer/reviewer checklist at the end of each BMP to further provide technical guidance.

In addition to this manual for Michigan, LID is becoming increasingly utilized throughout the country. Organizations such as the Center for Watershed Protection and the Low Impact Development Center, have been initiated at the national level to provide guidance. Locally, organizations such as GreenBuilt (www.greenbuiltmichigan.org) and Rain Gardens of West Michigan (wmeac.org/rain gardens/) provide technical resources throughout the state.

Finally, implementation of LID techniques is increasing throughout the state. The case studies included in the manual, as well as demonstration projects and tours, can be utilized to learn more technical information about LID. Also, the members of the state LID committee and the reviewers providing technical review would often be able to provide certain technical information.

Communities interested in sustainable practices, including LID can invest in staff training and development. Local government organizations such as SEMCOG can help facilitate training opportunities.

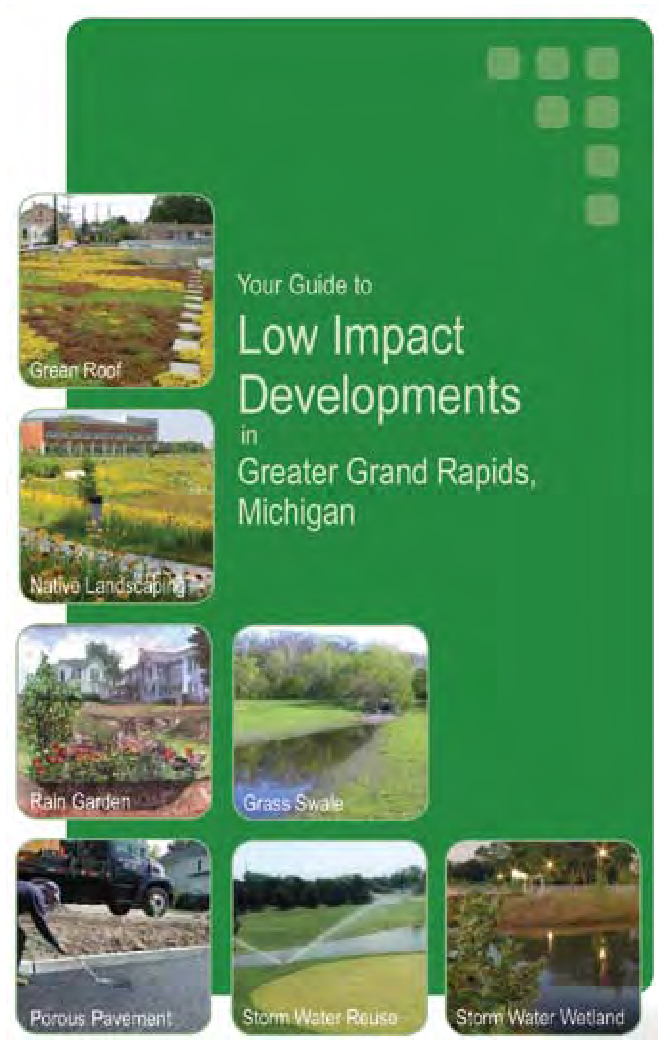
Lack of resources

Challenge: Many Michigan communities are facing financial challenges. Providing core essential services is their focus. Spending financial resources and staff time on implementing LID can be a challenge. For example, overcoming LID impediments will often cause the community to expend additional resources (e.g., sponsoring LID tours, developing and printing educational materials, updating ordinances and plans).

Opportunity: Organizations such as SEMCOG are working to reduce the impediments of LID by providing information that can be utilized by local communities. For example,

- Brochures are available for developers, the public, and municipal officials on the benefits of implementing LID.
- Tours and technical workshops are being held by organizations such as SEMCOG and the Michigan Water Environment Association.
- An online web tool featuring locations of LID practices has been developed as a pilot for three counties in Michigan by Lawrence Technological University.
- A map and driving tour has been developed for the Grand Rapids area.
- Workshops were held throughout the Grand Rapids area with developers and realtors.
- State Clean Michigan Initiative money was used to fund numerous LID demonstration sites.

In addition, SEMCOG and other organizations are working on expanding the availability of financing mechanisms to support stormwater management.



Grand Rapids, MI, LID Tour Guide
Source: Fishbeck, Thompson, Carr, & Huber, Inc.

Site constraints that may pose challenges to implementing LID (e.g., historical contamination, clay soils)

Challenge: Large areas throughout Michigan have challenging soils and geology where the opinion is that LID "can't be done" in their area.

Opportunity: One primary purpose of the manual (and a core principle) is that LID can be used anywhere. The manual strives to explain challenges that may occur on a site, but does provide options for incorporating LID principles. For example, Chapter 8 highlights some specific challenges, but provides specific information on utilizing LID in these challenging areas.

LID Tour in Washtenaw County, MI

Table 4.2
Entities with Stormwater Jurisdiction

Entity	Stormwater Jurisdiction
County Drain Commissioners	The Drain Commissioner and staff are responsible for construction, operation, and maintenance of legally established county drains. A county drain can be closed or open. It can be natural or man-made if it has been petitioned in accordance with the provisions of Act 40 of 1956, as amended (the "Drain Code"), to be a county drain. Typically, a county drain may be an open ditch, stream, underground pipe, detention/retention pond, or swale that conveys stormwater. These systems are designed to provide stormwater management, drainage, flood prevention, and stream protection for urban and agricultural lands. Drain Commissioners can establish stormwater standards that apply to discharges to the county drain. Again, this discharge can be conveyed directly to the water body, but can also include "tap ins" into the drainage-district-owned storm drain system that is part of the county drain. These stormwater standards often require the entity responsible for the perpetual maintenance of the non-county drain storm sewer system be identified. In cases of platted subdivisions and manufactured housing communities, maintenance is often transferred to the property owners (e.g., subdivision association). However, there are cases where the stormwater controls are deeded to the County or local unit of government. In addition to plan reviews of drainage facilities that discharge to a county drain, the Drain Commissioner is also responsible for review and approval of stormwater management systems in platted developments under the Michigan Land Division Public Act 288 of 1967, as amended, and for private development in response to local government requests. The Drain Commissioner has the authority to ensure that proposed stormwater facilities within the plat and stormwater outlet facilities of the plat, be improved or protected to established standards and specifications. (County Drain Commissioners have authority to review plat plans for single-family residential and industrial developments. They do not have authority to review plans for commercial developments or multi-family developments such as condos, apartments, and mobile home parks, unless a county drain is directly involved). According to the Drain Code of 1956, a "drain" may include the "main stream or trunk and all tributaries or branches of any creek or river, any watercourse or ditch, either open or closed, any covered drain, any sanitary or any combined sanitary and storm sewer or storm sewer or conduit composed of tile, brick, concrete, or other material, any structures or mechanical devices that will properly purify the flow of such drains, any pumping equipment necessary to assist or relieve the flow of such drains and any levee, dike, barrier, or a combination of any or all of same constructed, or proposed to be constructed, for the purpose of drainage or for the purification of the flow of such drains, but shall not include any dam and flowage rights used in connection therewith which is used for the generation of power by a public utility subject to regulation by the public service commission."

Entity	Stormwater Jurisdiction
Cities and Villages	Unlike townships, cities and villages, according to Michigan law, are allowed jurisdiction over roads within their boundaries. Over the years, some cities and villages have taken jurisdiction over some of the roads within their boundaries. Most often this has occurred at the time the community incorporated. The cities and villages have jurisdiction over all neighborhood or subdivision streets. Whether a city or village or the road commission has jurisdiction over major streets within the community depends upon a variety of factors and differs from community to community. The storm drainage system is typically along city/village-owned streets. The runoff enters the drainage system within the right-of-way (e.g., ditches, catch basins), but city/village jurisdiction continues until the runoff is outlet to a system with other ownership (e.g., county drain, waters of the state, private property). (However, most often the transfer of ownership happens at the end of the right-of-way). In addition, although the city/village may not own the system, they often provide operational maintenance under contract with the road commission. Finally, the city/village may own storm drainage systems in connection with municipally-owned property. Cities and villages also have the ability to manage stormwater runoff in their community through planning and zoning. For example, a stormwater ordinance is one tool cities/villages can use to ensure stormwater from new development and redevelopment projects meet water quality and quantity standards. These stormwater standards often require identifying the entity responsible for the perpetual maintenance of the storm sewer system. In many cases, maintenance is often transferred to the property owners (e.g., subdivision association). However, there are cases where the stormwater controls are deeded to the county or local unit of government.
Townships	Townships do not have jurisdiction over roads within their boundaries. Therefore, they are not responsible for the storm drainage system, as are county road commissions and cities/villages. However, some townships may own or operate a storm drainage system. These exceptions include: Townships may provide operational maintenance of the road/storm system instead of the County. Townships may own storm drainage systems in connection with municipally-owned property. Townships may accept transfer of ownership of the drainage system/structural controls from a private development. Townships do have the ability to manage stormwater runoff in their community through planning and zoning. For example, a stormwater ordinance is one tool townships can use to ensure stormwater from new development and redevelopment projects meet water quality and quantity standards.
Michigan Department of Transportation (MDOT)	MDOT has jurisdiction over the stormwater runoff leaving state highways that enter their storm drainage system. The runoff enters the drainage system within the right-of-way (e.g., ditches, catch basins), but MDOT jurisdiction continues until the runoff is outlet to a system with other ownership (e.g., private property, county drain, waters of the state). MDOT also may have jurisdiction of the culvert/easement area as its road passes over a waterway or waterbody. State highways include all highways with letters in their names, such as "M," "US," or "I." Examples include M-24, M-1, M-5, US-24, I-75, I-696, etc. Generally, all freeways fall under MDOT jurisdiction, as do the major inter-county roads such as Woodward Ave. (M-1) and Telegraph Road (US-24).

Entity	Stormwater Jurisdiction
County Road Commission	The County Road Commission is responsible for stormwater runoff from county roads and their storm drainage system. The runoff enters the drainage system within the right-of-way (e.g., ditches, catch basins), but County Road Commission jurisdiction continues until the runoff is outlet to a system with other ownership (e.g., county drain, waters of the state, private property). Road Commissions also may have jurisdiction of the culvert and right-of-way as the road passes over a waterway or waterbody. In addition, although the County may not own the system, they often provide operational maintenance under contract with MDOT. The Road Commission can also regulate the quantity of water entering the right-of-way to ensure it does not adversely affect maintenance or safety concerns. Every county in Michigan has a road agency. All but one has County Road Commissions. In Wayne County, the Road Commission merged with county general government in the 1980s. In every other county, the Road Commission is a separate unit of government, removed from county general government. Road Commissions have jurisdiction over all roads in the townships in the county. Additionally, County Road Commissions have jurisdiction over many of the primary roads in cities and villages within that county. Most road ditches are under the jurisdiction of the Road Commission, but some are county drains.
Public entities: jails, hospitals, schools	Public entities that own or operate storm sewer systems within their property have sole jurisdiction over those systems, but they may grant authority to the local unit of government to manage the system according to local stormwater requirements and Phase II stormwater regulations.

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Chapter 5

Incorporating LID into the Site Design Process

This chapter provides information to assist various stakeholders, including developers and builders, on a recommended LID site design process to ensure that the proper issues and questions are addressed at the appropriate time and by the appropriate people. Following such a process prior to official submission of the preliminary site plan will result in creating a comprehensive development concept that manages stormwater and existing natural resources to the fullest extent possible and practical.

Specifically, this chapter:

- Provides an overview of the LID site design process,
- Defines this process, step by step, and
- Includes a LID site design checklist.

Using LID successfully in a site design process requires considering the LID principles from the project's inception through the final design stages. Specifically, LID development approaches and techniques need to be assimilated into the various phases of the site design process, including:

- The initial stages of site analysis to determine features to be preserved and avoided during construction,

Kresge Foundation Headquarters in Troy
Source: Conservation Design Forum, Inc.

- The program or concept development process to determine what is constructed, and how much construction the site can support, and
- The site design and revision process to address stormwater issues that remain.

This site design process is based on the following LID principles described in Chapter 2:

- Plan first,
- Prevent. Then mitigate,
- Minimize disturbance,
- Manage stormwater as a resource – not a waste,
- Mimic the natural water cycle,
- Integrate natural systems,
- Disconnect. Decentralize. Distribute,
- Maximize the multiple benefits of LID,
- Use LID everywhere, and
- Make maintenance a priority.

Overview of the LID site design process

The LID site design process builds on the traditional approach to site design. It begins with analysis of the site, and incorporates steps to involve local decision makers early in the process. The process has been consolidated into nine basic steps (Figure 5.1). Each designer may want or need to adjust the process to fit specific site circumstances.

An essential objective of the site design process – and of LID – is to minimize stormwater runoff by preventing it from occurring. This can be accomplished through the use of nonstructural BMPs in the site design (Chapter 6). Once prevention is maximized, some amount of mitigation is needed to address stormwater peak rate, volume, and water quality from increased impervious surfaces. These mitigative stormwater management objectives can be met with structural BMPs (Chapter 7).

Step 1: Property acquisition and use analysis

The initial step in the land development process is typically some sort of action on the part of a site's owner, developer, or builder, such as a purchase of title, options, site clearances, or analyses. In many cases, developers acquiring/purchasing property will undertake some level of study in order to determine the type of use (residential, commercial, industrial, etc.) that can be developed in order to determine a purchase price for the property.

Step 2: Inventory and evaluate the site

Incorporating LID into site design begins with a thorough assessment of the site and its natural systems. Site assessment includes inventorying and evaluating the various natural resource systems which may pose challenges and/or opportunities for stormwater management and site development. Natural resource systems include:

- Floodplains,
- Riparian areas,
- Wetlands,
- Natural and man-made drainage ways,
- Soils and topography,
- Geology,
- Groundwater supplies, and
- Vegetation.

Natural systems range in scale from a watershed-scale down to the site specific scale. In evaluating the natural resources of a site, it is important to consider the applicable challenges or opportunities with implementing LID techniques.

Watershed-scale evaluation

LID, as described in the Site Design Process (Figure 5.1), begins with an understanding of the site in the broader context of its watershed and relevant natural systems, based on an inventory of the natural resource system characteristics. In evaluating these characteristics for LID opportunities, the following are examples of the types of questions that should be raised:

- Does the site drain to special water bodies with special water quality needs (e.g., impaired waters, groundwater aquifer, natural river designation)?
- Does the site ultimately flow into a reservoir, groundwater aquifer, or other type of impoundment where special water quality sensitivities exist, such as use as a water supply source?

Figure 5.1
LID Site Design Process

Step 1
Property acquisition and use analysis

Step 2
Inventory and evaluate the site

Step 3
Integrate municipal, county, state, and federal requirements

Step 4
Develop initial concept design using nonstructural BMPs

Step 5
Organize pre-submission meeting and site visit with local decision makers

Step 6
Incorporate revisions to development concept

Step 7
Apply structural BMP selection process

Step 8
Apply the LID calculation methodology

Step 9
Develop the preliminary site plan

- Do other special fishery issues exist (e.g., trout stream)?
- Is the site linked to a special habitat system? (For both water quality and temperature reasons, approaches and practices that achieve a higher order of protection may become especially important.)
- Are there known downstream flooding problems, or known problems with run-on from neighboring properties?
- Is additional development anticipated for the area that could lead to further restrictions (e.g., protection of downstream land and water uses) or opportunities (e.g., partnerships in multi-site water quality or quantity controls)?

Site specific scale evaluation

Site specific factors are critical in this part of the process as they influence comprehensive stormwater management throughout the development project. A list of site specific factors to evaluate are provided on the site Design Process Checklist at the end of this chapter. Example evaluation questions include:

- What are the important hydrological functions of the site, including both surface and groundwater movement?
- What important natural resources exist on site (high quality wetlands, woodlands, special habitat, etc.)?
- What are the existing soil types? Are there opportunities for infiltration?
- What is the depth to the water table?
- What is the depth to bedrock?
- How does size and shape of the site affect stormwater management?
- Are there areas where development should generally be avoided? (Determine where buildings, roads, and other disturbance should be avoided, in terms of avoiding existing natural resource systems and rights of way).
- Are there areas where LID infiltration practices should be avoided because of historical land uses and contamination?

Western Michigan University Business, Technology and Research Park

Source: Fishbeck, Thompson, Carr & Huber, Inc.

Step 3: Integrate municipal, county, state, and federal requirements

Municipal requirements will vary from one governmental entity to another. However, the land development process in Michigan is mostly regulated and managed on the local level, with the community master plan, zoning ordinance, and subdivision/land development ordinance being essential. In addition, county, state, and federal regulations need to be considered (e.g., county stormwater standards, state and federal wetland law, threatened and endangered species). Since regulations are also continuously updated, it is important for clear, updated communication between all stakeholders involved in the development process.

City of Wixom Habitat Park

Source: Hubbell, Roth & Clark, Inc.

Step 4: Develop initial concept design using nonstructural BMPs

Information gathered in the first three steps should be used in developing the initial concept design. This step should include the use of nonstructural BMPs such as woodland and wetland protection, clustering, minimizing impervious surfaces, or other techniques described in Chapter 6.

It may be beneficial on some sites to work through preliminary calculations (Chapter 9) to ensure stormwater goals are being met.

Step 5: Organize pre-submission meeting and site visit with local decision makers

Many municipalities strongly recommend and even require a pre-meeting with the developer to effectively communicate each entity's perceptions of the project early on, and potentially discern how each other's needs can be incorporated into the development concept. Many municipalities in Michigan and other states are also incorporating site visits into the pre-submission meeting to minimize or prevent future problems with the development.

Step 6: Incorporate revisions to development concept

The designer should integrate the information collected from the previous steps and revise the initial development concept, if appropriate.

Step 7: Apply structural BMP selection process

Determining the blend of structural BMPs that best achieve a specific site's stormwater needs is the next step in the site design process. Structural BMPs which can be used to achieve the recommended site design criteria for LID are detailed in Chapter 7. Not all structural BMPs are appropriate for every development at every site. The introduction to Chapter 7 details a selection process for determining the appropriate BMPs.

Towar Rain Garden Drains

Source: Fitzgerald Henne and Associates, Inc.

The calculations done in step 8 may be needed to make decisions on the structural BMPs that can be used at a site. Therefore, it may be necessary to combine steps 7 and 8 to complete the selection of BMPs.

Step 8: Apply the LID calculation methodology

A calculation methodology is presented in Chapter 9 of this LID manual. It allows for the integration of both nonstructural and structural BMPs. The calculation methodology is based on the recommended design criteria for total stormwater volume control, peak rate control, and water quality control that are central to LID performance.

Step 9: Develop the preliminary site plan

Once steps 1-8 of the site design process are implemented, the preliminary site plan is complete and ready to submit to the local unit of government. The result is a communicative process between developer and community to create a comprehensive development concept that manages stormwater and existing natural resources to the furthest extent possible and practical.

Reinforcing the site design process: A site design checklist for LID

The site design process for LID is structured to facilitate and guide an assessment of a site's natural features together with stormwater management needs. The LID Site Design Process Checklist will help implement the site design process. It provides guidance to the land development applicant, property owner, or builder/developer in terms of the analytical process which needs to be performed as the development proceeds. The outcome is the formulation of a LID concept for the site.

Local communities may also benefit by using this checklist for considering possible impacts to natural resources in the community and local watersheds.

Step 1: Property acquisition and use analysis

Step 2: Site inventory and evaluation

Watershed factors inventory

- ❑ Major/minor watershed location?
- ❑ State stream use/standards designation/ classification?
    - ❑ Special high quality designations? (e.g., natural rivers, cold water fishery)
    - ❑ Rare or endangered species or communities present?
    - ❑ Are there required standards?
- ❑ Any 303d/impaired stream listing classifications?
- ❑ Any existing or planned Total Maximum Daily Loads (TMDLs) for the waterbody?
- ❑ Aquatic biota, other sampling/monitoring?
- ❑ Do other special fishery issues exist?
- ❑ Is the site linked to a special habitat system?
- ❑ Are there known downstream flooding problems?
- ❑ Are there known problems with run-on from neighboring properties?
- ❑ Is additional development anticipated for the area that could lead to further restrictions? (e.g., protection of downstream land and water uses)
- ❑ Is additional development anticipated for the area that could lead to further opportunities (e.g., partnerships in multi-site or regional water quality or quantity controls)?

Site factors inventory

- ❑ Important natural site features have been inventoried and mapped?
    - ❑ Wetlands?
    - ❑ Floodplains?
    - ❑ Wellhead protection areas?
    - ❑ High quality woodlands, other woodlands, and vegetation?
    - ❑ Riparian buffers?
    - ❑ Naturally vegetated swales/drainageways?
    - ❑ Steep slopes or unique topographic features?
    - ❑ Special geologic conditions (limestone?)?
    - ❑ Historical values, certified or non-certified?
    - ❑ Known/potential archaeological values?
    - ❑ Existing hydrology (drainage swales, intermittent, perennial)?
    - ❑ Existing topography, contours?
    - ❑ Soils, their hydrologic soil groups?
    - ❑ Seasonal high water table? Depth to bedrock?
    - ❑ Special geological issues (e.g., karst)
    - ❑ Aesthetics/viewsheds?
    - ❑ Existing land cover/uses?
    - ❑ Existing impervious areas, if any?
    - ❑ Existing pervious maintained areas, if any?
    - ❑ Existing contaminants from past uses, if any?
    - ❑ Existing public sewer and water, if any?
    - ❑ Existing storm drainage system(s), if any?
    - ❑ Existing wastewater system(s), if any?
    - ❑ How does size and shape of the site affect stormwater management?
    - ❑ Are there areas where development should generally be avoided?

Step 3: Integrate municipal, county, state, and federal requirements

Master plan

- ❑ Is development concept consistent with the master plan?
  - ❑ Consistent with goals/policies of the plan?
  - ❑ Preservation of natural resources consistent with priority areas/maps?

Regulations (e.g., ordinances, engineering standards)

- ❑ Consistent with local existing regulations?
  - ❑ Wetland regulations?
  - ❑ Tree/woodlands ordinance?
  - ❑ Riparian buffer ordinance?
  - ❑ Open space requirements?
  - ❑ Clustering and/or PUD options?
  - ❑ Overlay districts?
  - ❑ Wellhead protection?
  - ❑ Floodplain ordinances?
  - ❑ Are LID solutions required?
    - ❑ or incentivized?
    - ❑ or enabled?
    - ❑ or prohibited?
- ❑ Reduced building setbacks allowed?
- ❑ Curbs required?
- ❑ Swales allowed?
- ❑ Street width, parking requirements, other impervious requirements?
- ❑ Grading requirements?
- ❑ Landscaping that allows native vegetation?
- ❑ Stormwater requirements?
  - ❑ Peak rate?
  - ❑ Total runoff volume?
  - ❑ Water quality provisions?
  - ❑ Maintenance requirements?
- ❑ Consistent with county/state road requirements?
- ❑ Consistent with local stormwater regulations?
- ❑ Consistent with erosion and sedimentation requirements?
- ❑ Contaminated sites have followed state "due care" requirements for soil and groundwater?
- ❑ Consistent with state and federal wetland and/or inland lakes and streams regulations?
- ❑ Consistent with state threatened and endangered species regulations?
- ❑ Meets state floodplain requirements?

Step 4: Develop initial concept design using nonstructural BMPs

Lot configuration and clustering?

- ❑ Reduced individual lot size?
- ❑ Concentrated/clustered uses and lots?
- ❑ Lots/development configured to avoid critical natural areas?
- ❑ Lots/development configured to take advantage of effective mitigative stormwater practices?
- ❑ Lots/development configured to fit natural topography?
- ❑ Connect open space/sensitive areas with larger community greenways plan?

Minimum disturbance?

- ❑ Define disturbance zones (excavation/grading) for site?
  - ❑ Protect maximum total site area from development disturbance?
  - ❑ Barriers/flagging proposed to protect designated non-disturbance areas?
  - ❑ Disturbance setbacks defined from BMP areas, vegetated areas, tree drip lines, etc.?
- ❑ Site disturbance (excavation/grading) minimized for each lot?
- ❑ Considered mitigative practices for minimal disturbance areas (e.g., Soil Restoration)
- ❑ Considered re-forestation and re-vegetation opportunities?

Impervious coverage reduced?

- ❑ Reduced road width?

- ❑ Cul-de-sacs and turnarounds at reduced width?
- ❑ Reduced driveway lengths and widths?
- ❑ Reduced parking ratios?
- ❑ Reduced parking sizes?
- ❑ Shared parking potential reviewed?
- ❑ Utilized porous surfaces for applicable features?

Stormwater disconnected from impervious area?

- ❑ Disconnected stormwater flows from roof leaders?
- ❑ Disconnected drives/walkways/small impervious areas to natural areas?
- ❑ Used rain barrels and/or cisterns for lot irrigation?

Step 5: Pre-submission meeting and site visit with local decision makers

Step 6: Revisions to development concept

Step 7: Apply structural BMP selection process

- ❑ Meets runoff quantity?
- ❑ Quality needs?
- ❑ Manage close to source with collection/ conveyance minimized?
- ❑ Consistent with site factors (e.g., soils, slope, available space, amount of sensitive areas, pollutant removal needs, location of historical pollutants)?
- ❑ Minimize footprint and integrate into already-disturbed areas/other building program components (e.g., recharge beneath parking areas, vegetated roofs)?
- ❑ Estimate costs for both construction and maintenance?
- ❑ Consider other benefits?
  - ❑ Aesthetic?
  - ❑ Habitat?
  - ❑ Recreational?
  - ❑ Educational benefits?
- ❑ Select based on maintenance needs that fit owner/users?
- ❑ Develop long-term maintenance plan?

Step 8: LID calculation methodology

Achieved additional comprehensive stormwater management objectives?

- ❑ Minimize the pre- to post-development increase for curve numbers?
- ❑ Maximize presettlement time of concentration?
- ❑ Assume "conservative" presettlement conditions?
- ❑ Respect natural sub-areas in the design and engineering calculations?

Iterative process occurring throughout low impact site plan development and low impact stormwater management plan development?

- ❑ Soil Cover Complex Method (TR-55) is industry standard for calculations.

Step 9: Develop the preliminary site plan

Chapter 6

Nonstructural Best Management Practices

A core concept of LID is preventing stormwater runoff by integrating site design and planning techniques that preserve natural systems and hydrologic functions, protect open spaces, as well as conserve wetlands and stream corridors on a site. This chapter provides detailed technical information on integrating nonstructural Best Management Practices (BMPs) early into the site design process.

The nonstructural BMPs are:

- Cluster development,
- Minimize soil compaction,
- Minimize total disturbed area,
- Protect natural flow pathways,
- Protect riparian buffers,
- Protect sensitive areas,
- Reduce impervious surfaces, and
- Stormwater disconnection.

Specifically, this chapter discusses:

- The benefits of using nonstructural BMPs,
- The process for selecting nonstructural BMPs,
- Fact sheet overviews of each BMP, and
- Detailed information for each BMP including design considerations, construction guidelines, stormwater calculations, and maintenance and cost information.

What does nonstructural mean?

The primary LID characteristic of nonstructural BMPs is preventing stormwater runoff from the site. This differs from the goal of structural BMPs which is to help mitigate stormwater-related impacts after they have occurred.

More specifically, nonstructural BMPs take broader planning and design approaches, which are less "structural" in their form. Many nonstructural BMPs apply to an entire site and often to an entire community, such as wetland protection through a community wetland ordinance. They are not fixed or specific to one location. Structural BMPs, on the other hand, are decidedly more location specific and explicit in their physical form.

Benefits of using nonstructural BMPs

There are numerous benefits of incorporating nonstructural BMPs into a site. While individual benefits are discussed in detail under each BMP, there are many benefits that apply to most, if not all, of the nonstructural BMPs. These include:

- Reduced land clearing costs,
- Reduced costs for total infrastructure,
- Reduced total stormwater management costs,
- Enhanced community and individual lot aesthetics, and
- Improved overall marketability and property values.

Figure 6.1
LID Site Design Process

Step 1
Property acquisition and use analysis

Step 2
Inventory and evaluate the site

Step 3
Integrate municipal, county, state, and federal requirements

Step 4
Develop initial concept design using nonstructural BMPs

Step 5
Organize pre-submission meeting and site visit with local decision makers

Step 6
Incorporate revisions to development concept

Step 7
Apply structural BMP selection process

Step 8
Apply the LID calculation methodology

Step 9
Develop the preliminary site plan

BMP Selection Process

This chapter focuses on Step 4 in the site design process for LID (Figure 6.1) to develop the initial concept design using nonstructural BMPs. Selection of nonstructural BMPs should focus on information gathered in Steps 1-3 of the site design process. Following are specific questions and issues to provide guidance in the selection process.

- How is the property being used? A residential development may have more applicability for certain nonstructural BMPs than other land uses. For example, cluster development is an applicable BMP for residential development, but may be less used in more urban situations.
- What natural features are on site? A thorough site inventory will provide the necessary information to assess the ability to implement many of the BMPs, including preserving sensitive and riparian areas.
- What local, county, state, and other regulations need to be met? A review of local, county, state, and other regulations can also provide guidance on selecting the right mix of nonstructural BMPs.

BMP Fact Sheet and Detailed Nonstructural BMP Information

Each BMP begins with a fact sheet that provides a quick overview of the BMP, along with a local case study. The fact sheets can be removed separately from the manual and serve as a stand-alone document for quick reference. Fact sheet ratings have been condensed to general categories (High, Medium, and Low) with these summary ratings often discussed in more detail in the BMP text. Stormwater Quality Functions are based on a compilation of recent national/international studies rating pollutant removal performance.

Following each fact sheet is detailed information on the BMP which includes:

Variations

Discusses the variations to the BMP, if there are applicable. Examples include alternatives in design that can increase storage capacity or infiltration rates.

Applications

Indicates land use types for which the BMP is applicable or feasible.

Design Considerations

This section includes a list of technical procedures to be considered when designing for the individual BMP. This specific design criteria is presented, which can assist planners in incorporating LID techniques into a site design, as well as provide a basis for reviewers to evaluate submitted LID techniques.

Stormwater Calculations and Functions

Provides specific guidance on achieving sizing criteria, volume reduction, and peak rate mitigation, as applicable. This section also references Chapter 9 which discusses in detail how to achieve a specific standard or implement measures that contribute to managing water onsite in a more qualitative manner.

Construction Guidelines

Provides a typical construction sequence for implementing the BMP. However, it does not specifically address soil erosion and sedimentation control procedures. Erosion and sediment control methods need to adhere to the latest requirements of MDEQ's Soil Erosion and Sedimentation Control Program and local standards.

Maintenance

Provides guidance on recommended maintenance procedures for the BMP.

Winter Considerations

Discusses how well the BMP performs in Michigan's cold climate.

Cost

Provides general cost information for comparison purposes. If specific dates of costs are not referenced in this section, the costs reflect 2007 conditions.

Designer/Reviewer's Checklist

Developed to assist a designer and or reviewer in evaluating the critical components of a BMP that is being designed. It references not only individual design considerations, but also suggests review of additional pertinent sections of the LID manual that may need to be considered for implementation of that BMP.

References

Provides a list of sources of information utilized in the creation of this section of the manual. This list also provides additional sources that can be used for additional information.

Each fact sheet includes:

BMP Fact Sheet

Title

Short definition of BMP

Applications – Indicates in what type of land use BMP is applicable or feasible (**Yes, No,** or **Limited**).

Stormwater Quantity Functions – Indicates how well the BMP functions in mitigating stormwater management criteria (**High, Medium,** or **Low**).

Stormwater Quality Functions – Indicates how well the BMP performs in terms of pollutant removal (**High, Medium,** or **Low**).

Applications		Stormwater Quantity Functions	
Residential		Volume	
Commercial		Groundwater Recharge	
Ultra Urban		Peak Rate	
Industrial		**Stormwater Quality Functions**	
Retrofit		**TSS** – Total Suspended Solids	
Highway/Road		**TP** – Total Phosphorus	
Recreational		**TN** or **NO3** – Total Nitrogen/Nitrate	
		Temperature	

Additional Considerations

Cost – Indicate whether cost is high, medium or low by the following categories

- **High** – => adds more than 5% to total project cost
- **Medium** – adds 1–5% to total project cost
- **Low** – =< adds less than 1% to total project cost

Maintenance – Indicates level of maintenance required to maintain BMP (**High, Medium,** or **Low**).

- **High** – Maintenance intensive (i.e., year-round maintenance)
- **Medium** – Several times per year
- **Low** – One time per year

Winter Performance – Indicates if BMP provides equivalent performance throughout the winter (**High, Medium,** or **Low**)

- **High** – BMP performs very well in winter conditions
- **Medium** – BMP has reduced performance in winter conditions
- **Low** – BMP still performs in winter conditions, but performance is significantly reduced.

Variations (optional)

List of variations to the BMP if applicable

Key Design Features

Bulleted list of information that is key to the design of BMP

Site Factors (optional)

List of specific factors that relate to BMP performance:

- Water table/bedrock separation distance
- Soil type
- Feasibility on steeper slopes
- Applicability on potential hotspots (e.g., brownfields)

Benefits

List of benefits directly related to implementing the BMP

Limitations

List of site constraints associated with implementation

Case Study: Title

The second page of the fact sheet includes a Michigan case study highlighting several features of the use of an individual BMP. Each case study includes a description of the project, as well as several site considerations including:

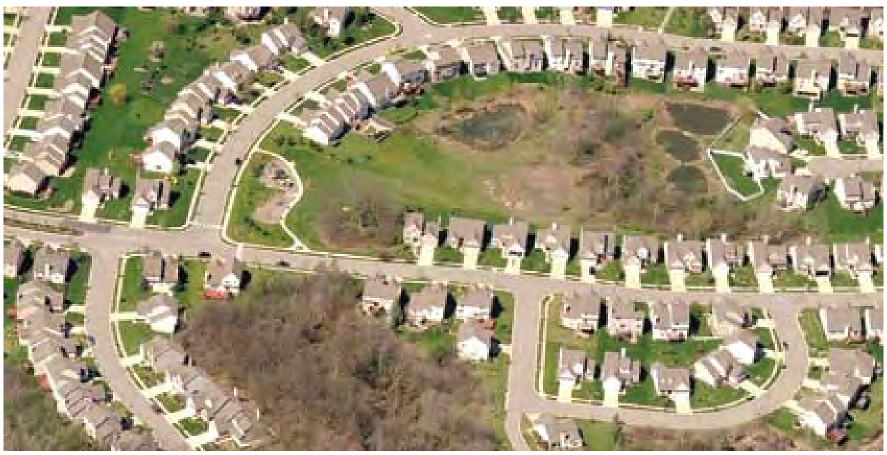
Case Study Site Considerations	
Project Type	
Soil Conditions	
Estimated Total Project Cost	
Maintenance Responsibility	
Project Contact	

BMP Fact Sheet

Cluster Development

Cluster development (also known as open space development) concentrates development on smaller lots on a portion of a larger site. Clustering allows the site planner to avoid resource sensitive and constrained areas at a site, such as steep slopes and water-sensitive areas including riparian buffers, wetlands, and floodplains without sacrificing the level of development.

Clustering reduces the amount of required infrastructure and various development-related costs. Clustering lends itself to residential development, with greatest potential in municipalities where large-lot residential development is typical. Clustering can reduce total impervious area and total disturbed areas at development sites, thereby reducing stormwater peak rates of runoff, reducing total volume of runoff, and reducing nonpoint source pollutant loads.



Aerial view of cluster development in Ann Arbor, MI

Source: Atwell Hicks

Potential Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	High
Commercial	Yes*	**Groundwater Recharge**	High
Ultra Urban	Limited	**Peak Rate**	High
Industrial	Limited	**Stormwater Quality Functions**	
Retrofit	No	**TSS**	High
Highway/Road	No	**TP**	High
Recreational	Limited	**NO_3**	High
		Temperature	High

Additional Considerations	
Cost	Low
Maintenance	Low/Med
Winter Performance	High

Variations
- Clustering as an option
- Clustering mandated by the municipality
- Clustering with incentives such as density bonuses

Key Design Features
- Develop inventory
- Map sensitive areas
- Reduce total site disturbance and develop cluster plan
- Increase undisturbed open space

Benefits
- Reduces required infrastructure
- Increases open space
- Protects environmentally sensitive natural resources

Limitations
- Site specific based on land topography and individual conditions

*Depending upon site size, constraints, and other factors.

Case Study: Pokagon Band of Potawatomi Indians Pokagonek Edawat Housing Development

Dowagiac, MI

The Dowagiac River Watershed Management Plan was used as the basis for the design principles in this project which led to integrating LID techniques into the development.

This Native American housing development used nine LID BMPs to arrive at an overall strategy to protect and use natural flow pathways and preserve natural features in overall stormwater planning and design. This development also maximized stormwater infiltration to groundwater through use of pervious pavement, rain gardens, and bioswales. In addition, homes were clustered to conserve open space and reduce infrastructure costs.

The housing units were clustered in loops following the site topography, with 17 units in the first phase and 16 units scheduled for the second phase. Clustering reduced costs by shortening roads and utility runs. Smaller lots have reduced lawn and yard maintenance. Clustering also allowed for shared bioswales to be established among the buildings, helping to manage runoff. The footprints of the homes were minimized, through minimizing hallway space and eliminating foyers, while still providing for maximum usable space.

Clustering of houses

Source: Pokagon Band of Potawatomi Indians

Case Study Site Considerations	
Project Type	Cluster development
Estimated Total Project Cost	Mostly associated with prescribed burns and turf maintenance
Maintenance Responsibility	Pokagon Banb Housing Department
Project Contact	Mark Parrish, mark.parrish@pokagon.com 269-782-9602

Description and Function

Cluster development is driven by reducing minimum lot size, though not necessarily changing the total number of lots or amount of development occurring. As lot sizes decrease, the portion of the site which remains as undisturbed open space increases. If clustering is done carefully, this remaining open space can and should include those areas which are most sensitive environmentally and/or which offer special value functions not otherwise protected from development (e.g., high-quality woodlands areas).

Several amendments were made to the Township Zoning Act (TZEA), the County Zoning Act (COZEA), and the City and Village Zoning Act (CVZEA) in 2001, requiring that municipalities (unless classified as "exempt") include clustering as an option in their respective zoning ordinances. According to the Michigan Association of Planning web site, regulatory provisions for clustering include:

"…land zoned for residential development may be developed using cluster development designs at the option of the land owner, the development of the specified land to be not more than 50% of the land that could have been developed (CVZEA 80%), density equivalency to be 2 or fewer dwelling units per acre, or if land is served by public sewer and water, 3 or fewer dwelling units per acre (all three statutes), land to remain perpetually in an undeveloped state to be not less than 50% for both TZEA and COZEA while CVZEA would be allowed 20%, all undeveloped land would be maintained as conservation easements, plat dedications, restrictive covenants, or other legal means; however land development would not depend upon the extension of public sewer or water unless the exercise of the option for development would depend upon an extension."

Variations

One variation to a typical cluster development allows for a density bonus to incentivize use of this technique. A density bonus allows for additional lots to be added to the site beyond what the yield plan would show with a conventional subdivision. Proponents of this method state that allowing an additional lot or two may be the incentive needed to increase implementation of this technique. Opponents of this variation state that a density bonus is not needed since the development already costs less due to less stormwater and transportation infrastructure.

A second clustering variation for municipalities to consider, subject to legal review, is establishing clustering as the baseline requirement, at least in some zoning categories. Conventional non-clustered development would still be an option (variance, conditional use, etc.), but only if a variety of performance standards are satisfied.

A third variation for consideration relates to the nature and extent of development types subject to clustering provisions. As discussed above, clearly single-family residential development at lower densities/on larger lots is ready-made for clustering. However, clustering concepts can provide LID benefits in larger corporate office parks, in retail centers, and other uses. Often this clustering concept takes on its own nomenclature e.g., New Urbanist, Smart Growth, Planned Integrated Development, and others. In these cases, not only are individual lots reduced in size, but the physical form of the development typically undergoes change (i.e., 50,000 square feet of retail can move from a one-story box to stacked development with a much different New Urbanist configuration). Depending upon the nature and extent of the uses involved, "clustering" of nonresidential uses (e.g., daytime offices with evening/weekend retail), if carefully planned can offer potential for reduced parking requirements.

Applications

Residential clustering

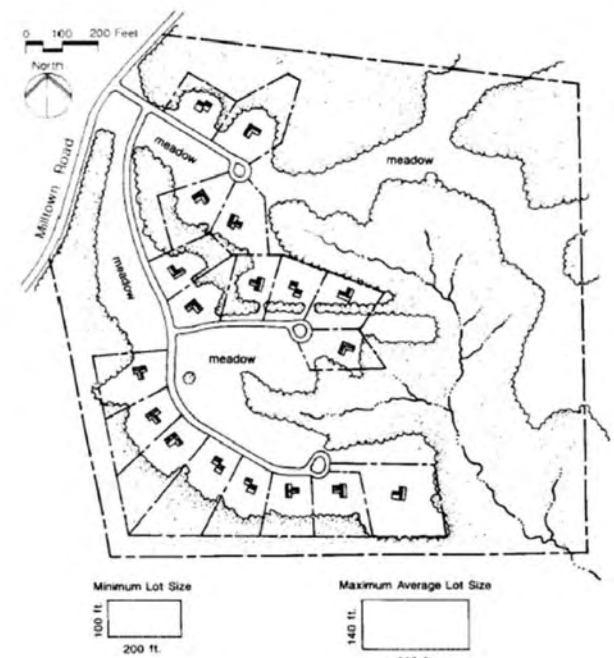
The most common clustering option is residential clustering on new development. Figure 6.2 illustrates a more traditional development scenario where lots are placed across the entire site. In this example, the lot and house placement does avoid major natural features such as floodplain and wetlands, but still substantially encroaches into woodlands and riparian buffer features. Such a development layout ("yield plan") provides an estimate of a site's capacity to accommodate lots and houses at the base density hypothetically allowed under a municipal zoning ordinance.

Figure 6.2
Conventional development

Source: Growing Greener: Putting Conservation into Local Codes. Natural Lands Trust, Inc., 1997

Figure 6.3 illustrates a "density-neutral" approach to clustering, where the number of lots and houses is held constant at 18 lots; however, the lot size has been reduced significantly allowing for 50 percent of open space area.

Figure 6.3
Clustered development



Source: Growing Greener: Putting Conservation into Local Codes. Natural Lands Trust, Inc., 1997

Nonresidential clustering

Conventional nonresidential development (e.g., retail commercial development) can also be configured in the form of low-rise (one story), relatively low-density strip or "big box" centers.

Design Considerations

The design process for implementing clustering at a proposed development site can occur in a variety of ways. Randall Arendt's *Growing Greener: Putting Conservation into Local Codes* (1997) provides clustering guidance in several straight-forward steps. The process typically begins with the applicant applying existing conventional code to the site with any necessary net outs to develop a "yield plan." The purpose is to determine how many units can be developed conventionally:

- Step 1: Identify land to be protected: Primary conservation areas,
  - Identify land to be protected: Secondary conservation areas, and
  - Delineate potential development area.
- Step 2: Locate house sites on potential development area
- Step 3: Connect with streets and trails
- Step 4: Draw in lot lines

A major issue to address is the extent to which a clustering process is consistent with municipal ordinance requirements. How many house sites with what lot size are going to be located in the potential development area?

If the existing municipal code is fully flexible, applicants can comprehensively "zone out" primary and secondary conservation areas and be confident that the baseline "yield plan" unit count can be loaded into the potential development area at whatever lot size is necessary (some applicants/developers believe that smaller lots translate into less valuable and marketable units and are reluctant to make considerable reductions in lot sizes). Often, however, such reduced lot sizes are less than the municipal ordinance allows. In such cases, the applicant is motivated to reduce primary and secondary conservation areas, so that the potential development area can be enlarged.

Cluster development at Pokagonek Edawat Housing Development
Source: Pokagon Band of Potawatomi Indians

Stormwater Functions and Calculations

Volume and peak rate

Cluster development is a technique that results in increased open space, which reduces stormwater peak rate and volume. These open spaces are often associated with other BMPs from this manual, including preserving sensitive areas and protecting riparian corridors. These BMPs are not to be included in the disturbed stormwater management area when calculating runoff volume (Chapter 9 and Worksheet 3).

Any portion of the open space that is mitigated or revegetated/reforested should be included in the disturbed stormwater management area, but may be granted credit in accordance with the applicable BMP for native revegetation, soil restoration, minimize soil compaction, riparian buffer restoration, or minimize total disturbed area.

Water quality improvement

Clustering minimizes impervious areas and their associated pollutant loads, resulting in improved water quality. In addition, clustering preserves open space and other natural features, such as riparian corridors, which allow for increased infiltration of stormwater and removal of pollutant loads. (See Chapter 9 for calculation methodology).

Maintenance

Preserving open space creates concerns regarding responsibility for maintenance activities. Legally, the designated open space may be conveyed to the municipality. More likely, ownership of these natural areas will be assumed by homeowners' associations or the specific individual property owners where these resources are located. Specific maintenance activities will depend on the type of vegetation present in the preserved natural area. For example, woodlands require little to no maintenance and open lawns require higher maintenance. An objective of cluster development is to conserve the existing natural systems with minimal, if any, intervention and disturbance.

Cherry Hill Village, Canton Township, MI

Cost

Clustering is beneficial from a cost perspective. Costs to build 100 clustered single-family residential homes is less due to less land clearing and grading, less road and sidewalk construction (including curbing), less lighting and street landscaping, potentially less sewer and water line construction, potentially less stormwater collection system construction, and other economies of scale.

Post-construction, clustering also reduces costs. A variety of studies from Rutgers University's landmark *Costs of Sprawl* studies and later updates show that delivery of a variety of municipal services such as street maintenance, sewer and water services, and trash collection are more economical on a per person or per house basis when development is clustered. Furthermore, services such as police protection are made more efficient when residential development is clustered.

Additionally, clustering has been shown to positively affect land values. Analyses of market prices of conventional development over time in contrast with comparable clustered residential developments (where size, type, and quality of the house itself is held constant) indicate that clustered development increases in value at a more rapid rate than conventionally designed developments. This is partly due to the proximity to permanently protected open space.

Designer/Reviewer Checklist for Cluster Development

ITEM	YES	NO	N/A	NOTES
Has nonstructural BMP Protect Sensitive Resources been applied? If not, complete this BMP.				
Has a baseline "yield plan" been developed by applicant?				
What municipal ordinance provisions - obstacles and opportunities - exist for clustering?				
Has a Potential Development Area, or comparable, which avoids Sensitive Resources, been delineated?				
Has "yield plan" house/unit count been loaded into Potential Development Area?				
What clustered lot size assumptions are being used? Compatible with municipal ordinance?				
Compare disturbed area/developed area of "yield plan" with clustered plan?				

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BMP Fact Sheet

Minimize Soil Compaction

Minimizing soil compaction is the practice of protecting and minimizing damage to existing soil quality caused by the land development process. Enhancing soil composition with soil amendments and mechanical restoration after it has been damaged is addressed in Chapter 7 as a separate structural BMP.

Minimizing disturbance of soil to protect wooded area
Source: City of Andover, Minnesota

Key Design Features

- Reduce disturbance through design and construction practices
- Limit areas of heavy equipment
- Avoid extensive and unnecessary clearing and stockpiling of topsoil
- Use top quality topsoil; maintain topsoil quality during construction

Benefits

- Increases infiltration capacity
- Provides healthy environment for vegetation
- Preserves low areas, which offer added benefit when runoff is directed there from impervious areas

Limitations

- Difficult to implement on small development sites

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Med/High
Commercial	Yes	**Groundwater Recharge**	Med/High
Ultra Urban	Limited	**Peak Rate**	Low/Med
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Limited	**TSS**	Med/High
Highway/Road	Limited	**TP**	Med/High
Recreational	Yes	**NO_3**	Low
		Temperature	Med/High

Additional Considerations	
Cost	Low/Med
Maintenance	Low
Winter Performance	Low/Med

Case Study: Minimizing soil compaction near an oak tree

City of Troy, MI

Minimizing soil compaction is not only important for drainage of a site, but also for minimizing impacts to established vegetation. In order to protect a culturally significant pin oak tree, the City of Troy utilized orange construction fencing at the drip line of the tree to protect the roots from any damage that could potentially be caused by machinery. The construction in the area included the assembly of a permanent picnic shelter that included a concrete foundation and steel I-beam construction. Prior to any construction commencing, the City placed the stakes and temporary fencing around the 30-inch oak tree, and notified the contractor that the area was to be protected.

Heavy equipment used within the drip line of a tree can cause soil compaction, resulting in the death of tree roots. Damage done to a tree's root system may take 3-4 years after construction to be present in a tree's canopy. Currently, the shelter has been completed, and the damage was successfully minimized to the pin oak tree.

Fencing around oak tree to minimize soil compaction
Source: City of Troy

Case Study Site Considerations	
Project Type	Minimize soil compaction
Estimated Total Project Cost	Minimal – Utilized DPW stakes
Maintenance Responsibility	City of Troy
Project Contact	Jennifer Lawson, 248-524-3881

Description and Function

Minimizing soil compaction relates directly to reducing total site disturbance, site clearing, site earthwork, the need for soil restoration, and the size and extent of costly, engineered stormwater management systems. Ensuring soil quality can significantly reduce the cost of landscaping vegetation (higher survival rate, less replanting) and landscaping maintenance. Fencing off an area can help minimize unnecessary soil compaction.

Preventing soil compaction adjacent to a stand of trees
Source: City of Andover, Minnesota

Soil is a physical matrix of weathered rock particles and organic matter that supports a complex biological community. This matrix has developed over a long time period and varies greatly within the state. Healthy soils, which have not been compacted, perform numerous valuable stormwater functions, including:

- Effectively cycling nutrients,
- Minimizing runoff and erosion,
- Maximizing water-holding capacity,
- Reducing storm runoff surges,
- Absorbing and filtering excess nutrients, sediments, and pollutants to protect surface and groundwater,
- Providing a healthy root environment,
- Creating habitat for microbes, plants, and animals, and
- Reducing the resources needed to care for turf and landscape plantings.

Undisturbed soil consists of pores that have water-carrying and holding capacity. When soils are overly compacted, the soil pores are destroyed and permeability is drastically reduced. In fact, the runoff response of vegetated areas with highly compacted soils closely resembles that of impervious areas, especially during large storm events (Schueler, 2000). Recent research studies indicate that compacted soils from development practices end up as dense as concrete.

Applications

Minimizing soil compaction can be performed at any land development site during the design phase. It is especially suited for developments where significant "pervious" areas (i.e., post-development lawns and other maintained landscapes) are being proposed. If existing soils have already been excessively compacted, soil restoration is applicable (see soil restoration BMP in Chapter 7).

Design Considerations

Early in a project's design phase, the designer should develop a soil management plan based on soil types and existing level of disturbance (if any), how runoff will flow off existing and proposed impervious areas, trees and natural vegetation that can be preserved, and tests indicating soil depth and quality. The plan should clearly show the following:

1. **No disturbance areas**. Soil and vegetation disturbance is not allowed in designated no disturbance areas. Protecting healthy, natural soils is the most effective strategy for preserving soil functions. Not only can the functions be maintained, but protected soil organisms are also available to colonize neighboring disturbed areas after construction.
2. **Minimal disturbance areas**. Limited construction disturbance occurs, but soil restoration may be necessary for such areas to be considered fully pervious after development. In addition, areas to be vegetated after development should be designated minimal disturbance areas. These areas may allow some clearing, but no grading due to unavoidable cutting and/or filing. They should be immediately stabilized, revegetated, and avoided in terms of construction traffic and related activity. Minimal disturbance areas do not include construction traffic areas.
3. **Construction traffic areas**. Construction traffic is allowed in these areas. If these areas are to be considered fully pervious following development, a soil restoration program will be required.

4. **Topsoil stockpiling and storage areas**. If these areas are needed, they should be protected and maintained. They are subject to soil restoration (including compost and other amendments) following development.
5. **Topsoil quality and placement**. Soil tests are necessary to determine if it meets minimum parameters. Critical parameters include: adequate depth (four inches minimum for turf, more for other vegetation), organic content (five percent minimum), and reduced compaction (1,400 kPa maximum) (Hanks and Lewandowski, 2003). To allow water to pass from one layer to the other, topsoil must be "bonded" (See Construction Guidelines #4) to the subsoil when it is reapplied to disturbed areas.

Construction site disturbance showing grading and soil compaction

Construction Guidelines

1. At the start of construction, no disturbance and minimal disturbance areas must be identified with signage and fenced as shown on the construction drawings.
2. No disturbance and minimal disturbance areas should be strictly enforced.
3. No disturbance and minimal disturbance areas should be protected from excessive sediment and stormwater loads while adjacent areas remain in a disturbed state.
4. Topsoil stockpiling and storage areas should be maintained and protected at all times. When topsoil is reapplied to disturbed areas it should be "bonded" with the subsoil. This can be done by spreading a thin layer of topsoil (2-3 inches), tilling it into the subsoil, and then applying the remaining topsoil. Topsoil should meet locally available specifications/requirements.

Stormwater Functions and Calculations

Volume and peak rate reduction

Minimizing soil compaction can reduce the volume of runoff by maintaining soil functions related to stormwater infiltration and evapotranspiration. Designers that use this BMP can select a lower runoff coefficient (i.e., curve number) for calculating runoff volume and peak rate from the area of minimized soil compaction. Chapter 9 and worksheets three and four show how to calculate the runoff credit for this BMP.

Where no-disturbance areas are specified, which are also sensitive areas maintained in their presettlement state, there will be no net increase in stormwater runoff from that area. Calculation methodology to account for the protection of sensitive areas is provided in Chapter 9.

Water quality improvement

Minimizing soil compaction improves water quality through infiltration, filtration, chemical and biological processes in the soil, and a reduced need for fertilizers and pesticides after development. See Chapter 9 for information on how to calculate the volume of runoff that needs water quality treatment.

Maintenance

Sites that have minimized soil compaction properly during the development process should require considerably less maintenance than sites that have not. Landscape vegetation, either retained or re-planted, will likely be healthier, have a higher survival rate, require less irrigation and fertilizer, and have better aesthetics.

Some maintenance activities such as frequent lawn mowing can cause considerable soil compaction after construction and should be avoided whenever possible. Planting low-maintenance native vegetation is the best way to avoid damage due to maintenance (Appendix C). No disturbance areas on private property should have an easement, deed restriction, or other legal measure imposed to prevent future disturbance or neglect.

Cost

Minimizing soil compaction generally results in significant construction cost savings. Design costs may increase slightly due to a more time intensive design.

Criteria to Receive Credits for Minimize Soil Compaction BMP

To receive credit under a local regulation, areas of no disturbance and minimal disturbance must meet the following criteria:

- ❑ The no disturbance and minimal disturbance areas are protected by having the limits of disturbance and access clearly shown on the Stormwater Plan, all construction drawings, and delineated/flagged/fenced in the field.
- ❑ No disturbance and minimal disturbance areas are not be stripped of existing topsoil.
- ❑ No disturbance and minimal disturbance areas are not be stripped of existing vegetation.
- ❑ No disturbance and minimal disturbance areas are not be subject to excessive equipment movement. Vehicle movement, storage, or equipment/material lay-down is not be permitted in these areas.
- ❑ Use of soil amendments and additional topsoil is permitted in other areas being disturbed, as described above. Light grading may be done with tracked vehicles that prevent compaction.
- ❑ Lawn and turf grass are acceptable uses. Planted meadow is an encouraged use.
- ❑ Areas receiving credit is located on the development project.

Designer/Reviewer Checklist for Minimize Soil Compaction

ITEM	YES	NO	N/A	NOTES
Have no disturbance areas been defined on plans (see minimize total disturbed area BMP)?				
Have no disturbance areas been fenced/flagged in field?				
Have minimal disturbance areas been defined on plans?				
Have construction traffic areas been defined on plans?				
Is soil restoration BMP committed to construction traffic areas, post-construction phase?				
Are soil stockpiling and storage areas defined on plan?				
Have proper topsoil quality and placement specifications been committed in the plans?				

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BMP Fact Sheet

Minimize Total Disturbed Area

A key component of LID is to reduce the impacts during development activities such as site grading, removal of existing vegetation, and soil mantle disturbance. This can be achieved through developing a plan to contain disturbed areas.

Minimizing disturbance to existing trees during residential construction
Source: Insite Design Studio, Inc.

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	High
Commercial	Yes	**Groundwater Recharge**	High
Ultra Urban	Limited	**Peak Rate**	High
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Limited	**TSS**	High
Highway/Road	Limited	**TP**	High
Recreational	Yes	**NO_3**	High
		Temperature	High

Additional Considerations	
Cost	Low
Maintenance	Low
Winter Performance	High

Key Design Features

- Identify and avoid special value and environmentally sensitive areas (See Protect Sensitive Areas BMP)
- Maximize undisturbed open space
- Minimize disturbance lot-by-lot
- Maximize soil restoration and restore soil permeability
- Minimize and control construction traffic areas
- Minimize and control construction stockpiling and storage areas

Benefits

- Reduced runoff volume
- Reduced peak rates
- High water quality benefits
- Increased infiltration capacity
- Provides healthy environment for vegetation

Limitations

- Difficult to achieve on small development sites

Case Study: Longmeadow Development

Niles, MI

Longmeadow is 400 acres of rolling land divided by ponds, meadows, clusters of trees, wetlands, and horse paddocks in Niles, MI. The development was picked by The Conservation Fund as a demonstration project in the State of Michigan for watershed protection.

The design was dictated by the land, resulting in separate areas for a variety of housing types and lot sizes. It also resulted in the preservation of 50 acres of open space, providing opportunities for fishing, community gardens, walking trails, private roads for biking and hiking. The design accounted for the need to preserve habitat for wildlife. This includes eliminating street lighting and maintaining animal corridors.

The wetland areas on site were not disturbed, and are maintained by a vegetated buffer greater than 75 feet wide. The site design also incorporated long vistas of seeded upland prairie meadows and homes tied in with miles of white horse fence.

Most of the trees on site were preserved and extra care was taken to preserve a very old, large oak tree at the entrance to the development. Visual separation of housing types was designed using existing fence rows of trees. In addition, bioswales were installed to provide infiltration along the roads and between homes.

View of existing wetland

Source: Longmeadow Development, Owner: Jane Tenney

Case Study Site Considerations	
Project Type	Bioswale, preservation of sensitive areas
Soil Conditions	Well drained soils on ridgetops, knolls, and plains. Permeability is moderate to moderately rapid. Suited well for most building and septic tank absorption. Main issue to address is maintaining slope and erosion control
Estimated Total Project Cost	N/A
Maintenance Responsibility	Longmeadow Homeowners Association
Project Contact	Jane Tenney: janetenney@comcast.net

Description and Function

Disturbance at a development site can occur through normal construction practices, such as grading, cutting, or filling. Minimizing the total disturbed area of the site requires the consideration of multiple BMPs, such as cluster development and identifying and protecting sensitive areas. These BMPs serve to protect area resources by reducing site grading and maintenance required for long-term operation of the site.

Minimizing the total disturbed area of a site specifically focuses on how to minimize the grading and overall site disturbance, maximizing conservation of existing native plant communities and the existing soil mantle of a site. If invasive plant species are present in the existing vegetation, proper management of these areas may be required in order for the vegetation to achieve its greatest hydrological potential.

Minimize grading

Reduction in grading can be accomplished in several ways, including conforming the site design with existing topography and land surface, where road alignments strive to follow existing contours as much as possible, varying the grade and alignment criteria as necessary to comply with safety limits.

Minimize overall site disturbance

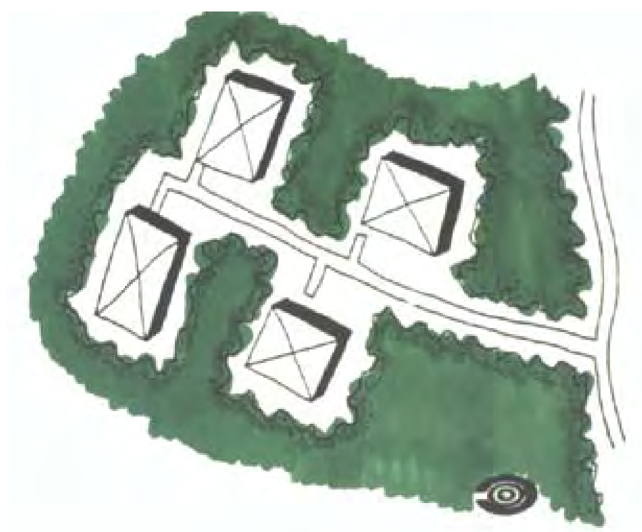
Site design criteria have evolved in municipalities to ensure that developments meet safety standards (i.e. sight distance and winter icing) as well as certain quality or appearance standards. Roadway design criteria should be flexible in order to optimize the fit for a given parcel and achieve optimal roadway alignment. The avoidance of environmentally sensitive resources, such as important woodlands, may be facilitated through flexible roadway layout.

Disturbance of native trees minimized during residential construction

From the single-lot perspective, the conventional lot layout can impose added earthwork and grading Although the intent of these municipal requirements is to provide privacy and spacing between units, the end result is often a cleared and graded lot, which reduces stormwater benefits. And although configuring lots in a rectilinear shape may optimize the number of units, municipalities should consider requiring that the total site be made to fit the natural landscape as much as possible.

Municipal criteria that impose road geometry are usually contained within the subdivision and land development ordinance. Densities, lot and yard setbacks, and minimum frontages are usually contained in the zoning ordinance. Flexibility in the following land development standards will help to minimize site disturbance on an individual lot basis, thereby achieving area-wide stormwater quality and quantity results:

- Road vertical alignment criteria (maximum grade or slope)
- Road horizontal alignment criteria (maximum curvature)
- Road frontage criteria (lot dimensions)
- Building setback criteria (yards dimensions)



Minimally disturbed development

Source: Metropolitan Washington Council of Governments

Applications

Minimizing the total disturbed area of a site is best applied in lower density single-family developments, but can also be applied in residential developments of all types including commercial, office park, retail center, and institutional developments. Larger industrial park developments can also benefit from this BMP. However, as site size decreases and density and intensity of development increases, this BMP is uniformly more difficult to apply successfully. At some larger sites where Ultra Urban, Retrofit, or Highway/Road development is occurring, limited application may be feasible.

Design Considerations

During the initial conceptual design phase of a land development project, the applicant's design engineer should provide the following information, ideally through development of a Minimum Disturbance/Minimum Maintenance Plan:

1. **Identify and Avoid Special Value/Sensitive Areas**
   Delineate and avoid environmentally sensitive resources using existing data from appropriate agencies (see Protect Sensitive Areas, Riparian Corridors, and Natural Flow Pathways BMPs).

Woodlands Protected through Minimum Disturbance Practices

2. **Minimize Disturbance at Site**
   Modify road alignments (grades, curvatures, etc.), lots, and building locations to minimize grading, and earthwork as necessary to maintain safety standards and municipal code requirements. Minimal disturbance design should allow the layout to best fit the land form without significant earthwork, such as locating development in areas of the site that has been previously cleared, if possible. If cut/fill is required, the use of retaining walls is preferable to earthwork. Limits of grading and disturbance should be designated on plan documentation submitted to the municipality for review/approval and should be physically designated at the site during construction via flagging, fencing, etc.

   In addition, utilizing natural drainage features generally results in less disturbance and requires less revegetation.

3. **Minimize Disturbance at Lot**
   To decrease disturbance, grading should be limited to roadways and building footprints. Municipalities should establish maximum setbacks from structures, drives, and walks. These setbacks should be designed to be rigorous but reasonable in terms of current feasible site construction practices. These standards may need to vary with the type of development being proposed and the context of that development (the required disturbance zone around a low density single-family home can be expected to be less than the disturbance necessary for a large commercial structure), given necessity for use of different types of construction equipment and the realities of different site conditions. For example, the U.S. Green Building Council's Leadership in Energy & Environmental Design Reference Guide (Version 2.0 June 2001) specifies:

   "…limit site disturbance including earthwork and clearing of vegetation to 40 feet beyond the building perimeter, 5 feet beyond the primary roadway curbs, walkways, and main utility branch trenches, and 25 feet beyond pervious paving areas that require additional staging areas in order to limit compaction in the paved area…

Stormwater Functions and Calculations

Volume

Any portion of a site that can be maintained in its presettlement state by using this BMP will not contribute increased stormwater runoff and will reduce the amount of treatment necessary. In addition, trees protected under this requirement can get a "credit" by receiving a curve number reflecting a woodlot in "good" condition. Calculation methodology to account for this BMP is provided in Chapter 9.

Peak rate

Runoff from the minimized disturbed area may be excluded from peak rate calculations for rate control, provided that the runoff from the area is not conveyed to and/or through stormwater management control structures. If necessary, runoff from the minimized disturbed area should be directed around BMPs and stormwater pipes and inlets by means of vegetated swales or low berms that direct flow to natural drainageways.

Water quality improvement

Water quality is benefited substantially by minimizing the disturbed area.

Maintenance

Minimizing site disturbance will result in a reduction of required maintenance of a site in both the short- and long-term. Areas of the site left as intact native plant communities do not typically require replacement with hard surfaces or additional vegetation to retain function. On the other hand, artificial surfaces such as pavement or turf grass require varying levels of maintenance throughout the life of a development. Higher levels of disturbance will also typically require significant maintenance of erosion control measures during the active development of a parcel, thus adding to short-term development costs.

While intact natural areas may require small amounts of occasional maintenance (typically through invasive species control) to maintain function, levels of maintenance required for hard surfaces or turf grass will remain static or, in most cases, increase over time. Avoiding disturbance to natural areas benefits the short term developer and the long-term owner by minimizing time and money needed to maintain artificial surfaces.

Cost

The reduced costs of minimized grading and earthwork should benefit the developer. Cost issues include both reduced grading and related earthwork as well as costs involved with site preparation, fine grading, and seeding.

Calculation of reduced costs is difficult due to the extreme variation in site factors, (amount of grading, cutting/filling, and haul distances for required trucking,). Some relevant costs factors are as follows (as based on R.S. Means, Site Work & Landscape Cost Data, 2007):

Site clearing

- Cut & chip light trees to six-inch diameter $3,475/acre
- Grub stumps and remove $1,600/acre
- Cut & chip light trees to 24-inch diameter $11,600/acre
- Grub stumps and remove $6,425/acre

Strip topsoil and stockpile

- Ranges from $0.52 to $1.78 / yard^3 because of Dozer horse power, and ranges from ideal to adverse conditions
- Assuming six inches of topsoil, 500 ft haul $2.75 - 9.86 per yard^3
- Assuming six inches of topsoil, 500 ft haul $9,922 -16,746 per acre

Site preparation, fine grading, seeding

- Fine grading w/ seeding $2.91 /sq. yd.
- Fine grading w/ seeding $14,084 /acre

In sum, total costs usually range from $29,000 - $49,000 per acre and could certainly exceed that figure substantially at more challenging sites.

Criteria to Receive Credits for Minimizing Total Disturbed Area

To receive credit for protection of existing trees under a local regulation, the following criteria must be met:

- ❑ Area has not be subject to grading or movement of existing soils.
- ❑ Existing native vegetation are in a healthy condition as determined through a plant inventory and may not be removed.
- ❑ Invasive vegetation may be removed.
- ❑ Pruning or other required maintenance of vegetation is permitted. Additional planting with native plants is permitted.
- ❑ Area is protected by having the limits of disturbance clearly shown on all construction drawings and delineated in the field.
- ❑ Area is located on the development project.

Designer/Reviewer Checklist for Minimize Total Disturbed Area

ITEM	YES	NO	N/A	NOTES
Do municipal requirements for open space and related resource protection exist? Applied here?				
Have related BMPs (Protect Sensitive Areas, Natural Flow Pathways, Riparian Buffers, Clustering) been applied?				
Has Potential Development Area been defined?				
Have infrastructure connections/constraints been analyzed?				
On site, have roads been aligned to fit topography, to parallel contours and minimize cut/fill? On areas previously cleared? With terracing? Compatible with natural flow pathways?				
On lots, have buildings been located to reduce disturbance?				
On lots, have maximum disturbance radii been established and applied?				
No disturbance areas shall be clearly delineated on construction plans and flagged/fenced in field				
Have no disturbance zones been assessed qualitatively for invasive management needs?				

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BMP Fact Sheet

Protect Natural Flow Pathways

A main component of LID is to identify, protect, and use natural drainage features, such as swales, depressions, and watercourses to help protect water quality. Designers can use natural drainage features to reduce or eliminate the need for structural drainage systems.

Natural flow pathway in residential development

Source: Brandywine Conservancy, Environmental Management Center, 1998

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Low/Med
Commercial	Yes	**Groundwater Recharge**	Low
Ultra Urban	No	**Peak Rate**	Med/High
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	Low/Med
Highway/Road	Yes	**TP**	Low/Med
Recreational	Yes	**NO_3**	Low
		Temperature	Low

Additional Considerations	
Cost	Low
Maintenance	Low/Med
Winter Performance	Low/Med

Variations

- Check dams to slow velocity
- Earthen berms for additional storage
- Additional native vegetation for increased infiltration

Key Design Features

- Identifies and maps natural drainage features (e.g., swales, channels, ephemeral streams, depressions, etc.)
- Uses natural drainage features to guide site design
- Distributes non-erosive surface flow to natural drainage features
- Keeps non-erosive channel flow within drainage pathways
- Uses native vegetative buffers

Benefits

- Maximizes natural hydrological functions
- Reduces structural management practices
- Reduces management costs

Limitations

- Minimal water quality benefits

Case Study: Marywood Health Center

Grand Rapids, MI

When the new Marywood Health Center was designed and constructed, care was taken to make a building and setting that met the needs of the nuns, preserved the natural beauty of the area, and protected the creek.

The design and construction of the health center building preserved the natural topography. The stormwater from the roof of the new health center has been diverted to create a pond landscaped with native perennial wildflowers. The stormwater from the health center parking lot is conveyed along a series of wildflower-planted swales and small ponds to a stormwater prairie that matured in 2007. An additional feature is a rain garden and detention pond next to the parking lot at Aquinata Hall.

The stormwater features on the campus created wildlife habitat and natural beauty, enhancing the grounds for the residents and local community to enjoy. The large prairie only needs to be mowed every other year to maintain the planting, reducing the cost of grounds keeping. The stormwater systems have become a regional attraction, as this is the first stormwater prairie planted in Grand Rapids, MI.

It takes three years for a prairie to mature, and until that time, it is not as attractive as it will be once flowers and grasses reach full size. During the first years of growth, the area can be beautifully enhanced with annual, non-invasive wildflowers such as cosmos, and the soil stabilized with annual ryegrass.

Native prairie vegetation in natural flow pathway

Case Study Site Considerations	
Project Type	Protect natural flow pathways, native vegetation, preserve sensitive areas.
Estimated Total Project Cost	$2,000 (Rain garden and soil replacement)
Maintenance Responsibility	Volunteers and Marywood staff
Project Contact	Maureen Geary, Grand Rapids Dominicans Leadership Vicaress (616) 647-0133

Description and Function

Many natural undeveloped sites have identifiable drainage features such as swales, depressions, and watercourses which effectively manage the stormwater that is generated on the site. By identifying, protecting, and using these features, a development can minimize its stormwater impacts. Instead of ignoring or replacing natural drainage features with engineered systems that rapidly convey runoff downstream, designers can use these features to reduce or eliminate the need for structural drainage systems.

Naturally vegetated drainage features tend to slow runoff and thereby reduce peak discharges, improve water quality through filtration, and allow some infiltration and evapotranspiration to occur. Protecting natural drainage features can provide for significant open space and wildlife habitat, improve site aesthetics and property values, and reduce the generation of stormwater runoff itself. If protected and used properly, natural drainage features generally require very little maintenance and can function effectively for many years.

Site designs should use and/or improve natural drainage pathways whenever possible to reduce or eliminate the need for stormwater pipe networks. This can reduce costs, maintenance burdens, and site disturbance related to pipe installation. Natural drainage pathways should be protected from significantly increased runoff volumes and rates due to development. The design should prevent the erosion and degradation of natural drainage pathways through the use of upstream volume and rate control BMPs, if necessary. Level spreaders, erosion control matting, revegetation, outlet stabilization, and check dams can also be used to protect natural drainage features.

Preservation of natural features in residential development

Variations

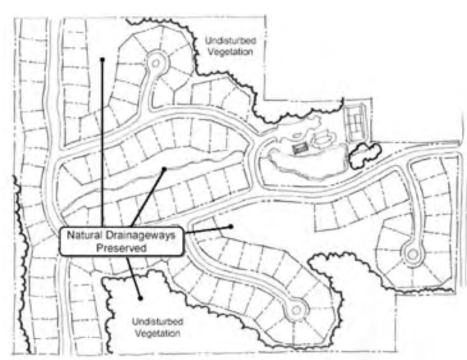
Natural drainage features can also be made more effective through the design process. Examples include constructing slight earthen berms around natural depressions or other features to create additional storage, installing check dams within drainage pathways to slow runoff and promote infiltration, and planting additional native vegetation within swales and depressions.

Applications

As density and overall land disturbance decreases, this BMP can be used with a greater variety of land uses and development types. It is best used in residential development, particularly lower density single-family residential development. Where municipal ordinances already require a certain percentage of the undeveloped site to remain as undeveloped open space, this open space requirement can be overlain onto natural flow pathways/drainage features, as well as floodplains, wetlands, and related riparian areas. After minimizing runoff as much as possible, reduced runoff quantities can then be distributed into this natural flow pathway system, on a broadly distributed basis, lot by lot.

Other land uses such as commercial and industrial developments tend to be associated with higher density development. This results in higher impervious coverage and maximum site disturbance allowances, making protecting and conserving natural flow pathways/drainage areas more difficult.

Applications for both retrofit and highway/road are limited. In terms of retrofitting, some developed sites may have elements of natural flow pathways/drainage features intact, although many presettlement site features may have been altered and/or eliminated. Developed sites of lower densities may offer limited retrofit potential. Similarly, highway/road projects are likely to be characterized by both limited site area, given the difficulties of right-of-way acquisition, as well as substantial disturbance of this limited site area.



Schematic of a site design protecting natural drainage features

Source: Georgia Stormwater Management Manual, Volume 2: Technical Handbook, First Edition. August, 2001

Design Considerations

1. **Identify natural drainage features**. Identifying and mapping natural drainage features is generally done as part of a comprehensive site analysis. This process is an integral first step of site design. Subtle site features such as swales, drainage pathways, and natural depressions should be delineated in addition to commonly mapped hydrologic elements such as wetlands, perennial and intermittent streams, and waterbodies.

Natural drainage features can guide the design

Source: Delaware Department of Natural Resources and Environmental Control - Conservation Design for Stormwater Management

2. **Use natural drainage features to guide site design.** Instead of imposing a two-dimensional paper design on a particular site, designers can use natural drainage features to steer the site layout. Drainage features define contiguous open space and other undisturbed areas as well as road alignment and building placement. The design should minimize disturbance to natural drainage features. Drainage features that are to be protected should be clearly shown on all construction plans. Methods for protection, such as signage and fencing, should also be noted on applicable plans.
3. **Use native vegetation**. Natural drainage pathways should be planted with native vegetative buffers and the features themselves should include native vegetation where applicable. If drainage features have been previously disturbed, they can be restored with native vegetation and buffers.

Stormwater Function and Calculations

Volume reduction

Protecting natural flow pathways can reduce the volume of runoff in several ways. Reducing disturbance and maintaining a natural cover reduces the volume of runoff through infiltration and evapotranspiration. Using natural flow pathways further reduces runoff volumes through allowing increased infiltration to occur, especially during smaller storm events. Encouraging infiltration in natural depressions also reduces stormwater volumes. Employing strategies that direct non-erosive sheet flow onto naturally vegetated areas also promotes infiltration – even in areas with relatively impermeable soils. (See Chapter 9 for volume reduction calculations.)

Artesian spring in Northville Ridge Subdivision, Northville Township, MI

When the subdivision was being developed, the Johnson Creek Protection Group requested that the developer relocate one of the proposed residential homes and create a small park above the spring so as not to interrupt the groundwater flow. They agreed and the spring still flows year around creating a focal point for the park.

Source: Wayne County Department of Environment

Peak rate mitigation

Protecting natural flow pathways can reduce the peak rate of runoff in several ways. Reducing disturbance and maintaining a natural cover reduces the runoff rate. Using natural flow pathways can lower discharge rates by slowing runoff and increasing onsite storage.

Water quality improvement

Protecting natural flow pathways improves water quality through filtration, infiltration, sedimentation, and thermal mitigation. (See Chapter 9 for Water Quality calculations.)

Maintenance

Natural drainage features that are properly protected and used as part of site development should require very little maintenance. However, periodic inspections are important. Inspections should assess erosion, bank stability, sediment/debris accumulation, and vegetative conditions, including the presence of invasive species. Problems should be corrected in a timely manner

Protected drainage features on private property should have an easement, deed restriction, or other legal measure to prevent future disturbance or neglect.

Cost

Protecting natural flow pathways generally results in significant construction cost savings. Protecting these features results in less disturbance, clearing, and earthwork and requires less revegetation. Using natural flow pathways reduces the need and size of costly, engineered stormwater conveyance systems. Together, protecting and using natural flow pathways reduces and even eliminates the need for stormwater management facilities (structural BMPs), lowering costs even more.

Designer/Reviewer Checklist for Protect Natural Flow Pathways

ITEM	YES	NO	N/A	NOTES
Identify in plan all natural flow pathways before proposed development?				
Identify in plan natural flow pathways protected post-development?				
Highlight in plan natural flow pathways which are integrated into stormwater management?				
Have measures been taken to guarantee that natural pathways won't be negatively impacted by stormwater flows?				
Have credits been calculated for natural flow pathways being protected?				

References

Center for Watershed Protection. *Better Site Design: A Handbook for Changing Development Rules in your Community.* Ellicott City, MD, 1998.

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BMP Fact Sheet

Protect Riparian Buffer Areas

Riparian buffer areas are important elements of local communities' green infrastructure and/or LID tool box. These areas are critical to the biological, chemical, and physical integrity of our waterways. Riparian buffer areas protect water quality by coolong water, stabilizing banks, mitigating flow rates, and providing for pollution and sediment removal by filtering overland sheet runoff before it enters the water. The Environmental Protection Agency defines buffer areas as, "areas of planted or preserved vegetation between developed land and surface water, [which] are effective at reducing sediment and nutrient loads."

Physical restoration of riparian buffer areas is located in Chapter 7 as a structural BMP. A detailed description of the characteristics of riparian buffer areas is combined with a discussion of their stormwater functions in the restoration BMP.

Maintaining a riparian buffer
Source: JFNew

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Low/Med
Commercial	Yes	**Groundwater Recharge**	Low/Med
Ultra Urban	Limited	**Peak Rate**	Low/Med
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	High
Highway/Road	Limited	**TP**	High
Recreational	Yes	**NO_3**	Medium
		Temperature	High

Additional Considerations	
Cost	Low/Med
Maintenance	Low
Winter Performance	High

Key Design Features

- Physical protection
- Protection through planning tools

Benefits

- Improves water quality
- Reduces runoff velocities
- Reduces flow
- Enhances site aesthetics, habitat
- Reduces shoreline and bank erosion
- Improves flood control
- Reduces water temperature

Limitations

- Limited in reducing total run-off volumes
- Size of lot and/or development site may reduce ability to protect riparian buffers

Case Study: Macomb County Public Works Riparian Corridor Preservation

Clinton Township, MI

Macomb County Public Works incorporated LID techniques into the development of their new public works building. One element of the property is a 35 acre riparian area located along the North Branch of the Clinton River.

The county is committed to preserving this riparian corridor and is researching the option of a permanent easement that would be under the under the ownership and maintenance of a local land conservancy.

Other LID techniques used on this project include:

- Rain garden to catch roof runoff,
- Bioswale that captures parking lot runoff,
- Porous pavers along the sidewalks entering the building, and
- Native plantings located around the site, including the rain garden and bioswale.

Source: Macomb County Public Works Office

Case Study Site Considerations	
Project Type	Protect riparian areas, porous pavers, rain garden, bioswale
Project Contact	Lynne Seymour, 586-307-8229

Applications

As with the “protect sensitive areas” nonstructural BMP, protecting riparian buffer areas has great value and utility for virtually all types of development proposals and land uses. This BMP works best on larger sites. Therefore, although riparian buffer programs should be advocated in the densest of settings, their application is likely to be limited in high density contexts. Creative design can maximize the potential of riparian buffers. Clustering and density bonuses are design methods available to increase the amount and connectedness of open space areas such as riparian buffers.

Design Considerations

Physical design

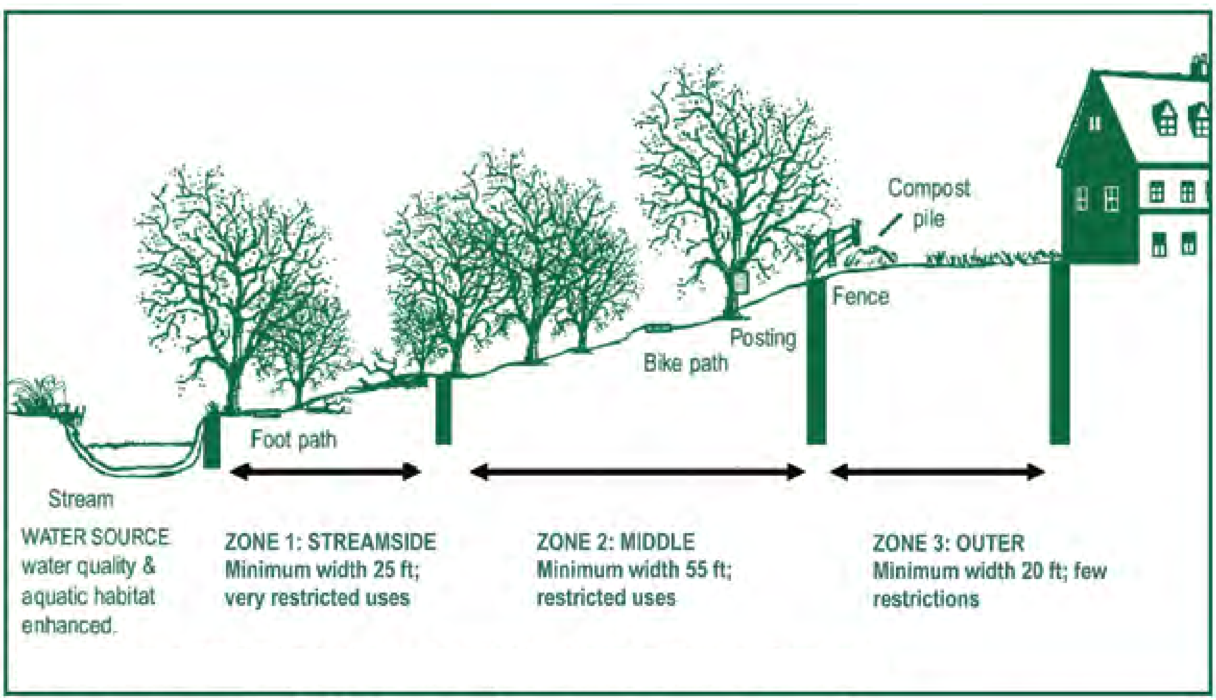
Consider the following when protecting the proper riparian buffer area width and related specifications:

- Existing or potential value of the resource to be protected,
- Site, watershed, and buffer characteristics,
- Intensity of adjacent land use, and
- Specific water quality and/or habitat functions desired. (*Chesapeake Bay Riparian Handbook*)

Riparian buffers can be divided into different zones that include various vegetation to enhance the quality of the body of water.

Zone 1: Also termed the “streamside zone,” begins at the edge of the stream bank of the active channel and extends a minimum distance of 25 feet, measured horizontally on a line perpendicular to the water body. Undisturbed vegetated area aims to protect the physical and ecological integrity of the stream ecosystem. The vegetative target for the streamside zone is undisturbed native woody species with native plants forming canopy, understory, and duff layer. Where such forest does not grow naturally, then native vegetative cover appropriate for the area (such as grasses, forbs, or shrubs) is the vegetative target. (*HRWC Model Ordinance*)

Zone 2: Also termed the “middle zone,” extends immediately from the outer edge of Zone 1 for a minimum distance of 55 feet. This managed area of native vegetation protects key components of the stream ecosystem and provides distance between upland development and the streamside zone. The vegetative target for the middle zone is either undisturbed or managed native woody species or, in its absence, native vegetative cover of shrubs, grasses, or forbs. Undisturbed forest, as in Zone 1, is encouraged strongly to protect future water quality and the stream ecosystem. (*HRWC Model Ordinance*)



Buffer width recommendations

Source: Schueler, Watershed Protection Techniques, 1994 (Graphic courtesy of the Center for Watershed Protection)

Zone 3: Also termed the "outer zone," it extends a minimum of 20 feet immediately from the outer edge of Zone 2. This zone prevents encroachment into the riparian buffer area, filters runoff from adjacent land, and encourages sheet flow of runoff into the buffer. The vegetative target for the outer zone is native woody and herbaceous vegetation to increase the total width of the buffer; native grasses and forbs are acceptable. (*HRWC Model Ordinance*)

Community planning and riparian buffers

Numerous tools exist at the community level to protect riparian buffers, including ordinances, integrating buffers into plans, and public education.

Community buffer regulations

To effectively manage riparian buffer areas, a community must properly plan for these resources. Some Michigan communities have riparian buffer ordinances that explicitly regulate these areas. Typical components of a riparian ordinance include:

- Exemptions,
- Width requirements,
- Permitted and prohibited uses within the riparian buffer,
- Maintenance requirements,
- Waivers and variances, and
- Maintenance and construction of utilities and public roads along the stream corridor.

Natural features setback standards establish a minimum setback (buffer width) from natural features to prevent physical harm or destruction of the feature. These standards recognize the relationship between terrestrial and aquatic ecosystems and should be applied to both lakes and rivers. Each community establishes buffer width standards at their discretion.

In general, the wider the buffer, the greater the number of ecological functions the riparian zone will provide. Communities may choose to establish fixed or variable width buffers or a combination of the two. (*Oakland County Planning & Economic Development Services*)

Integrating buffer protection into plans

In addition to implementing a riparian buffer ordinance, communities can include riparian buffer area protection in the following planning tools:

- Community master plans,
- Park and recreation plans, and
- Subdivision and land development ordinances.

Key planning elements of a local riparian area protection program*

- Provide ample setbacks for sanitary facilities on buffer areas.
- The wider the riparian buffer, the greater the water quality protection and habitat value of the area.
- Establish setbacks from rivers and streams.
- Regulate road placement adjacent to the riparian buffer area.
- Restrict clearing, construction, and development within the 100-year floodplain.
- Zone areas adjacent to riparian buffer areas for low intensity development.
- Establish minimum lot size, frontage, and width requirements.
- Include reference to floodplain, soil, and sedimentation controls administered by other agencies in riparian regulations.
- Screen new structures with native vegetation.
- Limit industrial use along riparian corridors and regulate through special use permits subject to pre-designated standards.
- Limit the amount of impervious surfaces allowed adjacent to buffer area.
- Clearly outline appropriate and inappropriate use of riparian buffer areas.
- Promote intergovernmental coordination of regulations among communities along the river corridor.

*Adapted from *Michigan Wetlands – Yours to Protect*

Combination of established and new riparian vegetation
Source: Huron River Watershed Council

Park and recreation plans can adopt the goals, policies, and objectives for riparian protection that are listed in the community master plan, or include its own park and recreation-specific recommendations for riparian buffer management. Content may focus on defining appropriate and inappropriate recreational uses for riparian areas located within parks. Park and recreation plans may also provide guidelines for proper construction and maintenance of river access points, and rules and regulations for public access as these topics relate to potential impacts on riparian buffers. (*Oakland County Planning & Economic Development Services*)

Riparian buffer education

Educational opportunities for the general public are an important component in community planning. Informing riparian owners of the importance of buffer areas will help to ensure these areas are understood and maintained over time. Public education activities include hosting public meetings, direct mailings to riparian homeowners, and educational workshops. These activities can be developed to meet the specific needs of your community through partnerships with local watershed groups.

Educational riparian booklet
Source: Huron River Watershed Council

Design measures

The following elements represent a menu of design measures for riparian and natural resource protection that communities may choose to encourage or require developers to incorporate during the site plan review process.

Conservation subdivision or open space regulations:

- Prepare natural features inventory on proposed project sites.
- Require certain percentage of total parcel acreage to be retained as open space.
- Reference minimum buffer widths for riparian buffer areas and identify upland areas adjacent to riparian buffer areas as preferred green space designated for low-impact residential recreation activities.
- Advocate cluster development that concentrates construction on land with less conservation value, and allows owners of house lots in the development to share undivided ownership of the portion of property remaining in a scenic and natural condition.
- Advocate lot averaging standards for retaining riparian resources and natural features on smaller sites.

Lot size and density regulations:

- Provide flexible lot size and density standards to guide development away from a stream buffer or other sensitive land.
- Provide developers with density bonuses for land-conserving design and density disincentives to actively discourage land-consuming layouts.

Minimum frontage and road setback regulations:

- Provide flexibility in frontage and road setback standards to minimize development intrusion on riparian buffer areas.

Stormwater management guidelines:

- Regulate erosion control before, during, and after construction.
- Encourage developers to retain natural vegetation already protecting waterways.
- Create a variable-width, naturally vegetated buffer system along lakes and streams that also encompasses critical environmental features such as the 100-year floodplain, steep slopes, and wetlands.

- Limit clearing and grading of forests and native vegetation at a site to the minimum amount needed to build lots, allow access, and provide fire protection.
- Promote riparian buffer areas as part of stormwater management planning.

Source: *Planning for Green River Corridors*, Oakland County Planning & Economic Development Services.

Wide buffer maintained during residential construction
Source: Huron River Watershed Council

Stormwater Functions and Calculations

Any portion of a site that can be maintained in its presettlement state by using this BMP will not contribute increased stormwater runoff and will reduce the amount of treatment necessary. Calculation methodology to account for this BMP is provided in Chapter 9.

Volume

Protected riparian buffers are not to be included in the disturbed stormwater management area when calculating runoff volume (Chapter 9 and Worksheet 3).

Any portion of a riparian buffer area that is mitigated or revegetated/reforested should be included in the disturbed stormwater management area, but may be granted credit in accordance with the applicable BMP for native revegetation, soil restoration, minimize soil compaction, riparian buffer restoration, or minimize total disturbed area.

Peak rate

Runoff from the riparian buffers may be excluded from peak rate calculations for rate control, provided that runoff from the riparian buffers is not conveyed to and/or through stormwater management control structures. If necessary, runoff from riparian buffers should be directed around BMPs and stormwater pipes and inlets by means of vegetated swales or low berms that direct flow to natural drainageways.

Water quality improvement

Water quality is benefited substantially by avoiding negative impacts which otherwise would have resulted from impacts to riparian buffers (e.g., loss of water quality functions from riparian buffers, from wetland reduction, etc.).

Cost

The costs of protecting riparian areas relate to a reduction in land available for development. However, most riparian areas are located in wetlands or floodplains, restricting the amount of buildable area.

Designer/Reviewer Checklist for Protect Riparian Buffer Areas

ITEM	YES	NO	N/A	NOTES
Define municipal programs requirements or resources for riparian buffer protection, if any				
Based on above and relevant sources, establish riparian buffer protection standards for development site				
Map riparian resources at the site which need buffer protection				
Apply Zone1/Zone2/Zone3 determinations; adjust for steep slopes and/or other natural/made factors.				
Overlay development program onto site, avoiding/minimizing Riparian Buffer Zone impacts.				
Provide for Riparian Buffer Zone maintenance?				
Provide for Riparian Buffer Zone protection in perpetuity (deed restrictions? covenants? easements?)?				

References

Center for Watershed Protection. *Better Site Design: A Handbook for Changing Development Rules in your Community*. Ellicott City, MD, 1998.

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BMP Fact Sheet

Protect Sensitive Areas

Protecting sensitive and special value features is the process of identifying and avoiding certain natural features during development. This allows these features to be used for various benefits, including reducing stormwater runoff.

Protecting sensitive areas can be implemented both at the site level and throughout the community. For prioritization purposes, natural resources and their functions may be weighted according to their functional value. Sensitive areas should be preserved in their natural state to the greatest extent possible and are not the appropriate place to locate stormwater infrastructure.

Protection of existing native woodlands and wetlands, Kalamazoo, MI
Source: Fishbeck, Thompson, Carr & Huber, Inc.

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	High
Commercial	Yes	**Groundwater Recharge**	High
Ultra Urban	Limited	**Peak Rate**	High
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	No	**TSS**	High
Highway/Road	Limited	**TP**	High
Recreational	Yes	**NO_3**	Low
		Temperature	High

Additional Considerations	
Cost	Low/Med
Maintenance	Low/Med
Winter Performance	High

Key Design Features

- Identify and map the following: floodplains, riparian areas, wetlands, woodlands, prairies, natural flow pathways, steep slopes, and other sensitive areas.
- Identify and map potential development areas

Benefits

- Improved water quality
- Mitigation of runoff volume and peak rates

Limitations

- Difficult to implement on smaller sites

Case Study: Western Michigan University

WMU, Business, Technology, and Research Park

Over 20 acres of this 200-acre development in Kalamazoo, MI was designated for a unique stormwater treatment system, which contained the preservation of natural features including woodlands and riparian corridors. In addition, other LID practices were also implemented on this site consisting of prairie restoration to provide habitat, minimize stormwater runoff, and improve water quality. Multi-cell ponds, bioretention, and wetlands were also designed to reduce outflow from the site to below the pre-developed rate and volume. The overall low impact design was imperative because it addressed the concerns of downstream residential neighbors who were very concerned that a large institutional development would negatively impact the quality of their lake.

Prior to development, over 10 acres of woodland and riparian areas were preserved as natural buffer areas and marked off during construction. These areas were supplemented with additional native herbaceous and woody plantings, which have matured into a beautiful landscape and nature area. All are low maintenance in terms of pest control and watering.

The benefits of sensitive area preservation are many for the park. One concern expressed by the neighborhood residents was the loss of greenspace because the former fields and woodland edge were used by many for nature hikes. In the end, the nature area preserved in the park is far more accessible to a wider range of people who enjoy the greenspace and diverse wildlife it attracts. The quality of life for these local residents was also preserved.

Trail through prairie restoration at the park

Source: Fishbeck, Thompson, Carr & Huber, Inc.

Case Study Site Considerations	
Project Type	Preservation of natural features, constructed wetlands, native vegetation.
Estimated Total Project Cost	$5 million
Maintenance Responsibility	WMU
Project Contact	David Dakin, 269-387-8543

Description and Function

Protecting sensitive areas challenges the site planner to inventory and then, to the greatest extent possible, avoid resource sensitive areas at a site, including riparian buffers, wetlands, hydric soils, floodplains, steep slopes, woodlands, valuable habitat zones, and other sensitive resource areas. Development, directed away from sensitive areas, can be held constant, if BMPs such as cluster development are also applied.

A major objective of LID is to accommodate development with fewer impacts to the site. If development avoids encroachment upon, disturbance of, and impact to those natural resources which are especially sensitive to land development impacts and/or have special functional value, then low impact development can be achieved.

The first step in protecting sensitive areas is for the site planner to define, inventory, and map which resources are especially sensitive and/or have special value at a site proposed for development. Although many sensitive areas are common to all municipalities across Michigan, they can vary by region. The most detailed inventories are often compiled at the municipal or county level. For those areas without municipal or county-level data, state-level data can be used. (Table 6.1 is a partial list of potential sensitive area resources.)

Table 6.1
Data Sources for Environmentally Sensitive Areas

Resource	Agency Responsible for Data Development/Upkeep
Lakes and Streams	Michigan Center for Geographic Information, municipal and county agencies
Designated Trout Lakes/Streams and Natural Rivers	Michigan Center for Geographic Information Michigan Geographic Data Library
Wetlands Indicators	SEMCOG, Michigan Center for Geographic Information
Flood Prone Areas	SEMCOG, FEMA, municipal and county agencies
Wellhead Protection Areas	Michigan State University and Michigan Department of Environmental Quality
Woodlands	SEMCOG, Michigan Center for Geographic Information
Parks and Recreation Areas	SEMCOG, Ducks Unlimited, municipal and county agencies
Historic Sites	Michigan Center for Geographic Information, municipal and county agencies
Heritage Routes and Natural Beauty Roads	Michigan Department of Transportation and County Road Commissions, municipal and county agencies
Historic Bridges	Michigan Department of Transportation
Nonmotorized Facilities	Michigan Trails and Greenways Alliance, Community Foundation for Southeast Michigan
Sand Dunes	Michigan Center for Geographic Information

Source: SEMCOG

Protection of sensitive areas in residential development in Washington Township, MI

Preserving open space in multiple development areas throughout a community can ultimately evolve to form a unified open space system, integrating important conservation areas throughout the municipality and beyond. Many communities within Michigan are undertaking "green infrastructure" planning initiatives to proactively map these systems in order to restore or protect them as development occurs. The objective of these plans is to avoid impacting sensitive areas by: 1) carefully identifying and mapping these resources (resource areas, primary and secondary) from the start of the site planning process, and 2) striving to protect resource areas by defining other portions of the site free of these resources (potential development areas).

At the community level, local governments can implement community-wide regulations that protect sensitive areas such as wetlands, woodlands, riparian areas, and floodplains. Appendix H contains model ordinances for various sensitive resources developed for communities in Michigan.

Potential Applications

Regardless of land use type, protecting sensitive areas is applicable across all types of land development projects, whether residential of varying densities or office park, retail center or industrial and institutional uses. As density and intensity of uses increases, ease of application of this BMP decreases. In such limited cases, it is especially important that sensitive areas be prioritized.

Environmentally Sensitive Resources

SEMCOG has analyzed possible impacts on environmentally sensitive resources from planned transportation projects in Southeast Michigan, which may be helpful in minimizing site disturbance in certain development areas.

SEMCOG has defined these environmentally sensitive resources and potential impacts of planned transportation projects in the document, *Integrating Environmental Issues in the Transportation Planning Process: Guidelines for Road and Transit Agencies.*

The transportation projects were identified from the *2030 Regional Transportation Plan for Southeast Michigan* (RTP) and were mapped using Geographic Information Systems (GIS).

Please visit www.semcog.org to download maps of the sensitive resources in PDF or to download data in GIS format.

Design Considerations

1. **Identify, map, and inventory sensitive areas**.

   Mapping a site's sensitive areas is an important step in preserving them (Figure 6.4). These features often include wetlands, steep slopes, woodlands, floodplains, and riparian areas. These data may give the community a general idea of the sensitive resources that could be on the site. In addition, the mapping will help the site designer define a potential development area which avoids encroachment upon and disturbance of defined and mapped sensitive areas.

   The inventory of sensitive areas should also include an assessment of the *quality* of the existing natural communities. Because plant communities will exist in a variety of states based on historic disturbance and degradation, the quality of the given community needs to be considered in comparison to other similar communities. For instance, two upland forests in adjacent parcels may have significantly differing floristic quality, thus influencing the selection of land for site development. A floristic quality inventory (FQI) may be used to quantify the quality of a given natural community. As a general rule of thumb, FQIs of 20 or lower have little ecological value, while those greater than 35 are have ecological importance across the state. FQIs greater than 50 represent only our highest quality plant communities and should never be considered for development.

The quality of a given plant community must also be considered in comparison to other plant communities in the state. For example, oak openings are considerably rarer in Michigan than dry southern forests. So, when given a choice of development for unregulated land, the more rare plant community should typically be avoided. A ranking system for Michigan's natural communities, characterizing all communities statewide and globally on a 1-5 scale, is available at https://mnfi.anr.msu.edu/communities/.

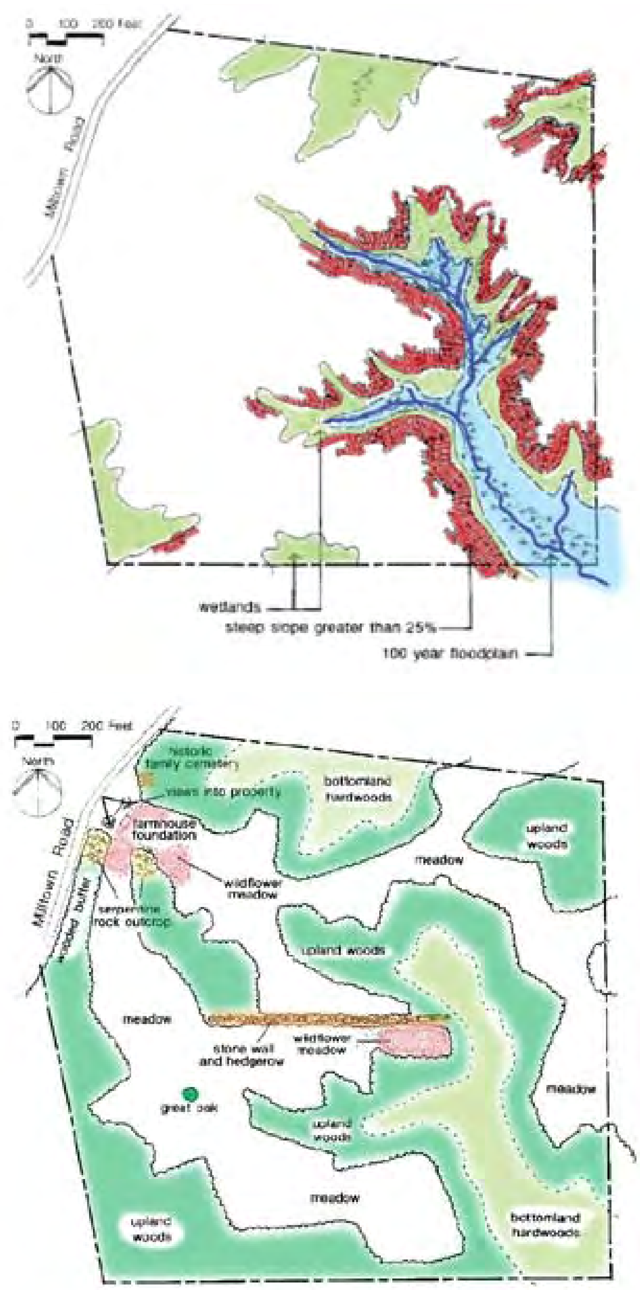
2. **Combine mapped natural features into a sensitive resource areas map, prioritizing areas to avoid development**.

   All sensitive resource mapping should be overlain to produce a sensitive areas map. Randall Arendt in *Growing Greener* acknowledges prioritizing or weighting of sensitive areas by defining them as either Primary Conservation Areas (the most critical – avoid at all costs) or Secondary Conservation Areas (important resources which should be avoided when possible). Mapping the secondary resources of the site is an important step; the community can provide input to determine which features are important for preservation. Additionally, Primary and Secondary Conservation Areas can be defined in different ways, possibly varying with watershed context, (e.g., woodlands in some contexts may be classified as Primary Conservation Areas, rather than secondary). Given the substantial variability in Michigan's natural resources from one ecoregion to another, this flexibility in weighting resource types is especially important.

3. **Map potential development areas; prioritize/ weight as necessary**.

   The potential development area should be delineated on the basis of protecting the primary and secondary resources on a site. Like the sensitive areas map, priorities and weightings may be reflected in the potential development area map. If sensitive areas have been prioritized,

Figure 6.4
Map of sensitive areas (top) and secondary resources (bottom)



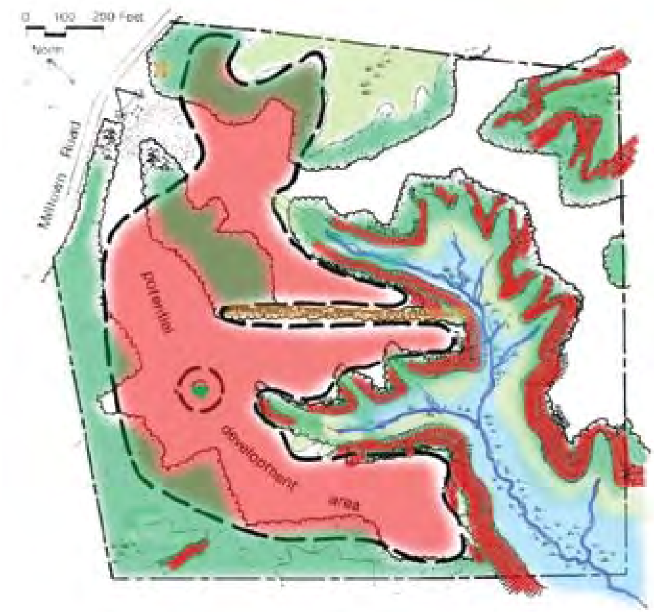
Source: Arndt, Randall G. 1997

then weightings of potential development also may be established, varying with lack of degree of sensitivity measured by the resources themselves or overlapping of resources.

4. **Municipal regulation**

   The level of regulation imposed on resource areas (primary and secondary) will likely vary by municipality. A municipal ordinance may prohibit and/or otherwise restrict development in primary and secondary resource areas, provided certain legal tests (such as a takings determination) are passed. Additional activities include:

   1. Conservation easement – Given to land conservancy or maintained by homeowners association.
   2. Requirements in the master deed and bylaws for protection and preservation.
   3. Boundary markers at edges of lots to minimize encroachment.
   4. Cooperative agreements for stewardship of sensitive areas between homeowners' associations and local conservation organizations.



Potential development area map
Source: Arndt, Randall G. 1997.

Stormwater Functions and Calculations

Any portion of a site that can be maintained in its presettlement state by using this BMP will not contribute increased stormwater runoff and will reduce the amount of treatment necessary. Calculation methodology to account for this BMP is provided in Chapter 9.

Volume

Protected sensitive areas are not to be included in the disturbed stormwater management area when calculating runoff volume (Chapter 9 and Worksheet 3).

Any portion of a sensitive area that is mitigated or revegetated/reforested should be included in the disturbed stormwater management area, but may be granted credit in accordance with the applicable BMP for native revegetation, soil restoration, minimize soil compaction, riparian buffer restoration, or minimize total disturbed area.

Peak rate

Runoff from the protected sensitive area may be excluded from peak rate calculations for rate control, provided that the runoff is not conveyed to and/or through stormwater management control structures. If necessary, runoff from protected sensitive areas should be directed around BMPs and stormwater pipes and inlets by means of vegetated swales or low berms that direct flow to natural drainageways.

Water quality improvement

Water quality is benefited substantially by avoiding negative impacts which otherwise would have resulted from impacts to sensitive areas (e.g., loss of water quality functions from riparian buffers, from wetland reduction, etc.).

Construction Guidelines

Although protecting sensitive areas happens early in the site plan process, it is equally important that the developer and builder protect these areas during construction.

The following guidelines describe good planning practices that will help ensure protection of a few common environmentally sensitive resources during construction.

Water resources

- If vegetation needs to be reestablished, plant native species, or use hydroseed and mulch blankets immediately after site disturbance.
- Use bioengineering techniques, where possible, to stabilize stream banks.

Native woodland area
Source: JFNew

- Block or protect storm drains in areas where construction debris, sediment, or runoff could pollute waterways.
- During and after construction activities, sweep the streets to reduce sediment from entering the storm drain system.
- Avoid hosing down construction equipment at the site unless the water is contained and does not get into the stormwater conveyance system.
- Implement spill control and clean-up practices for leaks and spills from fueling, oil, or use of hazardous materials. Use dry clean-up methods (e.g., absorbents) if possible. Never allow a spill to enter the stormwater conveyance system.
- Avoid mobile fueling of equipment. If mobile fueling is necessary, keep a spill kit on the fueling truck.
- Properly dispose of solid waste and trash to prevent it from ending up in our lakes and streams.
- When protecting riparian buffer areas, consider the three buffer zones in protection criteria:

  Zone 1: Also termed the "streamside zone," begins at the edge of the stream bank of the active channel and extends a minimum distance of 25 feet, measured horizontally on a line perpendicular to the water body. Undisturbed vegetated area aims to protect the physical and ecological integrity of the stream ecosystem. The vegetative target for the streamside zone is undisturbed native woody species with native plants forming canopy, understory, and duff layer; where such forest does not grow naturally, then native vegetative cover appropriate for the area (such as grasses, forbs, or shrubs) is the vegetative target. (*HRWC Model Ordinance*, p. 8)

  Zone 2: Also termed the "middle zone," extends immediately from the outer edge of Zone 1 for a minimum distance of 55 feet. This managed area of native vegetation protects key components of the stream ecosystem and provides distance between upland development and the streamside zone. The vegetative target for the middle zone is either undisturbed or managed native woody species or, in its absence, native vegetative cover of shrubs, grasses, or forbs. Undisturbed forest, as in Zone 1, is strongly encouraged to protect further water quality and the stream ecosystem. (*HRWC Model Ordinance*, p. 8)

  Zone 3: Also termed the "outer zone," it extends a minimum of 20 feet immediately from the outer edge of Zone 2. This zone prevents encroachment into the riparian buffer area, filters runoff from adjacent land, and encourages sheet flow of runoff into the buffer. The vegetative target for the outer zone is native woody and herbaceous vegetation to increase the total width of the buffer; native grasses and forbs are acceptable. (*HRWC Model Ordinance,* p. 8)

Wetlands

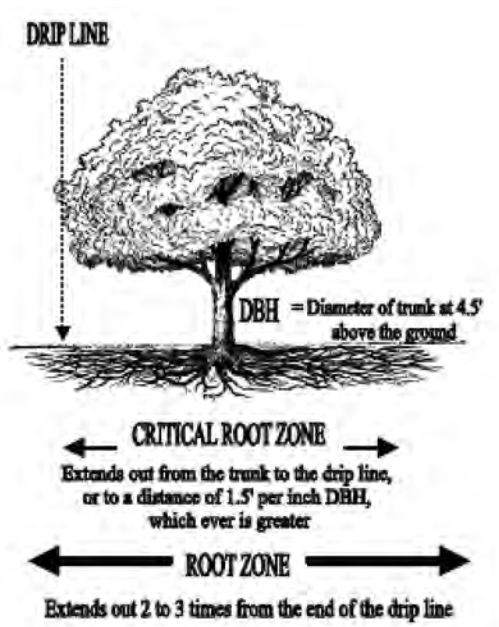
- Avoid impacts to wetlands whenever possible. If impractical, determine if a wetland permit is needed from the state or local government. (If any permit requirements or wetland regulations conflict with these guidelines, comply with the permit or regulation).
- Excavate only what is absolutely necessary to meet engineering requirements. Do not put excavated material in the wetland. (Excavated material could be used in other areas of the site to improve seeding success).
- If construction activities need to occur within a wetland, activities should be timed, whenever possible, when the ground is firm and dry. Avoid early spring and fish-spawning periods.
- Install flagging or fencing around wetlands to prevent encroachment.
- Travel in wetlands should be avoided. Access roads should avoid wetlands whenever possible. Crossing a wetland should be at a single location and at the edge of the wetland, if possible.
- Never allow a spill to enter area wetlands.

Floodplains

- Design the project to maintain natural drainage patterns and runoff rates if possible.
- Maintain as much riparian vegetation as possible. If riparian vegetation is damaged or removed during construction, replace with native species.
- Use bioengineering techniques to stabilize stream banks.
- Keep construction activity away from wildlife crossings and corridors.
- Stockpile materials outside of the floodplain and use erosion control techniques.

Woodlands

- Protect trees on sites with severe design limitations, such as steep slopes and highly erodible soils.
- Preserve trees along watercourses to prevent bank erosion, decreased stream temperatures, and to protect aquatic life.
- Protect the critical root zone of trees during construction. This is the area directly beneath a tree's entire canopy. For every inch of diameter of the trunk, protect 1.5 feet of area away from the trunk.



Critical root zone

Source: City of Falls Church, VA. Tree Preservation during Construction.

- Avoid trenching utilities through the tree's critical root zone.
- Avoid piling excavated soil around any tree.
- Replace trees removed during construction with native trees.
- Conduct post-construction monitoring to ensure trees impacted by construction receive appropriate care.

General construction considerations

- Conduct a pre-construction meeting with local community officials, contractors, and subcontractors to discuss natural resource protection. Communicate agreed-upon goals to everyone working on the project.
- Insert special requirements addressing sensitive natural areas into plans, specifications, and estimates provided to construction contractors. Note the kinds of activities that are not allowed in sensitive areas.
- Confine construction and staging areas to the smallest necessary and clearly mark area boundaries. Confine all construction activity and storage of materials to designated areas.
- Install construction flagging or fencing around sensitive areas to prevent encroachment.
- Excavate only what is absolutely necessary to meet engineering requirements. Do not put excavated material in sensitive areas. (Excavated material could be used in other areas of the site to improve seeding success.)
- Conduct onsite monitoring during construction to ensure sensitive areas are protected as planned. Conduct post-construction monitoring to ensure sensitive areas that were impacted by construction receive appropriate care.

Maintenance

The preservation of open space creates maintenance concerns related to who is required to perform the maintenance activities. Legally, the designated open space may be conveyed to the municipality. More likely, ownership of these natural areas will be assumed by homeowners' associations or simply the specific individual property homeowners where these resources are located. Specific maintenance activities will depend upon the type of vegetation present in the preserved natural area where woodlands require little to no maintenance and open lawn require higher maintenance.

Cost

When development encroaches into sensitive areas, dealing with their special challenges invariably adds to development and construction costs. Sometimes these added costs are substantial, as in the case of working with wetlands or steep slopes.

Sometimes costs emerge only in longer-term operation, like encroachment in floodplains. This can translate into added risk of building damage for future owners, as well as health and safety impacts, insurance costs, and downstream flooding. If all short- and long-term costs of impacting sensitive areas were quantified and tallied, total real costs of sensitive area encroachment would increase substantially. Conversely, protecting sensitive areas results not only in cost savings, but also in water quality benefits.

At the same time, reduction in potential development areas resulting from protecting and conserving sensitive areas can have the effect of altering — even reducing — a proposed development program, thereby reducing development yield and profit. To address this, this BMP can be applied in tandem with the cluster development BMP.

Designer/Reviewer Checklist for Protect Sensitive Areas

ITEM	YES	NO	N/A	NOTES
Define sensitive resources at proposed development site (see Key Design Features for list of sensitive resources)				
Map sensitive resources at proposed development site				
Prioritize/weight sensitive areas, as necessary and appropriate				
Develop potential development area map, or comparable, defined as converse/negative of sensitive areas, with priorities/weightings as necessary and appropriate.				
Determine baseline development plan, compatible with municipal ordinance.				
Iteratively fit baseline development plan to potential development area, minimizing sensitive area encroachment?				
Is this BMP process required by municipality? Yes or no, has applicant followed these steps, or comparable?				

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BMP Fact Sheet

Reduce Impervious Surfaces

Reducing impervious surfaces includes minimizing areas such as streets, parking lots, and driveways. By reducing the amount of paved surfaces, stormwater runoff is decreased while infiltration and evapotranspiration opportunities are increased.

Residential cul-de-sac with vegetation

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	High
Commercial	Yes	**Groundwater Recharge**	High
Ultra Urban	Limited	**Peak Rate**	High
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Limited	**TSS**	Medium
Highway/Road	Yes	**TP**	Low
Recreational	Yes	**NO_3**	Low
		Temperature	Medium

Additional Considerations	
Cost	Low
Maintenance	Low
Winter Performance	High

Key Design Features

Streets

- Evaluate traffic volumes and street parking requirements
- Consult with local fire department and road agencies
- If available, consider a private road ordinance as necessary to minimize width
- Minimize pavement widths and lengths by using alternative roadway layouts, restricting on-street parking, minimizing cul-de-sac radii, and using permeable pavers

Parking lots

- Evaluate parking requirements considering average demand as well as peak demand
- Consider smaller parking stalls and/or compact parking spaces
- Analyze parking lot layout to evaluate the applicability of narrowed traffic lanes and slanted parking stalls
- If appropriate, minimize impervious parking area by using overflow parking areas constructed of pervious paving materials

Lot level

- Use maximum lot coverage requirements to manage the amount of impervious surfaces
- Reduce front yard setbacks to allow for shorter driveways
- Use alternative materials for patios, sidewalks, driveways, as appropriate

Benefits

- Directly reduces runoff volumes and peak rates
- Reduces development and maintenance costs
- Enhances aesthetics and habitat

Limitations

- Must comply with local private road ordinances
- Must comply with vehicular safety standards

Case Study: Willard Beach Implementation Project

City of Battle Creek

The primary goal of the City of Battle Creek's Willard Beach Park Project consists of showcasing LID practices to community residents by installing porous asphalt throughout the park roadway system and rain gardens. By implementing these two LID techniques, the amount of impervious material on site was reduced. The project complemented other LID projects undertaken by the city, such as several bioretention basins, rain gardens, and a vegetated roof. All of these sites were used as examples for area developers to model.

Pervious asphalt at Willard Beach Park
Source: City of Battle Creek

The project also reduced the impact of stormwater by volume and pollutant loading from the park's four storm sewer discharge areas. Another goal of the project was to educate park users about the project and the importance of protecting water quality.

Porous asphalt requires vacuuming at least twice per year. Proper weeding of the rain gardens and bioretention basin causes the most concern. Keeping the native plants properly watered during establishment posed a challenge. Replanting was required in some areas. Estimated maintenance costs for the entire project are approximately $2,500/year.

Estimated annual pollutant load reductions for the project:

- Sediment – 6.6 tons
- Nitrogen – 176 lbs
- Phosphorous – 18 lbs
- Volume – 78%

Case Study Site Considerations	
Project Type	Reduce imperviousness
Estimated Total Project Cost	$450,425
Maintenance Responsibility	City of Battle Creek
Project Contact	Christine Kosmowski, 269-966-0712

Description and Function

Reducing street imperviousness performs valuable stormwater functions in contrast to conventional development in the following ways:

- Increases infiltration,
- Decreases runoff volumes,
- Increases stormwater time of concentration,
- Improves water quality by decreasing nonpoint source pollutant loading, and
- Decreases the concentration and energy of stormwater.

Imperviousness greatly influences stormwater runoff volume and quality by increasing the rapid transport of stormwater and collecting pollutants from atmospheric deposition, automobile leaks, and additional sources.

Stream degradation has been observed at impervious levels as low as 10-20 percent watershed-wide (Center for Watershed Protection, 1995), when these areas are managed conventionally. Recent findings indicate that degradation is observed even at much lower levels of imperviousness (Villanova University 2007 Stormwater Management Symposium, Thomas Schueler, Director, Chesapeake Stormwater Network). Reducing imperviousness improves an area's hydrology, habitat structure, and water quality.

Design Considerations

Street width

Streets usually are the largest single component of imperviousness in residential development. Universal application of high-volume, high-speed traffic design criteria results in excessively wide streets. Coupled with the perceived need to provide both on-street parking and emergency vehicle access, the end result is residential streets that may be 36 feet or greater in width (Center for Watershed Protection, 1998).

The American Society of Civil Engineers (ASCE) and the American Association of State Highway and Transportation Officials (AASHTO) recommend that low-traffic-volume roads (less than 50 homes or 500 daily trips) be as narrow as 22 feet. Some municipalities have reduced their lowest trafficable residential roads to 18 feet or less. Higher-volume roads are recommended to be wider. Table 6.2 provides sample road widths from different jurisdictions.

Need for adequate emergency vehicle access, notably fire trucks, also leads to wider streets. While it is perceived that very wide streets are required for fire trucks, some local fire codes permit roadway widths as narrow as 18 feet (Table 6.3). Concerns also exist relating to other vehicles and maintenance activities on narrow streets. School buses are typically nine feet wide, mirror to mirror. Prince George's and Montgomery Counties in Maryland require only a 12-foot driving lane for buses (Center for Watershed Protection, 1998). Similarly, trash trucks require only a 10.5-foot driving lane. Trash trucks have a standard width of nine feet (Waste Management, 1997; BFI, 1997). In some cases, road width for emergency vehicles may be added through use of permeable pavers for roadway shoulders.

Use of permeable pavers for roadway shoulders

Snow removal on narrower streets is readily accomplished with narrow, eight-foot snowplows. Restricting parking to one side of the street allows accumulated snow to be piled on the other side of the street. Safety concerns are also cited as a justification for wider streets, but increased vehicle-pedestrian accidents on narrower streets are not supported by research. In fact, wider streets have been shown to promote increased speeds and accidents. The Federal Highway Administration states that narrower streets reduce vehicle travel speeds, lessening the incidence and severity of accidents.

Higher density developments require wider streets, but alternative layouts can minimize street widths. For example, in instances where on-street parking is desired, impervious pavement is used for the travel lanes, with permeable pavers placed on the road apron for the parking lanes. The width of permeable pavers is often the width of a standard parking lane (six to eight feet). This design approach minimizes impervious area while

Table 6.2
Narrow residential street widths

Jurisdiction	Residential Street Pavement Width	Maximum Daily Traffic (trips/day)
State of New Jersey	20 ft. (no parking)	0-3,500
	28 ft. (parking on one side)	0-3,500
State of Delaware	12 ft. (alley)	---
	21 ft. (parking on one side)	---
Howard County, Maryland	24 ft. (parking not regulated)	1,000
Charles County, Maryland	24 ft. (parking not regulated)	---
Morgantown, West Virginia	22 ft. (parking on one side)	---
Boulder, Colorado	20 ft.	150
	20 ft. (no parking)	350-1,000
	22 ft. (parking on one side)	350
	26 ft. (parking on both sides)	350
	26 ft. (parking on one side)	500-1,000
Bucks County, Pennsylvania	12 ft (alley)	---
	16-18 ft. (no parking)	200
	20-22 ft. (no parking)	200-1,000
	26 ft. (parking on one side)	200
	28 ft. (parking on one side)	200-1,000

Source: Cohen, 1997; Bucks County Planning Commission, 1980; Center for Watershed Protection, 1998

Table 6.3
Fire Vehicle Street Requirements

Source	Residential Street Width
U.S. Fire Administration	18-20 ft.
Baltimore County, Maryland Fire Department	16 ft. (no on-street parking)
	24 ft. (on-street parking)
Virginia State Fire Marshall	18 ft. minimum
Prince George's County, Maryland Department of Environmental Resources	24 ft. (no parking)
	30 ft. (parking on one side)
	36 ft. (parking on both sides)
	20 ft. (fire truck access)
Portland, Oregon Office of Transportation	18 ft. (parking on one side)
	26 ft. (parking on both sides)

Source: Adapted from Center for Watershed Protection, 1998 also providing an infiltration and recharge area for the impervious roadway stormwater (**Maryland Stormwater Design Manual, 2000).**

Street length

Numerous factors influence street length, including clustering techniques. As with street width, street length greatly impacts the overall imperviousness of a developed site. While no one prescriptive technique exists for reducing street length, alternative street layouts should be investigated for options to minimize impervious cover. Successful clustering design consistently has shown to reduce required street lengths, holding development programs constant (i.e., 100 homes successfully clustered on a 100-acre property results in a significant reduction in street length and total imperviousness than 100 homes conventionally gridded in large-lot development format).

Cul-de-sacs

The use of cul-de-sacs introduces large areas of imperviousness into residential developments. Some communities require the cul-de-sac radius to be as large as 50 to 60 feet. Simply reducing the radius from 40 feet to 30 feet can reduce the imperviousness by 50 percent (Schueler, 1995).

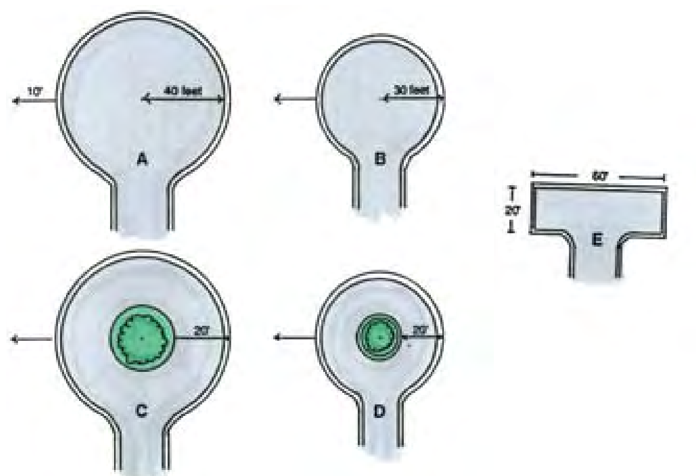
When cul-de-sacs are necessary, three primary alternatives can reduce their imperviousness; reduce the required radius, incorporate a landscaped island into the center of the cul-de-sac, or create a T-shaped (or hammerhead) turnaround (Figure 6.5).

To reduce the radius, many jurisdictions have identified required turnaround radii (Table 6.4).

A landscaped island in the center of a cul-de-sac can provide the necessary turning radius, minimizing impervious cover. This island can be designed as a depression to accept stormwater runoff from the surrounding pavement, thus furthering infiltration. A flat apron curb will stabilize roadway pavement and allow for runoff to flow into the cul-de-sac's open center.

A T-shaped turnaround reduces impervious surface even further – yielding a paved area less than half that of a 30-foot radius turnaround. Since vehicles need to make a three-point turn to drive out, T-shaped turnarounds are most appropriate on streets with 10 or fewer homes.

Figure 6.5
Five cul-de-sac options



Source: Center for Watershed Protection, 1998.

Table 6.4
Cul-de-sac turning radii

Source	Radius
Portland, Oregon Office of Transportation	35 ft (with fire dept. approval)
Buck County, Pennsylvania Planning Commission	38 ft (outside turning radius)
Fairfax County, Virginia Fire and Rescue	45 ft
Baltimore County, Maryland Fire Department	35 ft (with fire dept. approval)
Montgomery County, Maryland Fire Department	45 ft
Prince George's County, Maryland Fire Department	43 ft

Source: Adapted from Center for Watershed Protection 1998

Parking

Parking lots often comprise the largest percentage of impervious area. Parking lot size is dictated by lot layout, stall geometry, and parking ratios. Modifying any or all of these three aspects can serve to minimize the total impervious areas associated with parking lots.

Parking ratio requirements and accommodating peak parking demand often provide parking capacity substantially in excess of average parking needs. This results in vast quantities of unused impervious surface. A design alternative to this scenario is to provide designated overflow parking areas.

The primary parking area, sized to meet average demand, might still be constructed on impervious pavement to meet local construction codes and American with Disabilities Act requirements. However, the overflow parking area, designed to accommodate increased parking requirements associated with peak demand, could be constructed on pervious materials (e.g., permeable pavers, grass pavers, gravel. See Porous Pavement BMP in Chapter 7). This design approach, focused on average parking demand, will still meet peak parking demand requirements while reducing impervious pavement.

Parking ratios

Parking ratios express the specified parking requirements provided for a given land use. These specified ratios are often set as minimum requirements. Many developers seeking to ensure adequate parking provide parking in excess of the minimum parking ratios. Additionally, commercial parking is often provided to meet the highest hourly demand of a given site, which may only occur a few times per year. However, average parking demand is generally less than the typical required parking ratios (Table 6.5).

Parking spaces and lot layout

Parking spaces are comprised of five impervious components (Center for Watershed Protection, 1998):

1. The parking stall,
2. The overhang at the stall's edge,
3. A narrow curb or wheel stop,
4. The parking aisle that provides stall access, and
5. A share of the common impervious areas (e.g., fire lanes, traffic lanes).

Of these, the parking space itself accounts for approximately 50 percent of the impervious area, with stall sizes ranging from 160 to 190 square feet.

Several measures can be taken to limit parking space size. First, jurisdictions can review standard parking stall sizes to determine their appropriateness. A typical stall dimension may be 10 feet by 18 feet, much larger than needed for many vehicles. The great majority of SUVs and vehicles are less than seven feet in width, providing opportunity for making stalls slightly narrower and shorter. In addition, a typical parking lot layout includes parking aisles that accommodate two-way traffic and perpendicularly oriented stalls. The use of one-way aisles and angled parking stalls can reduce impervious area.

Municipalities can also stipulate that parking lots designate a percentage of stalls as compact parking spaces. Smaller cars comprise a significant percentage of vehicles and compact parking stalls create 30 percent less impervious cover than average-sized stalls (Center for Watershed Protection, 1998).

Table 6.5
Example minimum parking ratios

Land Use	Parking Ratio	Average Parking Demand
Single Family Home	2 spaces per dwelling unit	1.1 spaces per dwelling unit
Shopping Center	5 spaces per 1,000 ft^2 of GFA	3.97 spaces per 1,000 ft^2 of GFA
Convenience Store	3.3 spaces per 1,000 ft^2 of GFA	Not available
Industrial	1 space per 1,000 ft^2 of GFA	1.48 spaces per 1,000 ft^2 of GFA
Medical/Dental Office	5.7 spaces per 1,000 ft^2 of GFA	4.11 spaces per 1,000 ft^2 of GFA

GFA – gross floor area, excluding storage and utility space

Source: Institute of Transportation Engineers, 1987; Smith, 1984; Wells, 1994

Stormwater Functions and Calculations

Quantifying impervious areas at a proposed development site, pre- to post-development continues to dominate stormwater calculations. Stormwater calculations, as discussed in Chapter 9, are sensitive to pervious areas and their contribution to total volume of runoff, increased peak rate of runoff, and increased generation of nonpoint source pollutants. A reduction in imperviousness achieved through reduced street widths and lengths and reduced paved parking areas automatically reduces the volume and peak rate of runoff. To the extent that water quality is linked to runoff volume, reduction in imperviousness translates into a reduction in water quality management requirements as compared with standard design.

Maintenance

A reduction in impervious area results in decreased maintenance. For example, whether publicly or privately maintained, reducing roadway or parking lot imperviousness typically translates into reduction in all forms of maintenance required, from basic roadway repair to winter maintenance and snow removal.

Cost

Street width

Costs for paving are estimated to be approximately $15 per square yard (Center for Watershed Protection, 1998), which would be considerably higher in current dollars. At this cost, for each one-foot reduction in street width, estimated savings are $1.67 per linear foot of paved street. For example, reducing the width of a 500-foot road by five feet would result in a savings of over $4,100, which would be considerably higher in current dollars. This cost is exclusive of other construction costs including grading and infrastructure.

Street length

Factoring in pavement costs at $15 per square yard (as above), a 100-foot length reduction in a 25-foot-wide road would produce a savings in excess of $4,000 (much higher in current dollars).

In addition to pavement costs, costs for street lengths, including traditional curb and gutter and stormwater management controls, are approximately $150 per linear foot of road (Center for Watershed Protection, 1998), which would be considerably higher in current dollars.

Decreasing road length by 100 feet would save an additional $15,000, for a combined total of $19,100.

Parking

Estimates for parking construction range from $1,200 to $1,500 per space (Center for Watershed Protection, 1998), which would be significantly higher in current dollars. For example, assuming a cost of $1,200 per parking space, reducing the required parking ratio for a modest 20,000 square foot shopping strip from five spaces per 1,000 square feet to four spaces per 1,000 square feet would represent a savings of $24,000.

Designer/Reviewer Checklist for Reducing Impervious Surfaces

ITEM	YES	NO	N/A	NOTES
Check municipal ordinances for requirements/specifications for roads, drives, parking, walkways, other (problems vs. opportunities?), including safety requirements				
Have both macro (e.g., clustering) and micro site planning (e.g., reduced setbacks) activities been applied fully?				
Have LID impervious reduction standards for roads, drives, parking, and other impervious areas been consulted and applied?				
Have roads and drives been reduced or narrowed as much as possible?				
Have macro parking ratios, lot layout, sharing strategies, and micro strategies (sizes/dimensions) been applied fully?				
Have pervious surfaces been applied for roads, drives, walks, parking, patios, and other hard surfaces, with maintenance been provided?				

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BMP Fact Sheet

Stormwater Disconnection

Minimize stormwater volume by disconnecting roof leaders, impervious roads, and driveways and direct runoff to other BMPs including vegetated areas that infiltrate at the site.

Roofleader directed toward bioretention

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	High
Commercial	Yes	**Groundwater Recharge**	High
Ultra Urban	Limited	**Peak Rate**	High
Industrial	Limited	**Stormwater Quality Functions**	
Retrofit	Limited	**TSS**	High
Highway/Road	Limited	**TP**	High
Recreational	Yes	**NO_3**	Low/Med
		Temperature	High

Additional Considerations	
Cost	Low
Maintenance	Low
Winter Performance	Low

Variations

- Rooftop disconnection
- Driveway/walkway/ small parking areas/patio disconnection
- Minor roads
- Distribute to existing vegetated services
- Distribute to existing depressions, re-graded areas
- Distribute via curb cuts/curb removal

Key Design Features

- Encourages shallow sheet flow through vegetated areas,
- Directs flows into stabilized vegetated areas, including on-lot swales and bioretention areas,
- Limits the contributing rooftop area to a maximum of 500 sq. ft. per downspout,
- Maximizes overland flows, and
- Minimizes use of curb and gutter systems and piped drainage systems.

Site Factors

- Water table to bedrock depth = two-foot minimum
- Soils = A, B
- Slope = max. 5 percent
- Potential hotspots = No
- Max. drainage area = rooftop area of 1,000 sq. ft.

Benefits

- Reduces runoff volume and peak rate
- Increases water quality benefits

Limitations

- Requires area for infiltration

Case Study: Saugatuck Center for the Arts

Saugatuck, MI

The Saugatuck Center for the Arts (SCA), in conjunction with the City of Saugatuck, Michigan Department of Environmental Quality, and private donors constructed a public garden that treats rain water that falls on the SCA roof. The original design was modified to accommodate rain water that would otherwise have entered Kalamazoo Lake untreated. The resulting design for the garden absorbs and infiltrates 100 percent of the rain water from the SCA roof, resulting in zero discharge to the nearby lake.

In addition to the garden at the Saugatuck Center for the Arts, the revised design incorporated a series of alternative stormwater Best Management Practices on City of Saugatuck property. These include porous pavers in the adjacent city parking lot and a rain garden/vegetated swale series at Coghlin Park to treat rain water from the city parking lot.

The design incorporated native plants to address management in an urban setting while visually integrating with the contemporary social fabric of Saugatuck. The design also incorporated an innovative oil-and-grit separator to remove over 80 percent of sediment and nutrients draining from approximately nine acres of urban land surrounding the SCA and city parking lot. Through this series, or "treatment techniques," the SCA and City of Saugatuck are able to demonstrate a variety of innovative and unique alternatives for treating and reducing stormwater.

Center for the Arts stormwater disconnection

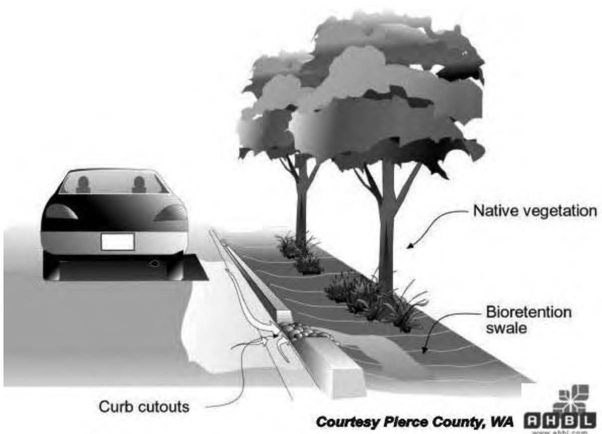
Case Study Site Considerations	
Project Type	Stormwater disconnection, porous pavement, rain garden.
Estimated Total Project Cost	$200,000
Maintenance Responsibility	City of Saugatuck
Project Contact	Gordon Gallagher, 269-857-2603

Description and Function

Roofs, roads, and driveways account for a large percentage of post-development imperviousness. These surfaces influence stormwater quality and runoff volume by facilitating the rapid transport of stormwater and collecting pollutants fromrainfall, automobile leaks, and additional sources.

Disconnecting roof leaders and routing road and driveway runoff from conventional stormwater conveyance systems allows runoff to be collected and managed onsite. Runoff can be directed to designed vegetated areas (discussed in Chapter 7) for onsite storage, treatment, and volume control. This is a distributed, low-cost method for reducing runoff volume and improving stormwater quality through:

- Increasing infiltration and evapotranspiration,
- Decreasing stormwater runoff volume, and
- Increasing stormwater time of concentration.



Curb cut-outs allow stormwater runoff from a parking lot to flow into a bioretention swale

Source – Pierce County, WA and RHBL

The suitability of vegetated swales to receive runoff depends on land use, soil type, imperviousness of the contributing watershed, and dimensions and slope of the vegetated swale system. Use of natural low-lying areas is encouraged; natural drainage courses should be used and preserved.

Some ponding of water in areas receiving runoff may occur. It is important to take into account site usage when applying this BMP so that ponding does not unnecessarily interfere with expected site use (including backyard play areas). These areas should be shown on plan documents and protected with easements and deed restrictions.

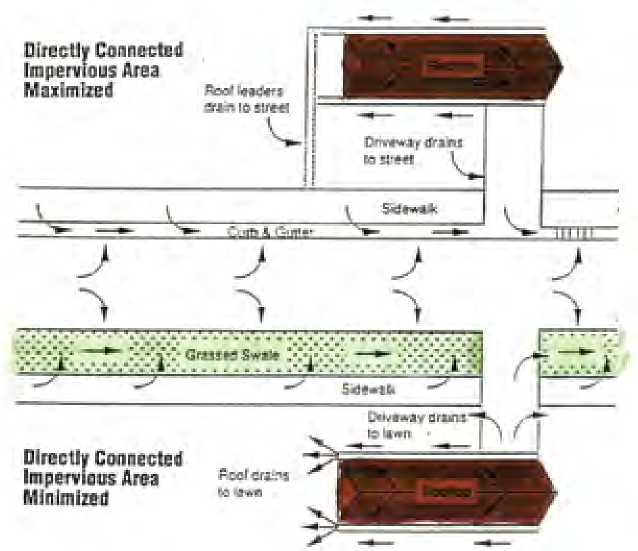
Although this BMP can be applied in a variety of development settings, it will likely be more successful as lot size increases and density decreases. In situations where clustering has not been fully exercised and lots remain relatively large, these lots and the large areas of perviousness make perfect candidates for stormwater disconnection.

Variations

Disconnecting stormwater can be achieved through identifying the source of runoff and how it will be managed once disconnection occurs.

Source

Stormwater can flow from rooftop areas or from impervious areas such as driveways, walkways, small parking areas, minor roadways, and ancillary outdoor areas such as patios. (Note: Roads and highways, because of their greater runoff generation require Structural BMPs.)



Difference between maximizing and minimizing runoff

Source – Center for Watershed Protection

Management practices

A common and successful management practice is to direct stormwater runoff to areas of existing vegetation. Vegetation can be of varying types, from established meadow to immature to mature woodland. A particular variation to consider is grading (crowning) of drives and minor roadways and eliminating curbing (or provision of curb cuts) so that runoff is allowed to flow in an even and unconcentrated manner onto adjacent vegetated areas.

In addition to directing runoff to vegetated areas, runoff may also be discharged to nonvegetated BMPs, such as dry wells, rain barrels, and cisterns for stormwater retention and volume reduction.

Another management practice includes routing runoff to existing grades and depressions that can be used to capture, store, and treat runoff. An important caveat is that applyingthis BMP should not prompt grading and disturbing areas which otherwise would not have been disturbed. However, assuming that grading and disturbance cannot be avoided, then subtle adjustments to grading may create additional management/storage opportunities for disconnected runoff.

An ideal coupling of BMPs is to minimize the total disturbed area of a site in coordination with stormwater disconnection. This not only reduces runoff volumes, peak rates, and pollutant loadings, but also provides multiple decentralized opportunities to receive disconnected flows.

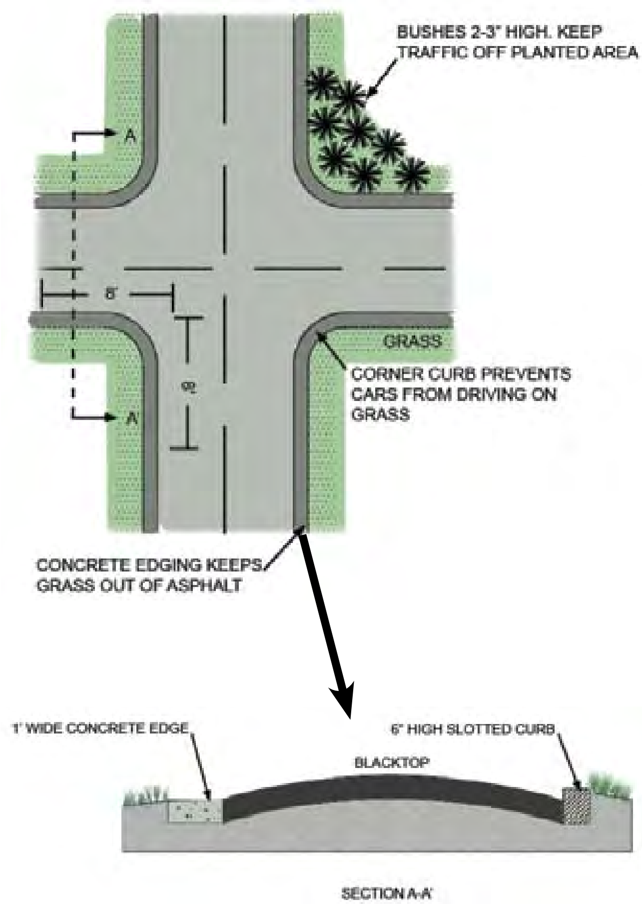
Applications

Disconnection is ideal for most single-family developments, but can also be applied to many development sites, including larger office parks and retails centers. Industrial developments, with their larger impervious covers and greater runoff volumes, make stormwater disconnection a challenge. Even so, there are isolated applications which are beneficial and promote LID objectives. Similarly, Ultra Urban and Highway/Road developments with large flows would be more limited in application.

If downspout disconnection is applied as a retrofit, downspouts should be extended away from the basement as many footing drains are attached to the sanitary sewer system.

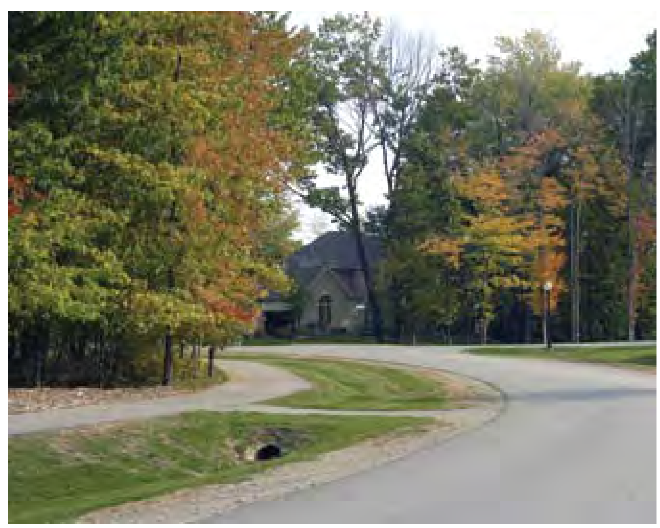
Design Considerations

Careful consideration should be given to the design of vegetated collection areas. Concerns pertaining to basement seepage and water-soaked yards are warranted, with the potential arising for saturated depressed areas and eroded water channels. Proper design and use of bioretention areas, infiltration trenches, and/or dry wells reduces or eliminates the potential for surface ponding and facilitates functioning during cold weather months. Where basements exist, considerthe direction of groundwater flow and proximity.



Curb cuts as a method of stormwater disconnection

Source: Center for Watershed Protection, modified by Cahill Associates, 2008



Stormwater disconnection in Washington Township, MI

Disconnection of small runoff flows can be accomplished in a variety of ways (Prince George's County Department of Environmental Protection, 1997; Maryland Department of the Environment, 1997; Cahill, 2008).

1. Encourage shallow sheet flow through vegetated areas.
2. Direct roof leader flow into BMPs designed specifically to receive and convey rooftop runoff.
3. Direct flows into stabilized vegetated areas, including on-lot swales and bioretention areas.
4. Rooftop runoff may also be directed to onsite depression storage areas.
5. The entire vegetated "disconnection" area should have a maximum slope of five percent.
6. Runoff should not be directed to vegetated areas if there is reason to believe that pollutant loadings will be elevated.
7. Roof downspouts or curb cuts should be at least 10 feet away from the nearest connected impervious surface to discourage "re-connections."
   a. Limit the contributing impervious area to a maximum of 1,000 sq. ft. per discharge point.
   b. Limit the contributing rooftop area to a maximum of 1,000 sq. ft. per downspout, where pervious area receiving runoff must be at least twice this size.
   c. For contributing areas greater than 1,000 sq. ft., leveling devices are recommended.
8. The maximum contributing impervious flow path length should be 75 feet.
9. For impervious areas, the length of the disconnection area must be at least the length of the contributing area (a minimum 75 feet for discharges which are concentrated; 25 feet for discharges which are not concentrated).
10. In all cases, flows from roof leaders should not contribute to basement seepage.

Stormwater runoff from disconnection needs to be monitored to ensure that flows do not become channelized that can result in erosion. Attention must be given to safe overflowing of larger storms, though clearly the more frequent smaller storms are of greatest interest and concern for successful design (use two-year storm for erosion analysis). Make sure flow of water and temporary ponding of water in management areas will not become a problem.

See Criteria and Credits below for additional design detailing.

Stormwater Functions and Calculations

Peak rate and volume

This BMP reduces total volume and peak rates of runoff, as runoff is minimized from centralized stormwater management systems at the development site. Disconnection directly reduces volume and peak rates, which reduces the need for structural BMPs.

Water quality improvement

In terms of rooftop disconnection, this BMP has limited water quality benefit because rooftops typically have minimal pollution. In terms of other impervious area runoff sources being disconnected (driveways, walkways, ancillary areas, minor roads), water quality benefits can be significant given their greater pollutant loadings.

Maintenance

When disconnecting stormwater from rooftops or other impervious surfaces, maintaining the vegetated areas is required, but is limited.

If using structural BMPs, such as bioretention or vegetated swales, follow their specific maintenance activities. Typical maintenance of vegetation includes a biannual health evaluation of the vegetation and subsequent removal of any dead or diseased vegetation plus mulch replenishment, if included in the design. This can be incorporated into regular maintenance of the site landscaping. In some cases, if leaders are directing stormwater to lawn depressions, maintenance may be as simple as mowing.

Cost

Stormwater disconnection reduces both construction and maintenance costs due to less reliance on traditional stormwater management infrastructure. In addition, using existing or planned bioretention areas within a site creates a double usage of these BMPs.

Designer/Reviewer Checklist for Disconnection

ITEM	YES	NO	N/A	NOTES
Are site factors conducive to disconnection (infiltration-related factors? slope? other?)				
Is proposed development type (e.g., residential, commercial) conducive to disconnection? Free of hot spots?				
Are there any municipal ordinance provisions, obstacles, and opportunities for disconnection?				
Have potential disconnection runoff sources been adequately reviewed/utilized in terms of proposed plan?				
Have potential disconnection management measures been used/exploited for all potential sources?				
Have Criteria and Credits specifications for both rooftop and non-rooftop sources of disconnection been satisfied?				
Have disconnection calculation credits been properly entered, as specified in Criteria and Credits?				

References

Coffman, Larry. *Low Impact Development Design Strategies: An Integrated Design Approach.* EPA 841 B 00 0023. Prince George's County, MD: Department of Environmental Resources, Programs and Planning, 2000.

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Rooftops to Rivers: A Policy Guide for Decision Makers on How to Use Green Infrastructure to Address Water Quality and Volume Reduction for Communities with Combined Sewer Overflow Issues. Washington, DC: Natural Resources Defense Council, June 2006. www.nrdc.org/sites/default/files/rooftops.pdf

Shaver, Earl. *Low Impact Design Manual for the Auckland Regional Council.* New Zealand: Auckland Regional Council, April 2000.

Urbanization and Streams: Studies of Hydrologic Impacts. Washington, DC: U.S. Environmental Protection Agency, 1997.

Chapter 7

Structural Best Management Practices

This chapter focuses on structural Best Management Practices (BMPs), Step 8 of the site design process for LID described in Chapter 5. The work of Step 8 is to figure out the most cost effective and environmentally sound array of structural BMPs needed to accomplish LID goals, once nonstructural BMPs have been applied.

This chapter provides guidance on selecting the proper BMPs for a site. Specifically, this chapter:

- Discusses the BMP selection process, including a matrix that compares the key applications and functions of each BMP,
- Discusses cold climate considerations,
- Provides overviews of the BMP in fact sheets, and
- Discusses detailed information for each BMP such as design considerations, construction guidelines, stormwater calculations, and maintenance and cost information.

This chapter also contains structural BMPs that may not traditionally be viewed as low impact development, such as water quality devices or retention basins. However, having all available BMPs listed in this manual may be helpful to municipalities or other regulatory agencies that may use the LID manual as their design guidance that accompanies a stormwater regulation.

BMP Selection Process

LID involves planning efforts that first prevent as much stormwater runoff as possible on a site (Chapter 6) and then mitigate stormwater runoff as efficiently as possible (Chapter 7). Selecting BMPs which accomplish as many stormwater functions as possible is important. At the same time, meeting a certain function or level of pollution control (Chapter 9) can require multiple BMPs integrated at the site, thus creating a "treatment train." Such treatment trains direct stormwater to or through multiple BMPs in order to achieve quantity and/or quality stormwater management objectives. In addition, implementing BMPs as part of a treatment train can also provide a level of backup and needed redundancy, which provides additional assurance if one BMP does not work as designed (e.g., maintenance problems, large storm event).

Some BMPs are more readily linked to other BMPs, better lending themselves to treatment train configurations. For example, water quality devices and constructed filters are often used in treatment trains to pre-treat runoff before entering different types of infiltration-driven BMPs. In addition, vegetated swales and vegetated filter strips link well with infiltration systems, rain gardens, wet ponds, and constructed wetlands in treatment trains.

How many of what BMPs should go where? Not all structural BMPs are appropriate for each land development at each site across Michigan's many communities. The selection process of the large array of structural BMPs can be complex, as multiple factors are juggled. The successful design process requires balancing technical and nontechnical factors summarized in Figure 7.1. In order to assist communities in quickly comparing the BMPs, Table 7.1 provides summary information on potential applications, stormwater quality and quantity functions, cost, maintenance, and winter performance for each BMP.

Lawrence Technological University green roof, Southfield, MI
Source: Lawrence Technological University

Table 7.1
BMP Summary Matrix

		Potential Applications						
		Residential	**Commercial**	**Ultra Urban**	**Industrial**	**Retro**	**Road**	**Rec**
Runoff Volume/ Infiltration	**Bioretention**	YES	YES	LIMITED	LIMITED	YES	YES	YES
	Vegetated Filter Strip	YES	YES	LIMITED[2]	LIMITED	YES	YES	YES
	Vegetated Swale	YES	YES	LIMITED[2]	YES	LIM	YES	YES
	Pervious Pavement	YES[3]	YES	YES	YES[3]	YES[3]	LIM[3]	YES
	Infiltration Basin	YES	YES	LIMITED[2]	YES	LIM	LIM	NO
	Subsurface Infiltration Bed	YES	YES	YES	YES	YES	LIM	NO
	Infiltration Trench	YES	YES	YES	YES	YES	YES	NO
	Dry Well	YES	YES	YES	LIMITED	YES	NO	NO
	Level Spreaders	YES	YES	NO	YES	YES	YES	YES
	Berming	YES	YES	LIMITED[2]	YES	YES	YES	NO
	Planter Box	YES	YES	YES	LIMITED	YES	NO	LIM
Runoff Volume/ Non-infiltration	**Vegetated Roof**	LIMITED	YES	YES	YES	YES	N/A	YES
	Capture Reuse	YES	YES	YES	YES	YES	NO	YES
Runoff Quality/ Non-infiltration	**Constructed Wetland**	YES	YES	YES	YES	YES	YES	YES
	Wet Ponds/ Retention Basins	YES	YES	YES	YES	YES	YES	YES
	Constructed Filters	LIMITED	YES	YES	YES	YES	YES	YES
	Water Quality Devices	YES	YES	YES	YES	YES	YES	YES
	Underground Detention	YES	YES	YES	YES	YES	YES	YES
	Extended Detention/ Dry Pond	YES	YES	YES	YES	YES	YES	YES
Restoration	**Riparian Buffer Restoration**	YES	YES	YES	YES	YES	LIM	YES
	Native Revegetation	YES	YES	LIMITED	YES	YES	LIM	YES
	Soil Restoration	YES	YES	YES	YES	LIM	YES	YES

Notes:
1 Reported as TN except as noted as (NO_3)
2 Difficult to apply due to space limitations typically associated with these land uses.
3 Applicable with special design considerations
4 This assumes TSS loads and their debris have been managed properly before entering the BMP to prevent clogging.
5 Requires infiltration planter box.

Stormwater Quantity Functions			Stormwater Quality Functions				Cost	Maint.	Winter Perform.
Volume	**GW Recharge**	**Peak Rate**	**TSS**	**TP**	**NITROGEN[1]**	**Temp**			
MED/ HIGH	MED/ HIGH	MEDIUM	HIGH	MEDIUM	MEDIUM	HIGH	MEDIUM	MEDIUM	MEDIUM
LOW	LOW	LOW	MED/ HIGH	MED/ HIGH	MED/HIGH (NO_3)	MED/ HIGH	LOW	LOW/MED	HIGH
LOW/MED	LOW/MED	LOW/MED	MED/ HIGH	LOW/ HIGH	MEDIUM	MEDIUM	LOW/MED	LOW/MED	MEDIUM
HIGH	HIGH	MED/ HIGH	HIGH[4]	MED/ HIGH	LOW	HIGH	MEDIUM	HIGH	MEDIUM
HIGH	HIGH	HIGH	HIGH[4]	MED/ HIGH	MED (NO_3)	HIGH	LOW/MED	LOW/MED	MED/HIGH
HIGH	HIGH	HIGH	HIGH[4]	MED/ HIGH	LOW	HIGH	HIGH	MEDIUM	HIGH
MEDIUM	HIGH	LOW/MED	HIGH[4]	MED/ HIGH	LOW/MED	HIGH	MEDIUM	LOW/MED	HIGH
MEDIUM	HIGH	MEDIUM	HIGH[4]	MED/ HIGH	LOW/MED	HIGH	MEDIUM	LOW/MED	HIGH
LOW	LOW	LOW	LOW	LOW	LOW (NO_3)	LOW	LOW	LOW	HIGH
LOW/MED	LOW/MED	MEDIUM	MED/ HIGH	MEDIUM	MEDIUM	MEDIUM	LOW/MED	LOW/MED	MED/HIGH
LOW/MED	MED[5]	MEDIUM	MEDIUM	LOW/ MED	LOW/MED	HIGH	MEDIUM	MEDIUM	MEDIUM
MED/ HIGH	LOW[6]	MEDIUM	MEDIUM	MEDIUM	MEDIUM	HIGH	HIGH	MEDIUM	MEDIUM
HIGH	LOW	LOW[3]	MED[4]	MEDIUM	MED (NO_3)	MEDIUM	Rain Barrel- LOW Cis- tern- MED	MEDIUM	MEDIUM
LOW	LOW	HIGH	HIGH	MEDIUM	MEDIUM	LOW/ MED	HIGH	LOW/MED	MED/HIGH
LOW	LOW	HIGH	HIGH	MEDIUM	MEDIUM	LOW/ MED	HIGH	LOW/MED	MED/HIGH
LOW[8]	LOW[8]	LOW[8]	HIGH[7]	MEDIUM[7]	MEDIUM[7]	LOW	MED/HIGH	HIGH	MEDIUM
N/A	N/A	N/A	VARIES	VARIES	VARIES (NO_3)	NONE	VARIES	VARIES	HIGH
LOW	LOW	HIGH	N/A	N/A	N/A	N/A	HIGH	MED/HIGH	MED/HIGH
LOW	LOW	HIGH	MEDIUM	MEDIUM	LOW	LOW	HIGH	Sediment - LOW, Vegetation - HIGH	MED/HIGH
LOW/MED	LOW/MED	LOW/MED	MED/ HIGH	MED/ HIGH	MED/HIGH (NO_3)	MED/ HIGH	LOW/MED	LOW	HIGH
LOW/MED/ HIGH	LOW/MED/ HIGH	LOW/MED	HIGH	HIGH	MED/HIGH	MEDIUM	LOW/MED	LOW	MEDIUM
MED	LOW	MEDIUM	HIGH	HIGH	MED /(NO_3)	MEDIUM	MEDIUM	LOW	HIGH

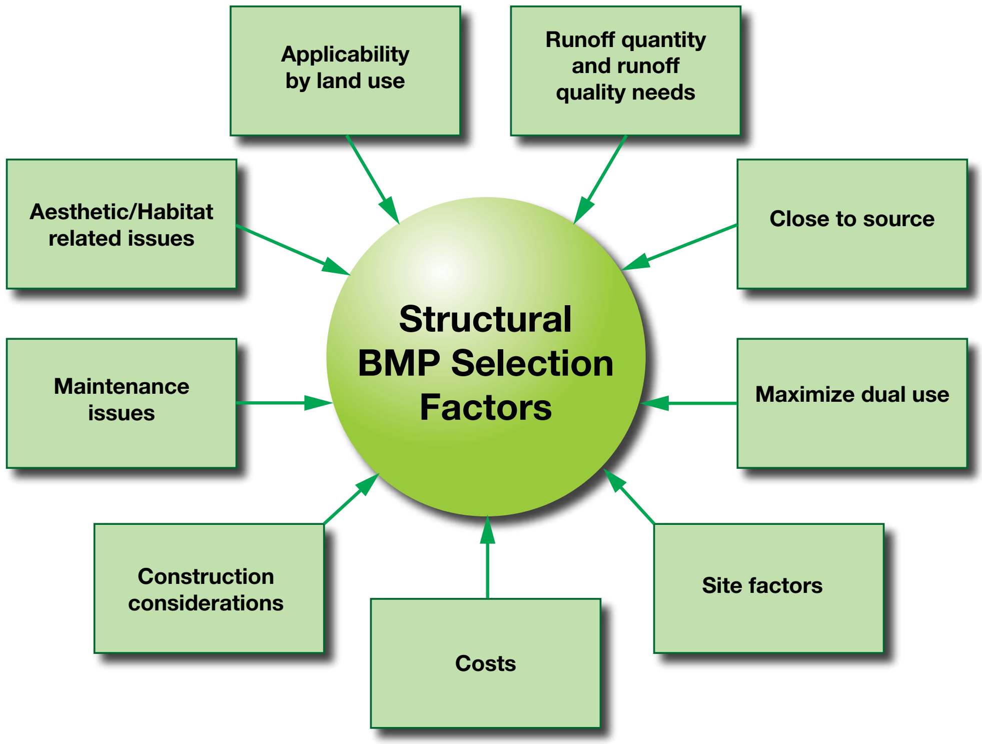
Notes:

6 Although vegetated roofs can be used very successfully in combination with infiltration systems.

7 Sand filters only (For filters with infiltration, see Subsurface Infiltration Bed section, or other infiltration BMP sections. For manufactured systems, see manufacturer's information, as well as results from independent verification.)

8 Increases with infiltration

Figure 7.1
Structural BMP Selection Factors



Site design plan developers should look for performance data that cites total volume into the BMP and out of the BMP, with pollutant concentration or load information for each. One of the most useful databases for deriving performance information for structural stormwater facilities is the International Stormwater BMP Database, which includes information on more than 300 BMP studies, performance analysis results, tools for use in BMP performance studies, monitoring guidance, and other study-related publications (www.bmpdatabase.org). Information in the database aids in estimating the total pollutant load removed by a BMP; i.e., input load minus output load. The total load can be calculated using the volume of water entering into or discharged from the BMP over a given period multiplied by the mean or average concentration of the pollutant. Another tool that summarizes BMP performance information is EPA's Urban BMP Performance Tool (nepis.epa.gov/Exe/ZyPDF.cgi/P100170R.PDF?Dockey=P100170R.PDF).

The factors in Figure 7.1 help guide comprehensive stormwater planning and LID site design. Selecting BMPs requires balancing numerous factors, including the following:

Runoff quantity and runoff quality needs

BMP selection is often based on the pollutant loadings and amount of stormwater runoff. For example, in areas with high phosphorus runoff, infiltration BMPs are excellent choices for removing phosphorus as long as other selection criteria (e.g., site factors) allow for these techniques. BMP fact sheets provide guidance relating to BMP performance in terms of runoff volume, groundwater recharge, peak rate, and water quality (total suspended solids, total phosphorous, nitrogen, and temperature).

Close to source

Manage stormwater runoff as close to the source, or origin, as possible. Implementing this factor will vary by site and by the proposed development. For example, vegetated swales may work well in new development, but would unlikely be used as part of a retrofit.

Maximize dual use

Consider integrating stormwater management into already disturbed areas (e.g., stormwater recharge beds beneath parking areas, play fields on infiltration basins). This can minimize total disturbed area and, in some cases, provide recreational opportunities for residents or employees. For example, Blue Cross Blue Shield of Michigan located in Detroit, built a green roof on their parking structure that incorporated a running track for their employees.

Site factors

Each site should be inventoried for certain characteristics (e.g., soil type, depth to water table, slopes) which should be incorporated into the BMP selection process. For example, some sites in Michigan might be characterized by a high water table, surface bedrock, or extremely slow-draining soils, which would make using infiltration BMPs challenging. BMP fact sheets highlight these site factors which are discussed in more detail in each BMP Design Considerations section. In addition, each BMP has a Designer/Reviewer's Checklist that allows for quick review of the consideration of each key site factor in the design process.

Costs

BMP costs include both construction and long-term maintenance activities. Costs are often related to the size and nature of the development. The BMP fact sheets, as well as the more detailed discussions, provide approximate cost information, although construction and maintenance costs tend to be site and development-specific.

Construction considerations

Many BMPs have construction guidelines to provide additional guidance. For example, locating and properly using excavation equipment is critical during construction of infiltration BMPs to avoid soil compaction. In addition, recommended construction materials specific to individual BMPs are listed in Appendix D.

Maintenance issues

Ease of maintenance and needed repairs are critical issues to consider in selecting a BMP. Some BMPs require greater maintenance to function properly. However, they may also achieve greater stormwater quantity and quality goals specific to the objectives of the site. Vegetated BMPs require various types of landscape care. Structural BMPs such as pervious pavement require periodic vacuuming, while infiltration basins, trenches, and dry wells are likely to require little maintenance. Some BMPs, especially those with plantings, may naturally improve in performance over time as vegetation grows and matures. In any case, general maintenance requirements are discussed for each BMP. Appendix F includes example Inspection Checklists for maintenance activities that should be considered. In addition, Appendix G includes Model Maintenance Agreements between property owners and communities for maintenance of BMPs.

Dual use at Blue Cross Blue Shield of Michigan parking structure.

Source: Turner Construction

Aesthetic/Habitat related issues

Landscape enhancement is becoming an ever-greater goal in most communities and developments. In some cases, developers are willing to pay for BMPs which serve to make their developments more attractive and improve value and marketability. For example, rain gardens make yard areas more attractive. Wet ponds and constructed wetlands, naturally planted swales and filter strips, vegetated roofs, and many other BMPs can be integrated into landscape design and create value in addition to solving stormwater problems. In addition, many of these BMPs add habitat values and provide other environmental benefits. BMP fact sheets and the detailed BMP discussions provide additional information on aesthetics.

Applicability by land use

Some land uses lend themselves to certain BMPs. Low density residential development lacks large congregate parking areas conducive to pervious pavement with infiltration. Conversely, rain barrels are especially good for residential use, but vegetated roofs are unlikely to be used on single-family homes. Successful LID programs strive to match the BMP with the land use and user type, as listed on BMP fact sheets (applications) and detailed in each BMP discussion.

Cold Climate Considerations

Another important design consideration is how the BMP will function in our cold climate. The detailed design considerations in each BMP is written to address typical cold climate issues. In addition, cold climate is discussed throughout each BMP's various recommendations including a specific section dedicated to winter considerations.

In general, the techniques described in this manual can be used very effectively in cold climate settings such as Michigan (when the appropriate recommendations are followed). In addition, LID encourages stormwater management systems and treatment trains that can offer increased resiliency for cold climate issues.

Critical aspects of winter conditions are extremely cold temperatures, sustained cold periods, and polluted snowmelt, as well as a short growing season (Table 7.2). Extreme cold can cause rapid freezing and burst pipes. Sustained cold can result in development of thick ice or frozen soil layers in some BMPs. On the other hand, the deeper and more persistent the snow layer, the less severe the soil freezing. Water quality problems associated with snow melt occur because of the large volume of water released during rain and snow events. This runoff carries material that has accumulated in the snowpack all winter, as well as material it picks up as it flows over the land's surface.

Chloride is the cause of many problems associated with snowmelt runoff. Chloride is a very soluble chemical that migrates easily through treatment systems and soil. Avoiding over-application of chloride, and routing runoff properly are effective ways to reduce damage to LID BMPs.

General considerations

Avoid pipe freezing by laying pipes and installing underground systems below the typical frost line. Pipe freezing for standpipes is not likely to be an issue, but conveyance pipes laid nearly horizontal should be below the freezing line. In Michigan, most communities plant at least a foot or two of groundcover over stormwater pipes to minimize the risk of pipe freezing. Over-excavation and filling with sand and gravel around stormwater pipes will also help with frost penetration and frost heave.

Figure 7.2
Chloride damaged white pines

Source: Michigan State University Extension

Table 7.2
Cold Climate Design Challenges

Climactic Condition	BMP Design Challenge
Cold Temperatures	• Pipe freezing • Permanent pool ice cover • Reduced biological activity • Reduced oxygen levels during ice cover • Reduced settling velocities
Deep Frost Line	• Frost heaving • Reduced soil infiltration • Pipe freezing
Short Growing Season	• Short time period to establish vegetation • Different plant species appropriate to cold climates than moderate climates
Significant Snowfall	• High runoff volumes during snowmelt and rain-on-snow • High pollutant loads during spring melt • Other impacts of road salt/deicers • Snow management may affect BMP storage

Research in the Saginaw River valley has shown (for the winter of 1996-1997) that soils in cultivated areas with little to no snow cover froze to depths of up to eight inches, while in areas with forest cover, leaf litter, and thin but persistent snow cover, frost depths only reached about an inch (Schaetzl and Tomczak, 2002). One conclusion that can be drawn from this is that plant material should be left in applicable stormwater BMPs to provide insulation through the winter. The ability of persistent snow cover to act as insulation also suggests that some BMPs such as bioretention areas, infiltration basins, and vegetated swales can be used for snow storage (as long as it does not cause physical damage to the vegetation or other BMP components). However, large amounts of sand or salt should be kept out of vegetated and infiltration BMPs. Sand and salt can smother and/or kill plants and reduce infiltration/storage capacity. Sand should also never be used on or adjacent to porous pavement systems (see detailed BMP section).

In addition, some BMPs, such as bioretention areas should be installed with a mulch layer that is two to three inches thick. For maximum insulation effectiveness, the mulch should be spread evenly and consistently throughout the BMP (for details on mulch see the individual BMP sections).

All biological activity is mediated by temperature. Cold winter temperatures significantly decrease nutrient uptake and pollutant conversion processes by plants and microbes; however, soil microbes still live and consume nutrients even in the dead of winter. Accumulation of chloride is generally not a problem in shallow biological systems, as long as very highly concentrated levels are not directly routed to them.

Infiltration considerations

As water cools its viscosity increases, reducing particle-settling velocities and infiltration rates into the soil. The problem with infiltration in cold weather is the ice that forms both over the tops of infiltration practices and in the soil pore spaces. To avoid these problems to the extent possible, the BMP must be actively managed to keep it dry before it freezes in the fall. This can be done by various methods including limiting inflow, under-drainage, and surface disking. Routing the first highly soluble portions of snowmelt to an infiltration BMP provides the opportunity for soil infiltration and treatment.

Winter Pollution Prevention Tips

- Choose proper de-icing materials
- Consider pre-wetting brine treatments to salt for better application
- Load salt trucks on covered, impervious pads
- Calibrate salting vehicles often
- Properly manage salt storage piles
- Identify and avoid salt-sensitive areas prior to plowing or salting

Snow Storage Tip

Commercial and industrial areas that plow their parking and paved areas into big piles on top of pavement could greatly improve runoff management if instead they dedicated a pervious area within their property for the snow. Even pushing the plowed snow up and over a curb onto a pervious grassed area will provide more treatment than allowing it to melt on a paved surface and run into a storm sewer.

Vegetation in winter at George George Park, Clinton Township, MI

Table 7.3
Additional BMP considerations for cold climate use

BMP Family	BMP	Considerations
Runoff Volume Minimization	Natural area conservation	Preserving pervious areas for meltwater to infiltrate is effective to control volume
	Soil amendments	Enhancing soil permeability will increase infiltration of meltwater
	Reducing impervious surface	Preserving pervious areas for meltwater to infiltrate is effective to control volume and minimize pollutants
	Grass drainage channel	Routing meltwater over a pervious surface will yield some reduction in flow and improved water quality
	Rain barrel/cistern	Capturing meltwater from a building will reduce volume but ice build-up could be a problem unless collection occurs below frost line
	Permeable pavement	Recent research has shown this approach to be successful in cold climates when properly installed and maintained, and when sanding is kept to a minimum
	Dry well	Effective as long as system is installed below the frost line to avoid ice build-up
	Planter box	These are designed more for the growing season, but they do provide a sump area for runoff to collect and will infiltrate some volume
	Vegetated roof	Recent research shows that slow melting in the spring reduces the volume running off of roof surfaces
Bioretention	Rain gardens	By definition, these are growing-season practices, but they do provide a sump area for storage and some infiltration during a melt
Filtration	Constructed filter	Surface systems need to be fully dry before freeze-up for these to work properly; subgrade systems can be very effective for meltwater treatment
	Vegetated filter	Vegetative filtering is reduced once vegetation dies back in fall; some physical filtering will occur if vegetation density and depth are sufficient
Infiltration	Trench	Effective when designed, installed, and maintained properly; caution applies to limitations on source area to avoid high concentrations of chloride and toxics
	Basin	See above comment
Detention Facilities	Forebay	Effective if designed with enough available volume to accommodate spring meltwater
	Storage components	Adaptations must be made to allow meltwater runoff to achieve appropriate amount of treatment; treatment effectiveness usually lower in warm weather
	Outlet	Proper design of the outlet structure can be the key to ponding effectiveness
Constructed Wetlands	Forebay	See comment for forebay above
	Storage components	Volume will be less than typical pond, but provide location for storage, some infiltration, filtration, and some microbial activity; biological activity at a minimum

Detention considerations

For BMPs with a permanent pool, winter conditions can create ice layers and reduce biological activity, oxygen levels, and settling velocities. Ice layers can reduce the permanent pool volume, act as an impervious surface during rainfall, and potentially force incoming water under ice layers and scour bottom sediments. Ice layers can also reduce the oxygen exchange between the air-water interface. If low oxygen levels extend to the sediment-water interface, they can cause some adsorbed pollutants, such as phosphorus and some metals to be released back into the water column. Reduced settling velocities will potentially result in lower pollutant removal rates.

Minimizing the effect of ice cover can help address these issues and can be accomplished by maintaining design storage volumes. Installing a control mechanism, such as a valve, weir, or stop-log, can reduce or eliminate outflow for the normal water quality volume. This volume is then made available for meltwater, which can be held and slowly released.

It is important to recognize the potential for detention facilities to incur a build up of pollutants (mostly chloride applied to impervious surfaces) throughout the winter. A balance needs to be considered in deciding whether to adjust the detention level to pass pollutant-laden runoff downstream or retain as much as possible for later release when flows are higher. Retaining polluted water all winter long only to discharge it all at once in the spring is not in the best interest of receiving waters, but this is what can happen in a detention BMP not managed for seasonal conditions. In no case should detention BMPs be drained in the spring after a winter-long accumulation of under-ice contaminants. If lowering is done, it should occur in late fall prior to freeze-up.

Chloride-laden runoff can be denser than water already in a basin, so it often pools at the bottom of the basin. Without some level of mixing in the basin, the pool can increase in chloride concentration over time. This is especially important to consider during dewatering, or if the pond will be used for irrigation and a pump is placed in the bottom of the pond. Altering pump placement or testing the bottom water before pumping are two methods to avoid discharge or use of salty water.

BMP Fact Sheet and Detailed Structural BMP Information

The remainder of the chapter focuses on individual structural BMPs. As with the nonstructural chapter, each BMP starts with a summary fact sheet. This fact sheet provides a quick overview of the BMP, along with a local case study. The fact sheets can be removed from the manual and serve as stand-alone documents for quick reference.

Following each fact sheet is detailed information on the BMP which includes:

Variations

Discusses the variations to the BMP, if they are applicable. Examples include alternatives in design that can increase storage capacity or infiltration rates.

Applications

Indicates in what type of land use the BMP is applicable or feasible.

Design Considerations

This section includes a list of technical procedures to be considered when designing for the individual BMP. This specific design criteria is presented, which can assist planners in incorporating LID techniques into a site design, as well as provide a basis for reviewers to evaluate submitted LID techniques.

Stormwater Calculations

Provides specific guidance on achieving sizing criteria, volume reduction, and peak rate mitigation, as applicable. This section also references Chapter 9 which discusses in detail how to achieve a specific standard or implement measures that contribute to managing water onsite in a more qualitative manner.

Construction Guidelines

Provides a typical construction sequence for implementing the BMP. However, it does not specifically address soil erosion and sedimentation control procedures. Erosion and sediment control methods need to adhere to the latest requirements of MDEQ's Soil Erosion and Sedimentation Control Program and local standards.

Maintenance

Provides guidance on recommended maintenance procedures for the BMP.

Winter Considerations

Discusses how well the BMP performs in Michigan's cold climate.

Cost

Provides general cost information for comparison purposes. If specific dates of costs are not referenced in this section, the costs reflect 2007 conditions.

Designer/Reviewer's Checklist

Developed to assist a designer and or reviewer in evaluating the critical components of a BMP that is being designed. It references not only individual design considerations, but also suggests review of additional pertinent sections of the LID manual that may need to be considered for implementation of that BMP.

References

Provides a list of sources of information utilized in the creation of this section of the manual. This list also provides additional sources that can be used for additional information.

References

Schaetzl, R.J. and Tomczak, D.M. "Wintertime Temperatures in the Fine-Textured Soils of the Sagniaw Valley, Michigan," *The Great Lakes Geographer*, v.8 (2), pp.87-99, 2001.

Minnesota Stormwater Manual, 2006. Minnesota Pollution Control Agency, St. Paul, MN.

SEMCOG, 2007. *Salt Storage and Application Techniques*, Streets and Parking Lots Fact Sheet.

BMP Fact Sheet

Bioretention (Rain Gardens)

Bioretention areas (often called rain gardens) are shallow surface depressions planted with specially selected native vegetation to capture and treat stormwater runoff from rooftops, streets, and parking lots.

Formal Rain Garden, Traverse City, MI

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Med/High
Commercial	Yes	**Groundwater Recharge**	Med/High
Ultra Urban	Limited	**Peak Rate**	Medium
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	High
Highway/Road	Yes	**TP**	Medium
Recreational	Yes	**TN**	Medium
		Temperature	High

Additional Considerations	
Cost	Medium
Maintenance	Medium
Winter Performance	Medium

Variations

- Subsurface storage/ infiltration bed
- Use of underdrain
- Use of impervious liner

Key Design Features

- Flexible in size and infiltration
- Ponding depths 6-18 inches for drawdown within 48 hours
- Native plants
- Amend soil as needed
- Provide positive overflow for extreme storm events

Site Factors

- Water table/bedrock separation: two-foot minimum, four foot recommended
- Soils: HSG A and B preferred; C & D may require an underdrain (see Infiltration BMP)
- Feasibility on steeper slopes: Medium
- Potential hotspots: Yes with pretreatment and/or impervious liner
- Max. drainage area: 5:1, not more than 1 acre to one area

Benefits

- Volume control and groundwater recharge, moderate peak rate control, filtration
- Versatile with broad applicability
- Enhance site aesthetics, habitat
- Potential air quality and climate benefits

Limitations

- Higher maintenance until vegetation is established
- Limited impervious drainage area
- Requires careful selection and establishment of plants

Case Study: Grayling Stormwater Project

The Grayling Stormwater Project is an example of a hybrid project that combines LID with end-of-pipe treatment. This project demonstrates that a small community is capable of making the fundamental shift in management towards LID and providing leadership for other communities to make similar changes.

The measures taken will eliminate approximately 80 percent of the water pollution from the city.

Typical Grayling Rain Garden, July 2007
Source: Huron Pines

This large-scale project includes 86 rain gardens along with installation of an "end-of-the-pipe" detention basin and seven underground Vortechnic oil-grit separator units. Several of the rain gardens that are smaller or that need to accommodate higher volumes of water were installed with underdrains, but most use the natural infiltration capacity of the area's sandy soils.

Currently, all major outfalls of stormwater from the City of Grayling are being treated by one or more of these measures. Future plans for the project include a maintenance program with incentives for landowners who water and weed their rain gardens, and an outreach program to educate the public and help other communities voluntarily integrate LID into their stormwater management.

Case Study Site Considerations	
Project Type	Protect sensitive/special value features, rain gardens/bioretention, detention/extended detention, filters (specifically oil-grease separators)
Soil Conditions	Sandy and extremely well drained
Estimated Total Project Cost	$1.2 million
Maintenance Responsibility	City of Grayling – maintenance of Vortechnic Units, Huron Pines – establishment of plants
Project Contact	Jennifer Muladore, 989-344-0753 ext 30, Jennifer@huronpines.org

Lessons Learned

The rain gardens were planted with seed and a few shrubs. The seed did not grow well, most likely due to the harsh cold winters and hot, dry summers in the Grayling area, where plants take a lot longer to establish in the extremely well-drained, sandy soils.

Plants that thrive in dry soils do need frequent watering to survive (project contracted out to a local landscaping company for watering).

In addition, many of the residents in the neighborhood are not happy with the "wild" seeded look and would rather have had more manicured gardens. In future phases, the City of Grayling will plant fewer gardens with larger plant stock and try to locate them where homeowners are more interested in helping to maintain them.

Description and Function

Bioretention is a method of managing stormwater by pooling water within a planting area and allowing the water to infiltrate the garden. In addition to managing runoff volume and reducing peak discharge rates, this process filters suspended solids and related pollutants from stormwater runoff. Bioretention can be implemented in small, residential applications (Figure 7.3) or as part of a management strategy in larger applications (Figure 7.4).

Figure 7.3
Residential Rain Garden

Source: Rain Gardens of West Michigan

Figure 7.4
Commercial Rain Garden

Source: Rain Gardens of West Michigan

Bioretention is designed into a landscape as a typical garden feature, to improve water quality while reducing runoff quantity. Rain gardens can be integrated into a site with a high degree of flexibility and can integrate nicely with other structural management systems including porous pavement parking lots, infiltration trenches, and other *non-structural* stormwater BMPs.

Bioretention vegetation serves to filter (water quality) and transpire (water quantity) runoff, and enhance infiltration. Plants absorb pollutants while microbes associated with the plant roots and soil break them down. The soil medium filters out pollutants and allows storage and infiltration of stormwater runoff, providing volume control. In addition, engineered soil media may serve as a bonding surface for nutrients to enhance pollutant removal.

Properly designed bioretention techniques provide a layer of compost that acts like a sponge to absorb and hold runoff. Vegetation in the rain garden can be diverse, through the use of many plant species and types, resulting in a system tolerant to insects, diseases, pollution, and climatic stresses.

The term "rain garden" is used to refer to smaller-scale bioretention facilities typically found on residential properties.

Bioretention can Accomplish the Following:

- Reduce runoff volume
- Filter pollutants, through both soil particles (which trap pollutants) and plant material (which take up pollutants)
- Provide habitat
- Recharge groundwater (if no underdrain is placed underneath)
- Reduce stormwater temperature impacts
- Enhance site aesthetics

Figure 7.5 illustrates a schematic of a relatively simple bioretention area (or rain garden). Figure 7.6 illustrates a schematic of a bioretention area that is a more technically engineered structure, designed to complete specific stormwater management goals. Pond depth, soil mixture, infiltration bed, perforated underdrains, domed risers, and positive overflow structures may be designed according to the specific, required stormwater management functions.

Figure 7.5
Schematic of a small residential rain garden

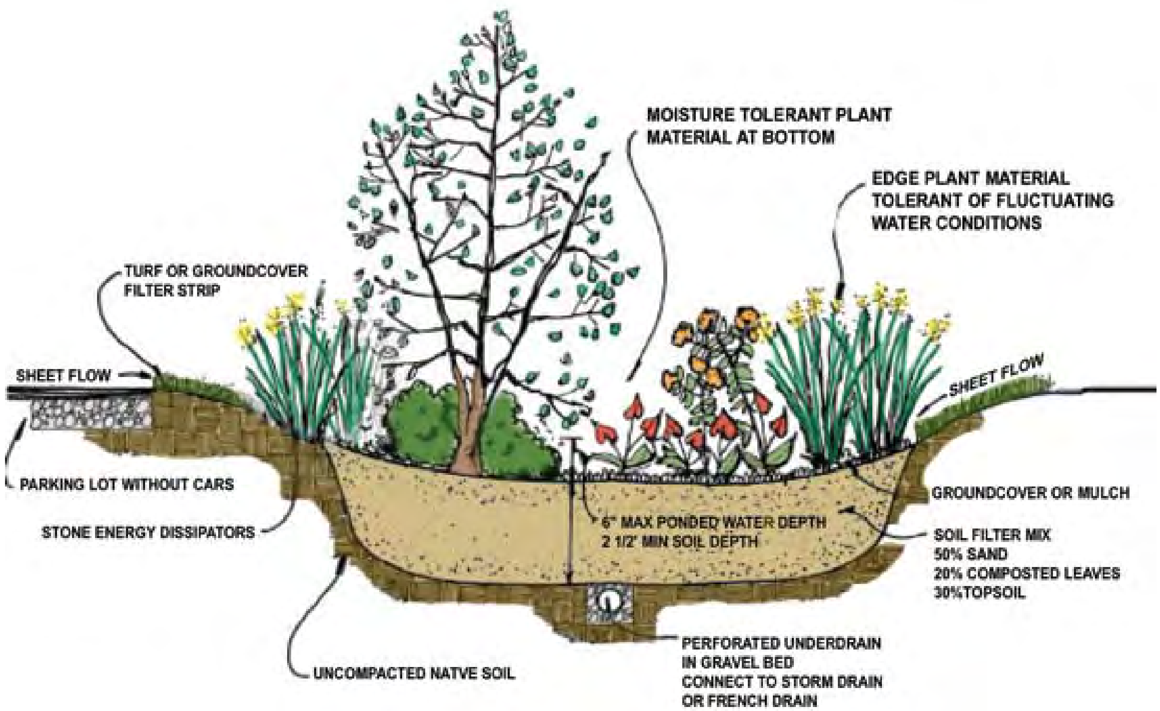
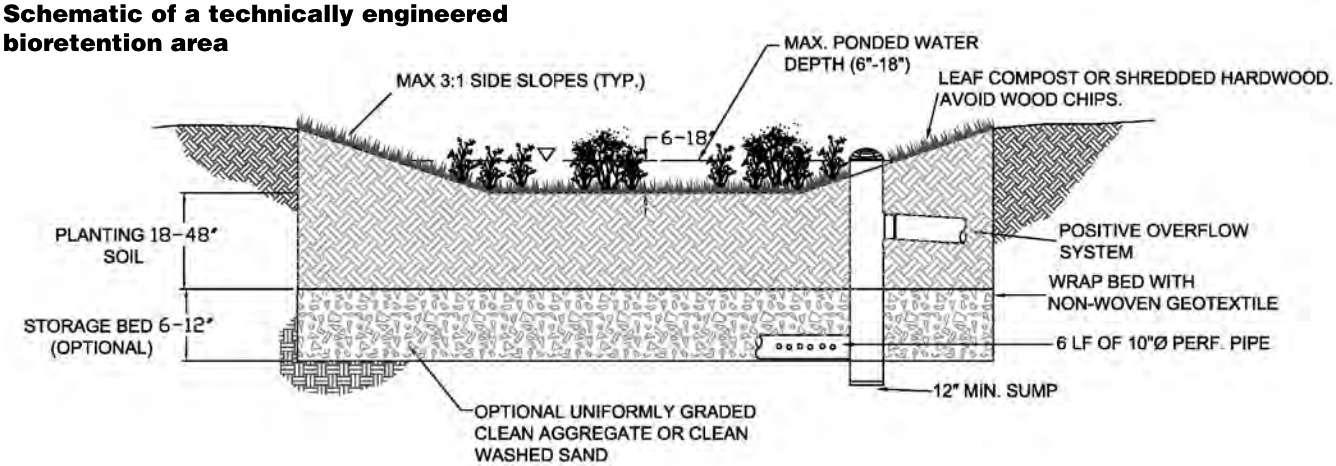


Figure 7.6
Schematic of a technically engineered bioretention area



Source: Prince George's County Bioretention Manual with modifications by Cahill Associates, 2004

Variations

A bioretention system is a depression in the ground planted like a garden that provides for the storage and infiltration of relatively small volumes of stormwater runoff, often managing stormwater on a lot-by-lot basis. This use of many small stormwater controls versus one large detention area promotes the low impact development goal of decentralized treatment of stormwater. But, if greater volumes of runoff must be managed or stored, a bioretention system can be designed with an expanded subsurface infiltration bed, or can be increased in size. Typically, the ratio of impervious area draining to the bioretention area should not exceed five-to-one, and the total impervious area draining to a single system should not be more than one acre. Variations noted relate to performance types, flow entrance, and positive overflow.

Performance types

Depending on varying site conditions, bioretention can be designed to allow for 1) complete infiltration, 2) infiltration/filtration, or 3) filtration. These variations will often determine the need for such design features as the gravel bed, underdrains, and impervious liners.

Bioretention using complete infiltration occurs in areas where groundwater recharge is beneficial and the soils have the permeability necessary to accommodate the inflow. This type of BMP is often less expensive to construct because there is no underdrain and the soils on site are often used.

The most common variation to this type of bioretention includes a gravel or sand bed underneath the planting bed and often accompanied by the use of an underdrain. This allows for additional storage or for areas with low permeability to use bioretention as infiltration, as well as, filtration (Figure 7.6). Some volume reduction will occur through infiltration, as well as evaporation and transpiration.

Signage at Rouge River rain garden

Another variation is to use bioretention primarily for filtration. This is often used in contaminated soils or hot spot locations using an impervious liner to prevent infiltration and groundwater contamination. The primary stormwater function then becomes filtration with some volume reduction through evaporation and transpiration.

For areas with low permeability, bioretention may achieve some infiltration while acting as detention with peak rate control for all storms up to the design storm.

Flow inlet

Pretreatment of runoff should be provided where sediment or pollutants entering the rain garden may cause concern or decreased BMP functionality. Soil erosion control mats, blankets, or rock must be used where runoff flows from impervious areas enter the rain garden.

Flow inlet: Trench drain

Trench drains can accept runoff from impervious surfaces and convey it to a rain garden (Figure 7.7). The trench drain may discharge to the surface of the rain garden or may connect directly to an aggregate infiltration bed beneath.

Figure 7.7
Trench drain and curb cut connected to bioretention area

Source: Macomb County Planning and Economic Development

Educational Signage

Once a bioretention area is established, installing signage will help the general public and maintenance crews recognize LID practices which can help promote sustainable stormwater management. Educational signs can incorporate LID goals, and maintenance objectives in addition to the type of LID project being employed.

Flow inlet: Curbs and curb cuts

Curbs can be used to direct runoff from an impervious surface along a gutter to a low point where it flows into the rain garden through a curb cut. Curb cuts may be depressed curbs (Figure 7.8), or may be full height curbs with openings cast or cut into them.

Figure 7.8
Curb cut into bioretention area/rain garden

Source: Huron Pines

Positive overflow

A positive overflow, via the surface or subsurface, is recommended to safely convey excessive runoff from extreme storm events.

Positive overflow: Domed riser

A domed riser may be installed to ensure positive, controlled overflow from the system (Figure 7.9). Once water ponds to a specified depth, it will begin to flow into the riser through a grate, which is typically domed to prevent clogging by debris.

Figure 7.9
Positive Overflow Device: Domed riser at Macomb County Public Works Office

Source: Macomb County Public Works Office

Positive overflow: Inlet structure

An inlet structure may also be installed to ensure positive, controlled overflow from the system. Once water ponds to a specified depth, it will begin to flow into the inlet.

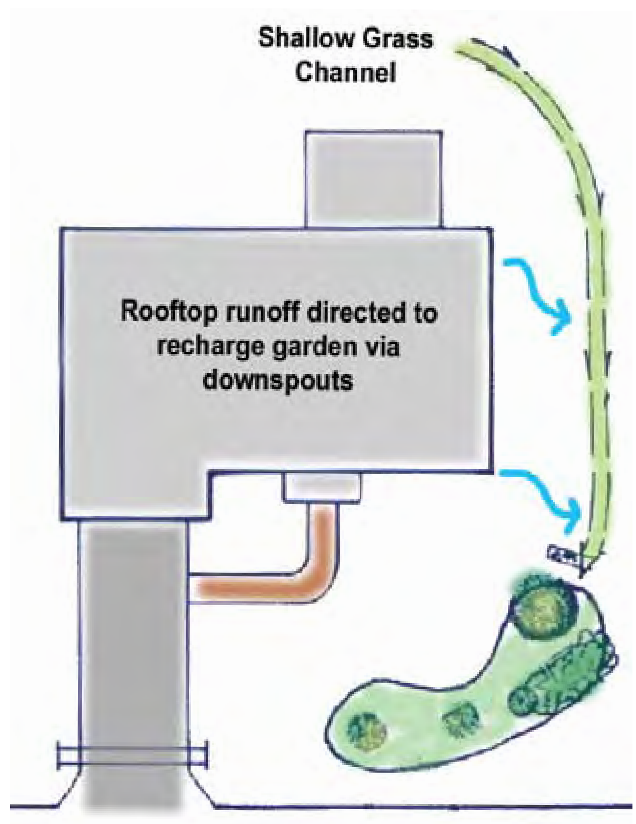
Applications

Bioretention areas can be used in a variety of applications, from small areas in residential lawns to extensive systems in commercial parking lots (incorporated into parking islands or perimeter areas). Industrial, retrofit, highway/road, and recreational areas can also readily incorporate bioretention. One key constraint in using bioretention in ultra-urban settings is space.

Residential

The residential property owner that wants to design and build a rain garden at home does not need to go through the engineering calculations listed under stormwater calculations and functions. Assistance with simple rain gardens is available from several sources listed under the Plant Selection portion of this BMP.

Figure 7.10
Single-family residential lot drainage schematic



Claytor and Schueler, 1995 with modifications by Cahill Associates

Figure 7.11
Residential rain garden

Source: Pokagon Band of Potawatomi Indians

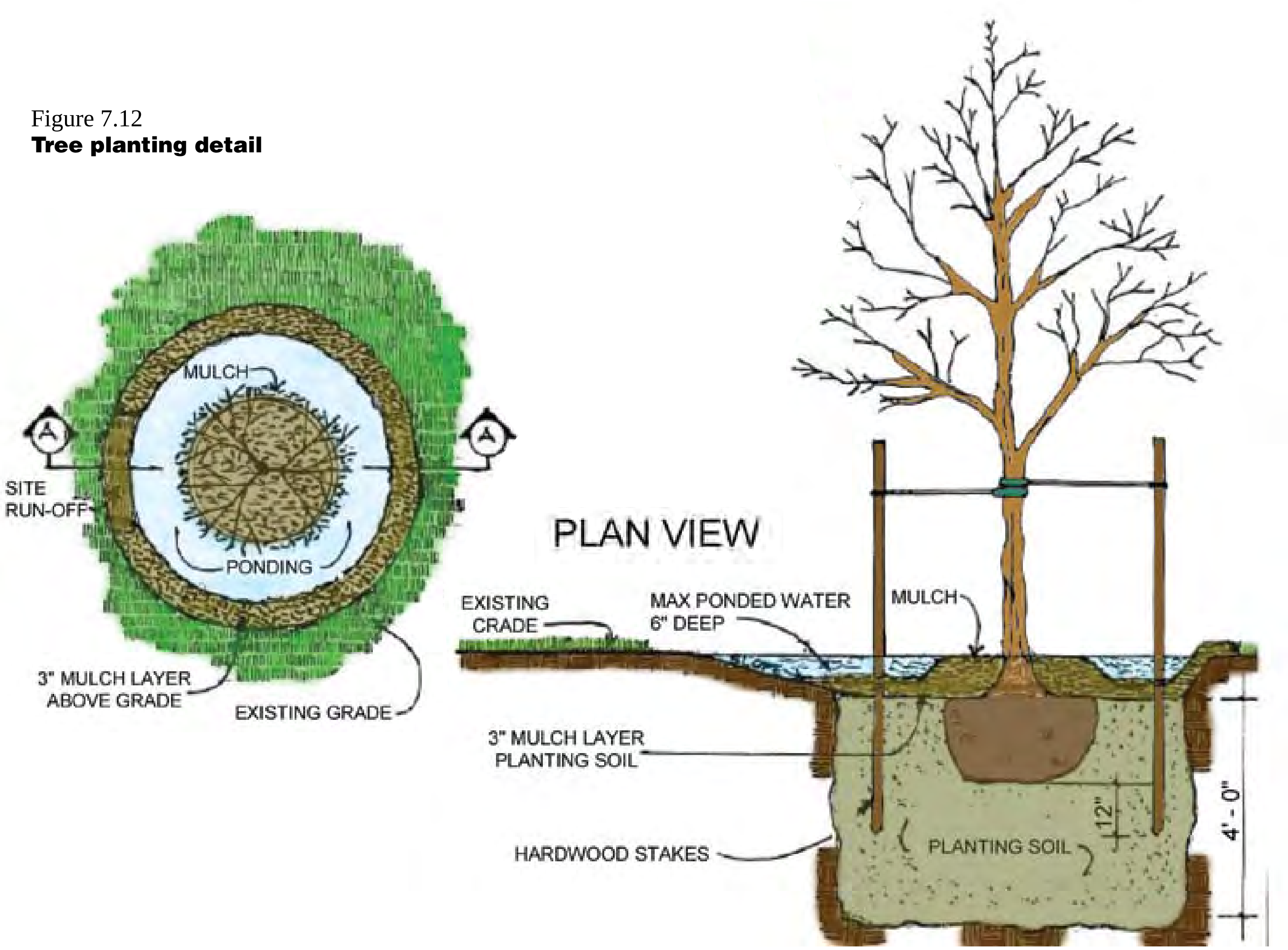
Figure 7.10 shows a typical rain garden configuration on a residential property. The rain garden shown in Figure 7.11 represents a simple design that incorporates a planting bed adjacent to an uncurbed road.

Another source of water for a small rain garden is connecting the roof leader from adjacent buildings. The stormwater may discharge to the surface of the bioretention area or may connect directly to an aggregate infiltration bed beneath.

Tree and shrub pits

Tree and shrub pits intercept runoff and provide shallow ponding in mulched areas around the tree or shrub (Figure 7.12). Mulched areas should typically extend to the tree's drip line.

Figure 7.12
Tree planting detail



Source: Prince George's County, Maryland, The Bioretention Manual with modifications by Cahill Associates, 2004

Roads and highways

Figure 7.13 shows a linear bioretention area feature along a highway. Runoff is conveyed along the concrete curb (bottom of photo) until it reaches the end of the gutter, where it spills into the vegetated area.

Figure 7.13
Linear Bioretention Area along Roadway

Source: Low Impact Development Center, Inc.

Parking lot island bioretention

In parking lots for commercial, industrial, institutional, and other uses, stormwater management and green space areas are limited. In these situations, bioretention areas for stormwater management and landscaping may provide multiple benefits (Figure 7.14).

A bioretention area in a parking lot can occur in parking lots with no curbs and with curbs. The no-curb alternative allows stormwater to sheet flow over the parking lot directly into the bioretention area.

In a curbed parking lot, runoff enters the bioretention area through a curb cut. If the runoff volume exceeds the ponding depth available, water overflows the bioretention area and enters a standard inlet (Figure 7.15).

A variation on this design is a direct underground connection to the standard inlet from the underground aggregate infiltration bed via an overflow pipe.

Figure 7.15
Standard inlet to allow for overflow from the bioretention area

Source: Low Impact Development Center, Inc.

Figure 7.14
Bioretention area within parking lot

Source: City of Rochester Hills

Primary Components of a Bioretention System

1. Pretreatment (may be necessary to help prevent clogging)

- Sediment removal through a vegetated buffer strip, cleanout, stabilized inlet, water quality inlet, or sediment trap prior to runoff entry into the bioretention area

2. Flow inlet

- Varies with site use (e.g., parking island versus residential lot applications – see Figures 7.11 through 7.14)
- Entering velocities must be non-erosive – use erosion control mats, blankets, or rock where concentrated runoff enters the bioretention area

3. Ponding area

- Provides temporary surface storage of runoff and allows sediment to settle
- Provides evaporation for a portion of runoff
- Depth no more than 6-18 inches for aesthetics, functionality, and safety

4. Plant material (see Appendix C for recommended plant lists)

- Absorbs stormwater through transpiration
- Root development creates pathways for infiltration
- Bacteria community resides within the root system creating healthy soil structure with water quality benefits
- Can improve aesthetics for site
- Provides habitat for animals and insects
- Reinforces long-term performance of subsurface infiltration
- Ensures plants are salt tolerant if in a location that would receive snowmelt chemicals
- Should be native plant species and placed according to drought and water tolerance

5. Organic layer or mulch

- Acts as a filter for pollutants in runoff
- Protects underlying soil from drying and eroding
- Simulates leaf litter by providing environment for microorganisms to degrade organic material
- Provides a medium for biological growth, decomposition of organic material, adsorption and bonding of heavy metals
- Wood mulch should be shredded – compost or leaf mulch is preferred

6. Planting soil/volume storage bed

- Provides water/nutrients to plants
- Enhances biological activity and encourages root growth
- Provides storage of stormwater by the voids within the soil particles
- Provides surface for adsorption of nutrients

7. Positive overflow

- Provides for the direct discharge of runoff during large storm events when the subsurface/surface storage capacity is exceeded
- Examples of outlet controls include domed risers, inlet structures, and weirs

Design Considerations

Bioretention is flexible in design and can vary in complexity according to site conditions and runoff volume requirements. Design and installation procedures may vary from very simple for "backyard" rain gardens to highly engineered bioretention areas in ultra-urban areas.

Infiltration BMPs should be sited so that they minimize risk to groundwater quality and present no threat to subsurface structures. Table 7.4 provides recommended setback distances of bioretetnion areas to various lot elements.

Table 7.4
Setback distances

Setback from	Minimum distance (feet)
Property line	10
Building foundation*	10
Private well	50
Public water supply well**	50
Septic system drainfield***	100

* minimum with slopes directed away from building

** At least 200 feet from Type I or IIa wells, 75 feet from Type IIb and III wells (MDEQ Safe Drinking Water Act, PA 399)

*** 50 feet for septic systems with a design flow of less than 1,000 gallons per day

The distance from the bottom of the infilration BMP to the seasonal high groundwater level or bedrock is recommended to be four feet. Two feet is allowable, but may reduce the performance of the BMP.

Bioretention is best suited for areas with at least moderate infiltration rates (more than 0.25 inches per hour) – see Infiltration BMP. In extreme situations where permeability is less than 0.25 inches per hour, special variations may apply, such as using amended subsoils or underdrains (or using constructed wetlands instead). The following procedures should be considered when designing bioretention areas:

1. The **flow entrance** must be designed to prevent erosion in the bioretention area. Some alternatives include flared end sections, erosion control mats, sheet flow into the facility over grassed areas, rock at entrance to bioretention area, curb cuts with grading for sheet flow, and roof leaders with direct surface connection.
2. **A positive overflow system** should be designed to safely convey away excess runoff. The overflow can be routed to the surface in a non-erosive manner or to another stormwater system. Some alternatives include domed risers, inlet structures, weirs, and berms.
3. Sizing criteria
   a. **Surface area** is dependent upon storage volume requirements, but should generally not exceed a maximum loading ratio of 5:1 impervious drainage area to bioretention area and no more than one acre drainage area to one bioretention cell. However, for design purposes, the total volume of water generated from the contributing drainage area must be used, not just the impervious portion. See Infiltration BMP for additional guidance on loading ratios.

      The required bioretention surface area is determined by taking the volume of runoff to be controlled according to LID criteria, maintaining the maximum ponding depth, the loading rate, and the emptying time. Infiltration and evapotranspiration are increased by increasing the surface area of the bioretention area. The total surface area needed may be divided into multiple cells. This configuration may be useful to collect runoff from both the front and back of a building.

   b. Surface side slopes should be gradual. For most areas, maximum 3:1 side slopes are recommended.
   c. The recommended surface ponding depth is six inches. Up to 18 inches may be used if plant selection is adjusted to tolerate water depth. Drain within 24-48 hours.
   d. **Ponding area** should provide sufficient surface area to meet required storage volume without exceeding the design ponding depth. The

Preparing bed with planting soil
Source: City of Troy

subsurface infiltration bed is used to supplement surface storage where appropriate.

4. **Planting soil depth** should generally be between 18 and 48 inches where only herbaceous plant species will be used. If trees and woody shrubs will be used, soil media depth may be increased, depending on plant species. Native soils can be used as planting soil or modified to be suitable on many sites. Small, backyard rain gardens can generally use existing soils without a specialized depth. Planting soil should be approximately four inches deeper than the bottom of the largest root ball.
5. **Planting soil** should be capable of supporting a healthy vegetative cover. Soils should be amended with a composted organic material. A recommended range of a soil mixture is 20-40 percent organic material (compost), 30-50 percent sand, and 20-30 percent topsoil, although any soil with sufficient drainage may be used for bioretention.

   Soils should also have a pH of between 5.5 and 6.5 (better pollutant adsorption and microbial activity), a clay content less than 10 percent (a small amount of clay is beneficial to adsorb pollutants and retain water although no clay is necessary if pollutant loadings are not an issue), be free of toxic substances and unwanted plant material, and have a 5-10 percent organic matter content. Additional organic matter can be added to the soil to increase water holding capacity.

   If brought from off site, **sand** should be clean, coarse, and conform to ASTM C-33 (Standard Specification for Concrete Aggregates).

   If the void space within an amended soil mix will be used in calculating runoff volume capacity in the system, tests should be conducted on the soil's porosity to determine the available storage capacity.

Selecting proper plants
Source: City of Troy

6. Proper **plant selection** is essential for bioretention areas to be effective. Typically, native floodplain or wet meadow plant species are best suited to the variable environmental conditions encountered in a bioretention area. Suggested species may include Cardinal Flower (*Lobelia cardinalis*), Blue Lobelia (*Lobelia siphilitica*), New England Aster (*Aster novae-angliae*), and Brown Fox Sedge (*Carex vulpinoidea*) (See recommended Plant List in Appendix C for a detailed list).

   In most cases, seed is not the preferred method for establishing plants in a bioretention area. The fluctuating water levels make it difficult for the seed to readily establish, while the random nature of seeding produces a look previous experience indicates is unacceptably "wild." Therefore, it is strongly recommended that live plant material in plug or gallon-potted form be used and installed on 1-2 foot centers for a more formal appearance. Shrubs and trees are also recommended to be included in a bioretention area.

   A landscape architect can be used to design a native planting layout. Additional resources for planting layouts are Rain Gardens for West Michigan (www.raingardens.org), Washtenaw County Free Designs, Wild Ones Natural Landscapers, and MDEQ Landscaping for Water Quality booklets.

7. **Planting periods** will vary but, in general, trees and shrubs should be planted from mid-April through early June, or mid-September through mid-November. Native seed should be installed between October 1 and June 1. Live plant material (plugs or gallon pots) should be installed between May 1 and June 15. Planting dates may be lengthened if a regular water source can be provided. Likewise, planting should be ceased at an earlier date in the event of a drought year.
8. A maximum of 2-3 inches of shredded hardwood **mulch** aged at least six months to one year or leaf compost (or other comparable product) should be uniformly applied immediately after shrubs and trees are planted to prevent erosion, enhance metal removals, and simulate leaf litter in a natural forest system. Wood chips should be avoided as they tend to float during inundation periods. Mulch or compost should not exceed three inches in depth or be placed directly against the stems or trunks of plants to maintain oxygen flow.
9. When working in areas with **steeper slopes**, bioretention areas should be terraced laterally along slope contours to minimize earthwork and provide level areas for infiltration.
10. A subsurface **storage/infiltration bed**, if used, should be at least six inches deep and constructed of clean gravel with a significant void space for runoff storage (typically 40 percent) and wrapped in geotextile fabric.
11. **Underdrains** are often not needed unless in-situ soils are expected to cause ponding lasting longer than 48 hours. If used, underdrains are typically small diameter (6-12-inches) perforated pipes in a clean gravel trench wrapped in geotextile fabric (or in the storage/infiltration bed). Underdrains should have a flow capacity greater than the total planting soil infiltration rate and should have at least 18 inches of soil/gravel cover. They can daylight to the surface or connect to another stormwater system. A method to inspect and clean underdrains should be provided (via cleanouts, inlet, overflow structure, etc.)

Underdrain in trench

Source: City of Rochester Hills

Recycled asphalt product (RAP) used throughout parking lot and left behind curb to give structural support.

Underdrain excavation, three feet wide, six inches deep. Peastone was placed in excavation.

Four-foot-diameter catch basins, used as overflows. Rim elevation set nine inches above mulch layer to allow nine inches of ponding before overflow occurs. Two catch basins used to ensure stormwater doesn't overflow to parking lot.

Source: City of Rochester Hills

Stormwater Functions and Calculations

When designing a bioretention area, it is recommended to follow a two-step process:

1. Initial sizing of the bioretention area based on the principles of Darcy's Law.
2. Verify that the loading ratio and the necessary volume reductions are being met.

Initial sizing of the bioretention area

Bioretention areas can be sized based on the principles of Darcy's Law, as follows:

With an underdrain:

$A_f = V \times d_f / [k \times (h_f + d_f) \times t_f]$

Without an underdrain:

$A_f = V \times d_f / [i \times (h_f + d_f) \times t_f]$

Where:

A_f = surface area of filter bed (ft^2)

V = required storage volume (ft^3)

d_f = filter bed depth (ft)

k = coefficient of permeability of filter media (ft/day)

i = infiltration rate of underlying soils (ft/day)

h_f = average height of water above filter bed (ft)

t_f = design filter bed drain time (days)

A "quick check" for sizing the bioretention area is to ignore the infiltration rate and calculate the storage volume capacity of the bioretention area as follows:

A_{inf} = (Area of bioretention area at ponding depth + Bottom area of bioretention area) divided by two = Infiltration area (average area)

The size of the infiltration area is determined by the volume of water necessary to remove as determined by LID criteria, depth of the ponded area (not to exceed 18 inches), infiltration rate of the soil, loading ratio, and, if applicable, any subsurface storage in the amended soil or gravel.

This volume can be considered removed if the bioretention is not underdrained. If the bioretention cell is underdrained, consider the bioretention cell as a detention device with the volume calculated above discharged to a surface water over time t_f.

Verification of meeting volume reduction requirements

The bioretention facility should be sized to accommodate the desired volume reductions (see Chapter 9 for Volume Control Criteria). This can be based on water quality volume (e.g., first inch of runoff from the site) or based on size storm event (e.g., no net increase based on presettlement conditions of the two-year, 24-hour event).

The volume of a bioretention area can have three components: surface storage volume, soil storage volume, and infiltration bed volume. These three components should be calculated separately and added together. The goal is that this total volume is larger than the required volume reduction that is often included in local ordinances. If the total volume is less than the required volume, another adjustment may be needed to the bioretention area (e.g., increased filter bed depth).

Total volume calculation:

1. Surface storage volume (ft^3) = Average bed area (ft^2) x Maximum design water depth (ft)
2. Soil storage volume (ft^3) = Infiltration area (ft^2) x Depth of amended soil (ft) x Void ratio of amended soil.
3. Subsurface storage/Infiltration bed volume (ft^3) = Infiltration area (ft^2) x Depth of underdrain material (ft) x Void ratio of storage material

Total bioretention volume = Surface storage volume + Soil storage volume (if applicable) + Infiltration bed volume (if applicable).

Peak rate mitigation

Chapter 9 provides information on peak rate mitigation methodology and addresses links between volume reduction and peak rate control. Underdrained bioretention acts as a detention practice with a discharge rate roughly equal to the infiltration rate of the soil x the average bed area.

Water Quality Improvement

The reported water quality benefits of bioretention can be expected to remove a high amount of total suspended solids (typically 70-90 percent), a medium amount of total phosphorus (approximately 60 percent), and a medium amount of total nitrogen (often 40-50 percent). In areas with high sediment loading, pretreatment of runoff can significantly reduce the amount of bioretention maintenance required (See Chapter 9 for water quality calculation procedures).

Construction Guidelines

The following is a typical construction sequence (Note for all construction steps: Erosion and sediment control methods need to adhere to the latest requirements of MDEQ's Soil Erosion and Sedimentation Control Program and local standards).

1. Complete site grading, minimizing compaction as much as possible. If applicable, construct curb cuts or other inflow entrance, but provide protection so that drainage is prohibited from entering the bioretention construction area. Construct pre-treatment devices (filter strips, swales, etc.) if applicable.
2. Subgrade preparation
   a Existing subgrade in rain gardens should not be compacted or subject to excessive construction equipment traffic. Loads on the subgrade should not exceed four pounds per square inch.
   b. Initial excavation can be performed during rough site grading, but should not be carried to within one foot of the final bottom elevation. Final excavation should not take place until all disturbed areas in the drainage area have been stabilized.
   c. Where erosion of subgrade has caused accumulation of fine materials and/or surface ponding in the graded bottom, this material should be removed with light equipment and the underlying soils scarified to a minimum depth of six inches with a york rake or equivalent by light tractor.
   d. Bring subgrade of bioretention area to line, grade, and elevations indicated. Fill and lightly regrade any areas damaged by erosion, ponding, or traffic compaction. All bioretention areas should be level grade on the bottom.
3. Stabilize grading except within the bioretention area. Bioretention areas may be used as temporary sediment traps provided the proposed finish elevation of the bed is at least 12 inches lower than the bottom elevation of the sediment trap (if used as such, all accumulated material and at least 12 inches of soil should be removed).
4. Excavate bioretention area to proposed invert depth and scarify the existing soil surfaces. Do not compact soils.
5. Backfill bioretention area with amended soil as shown on plans and specifications. Overfilling is recommended to account for settling. Light hand tamping is acceptable if necessary.
6. Complete final grading to achieve proposed design elevations, leaving space for upper layer of compost, mulch, or topsoil as specified on plans.
7. Bioretention area/rain garden installation
   a. Upon completing subgrade work, notify the engineer to inspect at his/her discretion before proceeding with bioretention installation.
   b. For the subsurface storage/infiltration bed installation, amended soils should be placed on the bottom to the specified depth.
   c. Planting soil should be placed immediately after approval of subgrade preparation/bed installation. Any accumulation of debris or sediment that takes place after approval of subgrade should be removed prior to installation of planting soil at no extra cost to the owner.
   d. If called for in the design, install approved planting soil in 18-inch maximum lifts and lightly compact (tamp with backhoe bucket or by hand). Keep equipment movement over planting soil to a minimum — **do not over-compact**. Install planting soil to grades indicated on the drawings. Loads on the soil should not exceed four pounds per square inch.
   e. Presoak the planting soil at least 24 hours prior to planting vegetation to aid in settlement.
   f. Plant trees and shrubs according to supplier's recommendations and only from mid-March through the end of June or from mid-September through mid-November.
   g. Install two or three inches of shredded hardwood mulch (minimum age six months) or compost mulch evenly as shown on plans. Do not apply mulch in areas where ground cover is to be grass or where cover will be established by seeding.
   h. Protect rain gardens from sediment at all times during construction. Compost socks, diversion berms, and/or other appropriate measures should be used at the toe of slopes that are adjacent to rain gardens to prevent sediment from washing into these areas during site development.
   i. When the site is fully vegetated and the soil mantle stabilized, notify the plan designer to inspect the rain garden drainage area at his/her discretion before the area is brought online and sediment control devices removed.
8. Mulch and install erosion protection at surface flow entrances where necessary.

Marking planting area
Source: City of Troy

Planting Tip

When planting your bioretention area, it is usually helpful to mark the different planting areas. An effective method is using spray paint and flags to mark designated areas. This is especially helpful when utilizing volunteers.

Maintenance

Properly designed and installed bioretention areas require some regular maintenance, most within the first year or two of establishment. Less maintenance is required when the native perennial vegetation becomes established.

1. Water vegetation at the end of each day for two weeks after planting is completed. Newly established plants should continue to receive approximately one inch of water per week throughout the first season, or as determined by the landscape architect.
2. While vegetation is being established, pruning and weeding may be required. Weeds should be removed by hand.
3. Organic material may also need to be removed approximately twice per year (typically by hand).
4. Perennial plantings may be cut down at the end of the growing season to enhance root establishment.
5. Mulch should be re-spread when erosion is evident and replenished once every one to two years or until the plants begin to fill in the area and the space between plants is minimized.

Watering newly established vegetation
Source: City of Troy

6. Bioretention area should be inspected at least two times per year for sediment buildup, erosion, and to evaluate the health of the vegetation. If sediment buildup reaches 25 percent of the ponding depth, it should be removed. If erosion is noticed within the bioretention area, additional soil stabilization measures should be applied. If vegetation appears to be in poor health with no obvious cause, a landscape specialist should be consulted.
7. Bioretention vegetation may require watering, especially during the first year of planting. Ensure the maintenance plan includes a watering schedule for the first year, and in times of extreme drought after plants have been established.
8. Bioretention areas should not be mowed on a regular basis. Trim vegetation as necessary to maintain healthy plant growth.

Winter Considerations

Use salt-tolerant vegetation where significant snowmelt containing deicing chemicals is expected. The use of sand, cinders, and other winter abrasives should be minimized. If abrasives are used, additional maintenance may be required to remove them in the spring. Bioretention soils can be expected to resist freezing and remain functioning for most of the year (although biological pollutant removal processes will be reduced during winter). Bioretention areas can even be used for snow storage assuming this will not harm the vegetation. Pipes, inlets, overflow devices, and other stormwater structures associated with bioretention should be designed according to general guidance on cold climate construction.

Cost

Bioretention areas often replace areas that were intensively landscaped and require high maintenance. In addition, bioretention areas can decrease the cost for stormwater conveyance systems on a site. Bioretention areas cost approximately $5-7 per cubic foot of storage to construct.

Designer/Reviewer Checklist for Rain Gardens/Bioretention

Item	Yes	No	N/A	Notes
Was Appendix E: *Soil infiltration Testing Protocol followed*?*				
Appropriate areas of the site evaluated?				
Infiltration rates measured?				
Were the bioretention design guidelines followed?				
Minimum 2-foot separation between the bed bottom and bedrock/SHWT?				
Soil permeability acceptable?				
If not, appropriate underdrain provided?				
Natural, uncompacted soils?				
Level infiltration area (bed bottom)?				
Excavation in rain garden areas minimized?				
Hotspots/pretreatment considered?				
Loading ratio below 5:1 (described in infiltration BMP)?				
Ponding depth limited to 18 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?				
Appropriate native plants selected?				
Maintenance accounted for and plan provided? Review of treatment volume? Review of calculations?				

* In general, the protocol should be followed as much as possible.

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BMP Fact Sheet

Capture Reuse

Structures designed to intercept and store runoff from rooftops allow for its reuse, reducing volume and overall water quality impairment. Stormwater is contained in the structures and typically reused for irrigation or other water needs.

Cistern at Fairlane Green shopping center, Allen Park, MI

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	High
Commercial	Yes	**Groundwater Recharge**	Low
Ultra Urban	Yes	**Peak Rate**	Low*
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	Med
Highway/Road	No	**TP**	Med
Recreational	Yes	**NO_3**	Med
		Temperature	Med

Additional Considerations	
Cost • Rain Barrel • Cistern • Manufactured porduct	 Low Med Varies
Maintenance	Med
Winter Performance	Med

Variations
- Rain barrels
- Cisterns, both underground and above ground
- Tanks
- Storage beneath a surface (using manufactured products)

Key Design Features
- Small storm events are captured with most structures
- Provide overflow for large storm events
- Discharge water before next storm event
- Consider site topography, placing structure up-gradient in order to eliminate pumping needs

Site Factors
- Water table to bedrock depth – N/A (although must be considered for subsurface systems)
- Soils – N/A
- Slope – N/A
- Potential hotspots – Yes with treatment
- Max. drainage area – N/A

Benefits
- Provides supplemental water supply
- Wide applicability
- Reduces potable water use
- Related cost savings and environmental benefits

Limitations
- Manages only relatively small storm events which requires additional management and use for the stored water.

* Depends on site design

Case Study: Stormwater Capture with an Underground Cistern

Fairmount Square, Grand Rapids, MI

All of the stormwater that falls onto Fairmount Square is handled onsite rather than at the municipal storm sewer. This four-acre site consists of a building, a new four-bay commercial building, and 37 town homes.

Several different LID techniques are used to manage all stormwater onsite, including rainwater capture, porous pavement, and rain gardens. The stormwater from the roofs of two buildings on Cherry Street in Fairmount Square is captured in an underground cistern and used to water the formal gardens and parking lot landscape. The cistern holds 30,000 gallons of water (up to two weeks of rainfall) and is 10’ x 15’ x 15’9” in size. A pump inside the cistern pumps rainwater to the formal garden area at the entrance to the Inner City Christian Federation building. The estimated savings using this cistern instead of standard irrigation is 1,340.3 cubic feet of water per year.

Maintenance activities and associated costs are minimal, as the cistern only requires periodic pump maintenance, which is contracted out as needed.

Underground cistern tank
Source: Fishbeck, Thompson, Carr, & Huber, Inc.

Case Study Site Considerations	
Project Type	Underground cistern
Estimated Total Project Cost	$40,269
Maintenance Responsibility	Contracted out as needed
Project Contact	Deb Sypien, Rockford Construction Company 616-285-8100 Rick Pulaski, Nederveld Inc. 616-575-5190

Description and Function

Capture reuse is the practice of collecting rainwater in a container and reusing it in the future. Other terms for this BMP include *storage/reuse, rainwater harvesting, and rainwater catchment system*.

This structural BMP reduces potable water needs while simultaneously reducing stormwater discharges. When rain barrels or cisterns are full, rooftop runoff should be directed to drywells, planters, or bioretention areas where it will be infiltrated.

Variations

Rain barrel

Commonly, rooftop downspouts are connected to a rain barrel that collects runoff and stores water until needed for a specific use. Rain barrels are often used at individual homes where water is reused for garden irrigation, including landscaped beds, trees, or other vegetated areas. Other uses include commercial and institutional facilities where the capacity of stormwater can be captured in smaller volume rain barrels.

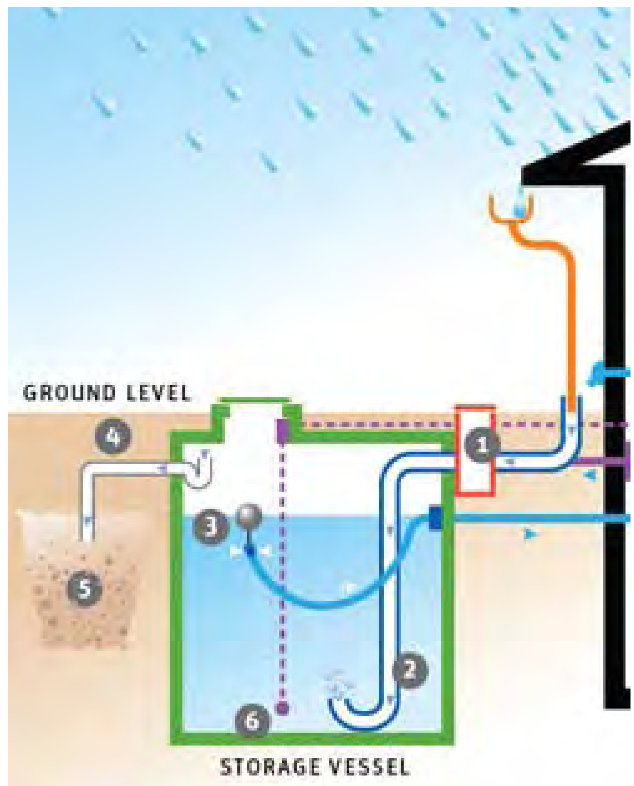
Residential rain barrel

Source: Harley Ellis Devereaux

Cisterns

A cistern is a container or tank that has a greater storage capacity than a rain barrel. Typically, cisterns are used to supplement greywater needs (i.e., toilet flushing, or some other sanitary sewer use) though they can also be used for irrigation. Cisterns may be comprised of fiberglass, concrete, plastic, brick, or other materials and can be located either above or below ground. The storage capacity of cisterns can range from 200 gallons to 10,000 gallons. Very large cisterns, essentially constructed like an underground parking level, can also be used. Figure 7.16 highlights the typical components of a cistern.

Figure 7.16
Typical cistern components



Source: This image generously provided by www.starkenviornmental.com/a-0-rainwater.html

Figure Description:

1. Filter/screening mechanism to filter runoff
2. Inflow into cistern
3. Intake for water use
4. Cistern overflow
5. Subsequent stormwater system (infiltration system in this case) for cistern overflow
6. Optional level gauge

Ford Rouge Plant cistern

Vertical storage

A vertical storage container is a structure designed to hold a large volume of stormwater drained from a large impervious area and is the largest of the capture reuse containers. The use of these structures is a function of drainage area and water needs. Vertical structures are best used for intensive irrigation needs or even fire suppression requirements, and should be designed by a licensed professional. These storage systems can be integrated into commercial sites where water needs may be high.

Storage beneath structure

Stormwater runoff can be stored below ground under pavement and landscaped surfaces through the use of structural plastic storage units and can supplement onsite irrigation needs. These structures can provide large storage volumes without the need for additional structural support from the building.

Designing a capture reuse system in which the storage unit is underground is best used in institutional or commercial settings. This type of subsurface storage is larger, more elaborate, typically designed by a licensed professional, and requires pumps to connect to the irrigation system.

Applications

Capture reuse containers can be used in urbanized areas where the need for supplemental onsite irrigation or other high water use exists. Areas that would benefit from using a capture reuse container include:

- Parking garage,
- Office building,
- Residential home or building, and
- Other building use (commercial, light industrial, institutional, etc.).

Vertical storage units for vegetated roof plaza maintenance are common in Germany

Underground cistern at Lawrence Technological University
Source: Lawrence Technological University

Rainstore™ cistern beneath brick pavers on a vegetated roof-top plaza at University of North Carolina – Chapel Hill

Design Considerations

Design and installation procedures for capture reuse containers can vary from simple residential rain barrels to highly engineered underground systems in ultra-urban areas. Table 7.5 provides general information on cistern holding capacity. The following procedures should be considered when designing sites with capture reuse containers.

1. Identify opportunities where water can be reused for irrigation or indoor greywater reuse and then calculate the water need for the intended uses. For example, if a 2,000 square foot landscaped area requires irrigation for four months in the summer at a rate of one inch per week, the designer must determine how much water will be needed to achieve this goal (1,250 gallons per week, approximately 22,000 gallons for the season), and how often the storage unit will be refilled with precipitation. The usage requirements and the expected rainfall volume and frequency must be determined.

Table 7.5
Round cistern capacity (Gallons)

Height (feet)	6-foot Diameter	12-foot Diameter	18-foot Diameter
6	1,269	5,076	11,421
8	1,692	6,768	15,227
10	2,115	8,460	19,034
12	2,538	10,152	22,841
14	2,961	11,844	26,648
16	3,384	13,535	30,455
18	3,807	15,227	34,262
20	4,230	16,919	38,069

Source: The Texas Manual on Rainwater Harvesting

2. Rain barrels and cisterns should be positioned to receive rooftop runoff.
3. If cisterns are used to supplement greywater needs, a parallel conveyance system must be installed to separate greywater from other potable water piping systems. Do not connect to domestic or commercial potable water system.
4. Consider household water demands (Table 7.6) when sizing a system to supplementing residential greywater use.

Table 7.6.
Household water demand chart

Fixture	Use	Flow Rate
Toilet	# flushes per person per day	1.6 gallons per flush (new toilet)
Shower	# minutes per person per day (5 minutes suggested max.)	2.75 gallons per minute (restricted flow head)
Bath	# baths per person per day	50 gallons per bath (average)
Faucets	Bathroom and kitchen sinks	10 gallons per day
Washing Machine	# loads per day	50 gallons per load (average)
Dishwasher	# loads per day	9.5 gallons per load

Source: Philadelphia Stormwater Manual

5. Discharge points and storage units should be clearly marked "Caution: Untreated Rainwater, Do Not Drink."
6. Screens should be used to filter debris from runoff flowing into the storage units. Screens should be made of a durable, non-corrodible material and be easily maintainable.
7. Protect storage elements from direct sunlight by positioning and landscaping. Limit light into devices to minimize algae growth.
8. The proximity to building foundations should be considered for overflow conditions. The minimum setback distance for capture and reuse systems is 10 feet.
9. If the capture and reuse system or any elements of the system are exposed to freezing temperatures, then it should be emptied during the winter months to prevent ice damage.
10. Cisterns should be watertight (joints sealed with nontoxic waterproof material) with a smooth interior surface.
11. Covers and lids should have a tight fit to keep out surface water, insects (mosquitoes), animals, dust, and light.

12. Release stored water between storm events for the necessary storage volume to be available.
13. Positive outlet for overflow should be provided a few inches from the top of the cistern and sized to safely discharge the appropriate design storms when the cistern is full.
14. Rain barrels require a release mechanism in order to drain empty between storm events. Connect a soaker hose to slowly release stored water to a landscaped area.
15. Observation risers should be at least six inches above grade for buried cisterns.
16. Reuse may require pressurization. Water stored has a pressure of 0.43 psi per foot of water elevation. A 10-foot tank when full would have a pressure of 4.3 psi (0.43*10). Most irrigation systems require at least 15 psi. To add pressure, a pump, pressure tank, and fine mesh filter can be used, while this adds to the cost of the system, it makes the system more versatile and therefore practical.
17. Capture/reuse can also be achieved using a subsurface storage reservoir which provides temporary storage of stormwater runoff for reuse. The stormwater storage reservoir may consist of clean uniformly graded aggregate and a waterproof liner or pre-manufactured structural stormwater storage units.

Stormwater Functions and Calculations

Volume reduction

In order to keep storage costs to a minimum, it makes sense to size the storage tank so that it does not greatly exceed the water need. Where this is done, especially where a high-volume demand greatly exceeds runoff (e.g., irrigation or industrial makeup water), then runoff volume reduction for a particular storm can be assumed to equal the total volume of storage.

Where the captured water is the sole source for a particular operation (e.g., flushing toilets) the user does not want the stored water to be depleted before the next runoff event that replenishes it. In that case, the appropriate volume to store will be relatively easy to calculate based on the daily water need. After water need is determined, use the table below to choose which structure will be large enough to contain the amount of water needed. The amount replenished by a particular storm is equal to the volume reduction.

Additional Volume Reduction Considerations

For storage vessels that are not drained down completely before the next runoff event, the volume available to be filled by a particular storm may be difficult to calculate. Typical LID sizing criteria is based on the volume that goes to storage during a particular storm. That volume can be subtracted from the runoff volume, and the designer/developer can size the storage unit to achieve the targeted volume reduction. But sizing criteria under these capture and reuse circumstances may become need based. The designer/builder may estimate the volume removal for a particular storm, but estimates should be realistic given the use rate and storm runoff frequency. The estimate can be based on an average available storage capacity or preferably on a water balance analysis based on actual rainfall statistics.

Available Volume for Capture (gallons) = Runoff Coefficient (unitless) x Precip (inches) x Area (SF) x 1 foot/12 inches x 7.4805 gallons/1 cubic foot

OR

$$V = 0.62 \times C \times P \times A$$

Where

V = available volume for capture (gallons)

0.62 = unit conversion (gal/in./square foot)

C = volumetric runoff coefficient (unitless), typically 0.9 to 0.95 for impervious areas

P = precipitation amount (inches)

A = drainage area to cistern (square feet)

Sizing the tank is a mathematical exercise that balances the available collection (roof) area, annual rainfall, intended use of rainwater and cost. In other words, balance what can be collected against how the rainwater will be used and the financial and spatial costs of storing it. In most areas of the country, it's possible to collect 80 percent of the rain that falls on the available roof area. (The 20 percent reduction accounts for loss due to mist and heavy storms that release more rain than the tank can accommodate.) (www.starkenvironmental.com/downloads/Interface_Engineering.pdf) That level of capture would yield approximately 500 gallons per inch of rain per 1000 SF of capture area. Table 7.7 includes available capture volumes based on drainage area and annual rainfall.

Peak rate mitigation

Overall, capture and reuse takes a volume of water out of site runoff and puts it back into the ground. This reduction in volume will translate to a lower overall peak rate for the site.

Water quality improvement

Pollutant removal takes place through filtration of recycled primary storage, and/or natural filtration through soil and vegetation for overflow discharge. Quantifying pollutant removal will depend on design. Sedimentation will depend on the area below the outlet that is designed for sediment accumulation, time in storage, and maintenance frequency. Filtration through soil will depend on flow draining to an area of soil, the type of soil (infiltration capacity), and design specifics (stone bed, etc.).

Maintenance

Rain barrels

- Inspect rain barrels four times per year, and after major storm events.
- Remove debris from screen as needed.
- Replace screens, spigots, downspouts, and leaders as needed.
- To avoid damage, drain container prior to winter, so that water is not allowed to freeze in devices.

Table 7.7
Annual rainfall yield (in gallons) for impervious surfaces

Annual Rainfall Yield in Gallons for Various Impervious Surface Sizes and Rainfall Amounts								
Impervious Surface Area (sf)	Rainfall (inches)							
	26	28	30	32	34	36	38	40
200	3,079	3,316	3,553	3,790	4,027	4,264	4,501	4,738
400	6,159	6,633	7,106	7,580	8,054	8,528	9,002	9,475
600	9,238	9,949	10,660	11,370	12,081	12,792	13,502	14,213
800	12,318	13,265	14,213	15,160	16,108	17,056	18,003	18,951
1,000	15,397	16,582	17,766	18,951	20,135	21,319	22,504	23,688
1,200	18,477	19,898	21,319	22,741	24,162	25,583	27,005	28,426
1,400	21,556	23,214	24,873	26,531	28,189	29,847	31,505	33,164
1,600	24,636	26,531	28,426	30,321	32,216	34,111	36,006	37,901
1,800	27,715	29,847	31,979	34,111	36,243	38,375	40,507	42,639
2,000	30,795	33,164	35,532	37,901	40,270	42,639	45,008	47,377
2,200	33,874	36,480	39,086	41,691	44,297	46,903	49,508	52,114
2,400	36,954	39,796	42,639	45,481	48,324	51,167	54,009	56,852
2,600	40,033	43,113	46,192	49,272	52,351	55,431	58,510	61,589
2,800	43,113	46,429	49,745	53,062	56,378	59,694	63,011	66,327
3,000	46,192	49,745	53,299	56,852	60,405	63,958	67,512	71,065
3,200	49,272	53,062	56,852	60,642	64,432	68,222	72,012	75,802
3,400	52,351	56,378	60,405	64,432	68,459	72,486	76,513	80,540
3,600	55,431	59,694	63,958	68,222	72,486	76,750	81,014	85,278
3,800	58,510	63,011	67,512	72,012	76,513	81,014	85,515	90,015

* Values represent the following percentage of precipitation (i.e., runoff coefficient) to account for losses: 95%

Cisterns

- Flush cisterns annually to remove sediment.
- Brush the inside surfaces and thoroughly disinfect twice per year.
- To avoid damage, drain container prior to winter, so that water is not allowed to freeze in devices.

Cost

Both rain barrels and cisterns are assumed to have a life span of 25 years.

	Capacity	Cost Range
Rain barrel	40-75 gal.	$100-$250
Cistern	200-10,000 gal.	Varies by manufacturer and material
Vertical storage	64-12,000 gal	$100-$11,000

Residential rain barrel with soaker hose

Source: http://www.urbangardencenter.com/index.html

Designer/Reviewer Checklist for Capture Reuse

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?				

* These items primarily relate to larger systems, not residential rain barrels.

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BMP Fact Sheet

Constructed Filter

Constructed filters are structures or excavated areas containing a layer of sand, compost, organic material, peat, or other media that reduce pollutant levels in stormwater runoff by filtering sediments, metals, hydrocarbons, and other pollutants. Constructed filters are suitable for sites without sufficient surface area available for bioretention.

Installation of a sand filter
Source: Rouge River National Wet Weather Demonstration Project

Applications		Stormwater Quantity Functions	
Residential	Limited	**Volume**	Low/High*
Commercial	Yes	**Groundwater Recharge**	Low/High*
Ultra Urban	Yes	**Peak Rate**	Low/High*
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	High**
Highway/Road	Yes	**TP**	Medium**
Recreational	Yes	**TN**	Medium**
		Temperature	Low

Additional Considerations	
Cost	Med/High
Maintenance	High
Winter Performance	Medium

* Function is low without infiltration and increases when infiltration is provided

** Sand filters only (For filters with infiltration, see Subsurface Infiltration Bed section, or other infiltration BMP sections. For manufactured systems, see manufacturer's information, as well as results from independent verification.)

Variations

- Surface non-vegetated
- Vegetated
- Infiltration
- Contained
- Linear perimeter
- Small subsurface
- Large subsurface
- Manufactured filtration systems

Key Design Features

- Depth of filtering medium 18-30"
- Surface ponding should drain down within 72 hours (3-6" ponding depth)
- May be designed to infiltrate
- May require pretreatment for debris and sediment
- Some systems require sufficient head (2-6 feet)
- Flow splitter or positive overflow required to bypass large storms
- Requires minimum permeability of filtration medium
- Underdrains may be needed if infiltration is infeasible

Site Factors

- Water table to bedrock depth – N/A
- Soils – N/A
- Slope – N/A
- Potential hotspots - Yes
- Max. drainage area – 5 acres

Benefits

- Good water quality performance
- Lots of variations for a variety of applications
- Can be used effectively as pretreatment for other BMPs

Limitations

- Limited water quantity benefits
- Relatively high cost
- High maintenance needs

Case Study: Constructed Linear Sand Filter

City of Wayne, MI

This BMP is a two-chambered linear concrete structure that improves water quality by providing sedimentation and filtration to the stormwater runoff. The site for this BMP serves a 0.9 acre parking lot at two senior citizen housing complexes in the City of Wayne, Michigan. The drainage area to the filter is approximately 0.8 acres. This filter inflow is a sheet flow from the parking lot through a linear steel grating.

The filter consists of two chambers. The first chamber is a sedimentation chamber, and the second is the filtration chamber. Runoff enters the filter structure through grates located in the parking lot next to an existing curb. The runoff overflows the weir between the two chambers and passes through an 18-inch sand filtration layer and a four- inch gravel drain bed. A four-inch perforated collector pipe runs along the length of the gravel layer to collect the filtered runoff. Geotechnical filter fabric is installed between the sand and the gravel layers. There is a clearwell chamber in the downstream side of the structure to capture the filtered runoff from the perforated pipe and the overflow runoff from the filter overflow weir.

The available depth of storage volume above the filtering material on this site is 1.8 feet. The width of the two chambers was fixed at 2 feet each. The design filtering material permeability is 3.5 ft/day. The maintenance of the filter includes cleaning the filtering material, and possibly replaced, if the treatment rate of the filter media becomes unacceptable due to clogging. In addition, the sedimentation chamber must be cleaned as required depending on the volume of sediments in the chamber.

Sand filter in the City of Wayne, MI

Source: Wayne County Department of Environment

Case Study Site Considerations	
Project Type	Constructed filter
Estimated Total Project Cost	$10,000
Maintenance Responsibility	Wayne County
Project Contact	Razik Alsaigh, 313-967-2283

Applicability of sand filters in the Rouge River Watershed is considered to be substantial. Sand filters could be installed in fully-developed areas in which land for more conventional and less expensive BMPs is unavailable. Example locations could include small convenience stores, industrial sites, small tributaries to lakes, and other identified problem areas.

Description and Function

A constructed filter is a structure or excavation filled with material that filters stormwater runoff to remove particulate matter and the pollutants attached to it. The filter media may be comprised of materials such as sand, peat, compost, granular activated carbon (GAC), perlite, or inorganic materials. In some applications the stormwater runoff flows through an unfilled "pretreatment" chamber to allow the large particles and debris to settle out. Surface vegetation is another good option for pretreatment, as long as it is extensive enough to protect the filter from sediment during large storm events. The runoff then passes through the filter media where additional pollutants are filtered out, and is collected in an underdrain and returned to the conveyance system, receiving waters, or infiltrated into the soil. In general, constructed filters are best applied at sites without sufficient surface area available for bioretention.

Variations

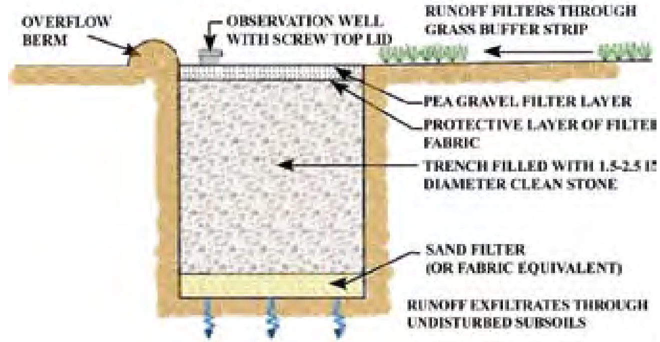
There are a wide variety of constructed filter applications, including surface and subsurface, vegetated, and with or without infiltration. There are also a variety of manufactured filter products that may be purchased (see water quality devices BMP). In general, constructed filters consist of some, if not all, of the following components: excavation or container for media, pretreatment, flow entrance/inlet, surface storage (ponding area), filter media, underdrain (if necessary), and positive overflow. Examples of these variations include:

- Surface non-vegetated filter,
- Surface vegetated filter,
- Surface contained filter,
- Surface linear "perimeter" filter,
- Small subsurface filter, and
- Large subsurface filter.

Surface Infiltration Filter

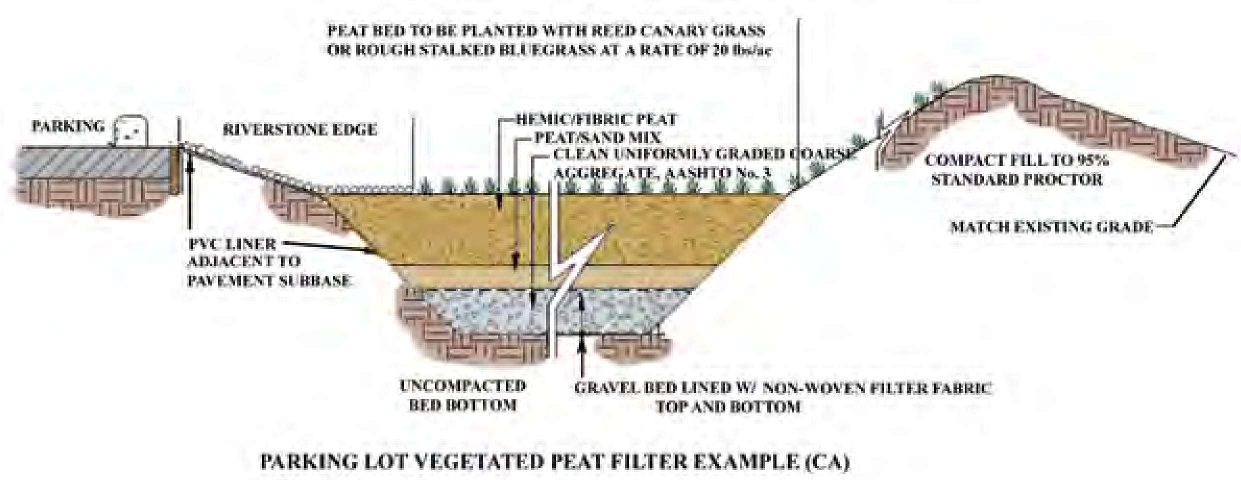
Filters may be designed to allow some or all of the treated water to infiltrate. Infiltration design criteria apply for all filters designed (Figure 7.18) with infiltration. In all cases, a positive overflow system is recommended.

Figure 7.18
Filter with infiltration to subsoils



Source: Pennsylvania Stormwater BMP Manual

Figure 7.17
Vegetated peat filter adjacent to a parking lot



Source: Pennsylvania Stormwater BMP Manual

Surface non-vegetated filter

A surface non-vegetated filter is constructed by excavation or by use of a structural container. The surface may be covered in gravel, sand, peat, river stone, or similar material.

Sand filter under construction
Source: University of Minnesota, NERC

Surface vegetated filter

A layer of vegetation is planted on top of the filtering medium (Figure 7.17). Compost-amended soil may serve as a filter medium. (See soil restoration BMP for precautions about compost materials, to prevent exporting phosphorus from the filter.) For filters composed of filtering media such as sand (where topsoil is required for vegetation), a layer of nonwoven, permeable geotextile should separate the topsoil and vegetation from the filter media.

Surface contained filter

In contained filters, infiltration is not incorporated into the design. Contained filters may consist of a physical structure, such as a precast concrete box, or they may be excavated chambers or trenches. For excavated contained filters, an impermeable liner is added to the bottom of the excavation to convey the filtered runoff downstream.

Surface contained filter
Source: Portland, OR BMP Manual

Surface linear "perimeter" filter

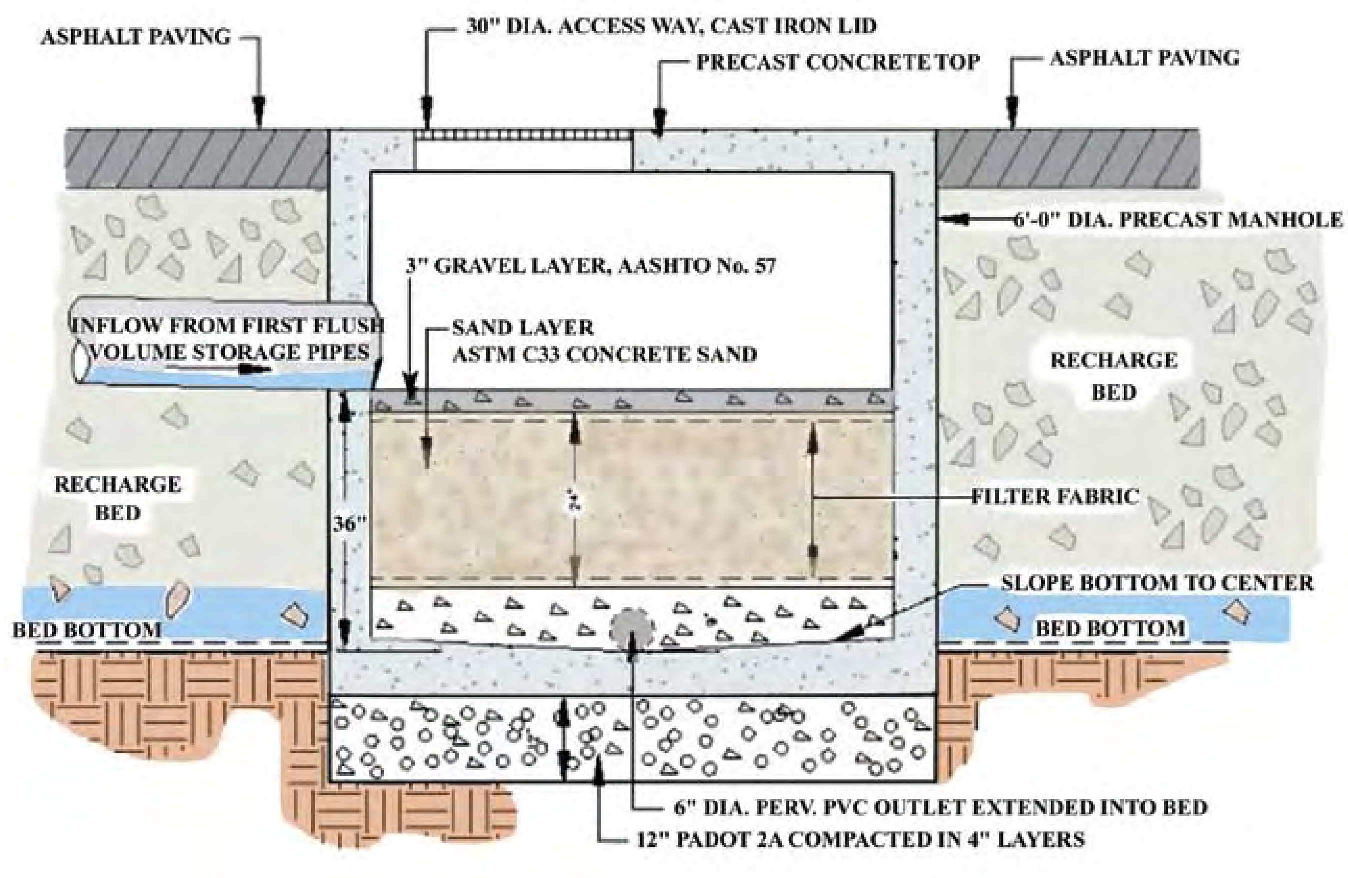
Perimeter filters may consist of enclosed chambers (such as trench drains) that run along the perimeter of an impervious surface. Perimeter filters may also be constructed by excavation, and be vegetated. All perimeter filters must be designed with the necessary filter medium and sized in accordance with the drainage area.

Linear perimeter filter in trench drain
Source: Georgia Stormwater BMP Manual

Small subsurface filter

A small subsurface filter (Figure 7.19) is an inlet designed to treat runoff at the collection source. Small subsurface filters are useful for hot spot pretreatment and are similar in function to water quality inlets/inserts. Small subsurface filters must be carefully designed and maintained so that runoff is directed through the filter media (see design considerations).

Figure 7.19
Small subsurface filter

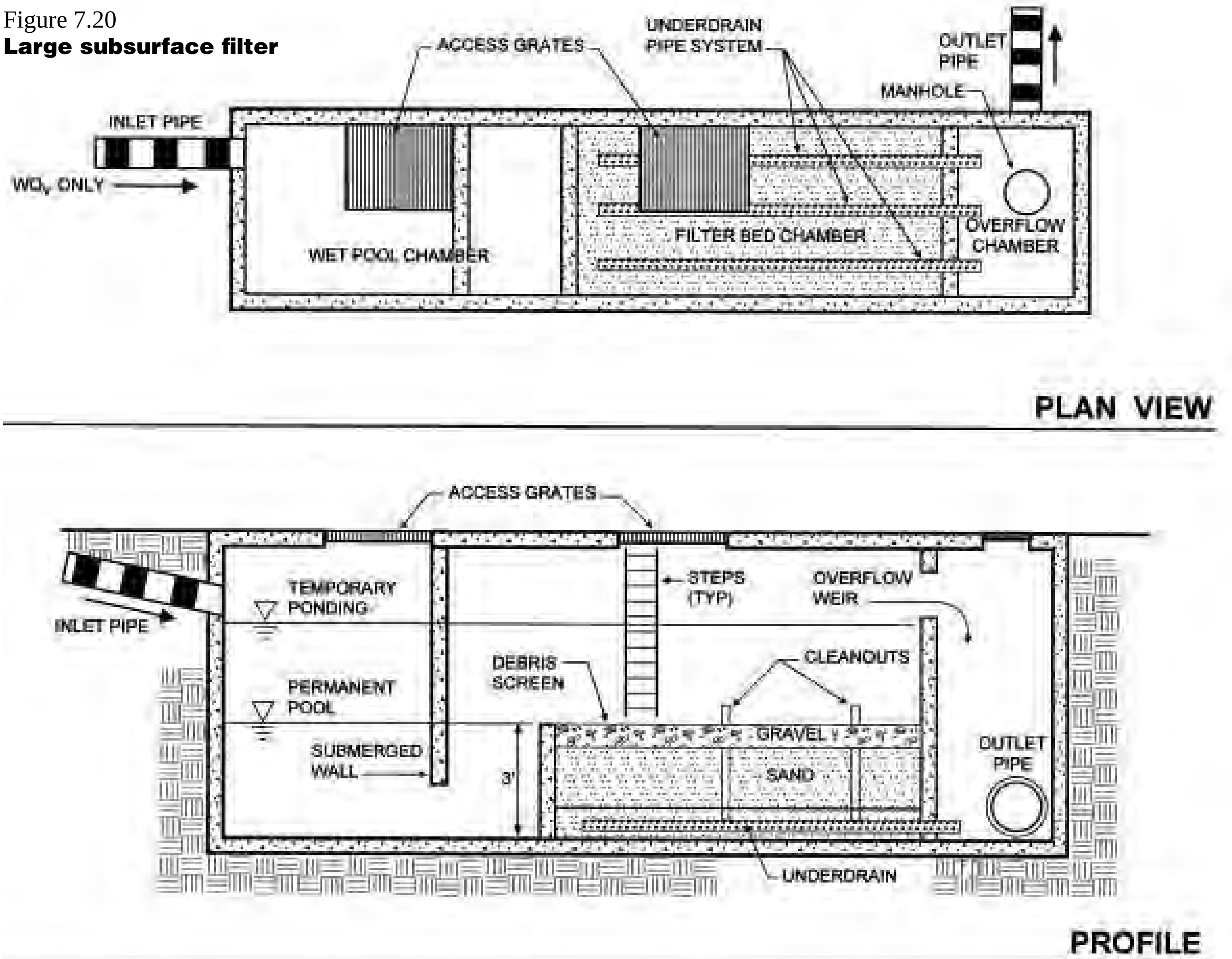


Source: Pennsylvania Stormwater BMP Manual

Large subsurface filter

Large Subsurface filters (Figure 7.20) receive relatively large amounts of flow directed into an underground box that has separate chambers. One chamber settles large particles, and the other chamber contains media to filter small particles. The water discharges through an outlet pipe and into the stormwater system.

Figure 7.20
Large subsurface filter



Source: New York Stormwater BMP Manual

Applications

Constructed filters can be used in a wide variety of applications, from commercial/industrial developments to ultra-urban sites and even transportation projects. Their application in residential settings, especially low-density residential, can be limited because they require extensive maintenance. Moreover, other BMPs are more cost effective for stormwater management in residential projects (constructed filters are generally used for areas with high impervious cover).

Filters are applicable in urban areas of high pollutant loads and are especially applicable where there is limited area for constructing BMPs. Filters may be used as a pretreatment BMP for other BMPs such as wet ponds or infiltration systems, but input to many filters also requires pretreatment to reduce large settled particulates or debris.

Filters may be used in hot spot areas for water quality treatment, and spill containment capabilities may be incorporated into a filter. Examples of typical areas that benefit from the use of a constructed filter include:

- Parking lots,
- Roadways and highways,
- Light industrial sites,
- Marina areas,
- Transportation fueling and maintenance facilities,
- Fast food and shopping areas,
- Waste transfer stations, and
- Urban streetscapes.

Design Considerations

1. All constructed filters must be designed so that larger storms may safely overflow or bypass the filters. Flow splitters, multi-stage chambers, or other devices may be used. A flow splitter may be necessary to allow only a portion of the runoff to enter the filter. This would create an "off-line" filter, where the volume and velocity of runoff entering the filter is controlled. If the filter is "on-line", excess flow should be designed to bypass the filter and continue to another water quality BMP.
2. **Entering velocity must be controlled**. A level spreader may be used to spread flow evenly across the filter surface during all storms without eroding the filter material. Level spreaders for this purpose should use a concrete lip or other non soil material to avoid clogging as a result of failure of the level spreader lip. Parking lots may be designed to sheet flow into filters. Small rip-rap or landscaped riverstone edges may be used to reduce velocity and distribute flows more evenly.
3. Contributing areas must be **stabilized** with vegetation or other permanent soil cover before runoff enters filters. Permanent filters should not be installed until the site is stabilized. Excessive sediment generated during construction can clog the filter and prevent or reduce the anticipated post-construction water quality benefits.
4. **Pretreatment** may be necessary in areas with especially high levels of debris, large settled particulates, etc. Pretreatment may include a forebay, oil/grit separators, vegetated filter strips, or grass swales. These measures will settle out the large particles and reduce velocity of the runoff before it enters the filter. Regular maintenance of the pretreatment is critical to avoid wastes being flushed though and causing the filter to fail.
5. There should be sufficient space (head) between the top of the filtering bed and the overflow of the filter to allow for the maximum head designed to be stored before filtration
6. The **filter media** may be a variety of materials (sand, peat, GAC, leaf compost, pea gravel, etc) and in most cases should have a minimum depth of 18 inches and a maximum depth of 30 inches, although variations on these guidelines are acceptable if justified by the designer. Coarser materials allow for greater hydraulic conductivity, but finer media filter particles of a smaller size.

   Sand has been found to provide a good balance between these two criteria, but different types of media remove different pollutants. While sand is a reliable material to remove total suspended solids, peat removes slightly more total phosphorous, copper, cadmium, and nickel than sand (Debusk and Langston, 1997).

   The filter media should have a minimum hydraulic conductivity (k) as follows:

   - Sand 3.5 feet/day
   - Peat 2.5 feet/day
   - Leaf compost 8.7 feet/day

   Depending on the characteristics of the stormwater runoff, a combination of filter materials will provide the best quality results. In addition to determining the degree of filtration, media particle size determines the travel time in the filter and plays a role in meeting release rate requirements.

   Sand filtration enhanced with steel wool, calcareous sand, or limestone provides a practical and cost-effective method for reducing levels of dissolved phosphorus (Erickson et al, Journal of Environmental Engineering, 2007). Sand enhanced with steel wool fabric proved especially effective, removing between 25 percent and 99 percent of dissolved phosphorus and enhancing the quantity and duration of phosphorous retention as compared to sand alone. Sand enhanced with calcareous sand or limestone exhibited signs of clogging in the Erickson et al study. The study also found that enhancing sand filtration with steel wool fabric would modestly increase construction costs by approximately three to five percent As with other sand filtration systems, steel-enhanced sand filters should be sized and installed according to local guidelines, with consideration given to proper pretreatment for influent solids, as necessary.

7. A **gravel layer** at least six inches deep is recommended beneath the filter media.

8. **Underdrain piping** should be four-inch minimum (diameter) perforated pipes, with a lateral spacing of no more than 10 feet. A collector pipe can be used, (running perpendicular to laterals) with a slope of one percent. All underground pipes should have clean-outs accessible from the surface. Underdrain design must minimize the chance of clogging by including a pea gravel filter of at least three inches of gravel under the pipe and six inches above the pipe.

9. Infiltration filters should be underlain by a layer of permeable nonwoven geotextile.

10. A total **drawdown time** of not more than 72 hours is recommended for constructed filters, though the surface should drawdown between 24 and 48 hours. The drawdown time can be estimated using the filter surface area and the saturated vertical infiltration rate of the filter media. If the storage does not drawdown in the time allowed, adjust pretreatment depth, filter media depth, and surface area. Adjust the design until the volume (if applicable) and drainage time constraints are met.

11. The filter **surface area** may be estimated initially using Darcy's Law, assuming the soil media is saturated:

$$A = V \text{ X } d_f /[k \text{ x } (h_f + d_f) \text{ x } t_f]$$

A = Surface area of filter (square feet)

V = Water volume (cubic feet)

d_f = Depth of filter media (min 1.5 ft; max 2.5 ft)

t_f = Drawdown time (days), not to exceed 3 days

h_f = Head (average head in feet; typically ½ of the maximum head on the filter media, which is typically ≤ to 6 ft)

k = Hydraulic conductivity (ft/day)

12. For vegetated filters, a layer of nonwoven geotextile between non-organic filter media and planting media is recommended.

13. Filters, especially those that are subsurface, must be **designed with sufficient maintenance access** (clean-outs, room for surface cleaning, entry space, etc.). Filters that are visible and simple in design are more likely to be maintained correctly. For underground vault heights greater than four feet, ladder access is necessary.

14. In areas where infiltration is infeasible due to a hot spot or unstable fill that threatens an existing structure, specify an **impervious liner**.

Placement of a pipe distribution network in a peat filter
Source: University of Minnesota, NERC

Stormwater Functions and Calculations

Volume reduction

If a filter is designed to include infiltration, the infiltration BMP should be followed. There is minimal, if any, volume reduction for filters that are not designed to infiltrate.

Peak rate mitigation

Constructed filters generally provide little, if any, peak rate reduction. However, if the filter is designed to infiltrate, then medium to high levels of peak rate attenuation can be expected. Also, as stated above, the selected media particle size determines the travel time in the filter and therefore might play a role in meeting release rate requirements. (See Chapter 9, LID Stormwater Calculations and Methodology, for more information on peak rate mitigation).

Water quality improvement

Constructed filters are considered an excellent stormwater treatment practice with the primary pollutant removal mechanism being filtration and settling. Less significant pollutant removal may result from evaporation, transpiration, biological and microbiological uptake, and soil adsorption.

Sand filters have been shown to have a high removal efficiency of Total Suspended Solids (TSS), and medium removal efficiencies for Total Nitrogen (TN) and Total Phosphorus (TP) (Table 7.8). Organic filter media also perform very well for TSS and standard for TP, but perform relatively poorly for TN.

For filters that are also designed to infiltrate, see the water quality summary in the subsurface infiltration bed section, or in the infiltration BMP. For manufactured, proprietary systems, see the manufacturer's information, as well as findings from independent studies consolidated by EPA at: https://nepis.epa.gov/Exe/ZyPDF.cgi/P100170R.PDF?Dockey=P100170R.PDF. Also see Chapter 9, LID Stormwater Calculations and Methodology, which addresses pollutant removal effectivenss of this BMP.

Construction Guidelines

1. Follow the recommended materials for constructed filters listed in Appendix D.
2. Structures such as inlet boxes, reinforced concrete boxes, etc. should be installed in accordance with the guidance of the manufacturers or design engineer.
3. Excavated or structural filters that infiltrate should be excavated in such a manner as to avoid compaction of the subbase. Structures may be set on a layer of clean, lightly compacted gravel (such as AASHTO #57).
4. Place underlying gravel/stone in maximum six-inch lifts and lightly compact. Place underdrain pipes in gravel during placement.
5. Wrap and secure gravel/stone with nonwoven geotextile to prevent clogging with sediments.
6. Lay filtering material. Do not compact.
7. Saturate filter media with water and allow media to drain to properly settle and distribute.

Maintenance

Filters require a regular inspection and maintenance program to maintain the integrity of filtering systems and pollutant removal mechanisms. Studies have shown that filters are very effective upon installation, but quickly decrease in efficiency as sediment accumulates in the filter. Odor is also a concern for filters that are not maintained. Inspection of the filter is recommended at least four times a year.

When a filter has accumulated sediment in its pore space, its hydraulic conductivity is reduced, and so is its ability to removal pollutants. Inspection and maintenance are essential for continued performance of a filter. Based upon inspection, some or all portions of the filter media may require replacement.

Table 7.8

Pollutant removal efficiencies for sand filters

Studies	No. of studies	TSS % Removal		TN % Removal		TP % Removal	
		Range	Median	Range	Median	Range	Median
U.S.*	18	80 - 92	86	30-47	32	41-66	59
International**	38		75		44		45
Organic media*	N/A	85-100		poor		50-85	

*The Center for Watershed Protection, in its National Pollutant Removal Performance Database – Version 3 (September 2007)

**The International Stormwater Best Management Practices (BMP) Database, October 2007

During inspection the following conditions should be considered:

- **Standing water** – any water left in a surface filter after the design drain down time indicates the filter is not functioning according to design criteria.
- **Film or discoloration** of any surface filter material – this indicates organics or debris have clogged the filter surface.

A discolored film on top of a sand filter indicates the need for maintenance

Source: California Stormwater BMP Handbook, New Development and Redevelopment, 2003

- Remove trash and debris as necessary
- Scrape silt with rakes, if collected on top of the filter
- Till and aerate filter area
- Replenish filtering medium if scraping/removal has reduced depth of filtering media
- Repair leaks from the sedimentation chamber or deterioration of structural components
- Clean out accumulated sediment from filter bed chamber and/or sedimentation chamber
- Clean out accumulated sediment from underdrains

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 Considerations

Michigan's winter temperatures can go below freezing four to five months out of every year and surface filtration does not work as well in the winter. Peat and compost may hold water freeze, and become relatively impervious on the surface. Design options that allow directly for subsurface discharge into the filter media during cold weather may overcome this condition. Otherwise, the reduced performance when the filter media may be temporarily frozen should be considered.

There are various filtration options available for treating snowmelt runoff. In some cases, installations are built below the frost line (trenches, subgrade proprietary chambers) and do not need further adaptation for the cold. However, some special consideration is highly recommended for surface systems.

The main problem with filtration in cold weather is the ice that forms both over the top of the facility and within the soil. To avoid these problems to the extent possible, it is recommended that the facility be actively managed to keep it dry before it freezes in the late fall. Additional modifications, such as increasing the size of underdrains to eight inches, increasing the slope of the underdrains to one percent, and increasing the thickness of the gravel layer to at least 12 inches can prevent freezing and are recommended by EPA.

Proprietary, subsurface filter systems provide an alternative to standard surface-based systems. Essentially, these systems provide an insulated (i.e., subsurface) location for pre-treated snowmelt to be filtered. The insulating value of these systems adds to their appeal as land conserving alternatives to ponds and surface infiltration basins.

Cost

Filter costs vary according to the filtering media (sand, peat, compost), land clearing, excavation, grading, inlet and outlet structures, perforated pipes, encasing structure (if used), and maintenance cost. Underground structures may contribute significantly to the cost of a filter. In general, filters are relatively costly and maintenance-intensive BMPs.

Underground sand filters are generally considered to be a high-cost option for water quality management. In 1994, the construction cost was estimated from $10,000 to $14,000 per impervious acre served, excluding real estate, design, and contingency costs (Schueler, 1994).

In ultra-urban areas where land costs are high, however, underground sand filters can represent significant cost savings in reduced land consumption. For small ultra-urban areas with no land available, they may be the only practical option for stormwater quality treatment as they can be placed under roads or parking lots.

In recent years, various manufacturers have made available prefabricated units that include precast vaults and inlets delivered to the site either partially or fully assembled. These units have generally resulted in decreased construction costs. Typical significant cost variables include the location of subsurface utilities, type of lids and doors, customized casting of weirs, sections, or holes, and depth of the vault.

The surface sand filter design is a moderately expensive water quality option to employ (Claytor and Schueler, 1996). However, the cost of installation is strongly correlated with the nature of the construction employed. If the filter is installed within an ultra-urban setting, it is likely that relatively expensive concrete walls will be used to create the various chambers. This type of installation will be significantly more expensive than an earthen-walled design, where relatively inexpensive excavation and compaction construction techniques lower the installation cost. However, earthen-wall designs require a greater land area commitment, which can offset the reduction in construction costs.

The construction cost of surface sand filters is also related to economies of scale: the cost per impervious acre served typically decreases with an increase in the service area. In 1994, the construction costs for surface sand or organic media filters were $16,000 per impervious acre for facilities serving less than two acres (Schueler, 1994). Once again, these construction cost estimates exclude real estate, design, and contingency costs.

Designer/Reviewer Checklist for Constructed Filters

Type of constructed filter(s) proposed: ______________________________

Type of filter media proposed: ______________________________

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?				
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?				

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BMP Fact Sheet

Detention Basins

Detention basins are temporary stormwater storage structures that help prevent downstream flooding. The primary purpose of detention basins is the attenuation of stormwater runoff peaks.

Detention basin with a no mow buffer in West Bloomfield Township, MI

Source: Hubbell, Roth, & Clark

Variations

- Dry ponds
- Wet ponds
- Underground detention
- Constructed wetlands
- Bioretention

Key Design Features

- Storage capacity highly dependent on available site area
- Outlet structure configuration determines peak rate reduction effectiveness
- Can be used in combination with other BMPs
- Regular maintenance of vegetation and sediment removal required
- Natural high groundwater table required for wet ponds and constructed wetlands
- Relatively impermeable soils or impermeable liner
- Forebay for sediment collection and removal
- Dewatering mechanism required for wet ponds and constructed wetlands
- Stabilized emergency overflow and energy dissipation at all outlets

Applications	
Residential	Yes
Commercial	Yes
Ultra Urban	Yes
Industrial	Yes
Retrofit	Yes
Highway/Road	Yes
Recreational	Yes

Stormwater Quantity Functions	
Volume	Low
Groundwater Recharge	None or Low
Peak Rate	High

Stormwater Quality Functions

Varies by type as follows:

Type	TSS	TP	TN	Temperature
Dry Pond	Medium	Medium	Low	Low
Wet Pond	High	Medium	Medium	Low/Medium
Constructed Wetland	High	Medium	Medium	Low/Medium
Underground Detention	N/A	N/A	N/A	N/A

Site Factors

Type	Basin Bottom Relative to Water Table	Soils	Slope	Potential Hotspots	Max. Drainage Area (acres)	Benefits	Limitations
Dry Pond	Above	N/A	Low/Med	Yes w/ considerations	50	Good peak rate performance, wide applicability, can be used as temporary sediment basin	Low volume/GW recharge and water quality benefits, must be combined with other BMPs, high total cost
Wet Pond	Can be below WT	C or D*	Low	Yes w/ considerations	50	Good peak rate & TSS performance, wide applicability, potential aesthetic value., can be used as temporary sediment basin	Low volume/GW recharge benefits, high total cost, potentially thermal impact
Const. Wetland	Can be below WT	C or D*	Low	Yes w/ considerations	50	Good peak rate & water quality performance, wide applicability, potential aesthetic/ habitat value	Limited volume/GW recharge benefits, high total cost, potentially thermal impact
Underground Detention	Above	N/A	Low/ Med	Yes w/ considerations	30	Dual use, good peak rate performance, wide applicability (including ultra-urban and redev.)	Low volume/GW recharge and water quality benefits, must be combined with other BMPs, high cost, maintenance considerations

*C or D soils typically work without modification. A and B soils may require modifications to reduce their permeability.

Additional Considerations

Cost

- High – Cost for above ground basins must include excavation of basin, construction of berm, and installation of storm sewer conveyance system, including pipes and structures. Wet ponds and constructed wetlands may add additional cost for enhanced vegetation
- The cost of each basin is highly dependent on the size of the basin and site characteristics.

Maintenance

Varies by type as follows:

Type	Maintenance
Dry Pond	High/Low - Year round maintenance for vegetation; one time per year sediment removal
Wet Pond	Low/Med
Constructed Wetland	Low/Med
Underground Detention	Med/High

Winter Performance

- Med/High

Case Study: Inkster Valley Constructed Wetlands Project

Wayne County

This project site is located in the Inkster Valley Golf Course in the City of Inkster, MI. There are a total of seven wetland mitigation and enhancement areas throughout the golf course. The intent of this demonstration project is to determine the effectiveness of, and develop design guidelines for, the use of existing and created freshwater wetlands for treating nonpoint source pollution. The evaluation will include identifying pollutants removed by the wetlands, the efficiency of the removal processes, and the effects of sediments on removal efficiency. Specific objectives of the wetland demonstration project include developing a site selection strategy for assessing the use of existing and restored wetlands and for developing a methodology that would identify feasible locations for designing and constructing new wetlands.

Site selection techniques were developed using an integrated approach, incorporating elements of the ecological features, wetland hydrology, water quality considerations, watershed characteristics, and surrounding land use. The design of the sites incorporated features that allow for manipulating stormwater flow quantity and duration, and allow for directly comparing the effectiveness of nonpoint source pollution control in existing and created wetlands receiving stormwater runoff from a single watershed.

Design criteria for each of the wetland areas were developed from modeled hydrological data combined with characteristics of the available treatment area. The wetland creation and enhancement areas contain similar design elements that provide comparable experimental data which can be related to known design parameters. These elements include using a sediment forebay to filter large particles before the stormwater enters the wetland system; treatment of "first flush" for most storm events; designed discharge outlets to the Rouge River with monitoring capabilities; and intermediate monitoring points where applicable.

Inkster Valley constructed wetland

Source: Rouge River National Wet Weather Demonstration Project

Case Study Site Considerations	
Estimated Total Project Cost	$464,826
Maintenance Responsibility	Wayne County
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Description and Function

Detention basins are surface (or underground) stormwater structures that provide temporary storage of stormwater runoff to prevent downstream flooding. The primary purpose of the detention basin is the attenuation of stormwater runoff peaks. Generally, detention basins may be dry ponds, wet ponds, constructed wetlands, or underground systems.

Dry ponds are earthen structures that provide temporary storage of runoff and release the stored volume of water over time to help reduce flooding. They are constructed either by impounding a natural depression or excavating existing soil, and are intended to enhance the settlement process in order to maximize water quality benefits, while achieving reduced runoff volume.

Wet ponds include a permanent pool for water quality treatment and additional capacity above the permanent pool for temporary storage. The pond perimeter should generally be covered by a dense stand of emergent wetland vegetation. While they do not achieve significant groundwater recharge or volume reduction, wet ponds can be effective for pollutant removal and peak rate mitigation.

Wet ponds can also provide aesthetic and wildlife benefits. Wet ponds require an adequate source of inflow to maintain the permanent water surface. Due to the potential to discharge warm water, wet ponds should be used with caution near temperature-sensitive waterbodies. Properly designed and maintained wet ponds generally do not support significant mosquito populations (O'Meara).

Wet pond in residential area, Troy, MI
Source: City of Troy

Constructed wetlands are shallow marsh systems planted with emergent vegetation designed to treat stormwater runoff. While they are one of the best BMPs for pollutant removal, constructed wetlands can also mitigate peak rates and even reduce runoff volume to a certain degree. They also can provide considerable aesthetic and wildlife benefits. Constructed wetlands use a relatively large amount of space and may require an adequate source of inflow if a permanent water surface is maintained. (Not all constructed wetlands maintain a water surface year round).

Constructed wetland at the Tollgate Center, Lansing, MI
Source: Fishbeck, Thompson, Carr & Huber, Inc.

Underground systems can be provided in a variety of subsurface structural elements, such as underground aggregate-filled beds or vaults, tanks, large pipes, or other fabricated structures placed in aggregate-filled beds in the soil mantle. All such systems are designed to provide runoff peak rate attenuation as their primary function. Regular maintenance is required, because sediment must be removed from the structures within their respective design periods to ensure detention capacity for subsequent rainfall events.

Underground system at Mid Towne Village, Grand Rapids, MI
Source: Driesenga & Associates, Inc.

Variations

For this manual, detention basins are classified into four main types:

- Dry ponds,
- Wet ponds,
- Constructed wetlands,
- Underground detention, and
- Bioretention (see Bioretention BMP for more information).

Additional variations exist within each of the types and some designs may not fit entirely into one classification. Some examples of further variations are described below.

Wet ponds

Wet ponds can be designed as either online or offline facilities. They can also be used effectively in series with other sediment-reducing BMPs, such as vegetated filter strips, swales, and filters. Wet ponds may be a good option for retrofitting existing dry detention basins. Wet ponds are often organized into the following three groups:

- **Wet ponds** primarily accomplish water quality improvement through displacement of the permanent pool and are generally only effective for small inflow volumes (often they are placed offline to regulate inflow).
- **Wet detention ponds** are similar to wet ponds but use extended detention as another mechanism for water quality and peak rate control. (Discussion of wet ponds in this BMP section focuses on wet detention ponds as described above because this tends to be the most common and effective design.)
- **Pocket wet ponds** are smaller wet ponds that serve drainage areas between approximately five and 10 acres and are constructed near the water table to help maintain the permanent pool. They often include extended detention.

Constructed wetlands

Constructed wetlands can be designed as either online (within the stormwater system) or offline facilities. They can be used effectively in series with other flow/sediment reducing BMPs that reduce the sediment load and equalize incoming flows to the constructed wetland. They are a good option for retrofitting existing detention basins and are often organized into the following four groups:

Special Storage

Special detention areas are locations on a site designed primarily for other uses but can also temporarily detain stormwater. By detaining and slowly releasing stormwater, special detention areas can attenuate peak discharge rates. However, they are not effective in either improving water quality or reducing runoff volume. Therefore, special detention areas should be combined with other BMPs that address water quality, quantity, and groundwater recharge.

Variations

- Parking lots - In depressed areas or along curbs by controlling flow at stormwater inlets.
- Rooftops - By restricting flow at scuppers, parapet wall openings, or roof drains.
- Plazas and athletic fields - Recessed areas can be designed with detention through the use of flow control structures and berms.

General design considerations

- Flow control structures should be designed to discharge stored runoff in a timely manner so that the primary use of the area can be restored.
- Storage areas should be adequately sloped towards outlets to ensure complete drainage after storm events.
- Emergency overflows should be designed to prevent excessive depths from occurring during extreme events or if the primary flow control structures become clogged. Emergency overflows must be designed to safely and effectively convey flows away from the special detention area.

25 acre constructed wetland development along M-53 in Romeo, MI

Source: Hubbell, Roth, & Clark

- **Shallow wetlands** are large surface area constructed wetlands that primarily accomplish water quality improvement through displacement of the permanent pool.
- **Extended detention shallow wetlands** are similar to shallow wetlands but use extended detention as another mechanism for water quality and peak rate control.
- **Pocket wetlands** are smaller constructed wetlands that serve drainage areas between approximately five and 10 acres and are constructed near the water table.
- **Pond/wetland** systems are a combination of wet ponds and constructed wetlands.

Although discussion of constructed wetlands in this BMP focuses on surface flow as described above, subsurface flow constructed wetlands can also be used to treat stormwater runoff.

While typically used for wastewater treatment, subsurface flow constructed wetlands for stormwater can offer some advantages over surface flow wetlands, such as improved reduction of total suspended solids and biological oxygen demand. They also can reduce the risk of disease vectors (especially mosquitoes) and safety risks associated with open water. However, nitrogen removal may be deficient (Campbell and Ogden, 1999) if most of the incoming nitrogen is in the form of ammonia. Subsurface flow wetlands are poor converters of ammonia to nitrate (nitrification) but are excellent converters of nitrate to nitrogen gas (denitrification). Perhaps the biggest concern regarding subsurface constructed wetlands is their relatively high cost. They can be two to three times more expensive to construct than surface flow constructed wetlands.

Constructed wetland at Okemos High School
Source: Tetra Tech

Underground detention

These facilities are usually intended for applications on sites where space is limited and are not intended to provide significant water quality treatment. Examples include:

Underground detention beds

Underground detention beds can be constructed by excavating a broad area and filling it with uniformly graded aggregate. Runoff can be stored within the void spaces of the aggregate while the aggregate bed structurally supports overlying land uses.

- Storage design and routing methods are the same as for surface detention basins.
- Underground detention beds may be used where space is limited, but subsurface infiltration is not feasible due to high water table conditions, shallow soil mantle, or poorly draining soils.
- Underground detention beds provide minimal water quality treatment and should be used in combination with a pretreatment BMP.
- Except where runoff is or may become toxic and contamination of soil or the water table below the site is possible, underground detention beds should not be lined with an impervious geomembrane. By not installing a geomembrane, a minimal amount of infiltration may still occur. If infiltration is allowed, proper pretreatment is necessary to avoid polluting groundwater. See the infiltration practices BMP for more information.

Underground vaults

Underground vaults are stormwater storage facilities usually constructed of precast reinforced concrete or a structural high density polyethylene plastic system. Tanks are usually constructed of large diameter metal or plastic pipe. Concrete, metal, or plastic pipes may also be installed with no slope as part of a network designed for storage.

- Storage design and routing methods are the same as for surface detention basins.
- Underground detention beds may be used where space is limited but subsurface infiltration is not feasible due to high water table conditions, a shallow soil mantle, or poorly draining soils.
- Underground vaults provide minimal water quality treatment and should be used in combination with a pretreatment BMP.

Precast concrete vault
Source: American Concrete Industries

Applications

Detention systems can be used in a wide variety of applications when the necessary space is available. Their use is limited in ultra urban areas and some redevelopment projects simply due to a lack of available space (in these cases underground and/or special detention may be used). The following applications can readily use detention systems:

- Residential development,
- Industrial development,
- Commercial development, and
- Urban areas.

Design Considerations

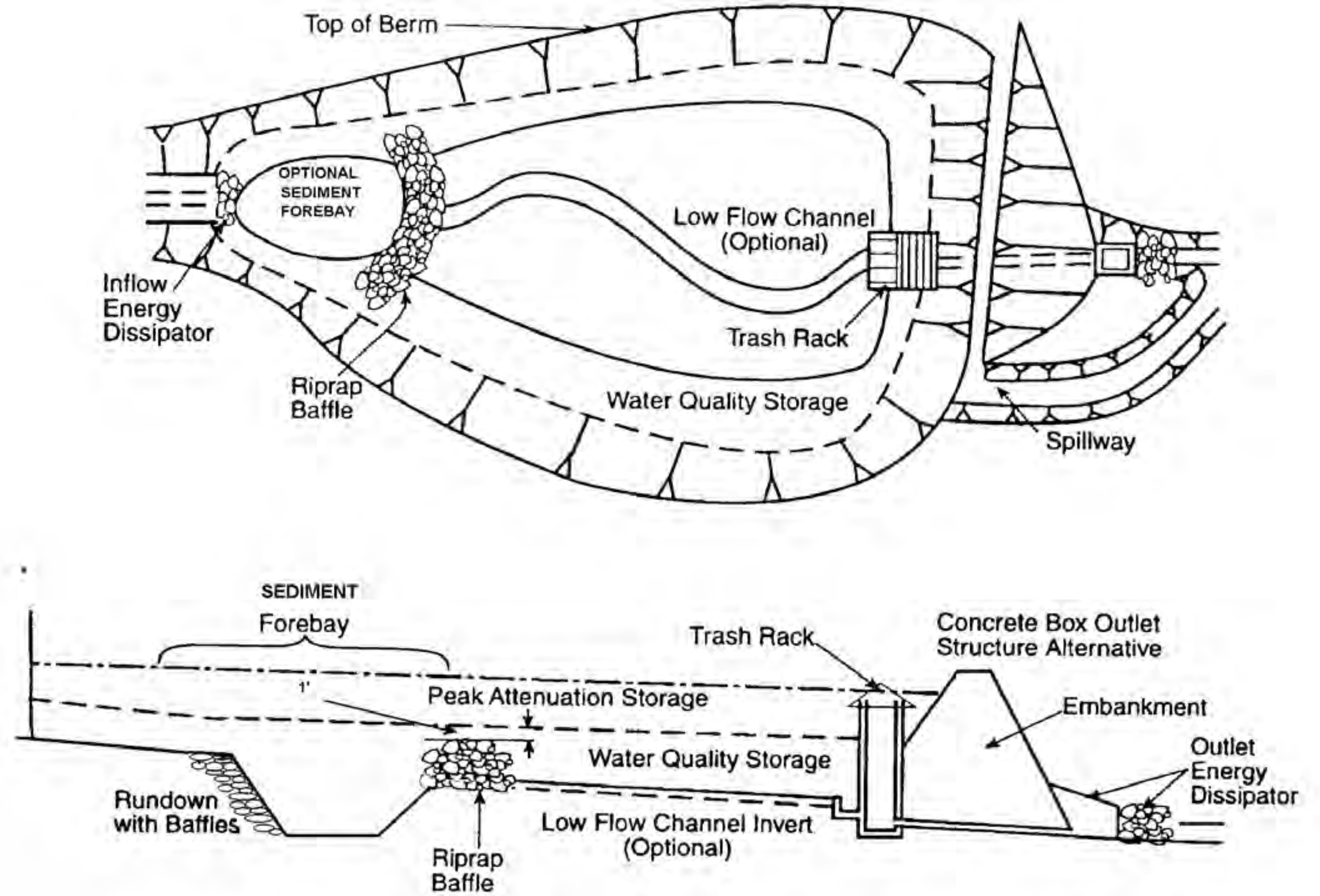
Storage volume, depth, and duration

- Detention basins should be designed to mitigate runoff peak rates for the one-year through 100-year rainfall events.
- An emergency outlet or spillway capable of conveying the spillway design flood (SDF) must be included in the design. The SDF is usually equal to the 100-year design flood.
- Detention basins should be designed to treat the runoff volume produced by the water quality design storm unless additional upstream BMPs are provided.
- Detention time is defined as the time from when the maximum storage volume is reached until only 10 percent of that volume remains in the basin. In order to achieve a 60 percent total suspended solids removal rate, a 24-hour detention time is required within an extended detention basin.
- The lowest elevation within an extended dry detention basin should be at least two feet above the seasonal high water table. If high water table conditions are anticipated, then the design of a wet pond, constructed wetland, or bioretention facility should be considered.
- The maximum water depth of the basin should not exceed 10 feet.
- Inflow and discharge hydrographs should be calculated for each selected design storm. Hydrographs should be based on the 24-hour rainfall event. Specifically, the NRCS 24-hour Type II rainfall distribution should be utilized to generate hydrographs.
- Basins should have one or more sediment forebays or equivalent upstream pretreatment to trap coarse sediment, prevent short circuiting and facilitate maintenance (i.e., sediment removal). The forebay should consist of a separate cell, formed by a structural barrier. The forebay will require periodic sediment removal.
- Distances of flow paths from inflow points to outlets should be maximized.

Detention basin location

- Basins should be located down gradient of disturbed or developed areas on the site. The basin should collect as much site runoff as possible, especially from the site's impervious surfaces (roads, parking, buildings, etc.), and where other BMPs are not proposed.
- Basins should not be constructed on steep slopes, nor should slopes be significantly altered or modified to reduce the steepness of the existing slope, for the purpose of installing a basin.
- Basins should not worsen the runoff potential of the existing site by removing trees for the purpose of installing a basin.
- Basins should not be constructed within 10 feet of the property line or within 50 feet of a private well or septic system.
- Detention basins should not be constructed in areas with high quality and/or well draining soils, which are adequate for installing BMPs capable of achieving stormwater infiltration and, hence, volume reduction.

Figure 7.21
Extended detention basin



Source: New Jersey BMP Manual

Additional design considerations for extended detention basins (Figure 7.21)

- Extended detention basins should not be constructed within jurisdictional waters, including wetlands, or their regulated buffers.
- The low flow orifice should be sized and positioned to detain the calculated water quality runoff volume for at least 24 hours.

Basin sizing and configuration

- Basins, wet ponds, and constructed wetlands should be shaped to maximize the hydraulic length of the stormwater flow pathway. A minimum length-to-width ratio of 2:1 is recommended to maximize sedimentation. If the length-to-width ratio is lower, the flow pathway should be maximized. A wedge-shaped pond with the major inflows on the narrow end can prevent short-circuiting and stagnation.
- Irregularly shaped basins are acceptable and may even be encouraged to improve site aesthetics.
- If site conditions inhibit construction of a long, narrow basin, baffles consisting of earthen berms or other materials can be incorporated into the pond design to lengthen the stormwater flow path.
- Permanent access must be provided to the forebay, outlet, and embankment areas. It should be at least nine feet wide, have a maximum slope of 15 percent, and be stabilized for vehicles.

Additional design considerations for wet ponds

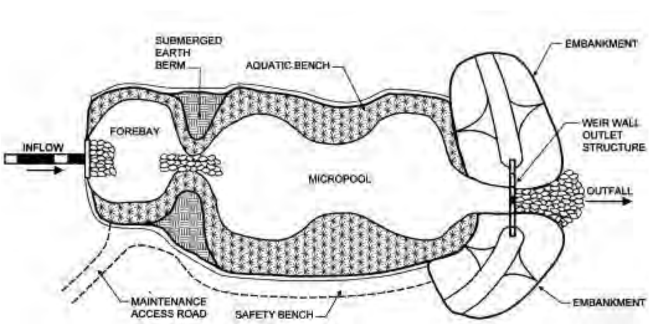
- The area required for a wet pond is generally one to three percent of its drainage area. Wet ponds should be sized to treat the water quality volume and, if necessary, to mitigate the peak rates for larger events.
- All areas that are deeper than four feet should have two safety benches, totaling 15 feet in width. One should start at the normal water surface and extend up to the pond side slopes at a maximum slope of 10 percent. The other should extend from the water

surface into the pond to a maximum depth of 18 inches, also at slopes no greater than 10 percent.

- Slopes in and around wet ponds should be 4:1 to 5:1 (horizontal:vertical) or flatter whenever possible (10:1 max. for safety/aquatic benches). Wet ponds should have an average depth of three to six feet and a maximum depth of eight feet. This should be shallow enough to minimize thermal stratification and short-circuiting and deep enough to prevent sediment resuspension, reduce algal blooms, and maintain aerobic conditions.

Additional design considerations for constructed wetlands

- Constructed wetlands should be designed so that the 10-year water surface elevation does not exceed the normal water surface elevation by more than three feet. Slopes in and around constructed wetlands should be 4:1 to 5:1 (horizontal:vertical) whenever possible.
- All areas that are deeper than four feet should have two safety benches, each four to six feet wide. One should be situated about one to 1.5 feet above the normal water elevation and the other two to 2.5 feet below the water surface.



Pocket wet pond

Source: Maryland Stormwater Manual, 2000

Embankments

- Vegetated embankments less than or equal to three feet in height are recommended. However, embankments must be less than 15 feet in height and should have side slopes no steeper than 3:1 (horizontal to vertical).
- The basin should have a minimum freeboard of one foot above the SDF elevation to the top of the berm.
- Woody vegetation is generally discouraged in the embankment area because of the risk of compromising the integrity of the embankment.
- Embankments should incorporate measures such as buried chain link fencing to prevent or discourage damage from tunneling wildlife (e.g., muskrat).

Inlet structures

Erosion protection measures should be used to stabilize inflow structures and channels.

Outlet design

- The low-flow orifice should typically be no smaller than 2.5 inches in diameter. However, the orifice diameter may be reduced to one inch if adequate protection from clogging is provided.
- The hydraulic design of all outlet structures must consider any significant tailwater effects of downstream waterways.
- The primary and low flow outlets should be protected from clogging by an external trash rack or other mechanism.
- Online facilities should have an emergency spillway that can safely pass the 100-year storm with one foot of freeboard. All outflows should be conveyed downstream in a safe and stable manner.

Additional design considerations for dry detention

- When designed to meet discharge criteria for a range of storms, basins should incorporate a multistage outlet structure. Three elements are typically included in this design:
    - A low-flow outlet that controls the extended detention and functions to slowly release the water quality or channel protection design storm.
    - A primary outlet that functions to attenuate the peak of larger design storms.
    - An emergency overflow outlet/spillway. The emergency spillway should be at the top of the berm.
- The primary outlet structure should incorporate weirs, orifices, pipes, or a combination of these to control runoff peak rates for multiple design storms. Water quality storage should be provided below the invert of the primary outlet. When routing basins, the low-flow outlet should be included in the depth-discharge relationship.
- Energy dissipaters should be placed at the end of the primary outlet to prevent erosion. If the basin discharges to a channel with dry weather flow, care should be taken to minimize tree clearing along the downstream channel, and to reestablish a forested

riparian zone between the outlet and natural channel. Where feasible, a multiple orifice outlet system is preferred to a single pipe.

Additional design considerations for wet ponds

- Outlet control devices should draw from open water areas five to seven feet deep to prevent clogging and allow the wet pond to be drained for maintenance. A reverse slope pipe terminating two to three feet below the normal water surface, minimizes the discharge of warm surface water and is less susceptible to clogging by floating debris. A pond drain should also be included which allows the permanent pool to be completely drained for maintenance within 24 hours. The outlet pipe should generally be fitted with an anti-seep collar through the embankment.

Additional design considerations for constructed wetlands

- Outlet control devices should be in open water areas four to six feet deep comprising about five percent of the total surface area to prevent clogging and allow the CW to be drained for maintenance. Outlet devices are generally multistage structures with pipes, orifices, or weirs for flow control. All outflows should be conveyed downstream in a safe and stable manner.

Sediment forebay

- Forebays should be incorporated into the basin design. Forebays should be provided at all major inflow points to capture coarse sediment, prevent excessive sediment accumulation in the main basin, and minimize erosion by inflow.
- Forebays should be vegetated to improve filtering of runoff, to reduce runoff velocity, and to stabilize soils against erosion. Forebays should adhere to the following criteria:
  - A minimum length of 10 feet.
  - Storage should be provided to trap sediment over from storms with return periods between one and 10 years.
  - Forebays should be physically separated from the rest of the pond by a berm, gabion wall, etc.
  - Flows exiting the forebay must be non-erosive to the newly constructed basin.
  - Forebays should be installed with permanent vertical markers that indicate sediment depth.
  - Storage volume of 10 to 15 percent of the total permanent pool volume and is four to six feet deep.
  - All major inflow points to dry detention basins should include sediment forebays sized for 10 percent of the water quality volume.

Vegetation and soils protection

Additional design considerations for extended detention basins:

- Care should be taken to prevent compaction of soils in the bottom of the extended detention basin in order to promote healthy plant growth and encourage infiltration. If soils compaction is not prevented during construction, soils should be restored as discussed in the Soils Restoration BMP.
- Basin bottoms and side slopes should be vegetated with a diverse native planting mix to reduce maintenance needs, promote natural landscapes, and increase infiltration potential.
- Vegetation may include trees, woody shrubs, and meadow/wetland herbaceous plants.
- Woody vegetation is generally discouraged in the embankment.
- Meadow grasses or other deeply rooted herbaceous vegetation is recommended on the interior slope of embankments.
- Fertilizers and pesticides should not be used.

Additional design considerations for wet ponds

- Underlying soils must be identified and tested. Generally, hydrologic soil groups "C" and "D" are suitable without modification, though "A" and "B" soils may require modification to reduce their natural permeability. Soil permeability must be tested in the proposed wet pond location to ensure that excessive infiltration will not cause the wet pond to dry out.
- Organic soils should be used for shallow areas within wet ponds. Organic soils can serve as a

Sediment Forebay

Source: Chester County, PA Conservation District sink for pollutants and generally have high water holding capacities. They will also facilitate plant growth and propagation and may hinder invasion of undesirable species. Care must be taken to ensure that soils used are free of invasive or nuisance plant seeds.

- To enhance habitat value, visual aesthetics, water temperature, and pond health, a 25-foot buffer should be provided, measured outward from the maximum water surface elevation. The buffer should be planted with trees, shrubs, and native ground covers. Except in maintenance access areas, turf grass should not be used. Existing trees within the buffer should be preserved. If soils in the buffer will become compacted during construction, soil restoration should take place to aid buffer vegetation.

Additional design considerations for constructed wetlands

- Underlying soils must be identified and tested. Generally, hydrologic soil groups "C" and "D" are suitable without modification, "A" and "B" soils may require a clay or synthetic liner. Soil permeability must be tested in the proposed constructed wetland location to ensure that excessive infiltration will not cause it to dry out. Field results for permeability should be used in the water balance calculations to confirm suitability. If necessary, constructed wetlands should have highly compacted subsoil or an impermeable liner to minimize infiltration.
- Organic soils should be used for constructed wetlands. Organic soils can serve as a sink for pollutants and generally have high water holding capacities. They will also facilitate plant growth and propagation and may hinder invasion of undesirable species. Care must be taken to ensure that soils used are free of invasive or nuisance plant seed.
- About half of the emergent vegetation zone should be high marsh (up to six inches deep) and half should be low marsh (six to 18 inches deep). Varying depths throughout the constructed wetland can improve plant diversity and health (Table 7.9).
- The open water zone (approx. 35 to 40 percent of the total surface area) should be between 18 inches and six feet deep. Allowing a limited five-foot deep area can prevent short-circuiting by encouraging mixing, enhance aeration of water, prevent resuspension, minimize thermal impacts, and limit mosquito growth. Alternating areas of emergent vegetation zone (up to 18 inches deep) and open water zone– can also minimize short-circuiting and hinder mosquito propagation.

Wet Pond with Buffer
Source: Township of West Bloomfield

Additional design considerations for underground detention

- Underground systems that provide storage within the void space of a stone layer should be wrapped (bottom, top, and sides) in nonwoven geotextile filter fabric to prevent migration of the subsoils into the voids.
- Control of sediment is critical. Rigorous erosion and sediment control measures are required to prevent sediment deposition within the underground system. Nonwoven geotextile may be folded over the edge of the system until the site is stabilized. To minimize maintenance and prevent siltation of the system, pretreatment devices are strongly recommended.
- Aggregate, if used for storage, should be clean, durable and contain a high percentage of void space (typically 40 percent).
- Perforated pipes, if used to distribute runoff to/from the system, should connect structures (such as cleanouts and inlet boxes).
- Cleanouts or inlets should be installed at a few locations within the system at appropriate intervals to allow access to the piping network and/or storage media and complete removal of accumulated sediment.

Hydrology

Additional design considerations for wet ponds

- Wet ponds must be able to receive and retain enough flow from rain, runoff, and groundwater to ensure long-term viability. A permanent water surface in the deeper areas of the wet pond should be maintained during all but the driest periods. A relatively stable permanent water surface elevation will reduce the stress on vegetation in an area adjacent to the pond. A wet pond should have a drainage area of at least 10 acres (five acres for pocket wet ponds) or some means of sustaining constant inflow. Even with a large drainage area, a constant source of inflow can improve the biological health and effectiveness of a wet pond while discouraging mosquito growth.

Additional considerations for constructed wetlands

- Constructed wetlands must be able to receive and retain enough flow from rain, runoff, and groundwater to ensure long-term viability. Hydrologic calculations (e.g., a water balance) should be performed to verify this. Shallow marsh areas can become dry at the surface but not for greater than one month, even in the most severe drought. A permanent water surface in the deeper areas of the constructed wetland should be maintained during all but the driest periods. The average target pool depth to maintain emergent wetland vegetation is six to 12 inches. Maximum water depths of three to four feet should not be exceeded for more than 12 hours at a time, for more than a few days out of the year. The deeper the water and the longer it sits the greater the chances that a wetland vegetation monoculture, such as cattails, will develop. A relatively stable normal water surface elevation reduces the stress on wetland vegetation. A constructed wetland must have a drainage area of at least 10 acres (five acres for "pocket" wetlands) or some means of sustaining constant inflow. Even with a large drainage area, a constant source of inflow can improve the biological health and effectiveness of a constructed wetland. Michigan's precipitation is generally well distributed throughout the year and is therefore suited for constructed wetlands.

Stormwater Functions and Calculations

Volume reduction

Dry ponds and underground detention systems do not provide an appreciable amount of volume reduction.

Although not typically considered a volume-reducing BMP, wet ponds and constructed wetlands can achieve some volume reduction through infiltration and evapotranspiration, especially during small storms and high temperature periods.

According to the International Stormwater BMP Database, wet ponds have an average annual volume reduction of seven percent (Strecker et al., 2004). Hydrologic calculations should be performed to verify that the wet pond or constructed wetland will have a viable amount of inflow can also predict the water surface elevation under varying conditions. The volume stored between the predicted water level and the lowest outlet elevation will be removed from the storm that occurs under those conditions.

Peak rate mitigation

Inflow and discharge hydrographs must be calculated for each design storm. Hydrographs should be based on a 24-hour rainfall event. The Natural Resources Conservation Service's (NRCS) 24-hour Type II rainfall distribution should be used.

Table 7.9
Definitions of Wetland Vegetation Zones

Vegetation Zone	Description
Open Water	Areas between 18-inches and 6-feet deep
Emergent	Areas up to 18-inches deep
Low Marsh	Portion of the emergent zone between 6- and 18-inches deep
High Marsh	Portion of the emergent zone up to 6-inches deep
Ephemeral Storage	Areas periodically inundated during runoff events
Buffer	Area outside of maximum water surface elevation

The presettlement and post-development hydrographs for the drainage area should be calculated using the NRCS's methodology described in the *NRCS National Engineering Handbook* Part 630, Chapter 10. The NRCS's method uses a non-dimensional unit hydrograph and the soil cover complex method to estimate runoff peak rates. Once the hydrograph has been computed, it can be routed manually or with a computer-modeling program.

Peak rate is primarily controlled in detention facilities through the transient storage above any permanent water surface. The degree to which peak rate is controlled is a function of the transient storage volume provided (i.e., depth and area) and the configuration of the outlet control structure. (See Chapter 9, LID Stormwater Calculations and Methodology.)

Water quality improvement

Wet ponds and constructed wetlands rely on physical, biological, and chemical processes to remove pollutants from influent stormwater runoff. The primary treatment mechanism is settling by gravity of particulates and their associated pollutants while stormwater is retained in the pond. Another mechanism for the removal of pollutants, especially nutrients, is uptake by algae and aquatic vegetation. Table 7.10 summarizes the pollutant removal efficiencies.

The longer the runoff remains in a wet pond or constructed wetland, the more settling (and associated pollutant removal) and other treatment can occur, and after the particulates reach the bottom the permanent pool protects them from resuspension when additional runoff enters.

The long detention or retention time associated with wet ponds can be problematic in coldwater fisheries due to the potential increase in water temperature. In these situations, detention times should be limited to a maximum of 12 hours, or other treatment alternatives (e.g., infiltration) should be explored.

Underground detention facilities are usually intended for applications on sites where space is limited and are not intended to provide significant water quality treatment.

Construction Guidelines

- The following guidelines pertain to dry ponds, wet ponds, and constructed wetlands. Underground detention systems should be installed per the manufacturer's recommendations.
    - Install all temporary erosion and sedimentation controls.
    - Separate pond area from contributing drainage area:
    - All channels/pipes conveying flows to the pond must be routed away from the pond area until it is completed and stabilized.
    - The area immediately adjacent to the pond must be stabilized in accordance with the Michigan DEQ's Soil Erosion and Sedimentation Control Program prior to construction of the pond.
    - Prepare site for excavation and/or embankment construction.
    - All existing vegetation should remain if feasible and 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 of all vegetation. Remove all tree roots, rocks, and

Table 7.10
Pollutant removal efficiencies by detention facility

Type	TSS	TP	TN	Temperature
Dry Pond	40-60%	35%	25%	Low
Wet Pond	60-88%	16-41%	39-76%	Low/Medium
Constructed Wetland*	60-99%	13-73%	33-90%	High
Underground Detention				

** Studies have shown that shallow marsh wetlands are more effective (13 to 75 percent TN removal; 33 to 90 percent TP removal) then constructed wetlands (0 to 30 percent TN; 15 to 70 percent TP).*

For more information, see Chapter 9, LID Stormwater Calculations and Methodology, which discusses water quality criteria.

boulders only in excavation area.

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

- Install surrounding embankments and inlet and outlet control structures.
- Grade and prepare subsoil in bottom of basin. For dry ponds, take care to prevent compaction. Equipment that will apply pressure to the basin bottom of less than or equal to four pounds per square inch is recommended. Compact only the surrounding embankment areas and around inlet and outlet structures. Compact bottom of basin in wet ponds and constructed wetlands.
  - Apply and grade planting soil. Matching design grades is crucial especially in wet ponds and constructed wetlands because aquatic plants can be very sensitive to depth.
  - Apply geo-textiles and other erosion-control measures.
- Seed, plant, and mulch according to landscaping plan.
- Install any safety or anti-grazing measures, if necessary.
- Follow required maintenance and monitoring guidelines.

Maintenance

Detention facilities must have a maintenance plan and privately owned facilities should have an easement, deed restriction, or other legal measure to prevent neglect or removal.

Maintenance activities required for underground detention systems focus on regular sediment and debris removal. All catch basins, inlets, and pretreatment devices draining to the underground bed should be inspected and cleaned at least two times per year. The underground bed and its outlet should be inspected at least once per year and cleaned as needed. A basin maintenance plan should be developed which includes the following measures:

- All basin structures should be inspected for clogging and excessive debris and sediment accumulation at least four times per year, as well as after every storm greater than one inch. Structures that should be inspected include basin bottoms, trash racks, outlets structures, riprap or gabion structures, and inlets.
- Sediment should be removed from the forebay before it occupies 50 percent of the forebay, typically every three to 10 years. Sediment removal should be conducted when the basin is completely dry.

  Wet ponds and constructed wetlands should be drained prior to sediment removal. Sediment should be disposed of properly and once sediment is removed, disturbed areas need to be immediately stabilized and revegetated. Proper disposal of removed material depends on the nature of the drainage area and the intent and function of the detention basin. Material removed from detention basins that treat hot spots such as fueling stations or areas with high pollutant concentrations should be disposed according to Michigan DEQ regulations for solid waste. Detention basins that primarily catch sediment from areas such as lawns may redistribute the waste on site.
- The pond drain should be inspected and tested four times per year.
- The embankment should be inspected for evidence of tunneling or burrowing wildlife at least twice during the growing season. If damage is found, the damage should be repaired and remove the animals.
- Mowing and/or trimming of vegetation should be performed as necessary to sustain the system, but all detritus must be removed from the basin. Embankment should be mowed 1–2 times per year to prevent the establishment of woody vegetation.
- Inspections should assess the vegetation, erosion, flow channelization, bank stability, inlet/outlet conditions, embankment, and sediment/debris accumulation.
- Vegetated areas should be inspected annually for unwanted growth of invasive species.
- Vegetative cover should be maintained at a minimum of 85 percent.

Winter Considerations

Dry ponds should be inspected and maintained during winter months. Application of sand, ash, cinders, or other anti-skid materials may cause sediment forebays to fill more quickly. Otherwise, dry ponds should function as intended in cold weather.

One of the biggest problems associated with proper wet pond and constructed wetland operation during cold weather is the freezing and clogging of inlet and outlet pipes. To avoid these problems, the Center for Watershed Protection (Caraco and Claytor, 1997) made some general design suggestions, which are adapted as follows:

- Inlet pipes should typically not be submerged, since this can result in freezing and upstream damage or flooding.
- Burying all pipes below the frost line can prevent frost heave and pipe freezing. Wind protection can also be an important consideration for pipes above the frost line. In these cases, designs modifications that have pipes “turn the corner” are helpful.
- Incorporate lower winter operating levels as part of the design to introduce available storage for melt events.
- Increase the slope of inlet pipes to a minimum of one percent to prevent standing water in the pipe, reducing the potential for ice formation. This design may be difficult to achieve at sites with flat local slopes.
- If perforated riser pipes are used, the minimum opening diameter should be ½-inch. In addition, the pipe should have a minimum eight-inch diameter.
- When a standard weir is used, the minimum slot width should be three inches, especially when the slot is tall.
- Baffle weirs can prevent ice reformation during the spring melt near the outlet by preventing surface ice from blocking the outlet structure.
- In cold climates, riser hoods should be oversized and reverse slope pipes should draw from at least six inches below the typical ice layer.
- Alternative outlet designs that have been successful include using a pipe encased in a gravel jacket set at the elevation of the aquatic bench as the control for water-quality events. This practice both avoids stream warming and serves as a non-freezing outlet.
- Trash racks should be installed at a shallow angle to prevent ice formation.

Constructed wetland performance can be decreased in spring months when large volumes of runoff occur in a relatively short time carrying the accumulated pollutant load from the winter months. Since constructed wetlands are relatively shallow, freezing of the shallow pool can occur.

Cost

Costs for detention facilities will vary depending on the type as indicated below.

The construction costs associated with dry ponds can vary considerably. One study evaluated the cost of all pond systems (Brown and Schueler, 1997). Adjusting for inflation, the cost of dry extended detention ponds can be estimated with the equation:

$$C = 12.4V^{0.760}$$

Where:

C = Construction, design and permitting cost
V = Volume needed to control the 10-year storm (cubic feet)
Using this equation, typical construction costs are:
$41,600 for a one acre-foot pond
$239,000 for a 10 acre-foot pond
$1,380,000 for a 100 acre-foot pond

Dry ponds using highly structural design features (riprap for erosion control, etc.) are more costly than natural basins. An installation cost savings is associated with a natural vegetated slope treatment, which is magnified by the additional environmental benefits provided. Long-term maintenance costs for processes such as mowing and fertilizing are reduced when more naturalized approaches are used due to the ability of native vegetation to adapt to local weather conditions and a reduced need for maintenance.

The construction cost of wet ponds varies greatly depending on the configuration, location, site specific conditions, etc. Typical construction costs in 2007 dollars range from approximately $30,000 to $60,000 per acre-foot of storage (based on USEPA, 1999). Alternately, the construction cost of a wet pond can be estimated as $6,000 per acre of contributing drainage area. Costs are generally most dependent on the amount of earthwork and the planting.

In addition to the water resource protection benefits of wet ponds, there is some evidence to suggest that they may provide an economic benefit by increasing property values. The results of one study suggest that “pond front” property can increase the selling price of new properties by about 10 percent (USEPA, 1995). Another study reported that the perceived value (i.e., the value estimated by residents of a community) of homes was increased by about 15 to 25 percent when located near a wet pond (Emmerling-Dinovo, 1995).

The construction cost of constructed wetlands varies greatly depending on the configuration, location, site specific conditions, etc. Typical construction costs in 2004 dollars range from approximately $30,000 to $65,000 per acre (USEPA Wetlands Fact Sheet, 1999). Costs are generally most dependent on the amount of earthwork and planting. Annual maintenance costs have been reported to be approximately two to five percent of the capital costs (USEPA, 2000).

The construction cost of underground detention can vary greatly depending on the design, configuration, location, storage volume and media, and site specific conditions, among other factors. Typical construction costs are approximately $8 to $10 per cubic foot for proprietary high capacity storage systems. Systems using uniformly graded aggregate as the primary storage media will typically be less expensive but require additional area and/or depth for an equivalent storage volume.

Annual maintenance costs for dry ponds and wet ponds have been reported to be approximately three to five percent of the capital costs, though there is little data available to support this. Alternatively, a community can estimate the cost of the maintenance activities outlined in the maintenance section. Ponds are long-lived facilities (typically longer than 20 years). Thus, the initial investment into pond systems may be spread over a relatively long time period.

General Specifications

The following specifications are provided for information purposes only. These specifications include information on acceptable materials for typical applications, but are by no means exclusive or limiting. The designer is responsible for developing detailed specifications for individual design projects in accordance with the project conditions.

Dry detention and underground structures

Site preparation

All excavation areas, embankments, and structure locations should be cleared and grubbed as necessary, but trees and existing vegetation should be retained and incorporated within the dry detention basin area where possible. Trees should not be removed unless absolutely necessary.

Where feasible, trees and other native vegetation should be protected, even in areas where temporary inundation is expected. A minimum 10-foot radius around the inlet and outlet structures can be cleared to allow room for construction.

Any cleared material should be used as mulch for erosion control or soil stabilization.

Care should be taken to prevent compaction of the bottom of the reservoir. If compaction should occur, soils should be restored and amended.

Earth fill material & placement

- The fill material should be taken from approved designated excavation areas. It should be free of roots, stumps, wood, rubbish, stones greater than six inches, or other objectionable materials. Materials on the outer surface of the embankment must have the capability to support vegetation.
- Areas where fill is to be placed should be scarified prior to placement. Fill materials for the embankment should be placed in maximum eight-inch lifts. The principal spillway must be installed concurrently with fill placement and not excavated into the embankment.
- Control movement of the hauling and spreading equipment over the site.

Embankment core

- The core should be parallel to the centerline of the embankment as shown on the plans. The top width of the core should be at least four feet. The height should extend up to at least the 10-year water elevation or as shown on the plans. The side slopes should be 1:1 or flatter. The core should be compacted with construction equipment, rollers, or hand tampers to assure maximum density and minimum permeability. The core should be placed concurrently with the outer shell of the embankment.
- Construction of the berm should follow specifications by the project's geotechnical engineer.

Structure backfill

- Backfill adjacent to pipes and structures should be of the type and quality conforming to that specified for the adjoining fill material. The fill should be placed in horizontal layers not to exceed eight inches in thickness and compacted by hand tampers or other manually directed compaction equipment. The material should fill completely all spaces under and adjacent to the pipe. At no time during the backfilling operation should driven equipment be allowed to operate closer than four feet to any part of the structure. Equipment should not be driven over any part of a concrete structure or pipe, unless there is a compacted fill of 24 inches or greater over the structure or pipe.

- Backfill content and placement should follow specifications by the project's geotechnical engineer.

Pipe conduits

- Corrugated metal pipe – All of the following criteria should apply for corrugated metal pipe:
    - Materials - Polymer coated steel pipe, aluminum coated steel pipe, aluminum pipe. This pipe and its appurtenances should conform to the requirements of AASHTO specifications with watertight coupling bands or flanges.
    - Coupling bands, anti-seep collars, end sections, etc., must be composed of the same material and coatings as the pipe. Metals must be insulated from dissimilar materials with use of rubber or plastic insulating materials at least 24 mils in thickness.
    - Connections – All connections with pipes must be completely watertight. The drain pipe or barrel connection to the riser should be welded all around when the pipe and riser are metal. Anti-seep collars should be connected to the pipe in such a manner as to be completely watertight. Dimple bands are not considered to be watertight.
    - Bedding – The pipe should be firmly and uniformly bedded throughout its entire length. Where rock or soft, spongy or other unstable soil is encountered, all such material should be removed and replaced with suitable earth compacted to provide adequate support.
    - Backfilling should conform to "structure backfill."
    - Other details (anti-seep collars, valves, etc.) should be as shown on drawings.
- Reinforced concrete pipe - All of the following criteria should apply for reinforced concrete pipe:
    - Materials – Reinforced concrete pipe should have bell and spigot joints with rubber gaskets and should equal or exceed ASTM standards.
    - Laying pipe – Bell and spigot pipe should be placed with the bell end upstream. Joints should be made in accordance with recommendations of the manufacturer of the material. After the joints are sealed for the entire line, the bedding should be placed so that all spaces under the pipe are filled. Take care to prevent any deviation from the original line and grade of the pipe.
        - Backfilling should conform to "structure backfill."

Other details (anti-seep collars, valves, etc.) should be as shown on drawings.

-
    - Plastic pipe
        - Materials – PVC pipe should be PVC-1120 or PVC-1220 conforming to ASTM standards. Corrugated High Density Polyethylene (HDPE) pipe, couplings, and fittings should meet AASHTO specifications.
        - Joints and connections to anti-seep collars should be completely watertight.
        - Bedding – The pipe should be firmly and uniformly bedded throughout its entire length. Where rock or soft, spongy or other unstable soil is encountered, all such material should be removed and replaced with suitable earth compacted to provide adequate support.
        - Backfilling should conform to "structure backfill."
        - Other details (anti-seep collars, valves, etc.) should be as shown on drawings.
    - Drainage diaphragms – When a drainage diaphragm is used, a registered professional engineer must supervise the design and construction inspection.

Rock riprap

Rock riprap should meet the requirements of Michigan DEQ's Soil Erosion and Sedimentation Control Program.

Stabilization

All borrow areas should be graded to provide proper drainage and left in a stabilized condition All exposed surfaces of the embankment, spillway, spoil and borrow areas, and berms should be stabilized by seeding, planting, and mulching in accordance with Michigan DEQ's Soil Erosion and Sedimentation Control Program.

Operation and maintenance

An operation and maintenance plan in accordance with local or state regulations must be prepared for all basins. At a minimum, include a dam and inspection checklist as part of the operation and maintenance plan and perform at least annually.

Wet pond and constructed wetland

Excavation

- The area to be used for the wet pond should be excavated to the required depth below the desired bottom elevation to accommodate any required impermeable liner, organic matter, and/or planting soil.
- The compaction of the subgrade and/or the installation of any impermeable liners will follow immediately.

Subsoil preparation

- Subsoil should be free from hard clods, stiff clay, hardpan, ashes, slag, construction debris, petroleum hydrocarbons, or other undesirable material. Subsoil must not be delivered in a frozen or muddy state.
- Scarify the subsoil to a depth of eight to 10 inches with a disk, rototiller, or similar equipment.
- Roll the subsoil under optimum moisture conditions to a dense seal layer with four to six passes of a sheepsfoot roller or equivalent. The compacted seal layer should be at least eight inches thick.

Impermeable liner

- If necessary, install impermeable liner in accordance with manufacturer's guidelines.
- Place a minimum 12 inches of subsoil on top of impermeable liner in addition to planting soil.

Planting soil (topsoil)

- See local specifications for general planting soil requirements.
- Use a minimum of 12 inches of topsoil in the emergent vegetation zone (less than 18" deep) of the pond. If natural topsoil from the site is to be used it must have at least eight percent organic carbon content (by weight) in the A-horizon for sandy soils and 12 percent for other soil types.
- If planting soil is imported, it should be made up of equivalent proportions of organic and mineral materials. All soils used should be free of invasive or nuisance seeds.
- Lime should not be added to planting soil unless absolutely necessary as it may encourage the propagation of invasive species.
- The final elevations and hydrology of the vegetative zones should be evaluated prior to planting to determine if grading or planting changes are required.

Vegetation

- See Appendix C for plant lists for wet ponds. Substitutions of specified plants should be subject to prior approval of the designer. Planting locations should be based on the planting plan and directed in the field by a qualified wetland ecologist.
- All wet pond plant stock should exhibit live buds or shoots. All plant stock should be turgid, firm, and resilient. Internodes of rhizomes may be flexible and not necessarily rigid. Soft or mushy stock should be rejected. The stock should be free of deleterious insect infestation, disease, and defects such as knots, sun-scald, injuries, abrasions, or disfigurement that could adversely affect the survival or performance of the plants.
- All stock should be free from invasive or nuisance plants or seeds.
- During all phases of the work, including transport and onsite handling, the plant materials should be carefully handled and packed to prevent injuries and desiccation. During transit and onsite handling, the plant material should be kept from freezing and be covered, moist, cool, out of the weather, and out of the wind and sun. Plants should be watered to maintain moist soil and/or plant conditions until accepted.
- Plants not meeting these specifications or damaged during handling, loading, and unloading will be rejected.

Outlet control structure

- Outlet control structures should be constructed of non-corrodible material.
- Outlets should be resistant to clogging by debris, sediment, floatables, plant material, or ice.
- Materials should comply with applicable specifications (MDOT or AASHTO, latest edition).
- For maximum flexibility with wetland water levels (if actual depths are uncertain) adjustable water level control structures are recommended (see EPA, 2000 in reference section for design concepts).

Designer/Reviewer Checklist for Dry Extended Detention Ponds

ITEM	YES	NO	N/A	NOTES
Used in conjunction with other BMPs for water quality and groundwater recharge?				
Stable inflow points provided?				
Forebay and/or pretreatment provided for sediment removal?				
Adequate length to width ratio?				
Total depth limited?				
Acceptable side slopes?				
Properly designed outlet structure?				
Trash rack provided to prevent clogging?				
Stable emergency overflow and outflow points?				
Drawdown time less than 72 hours?				
Soil compaction minimized?				
Appropriate native plants selected?				
Erosion and sedimentation control considered?				
Maintenance accounted for and plan provided?				

Designer/Reviewer Checklist for Wet Detention Ponds

ITEM	YES	NO	N/A	NOTES
Used in conjunction with other BMPs for groundwater recharge and/or water quality?				
Adequate drainage area/water supply/groundwater table to maintain permanent water surface?				
Relatively impermeable soils and/or soil modification?				
Stable inflow points provided?				
Forebay and/or pretreatment provided for sediment removal?				
Adequate length to width ratio?				
Appropriate and varying water depths?				
Acceptable side slopes?				
Safety benches provided?				
Properly designed outlet structure?				
Dewatering mechanism provided?				
Trash rack provided to prevent clogging?				
Stable emergency overflow and outflow points?				
Adequate soils for plantings?				
Appropriate native plants selected in and around pond?				
25-foot buffer provided?				
Erosion and sedimentation control considered?				
Maintenance accounted for and plan provided?				

Designer/Reviewer Checklist for Constructed Wetlands

ITEM	YES	NO	N/A	NOTES
Used in conjunction with other BMPs for groundwater recharge and/or water quality?				
Adequate drainage area/water supply/groundwater table to maintain permanent water surface?				
Relatively impermeable soils and/or soil modification?				
Hydrologic calculations (e.g., water balance) performed?				
Stable inflow points provided?				
Forebay and/or pretreatment provided for sediment removal?				
Adequate length to width ratio?				
Appropriate and varying water depths for diverse vegetation?				
Sudden water level fluctuations minimized to reduce stress on vegetation?				
Acceptable side slopes?				
Safety benches provided?				
Properly designed outlet structure?				
Adjustable permanent pool and dewatering mechanism provided?				
Trash rack provided to prevent clogging?				
Stable emergency overflow and outflow points?				
Adequate soils for plantings?				
Appropriate native plants selected in and around wetland?				
25-foot buffer provided?				
Erosion and sedimentation control considered?				
Maintenance accounted for and plan provided?				

Designer/Reviewer Checklist for Underground Detention

ITEM	YES	NO	N/A	NOTES
Used in conjunction with other BMPs for water quality and groundwater recharge?				
Stable inflow points provided?				
Pretreatment provided for sediment removal?				
Properly designed outlet structure?				
Adequate cleanouts/maintenance access provided?				
Stable emergency overflow and outflow points?				
Drawdown time less than 72 hours?				
Soil compaction minimized?				
Clean, washed, open-graded aggregate specified, if applicable?				
Geotextile specified?				
If proprietary storage media is used, were the manufacturer recommendations followed?				
Appropriate native plants selected, if applicable?				
Erosion and sedimentation control considered?				
Maintenance accounted for and plan provided?				

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BMP Fact Sheet

Infiltration Practices

Infiltration practices are natural or constructed land areas located in permeable soils that capture, store, and infiltrate the volume of stormwater runoff into surrounding soil.

Infiltration Trench, City of Grayling, MI
Source: Huron Pines

Variations

- **Dry wells**, also referred to as seepage pits, French drains or Dutch drains, are a subsurface storage facility (structural chambers or excavated pits, backfilled with a coarse stone aggregate) that temporarily store and infiltrate stormwater runoff from rooftop structures. Due to their size, dry wells are typically designed to handle stormwater runoff from smaller drainage areas, less than one acre in size.
- **Infiltration basins** are shallow surface impoundments that temporarily store, capture, and infiltrate runoff over a period of several days on a level and uncompacted surface. Infiltration basins are typically used for drainage areas of 5 to 50 acres with land slopes that are less than 20 percent.
- **Infiltration berms** use a site's topography to manage stormwater and prevent erosion. Berms may function independently in grassy areas or may be incorporated into the design of other stormwater control facilities such as Bioretention and Constructed Wetlands. Berms may also serve various stormwater drainage functions including: creating a barrier to flow, retaining flow for volume control, and directing flows.
- **Infiltration trenches** are linear subsurface infiltration structures typically composed of a stone trench wrapped with geotextile which is designed for both stormwater infiltration and conveyance in drainage areas less than five acres in size.
- **Subsurface infiltration beds** generally consist of a rock storage (or alternative) bed below other surfaces such as parking lots, lawns, and playfields for temporary storage and infiltration of stormwater runoff with a maximum drainage area of 10 acres.
- **Bioretention** can be an infiltration practice and is discussed in the Bioretention BMP.
- **Level spreaders** can be an infiltration practice and is discussed in the Level Spreader BMP.

Key Design Features

- Depth to water table or bedrock
- Pretreatment is often needed to prevent clogging
- Often requires level infiltration surface
- Proximity to buildings, drinking water supplies, karst features, and other sensitive areas
- Soil types
- Provide positive overflow in most uses

Site Factors

- Maximum Site Slope: 20 percent
- Minimum depth to bedrock: Two feet
- Minimum depth to seasonally high water table: Two feet
- Potential Hotspots: Yes with pretreatment and/or impervious liner
- NRCS Soil type: A, B, C*, D*

*C & D soils have limited infiltration ability and may require an underdrain.

Infiltration BMP	Max. Drainage Area
Berming	5 acres
Dry Well	1 acre
Infiltration Basin	10 acres
Infiltration Trench	2 acres
Subsurface Infiltration Bed	5 acres

Benefits

- Reduces volume of stormwater runoff
- Reduces peak rate runoff
- Increases groundwater recharge
- Provides thermal benefits

Limitations

- Pretreatment requirements to prevent clogging
- Not recommended for areas with steep slopes

Erosion control matting and rock can be used at surface flow entrances

Bioretention is one variation of an infiltration BMP, such as this rain garden at the Macomb County Public Works Building

Applications

	Residential	Commercial	Ultra Urban	Industrial	Retrofit	Highway/Road	Recreational
Dry well	Yes	Yes	Yes	Limited	Yes	No	No
Infiltration basin	Yes	Yes	Limited	Yes	Limited	Limited	No
Infiltration berm	Yes	Yes	Limited	Yes	Yes	Yes	No
Infiltration trench	Yes	Yes	Yes	Yes	Yes	Yes	No
Subsurface infiltration bed	Yes	Yes	Yes	Yes	Yes	Limited	No

Stormwater Quantity Functions

	Volume	Groundwater Recharge	Peak Rate
Dry well	Medium	High	Medium
Infiltration basin	High	High	High
Infiltration berm	Low/Medium	Low/Medium	Medium
Infiltration trench	Medium	High	Low/Medium
Subsurface infiltration bed	High	High	High

Stormwater Quality Functions

	TSS	TP	NO3	Temperature
Dry well	High	High/Medium	Medium/Low	High
Infiltration basin	High	Medium/High	Medium	High
Infiltration berm	Medium/High	Medium	TN-Medium	Medium
Infiltration trench	High	High/Medium	Medium/Low	High
Subsurface infiltration bed	High	Medium/High	Low	High

Case Study: Saugatuck Center for the Arts

The Saugatuck Center for the Arts (SCA), in conjunction with the City of Saugatuck, Michigan Department of Environmental Quality, and private donors, constructed a public garden that treats rain water that falls on the SCA roof. The original design was modified to accommodate rain water that would otherwise have entered Kalamazoo Lake untreated. The resulting design for the garden absorbs and infiltrates 100 percent of the rain water from the SCA roof, resulting in zero discharge to the nearby lake.

Subsurface Infiltration
Source: JFNew

In addition to the garden at the Saugatuck Center for the Arts, the revised design incorporated a series of alternative stormwater Best Management Practices on City of Saugatuck property, including subsurface infiltration under porous pavers in the adjacent city parking lot and a rain garden/vegetated swale series at Coghlin Park to treat rain water from the city parking lot. The design incorporated native plants to address management in an urban setting while visually integrating with the contemporary social fabric of Saugatuck. The design also incorporated an innovative oil-and-grit separator to remove over 80 percent of sediment and nutrients draining from approximately nine acres of urban land surrounding the SCA and city parking lot. Through this series, or "treatment techniques," the SCA and City of Saugatuck are able to demonstrate a variety of innovative and unique alternatives for treatment and reduction of stormwater.

Case Study Site Considerations	
Project Type	Subsurface infiltration, rain gardens, porous pavers, native plants, water quality device
Estimated Total Project Cost	$200,000
Maintenance Responsibility	City of Saugatuck
Project Contact	Kirk Harrier, City Manager, 269-857-2603

Description and Function

Infiltration practices are designed to store, capture, and infiltrate stormwater runoff into the surrounding soils. During periods of rainfall, infiltration BMPs reduce the volume of runoff and help to mitigate potential flooding events, downstream erosion, and channel morphology changes. This recharged water serves to provide baseflow to streams and maintain stream water quality.

Infiltration BMPs provide excellent pollutant removal effectiveness because of the combination of a variety of natural functions occurring within the soil mantle, complemented by existing vegetation (where this vegetation is preserved). Soil functions include physical filtering, chemical interactions (e.g., ion exchange, adsorption), as well as a variety of forms of biological processing, conversion, and uptake. The inclusion of appropriate vegetation for some infiltration basins reinforces the work of the soil by reducing velocity and erosive forces, soil anchoring, and further uptake of nonpoint source pollutants. In many cases, even the more difficult-to-remove soluble nitrates can be reduced as well. It should be noted that infiltration BMPs tend to be excellent for removal of many pollutants, especially those that are in particulate form. However, there are limitations to the removal of highly soluble pollutants, such as nitrate, which can be transmitted through the soil.

Infiltration basin

In addition to the removal of chemical pollutants, infiltration can address thermal pollution. Maintaining natural temperatures in stream systems is recognized as an issue of increasing importance for protection of overall stream ecology. While detention facilities tend to discharge heated runoff flows, the return of runoff to the groundwater through use of infiltration BMPs guarantees that these waters will be returned at natural groundwater temperatures, considerably cooler than ambient air in summer and warmer in winter. As a result, seasonal extreme fluctuations in stream water temperature are minimized. Fish, macro-invertebrates, and a variety of other biota will benefit as the result.

Infiltration Limitations

The use of sediment pretreatment with infiltration BMPs is required for many infiltration BMPs to prevent clogging of the infiltration surface area. Sediment pretreatment can take the form of a water quality filtering device, a settling basin, filter strips, sediment trap, or a combination of these practices upstream of the infiltration practice. Pretreatment practices should be inspected and maintained at least once per year. Before entering an infiltration practice, stormwater should first enter a pretreatment practice sized to treat a minimum volume of 25% of the water quality volume (Vwq).

Sites that include hot spots, such as gasoline stations, vehicle maintenance areas, and high intensity commercial uses, may need additional pretreatment practices to prevent impairment of groundwater supplies. Infiltration may occur in areas of hot spots provided pretreatment is suitable to address concerns.

Pretreatment devices that operate effectively in conjunction with infiltration include grass swales, vegetated filter strips, bioretention, settling chambers, oil/grit separators, constructed wetlands, sediment sumps, and water quality inserts. Selection of pretreatment practices should be guided by the pollutants of greatest concern, and the extent of the land development under consideration.

Selection of pretreatment techniques will vary depending upon whether the pollutants are of a particulate (sediment, phosphorus, metals, etc.) versus a soluble (nitrogen and others) nature.

Applications

Infiltration systems can be used in a variety of applications, from small areas in residential properties to extensive systems under commercial parking lots or large basins in open space. Industrial, retrofit, highway/road, and recreational areas can also readily incorporate infiltration to varying degrees. The use of infiltration basins and berming in ultra urban and redevelopment settings is limited primarily due to space constraints.

Dry wells have limited applicability in industrial settings as they are designed for runoff from relatively small roof areas (therefore they are also not applicable to transportation corridors).

Infiltration basins, subsurface infiltration beds, and berming are also limited for transportation projects due to space constraints and grading requirements (however berming can be used to some degree — especially along the edge of the right of way — to capture runoff).

Variations

Subsurface infiltration

A subsurface infiltration bed generally consists of a rock storage (or alternative) bed below other surfaces such as parking lots, lawns and playfields for temporary storage and infiltration of stormwater runoff. Often subsurface storage is enhanced with perforated or open bottom piping. Subsurface infiltration beds can be stepped or terraced down sloping terrain provided that the base of the bed remains level. Stormwater runoff from nearby impervious areas is conveyed to the subsurface storage media, receives necessary pretreatment and is then distributed via a network of perforated piping.

The storage media for subsurface infiltration beds typically consists of clean-washed, uniformly graded aggregate. However, other storage media alternatives are available. These alternatives are generally variations on plastic cells that can more than double the storage capacity of aggregate beds. Storage media alternatives are ideally suited for sites where potential infiltration area is limited.

Subsurface infiltration at Saugatuck Performing Arts Center.
Source: JFNew

If designed, constructed, and maintained using the following guidelines, subsurface infiltration features can stand alone as significant stormwater runoff volume, rate, and quality control practices. These systems can also provide some aquifer recharge, while preserving or creating valuable open space and recreation areas. They have the added benefit of functioning year-round, because the infiltration surface is typically below the frost line.

Various methods can be utilized to connect to subsurface infiltration areas:

- **Connection of roof leaders**

  Runoff from nearby roofs can be directly conveyed to subsurface beds via roof leader connections to perforated piping. Roof runoff generally has relatively low sediment levels, making it ideally suited for connection to an infiltration bed.

- **Connection of inlets**

  Catch basins, inlets, and area drains may be connected to subsurface infiltration beds. However, sediment, oil and grease, and debris removal must be provided. Storm structures should include sediment trap areas below the inverts of discharge pipes to trap solids and debris. Parking lots and roadways must provide for the removal of oil and grease and other similar constituents through appropriate treatment. In areas of high traffic or excessive generation of sediment, litter, and other similar materials, a water quality insert or other pretreatment device may be required.

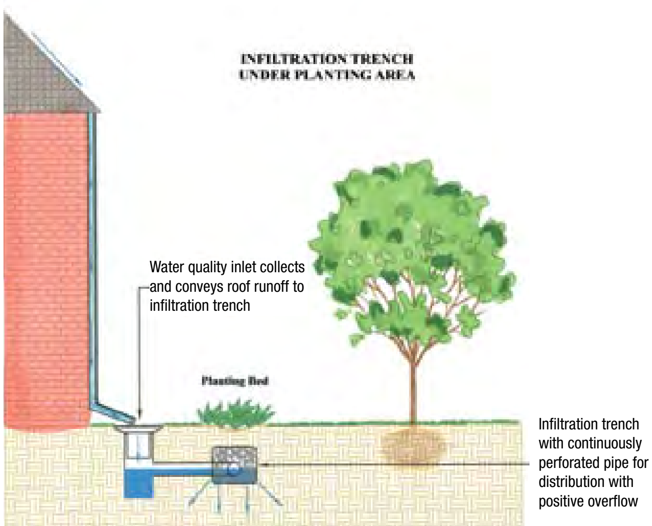
Infiltration trench

An infiltration trench is a linear stormwater BMP consisting of a continuously perforated pipe within a sub-surface stone-filled trench wrapped with geotextile. Usually, an infiltration trench is part of a conveyance system and is designed so that large storm events are conveyed through the pipe with some runoff volume reduction. During small storm events, volume reduction may be significant and there may be little or no discharge.

All infiltration trenches should be designed with a positive overflow. Sediment pretreatment of runoff from impervious areas should be considered to prevent clogging within the trench, particularly when conveying runoff from roadways and parking areas.

An infiltration trench differs from an infiltration bed in that it may be constructed in more confined areas. The designer must still consider the impervious area to infiltration area loading rate. It can be located beneath or within roadways or impervious areas (Figure 7.22) and can also be located down a mild slope by "stepping" the sections between control structures.

Figure 7.22
Residential rain garden with surface connection to subsurface infiltration bed under garden.



Infiltration basin

Infiltration basins (Figure 7.23) are shallow, impounded areas designed to temporarily store and infiltrate stormwater runoff. The size and shape can vary from one large basin to multiple, smaller basins throughout a site.

Infiltration basins use the existing soil and native vegetation to reduce the volume of stormwater runoff by infiltration and evapotranspiration. Therefore, the use of sediment pretreatment is imperative to prevent clogging of the infiltration surface area within the basin. Sediment pretreatment can take the form of a water quality filtering device, vegetative filter strips, a settling basin, or a sediment trap. The key to promoting infiltration is to provide enough surface area for the volume of runoff to be absorbed within 72 hours.

An engineered overflow structure must be provided for the larger storms and can be designed for peak rate attenuation. With the use of a properly designed outlet structure, infiltration basins can be designed to mitigate volume and water quality for small frequent storms, while managing peak rates for large design storms.

Dry well

A dry well (Figure 7.24) is a subsurface storage facility that temporarily stores and infiltrates stormwater runoff from rooftops. Roof leaders usually connect directly into the dry well, which may be either an excavated pit filled with uniformly graded aggregate wrapped in geotextile or a prefabricated storage chamber or pipe segment. For structures without gutters or downspouts, runoff can be designed to sheet flow off a pitched roof surface and onto a stabilized ground cover that is then directed toward a dry well via stormwater pipes or swales.

Dry wells discharge the stored runoff via infiltration into the surrounding soils. In the event that the dry well is overwhelmed in an intense storm event, an overflow mechanism (e.g., surcharge pipe, connection to larger infiltration area, etc.) will ensure that additional runoff is safely conveyed downstream.

Figure 7.23
Schematic of infiltration basin

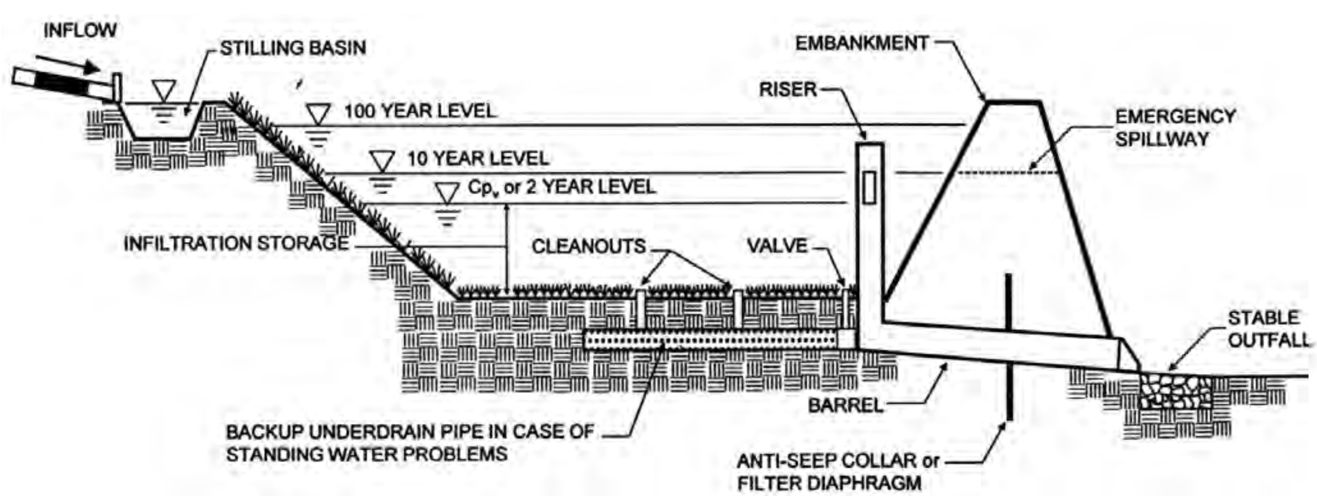
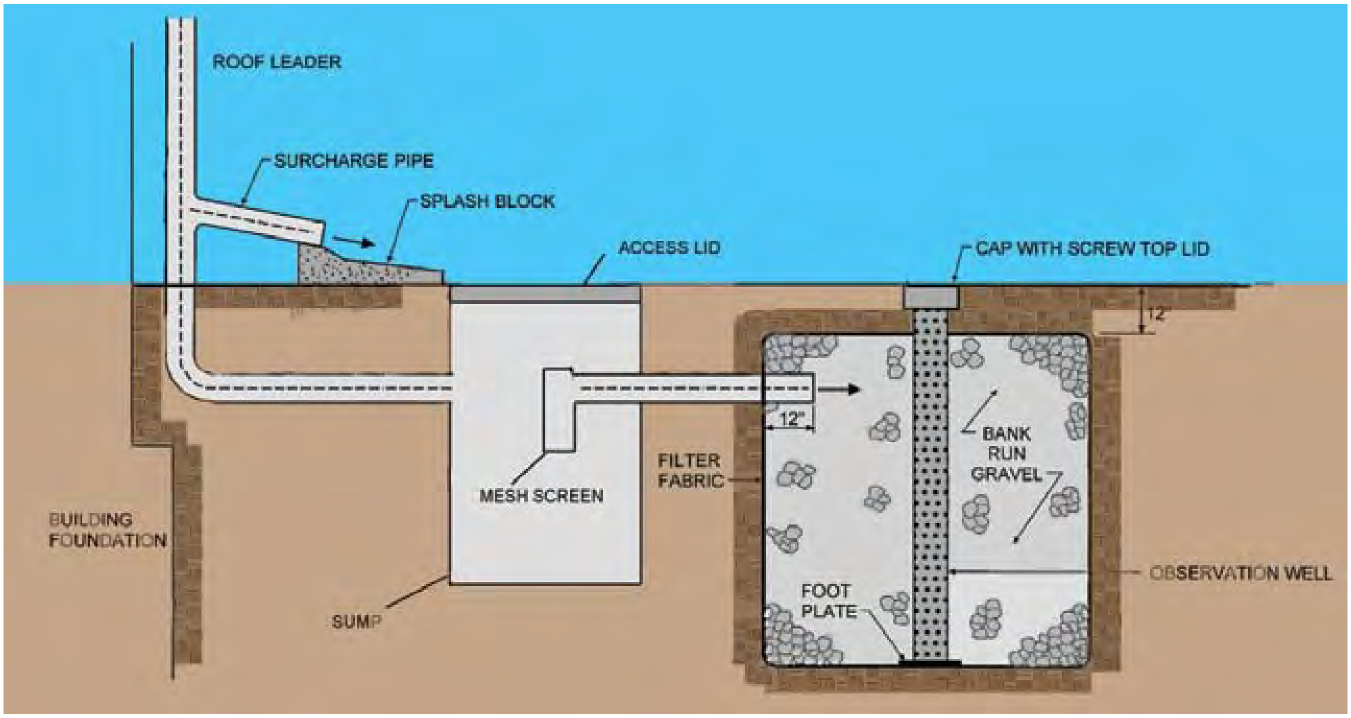


Figure 7.24
Cross-section of dry well with "sumped" catch basin for sediment pretreatment



Infiltration berm

Infiltration berms are linear vegetation features located along (i.e. parallel to) existing site contours in a moderately sloping area. They are built-up earthen embankments with sloping sides, which function to retain, slow down, or divert stormwater flows. Infiltration berms also have shallow depressions created by generally small earthen embankments that collect and temporarily store stormwater runoff allowing it to infiltrate into the ground and recharge groundwater.

Infiltration berms can be constructed in various areas on the site, including:

- **Diversion berms**

  Diversion berms can be used to protect slopes from erosion and to slow runoff rate. Like swales, berms may divert concentrated discharge from a developed area away from the sloped area. Additionally, berms may be installed in series down the slope to retain flow and spread it out along multiple, level berms to discourage concentrated flow.

- Diversion berms can also be used to direct stormwater flow in order to promote longer flow pathways, thus increasing the time of concentration. For example, berms can be installed such that vegetated stormwater flow pathways are allowed to "meander" so that stormwater travel time is increased.

Prefabricated dry wells

There are a variety of prefabricated, predominantly plastic subsurface storage chambers on the market today that can replace aggregate dry wells. Since these systems have significantly greater storage capacity than aggregate, space requirements are reduced and associated costs may be defrayed. If the following design guidelines are followed and infiltration is still encouraged, prefabricated chambers can prove just as effective as standard aggregate dry wells.

- **Meadow/woodland infiltration berms**

  Woodland infiltration berms can be installed within existing wooded areas for additional stormwater management. Berms in wooded areas can even improve the health of existing vegetation, through enhanced groundwater recharge. Care should be taken during construction to ensure minimum disturbance to existing vegetation, especially tree roots.

Berms are also utilized for a variety of reasons independent of stormwater management, such as to add aesthetic value to a flat landscape, create a noise or wind barrier, separate land uses, screen undesirable views or to enhance or emphasize landscape designs. Berms are often used in conjunction with recreational features, such as pathways through woodlands. In summary, even when used for stormwater management, berms can be designed to serve multifunctional purposes and are easily incorporated into the landscape.

Design Considerations

The following general design considerations are for all BMPs utilizing infiltration. These include: site conditions and constraints, as well as general design considerations. Specific design considerations for each BMP follow these same considerations.

Site conditions and constraints for all infiltration BMPs

- **Depth to seasonal high water table**. A four-foot clearance above the seasonally high water table is recommended. A two-foot clearance can be used, but may reduce the performance of the BMP. This reduces the likelihood that temporary groundwater mounding will affect the system, and allows sufficient distance of water movement through the soil to assure adequate pollutant removal. In special circumstances, filter media may be employed to remove pollutants if adequate soil layers do not exist.
- **Depth to bedrock**. A four-foot minimum depth to bedrock is recommended to assure adequate pollutant removal and infiltration. A two-foot depth can be used, but may reduce the performance of the BMP. In special circumstances, filter media may be employed to remove pollutants if adequate soil mantle does not exist.
- **Soil infiltration**. Soils underlying infiltration devices should have infiltration rates between 0.1 and 10 inches per hour, which in most development programs should result in reasonably sized infiltration systems. Where soil permeability is extremely low, infiltration may still be possible, but the surface area required could be large, and other volume reduction methods may be warranted. Undisturbed Hydrologic Soil Groups A, B, and C often fall within this range and cover most of the state. Type D soils may require the use of an underdrain.

  Soils with rates in excess of six inches per hour may require an additional soil buffer (such as an organic layer over the bed bottom) if the Cation Exchange Capacity (CEC) is less than 10 and pollutant loading is expected to be significant. In carbonate soils, excessively rapid drainage may increase the risk of sinkhole formation, and some compaction or additional measures may be appropriate.
- **Setbacks**. Infiltration BMPs should be sited so that any risk to groundwater quality is minimized and they present no threat to sub-surface structures such as foundations and septic systems. (Table 7.11)

Table 7.11
Setback Distances

Setback from	Minimum Distance (feet)
Property Line	10
Building Foundation*	10
Private Well	50
Public Water Supply Well**	50
Septic System Drainfield***	100

* minimum with slopes directed away from building. 100 feet upgradient from basement foundations.

** At least 200 feet from Type I or IIa wells, 75 feet from Type IIb and III wells (MDEQ Safe Drinking Water Act, PA 399)

*** 50 feet for septic systems with a design flow of less than 1,000 gallons per day

General design considerations for all infiltration BMPs

- **Do not infiltrate in compacted fill**. Infiltration in native soil without prior fill or disturbance is preferred but not always possible**.** Areas that have experienced historic disturbance or fill are suitable for infiltration provided sufficient time has elapsed and the soil testing indicates the infiltration is feasible. In disturbed areas it may be necessary to infiltrate at a depth that is beneath soils that have previously been compacted by construction methods or long periods of mowing, often 18 inches or more. If site grading requires placement of an infiltration BMP on fill, compaction should be minimal to prevent excess settlement and the infiltration capacity of the compacted fill should be measured in the field to ensure the design values used are valid.
- **A level infiltration area (one percent or less slope) is preferred**. Bed bottoms should always be graded into the existing soil mantle, with terracing as required to construct flat structures. Sloped bottoms tend to pool and concentrate water in small areas, reducing the overall rate of infiltration and longevity of the BMP. The longitudinal slope may range only from the preferred zero percent up to one percent, and that lateral slopes are held at zero percent. It is highly recommended that the maximum side slopes for an infiltration practice be 1:3 (V: H).

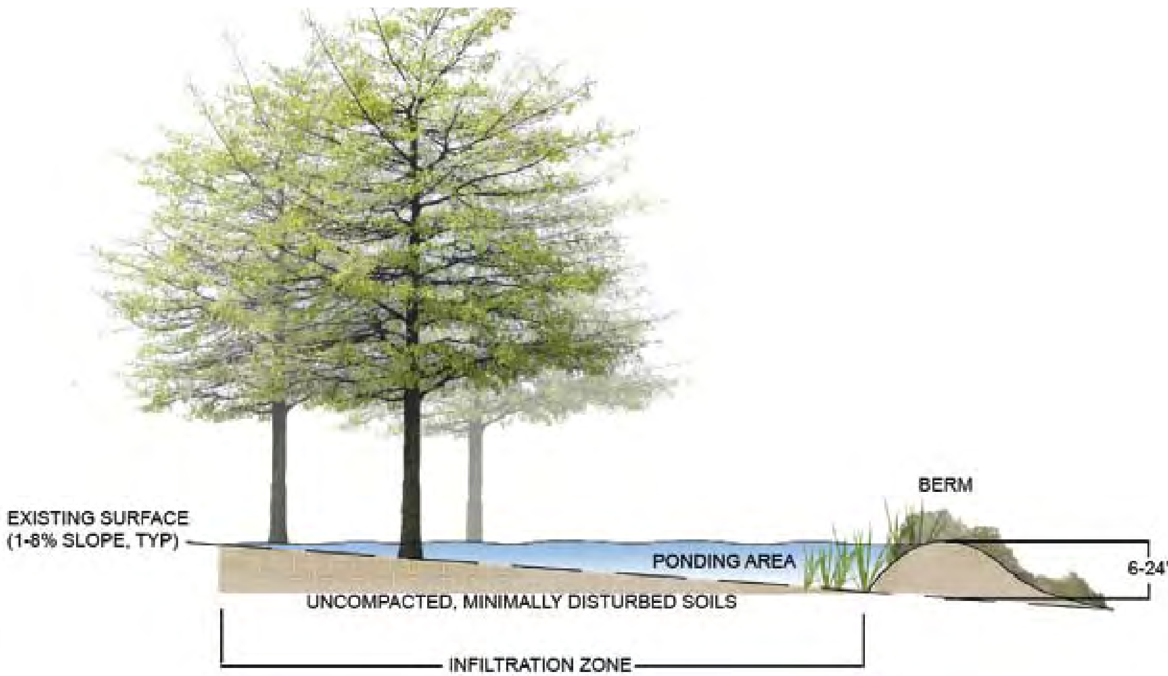
- **The soil mantle should be preserved for surface infiltration BMPs** and excavation should be minimized. Those soils that do not need to be disturbed for the building program should be left undisturbed. Macropores can provide a significant mechanism for water movement in surface infiltration systems, and the extent of macropores often decreases with depth. Maximizing the soil mantle also increases the pollutant removal capacity and reduces concerns about groundwater mounding. Therefore, excessive excavation for the construction of infiltration systems is strongly discouraged.
- **Isolate hot spot areas**. Site plans that include infiltration in hot spots need to be reviewed carefully. Hot spots are most often associated with some industrial uses and high traffic – gasoline stations, vehicle maintenance areas, and high intensity commercial uses (fast food restaurants, convenience stores, etc.). Infiltration may occur in areas of hot spots provided pretreatment is suitable to address concerns.
- **Utilize pretreatment**. Pretreatment should be utilized for most infiltration BMPs, especially for hot spots and areas that produce high sediment loading. Pretreatment devices that operate effectively in conjunction with infiltration include grass swales, vegetated filter strips, settling chambers, oil/grit separators, constructed wetlands, sediment sumps, and water quality inserts. Selection of pretreatment should be guided by the pollutants of greatest concern, site by site, depending upon the nature and extent of the land development under consideration. Selection of pretreatment techniques will vary depending upon whether the pollutants are of a particulate (sediment, phosphorus, metals, etc.) versus soluble (nitrogen and others) nature. Types of pretreatment (i.e., filters) should be matched with the nature of the pollutants expected to be generated.
- **The loading ratio of impervious area to bed bottom area must be considered**. One of the more common reasons for infiltration system failure is the design of a system that attempts to infiltrate a substantial volume of water in a very small area. Infiltration systems work best when the water is "spread out". The loading ratio describes the ratio of imperious drainage area to infiltration area, or the ratio of total drainage area to infiltration area. In general, the following loading ratios are recommended (some situations, such as highly permeable soils, may allow for higher loading ratios):
  - Maximum impervious loading ratio of 5:1 relating impervious drainage area to infiltration area.
  - Maximum total loading ratio of 8:1 relating total drainage area to infiltration area.
- **The hydraulic head or depth of water should be limited**. The total effective depth of water within the infiltration BMP should generally not be greater than two feet to avoid excessive pressure and potential sealing of the bed bottom. Typically the water depth is limited by the loading ratio and drawdown time and is not an issue.
- **Drawdown time must be considered**. In general, infiltration BMPs should be designed so that they completely empty within a 72-hour period in most situations (a 48-hour period is preferred).
- **All infiltration BMPs should be designed with a positive overflow** that discharges excess volume in a non-erosive manner, and allows for controlled discharge during extreme rainfall events or frozen bed conditions. Infiltration BMPs should never be closed systems dependent entirely upon infiltration in all storm frequency situations.
- **Geotextiles should be incorporated into the design as necessary**. Infiltration BMPs that are subject to soil movement into the stone medium or excessive sediment deposition must be constructed with suitably permeable non-woven geotextiles to prevent the movement of fines and sediment into the infiltration system. The designer is encouraged to err on the side of caution and use geotextiles as necessary within the BMP structure.
- **Aggregates used in construction should be washed**. In general, bank run material will contain fines that will wash off and clog the infiltration surface.
- **Infiltration utilizing vegetation**. Adequate soil cover (generally 12 to 18 inches) must be maintained above the infiltration bed to allow for a healthy vegetative cover. Vegetation over infiltration beds can be native grasses, meadow mix, or other low-growing, dense species (Appendix C). These plants have longer roots than traditional grass and will likely benefit from

Infiltration trench with geotextile

the moisture in the infiltration bed, improving the growth of these plantings and, potentially increasing evapotranspiration.

- **Using underdrains in poor draining soils**. Underdrains can be used in infiltration BMPs where in-situ soils are expected to cause ponding lasting longer than 48 hours. If used, underdrains are typically small diameter (6 to 12 inches) perforated pipes in a clean gravel trench wrapped in geotextile fabric (or in the storage/infiltration bed). Underdrains should have a flow capacity greater than the total planting soil infiltration rate and should have at least 18 inches of soil/gravel cover. They can daylight to the surface or connect to another stormwater system. A method to inspect and clean underdrains should be provided (via cleanouts, inlet, overflow structure, etc.)
- **Freeboard**. It is recommended that two feet of freeboard be provided from the 100-year flood elevation of the infiltration practice to the lowest basement floor elevation of residential, commercial, industrial, and institutional buildings located adjacent to the BMP, unless local requirements recommend or stipulate otherwise.

Figure 7.25
Typical components of a berm



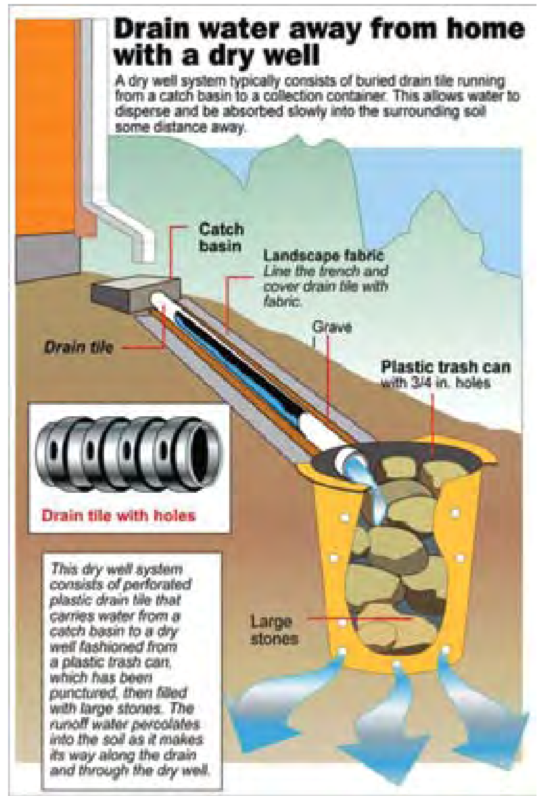
Additional design considerations for infiltration berms

- Sizing criteria (Figure 7.25) are dependent on berm function, location, and storage volume requirements.
    - Low **berm height** (less than or equal to 24 inches) is recommended to encourage maximum infiltration and to prevent excessive ponding behind the berm. Greater heights may be used where berms are being used to divert flow or to create "meandering" or lengthened flow pathways. In these cases, stormwater is designed to flow adjacent to (parallel to), rather than over the crest of the berm. Generally, more berms of smaller size are preferable to fewer berms of larger size.
    - **Berm length** is dependent on functional need and site size. Berms installed along the contours should be level and located across the slope. Maximum length will depend on width of the slope.
- Infiltration berms should be constructed along (parallel to) contours at a **constant level elevation**.
- **Soil**. The top one foot of a berm needs to consist of high quality topsoil, with well-drained, stable fill material making up the remainder of the berm. A berm may also consist entirely of high quality topsoil, but this the more expensive option.

  The use of gravel is not recommended in the layers directly underneath the topsoil because of the tendency of the soil to wash through the gravel. In some cases, the use of clay may be required due to its cohesive qualities (especially where the berm height is high or relatively steeply sloped). However, well-compacted soil is usually sufficient provided that the angle of repose, the angle at which the soil will rest and not be subject to slope failure (see #5 below), is adequate for the soil medium used.
- The **angle of repose of** any soil will vary with the texture, water content, compaction, and vegetative cover. Typical angles of repose are given below:
    - Non-compacted clay: 5 to 20 percent
    - Dry Sand: 33 percent
    - Loam: 35 to 40 percent
    - Compacted clay: 50 to 80 percent
- **Slope**. The angle of repose for the soil used in the berm should determine the maximum slope of the berm with additional consideration to aesthetic, drainage, and maintenance needs. 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 slope ratio may promote increased runoff rate and erosive conditions. Berm side slopes should never exceed a 2:1 ratio.
- **Plant materials**. It is important to consider the function and form of the berm when selecting plant materials. When using native trees and shrubs, plant them in a pattern that appears natural and accentuates the form of the berm. Consider native species from a rolling prairie or upland forest habitat. If turf will be combined with woody and herbaceous plants, the turf should be placed to allow for easy maneuverability while mowing. Low maintenance native plantings, such as trees and meadow plants, rather than turf and formal landscaping, are encouraged and can be found in Appendix C.
- **Infiltration trench option**. Soil testing is required for infiltration berms that will utilize a subsurface infiltration trench. Infiltration trenches are not recommended in existing woodland areas as excavation and installation of subsurface trenches could damage tree root systems. See the infiltration trench section for information on infiltration trench design.
- **Aesthetics**. To the extent possible, berms should reflect the surrounding landscape. Berms should be graded so that the top of the berm is smoothly convex and the toes of the berms are smoothly concave. Natural, asymmetrical berms are usually more effective and attractive than symmetrical berms, which tend to look more artificial. The crest of the berm should be located near one end of the berm rather than in the middle.
- Pretreatment. The small depression created by an infiltration berm can act as a sediment forebay prior to stormwater entering a down slope BMP, such as a bioretention basin, a subsurface infiltration bed, or another such facility.

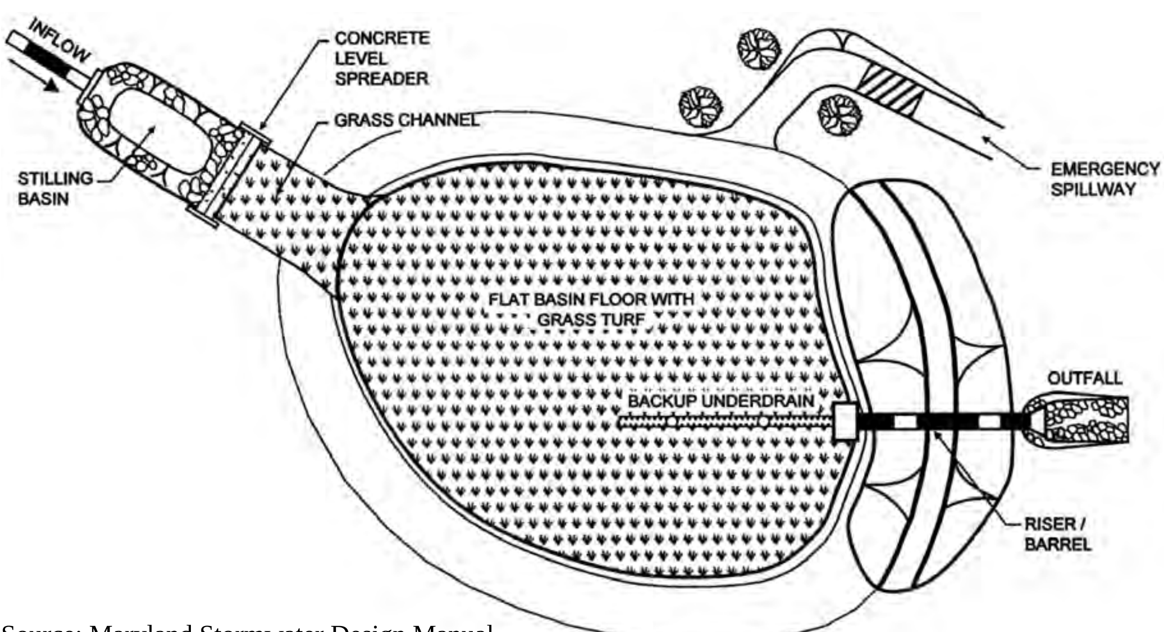
Additional design considerations for dry wells

- Dry wells typically consist of 18 to 48 inches of clean washed, uniformly graded aggregate with 40 percent void capacity (AASHTO No. 3, or similar). Dry well aggregate is wrapped in a nonwoven geotextile, which provides separation between the aggregate and the surrounding soil. Typically, dry wells will be covered in at least 12 inches of soil or six inches of gravel or riverstone. An alternative form of dry well is a subsurface, prefabricated chamber, a number of which are currently available on the market.
- All dry wells must be able to convey system overflows to downstream drainage systems. System overflows can be incorporated either as surcharge (or overflow) pipes extending from roof leaders or via connections from the dry well itself.
- The design depth of a dry well should take into account frost depth to prevent frost heave.
- A removable filter with a screened bottom should be installed in the roof leader below the surcharge pipe in order to screen out leaves and other debris.
- Inspection and maintenance access to the dry well should be provided. Observation wells not only provide the necessary access to the dry well, but they also provide a conduit through which pumping of stored runoff can be accomplished in case of slowed infiltration.



Residential dry well
Source - AP/Stan Kohler

Figure 7.26
Infiltration basin sketch



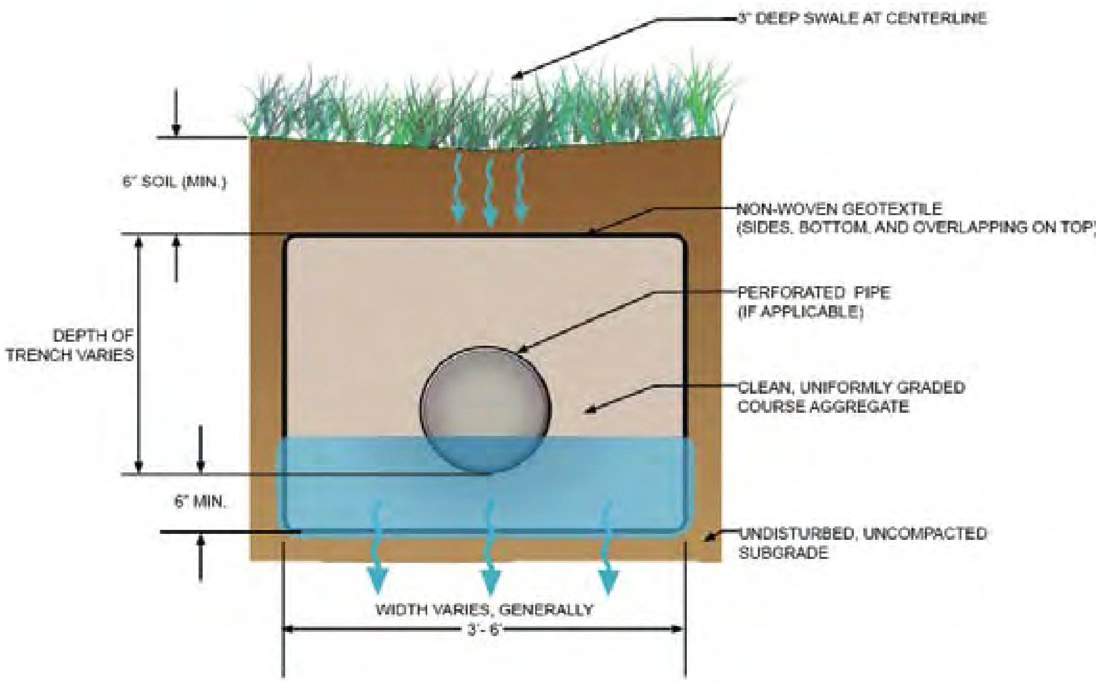
Source: Maryland Stormwater Design Manual

- Though roofs are generally not a significant source of runoff pollution, they can still be a source of particulates and organic matter, as well as sediment and debris during construction. Measures such as roof gutter guards, roof leader clean-outs with sump, or an intermediate sump box can provide pretreatment for dry wells by minimizing the amount of sediment and other particulates that enter it.

Additional Design Considerations for Infiltration Basins

- Infiltration basins are typically used for drainage areas of five to 50 acres with land slopes that are less than 20 percent.
- A six-inch layer of sand must be placed on the bottom of an infiltration basin (Figure 7.26). This sand layer can intercept silt, sediment, and debris that could otherwise clog the top layer of the soil below the basin.
- An infiltration basin does not normally have a structural outlet to discharge runoff from the stormwater quality design storm. Instead, outflow from an infiltration basin is through the surrounding soil. An infiltration basin may also be combined with an extended detention basin to provide additional runoff storage for both stormwater quality and quantity management. A structural outlet or emergency spillway is provided for storms that exceed the design of the infiltration basin.
- The berms surrounding the basin should be compacted earth with a slope of not less than 3:1, and a top width of at least two feet.
- The overflow from the infiltration basin must be properly designed for anticipated flows. Large infiltration basins may require multiple outlet control devices to effectively allow for overflow water during the larger storms. Emergency overflow systems can be constructed to direct large storm overflows.
- The sediment pre-treatment structure should be designed to provide for access and maintenance.
- In some cases, basins may be constructed where impermeable soils on the surface are removed and where more permeable underlying soils then are used for the basin bottom. Care should be taken in the excavation process to make sure that soil compaction does not occur.
- The inlets into the basin should have erosion protection.
- Use of a backup underdrain or low-flow orifice may be considered in the event that the water in the basin does not drain within 72 hours.

Figure 7.27
Infiltration trench cross section



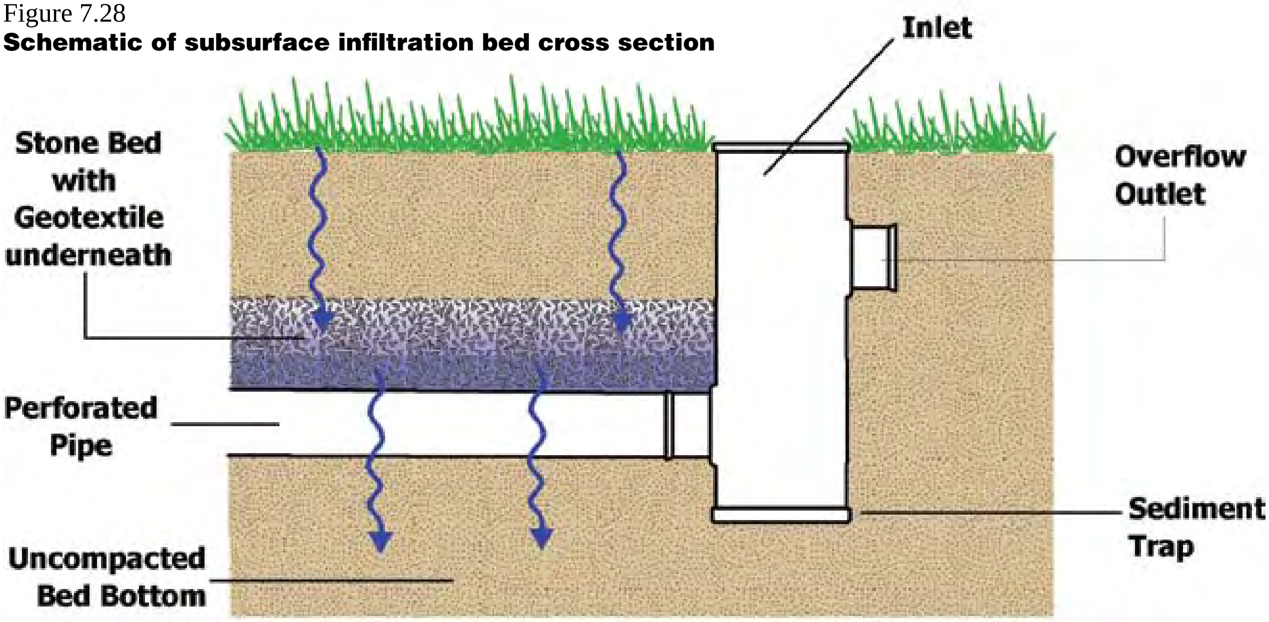
Additional design considerations for infiltration trenches

- The infiltration trench (Figure 7.27) is typically comprised of a section of uniformly graded aggregate, such as AASHTO No. 3, which ranges one to two inches in gradation. Depending on local aggregate availability, both larger and smaller size aggregate may be used. The critical requirements are that the aggregate be uniformly-graded, clean-washed, and contain at least 40 percent void space. The depth of the trench is a function of stormwater storage requirements, frost depth considerations, and site grading.
- Water quality inlets or catch basins with sumps are required for all surface inlets to prevent clogging of the infiltration trench with sediment and debris. Parking lot and street runoff must be treated by vegetated filter strips, bioretention, or water quality inlets capable of removing oil and grease and similar pollutants. Untreated parking lot and road runoff should never be directly discharged underground.
- Cleanouts, observation wells, or inlets must be installed at both ends of the infiltration trench and at appropriate intervals to allow access to the perforated pipe.
- When designed as part of a storm sewer system, a continuously perforated pipe that extends the length of the trench and has a positive flow connection may be include to allow high flows to be conveyed through the infiltration trench. Depending on size, these pipes may provide additional storage volume.
- Trees may be planted over the infiltration trench provided that adequate soil media is provided above the trench (a minimum of three feet).
- While most infiltration trenches areas consist of an aggregate storage bed, alternative subsurface storage products may also be employed. These include a variety of proprietary, interlocking plastic units that contain much greater storage capacity than aggregate, at an increased cost.

Additional design considerations for subsurface infiltration beds

- The infiltration bed must be wrapped in nonwoven geotextile filter fabric to prevent migration of the subsoils into the stone voids. (Bottom, top, and sides).
- The subsurface infiltration bed (Figure 7.28) is typically comprised of a 12 to 36-inch section of aggregate, such as AASHTO No.3, which ranges from one to two inches in gradation. Depending on local aggregate availability, both larger and smaller size aggregate has been used. The critical requirements are that the aggregate be uniformly-graded, clean-washed, and contain at least 40 percent void space. The depth of the bed is a function of stormwater storage requirements, frost depth considerations, and site grading. Infiltration beds are typically sized to mitigate the increased runoff volume from a two-year design storm.
- A water quality inlet or catch basin with sump is required for all surface inlets to avoid standing water for periods greater than 72 hours.

Figure 7.28
Schematic of subsurface infiltration bed cross section



Subsurface infiltration bed
Source: Driesenga & Associates, Inc.

- Perforated pipes along the bottom of the bed can be used to evenly distribute runoff over the entire bed bottom. Continuously perforated pipes should connect structures (such as cleanouts and inlet boxes). Pipes should lay flat along the bed bottom to provide for uniform distribution of water. Depending on size, these pipes may provide additional storage volume.
- Cleanouts or inlets should be installed at a few locations within the bed at appropriate intervals to allow access to the perforated piping network and storage media.
- Grading of adjacent contributing areas should be mildly sloped between one percent and three percent to facilitate drainage.
- In areas with poorly-draining soils, subsurface infiltration areas may be designed to slowly discharge to adjacent wetlands or bioretention areas.
- The subsurface bed and overflow may be designed and evaluated in the same manner as a detention basin to demonstrate the mitigation of peak flow rates. In this manner, detention basins may be eliminated or significantly reduced in size.
- During construction, the excavated bed may serve as a temporary sediment basin or trap, which can reduce overall site disturbance. The bed should be excavated to at least one foot above the final bed bottom elevation for use as a temporary sediment trap or basin. Following construction and site stabilization, sediment should be removed and final grades established.

Incorporating a Safety Factor into Infiltration BMP Design

For the purposes of site suitability, areas with tested soil infiltration rates as low as 0.1 inches per hour may be used for infiltration BMPs. However, in the design of these BMPs and the sizing of the BMP, the designer should incorporate a safety factor. Safety factors between 1 (no adjustment) and 10 have been used in the design of stormwater infiltration systems, with a factor of two being used in most cases. Therefore a measured infiltration rate of 0.5 inches per hour should generally be considered as a rate of 0.25 inches per hour in design. See the Soil Infiltration Testing Protocol in Appendix E for guidance on performing infiltration tests.

Modeling Infiltration Systems

As discussed in Chapter 9 of this manual, infiltration systems can be modeled similarly to traditional detention basins. The marked difference with modeling infiltration systems is the inclusion of the infiltration rate, which can be considered as another outlet. For modeling purposes, it is sometimes useful to develop infiltration rates that vary (based on the infiltration area provided as the system fills with runoff) for inclusion in the stage-storage-discharge table.

Table 7.12
Stormwater Functions by Infiltration BMP Type

	Volume	Peak Rate	Water Quality
Infiltration Berms	Can be used to reduce the volume of runoff and provide infiltration in accordance with LID stormwater goals. The volume reduction potential of berms is a function of the storage provided (surface and subsurface, if applicable) and the infiltration that will occur.	Can be used at mitigating peak rates for larger storms through two mechanisms: providing storage for detention (and on-going infiltration) behind them and, in some cases, elongating the flow path through a site, thereby extending the time of concentration.	Can be expected to achieve pollutant removals between 30% - 70% and in the upper ranges especially for smaller storms.
Infiltration Basins	Provides an excellent means of capturing and infiltrating runoff. Provides runoff volume storage during storm events, while the undisturbed vegetated surface allows infiltration of runoff into the underlying soil mantle. Can be sized to meet the entire channel protection volume recommended by LID criteria or sized smaller and used in conjunction with other LID practices.	Provides effective management of peak rates to meet the LID design criteria. The basin acts as a storage reservoir during large storm events, even while runoff infiltrates. Outlet structures can be designed to manage peak rates with the use of weir and orifice controls and systems can be designed to manage peak rates for storms up to and including the 100-year storm.	Effective in reducing total suspended solids, nutrients, metals, and oil and grease. Both the vegetative surface and the underlying soils allow pollutant filtration. When designed to capture and infiltrate runoff volumes from small storm events, they provide very high pollutant reductions.
Infiltration Trenches	Provides an excellent means of capturing and infiltrating runoff from small storms. The trench provides runoff volume storage and infiltration during small storm events, while the perforated pipe allows runoff conveyance during large design storms or more extreme events.	Provides limited management of peak rates. The trench may provide more peak rate benefit for small frequent storms, rather than large design storms. Because infiltration trenches help to provide a decentralized approach to stormwater management, they may benefit peak rate mitigation by contributing to increased stormwater travel time.	Effective in reducing total suspended solids, metals, and oil and grease. They provide very high pollutant reductions when designed to capture the volume from small storms because there is little if any discharge of runoff carrying the highest pollutant loads. Provide limited treatment of dissolved pollutants, such as nitrates.
Dry Wells	Dry wells are typically designed to capture and infiltrate runoff volumes from small storm events from roof area.	Provides limited management of peak rates. Provides some peak rate benefit by reducing direct connections of impervious area to storm sewer collection systems, and by contributing to increased stormwater travel time.	Effective at capturing and infiltrating the water quality volume or "first flush". Provides very high pollutant reductions because there is little if any discharge of "first flush" runoff which carries the highest pollutant loads.
Subsurface Infiltration	Provides effective management of volume. A well-designed system is capable of infiltrating the majority of small frequent storms on an annual basis.	Can be designed to manage peak rates by utilizing the stormwater storage bed, including simple rate controls such as weirs and orifices in the overflow control structure. Capable of infiltrating the majority of small frequent storms, while managing peak rates for designs storms up to the 100-year frequency storm.	Very effective at reducing total suspended solids, phosphorus, metals, and oil and grease. Because many systems are designed to capture and infiltrate small, frequent storms, they provide effective water quality control by reducing pollutants associated with the "first-flush".

Stormwater Functions and Calculations

Infiltration practices can provide excellent benefits for managing volume and water quality protection. While some BMPs are better than others in managing peak rates, all infiltration BMPs provide some peak rate benefit by removing direct connections from impervious surfaces and increasing time of travel. Table 7.12 provides a summary of the stormwater functions by BMP type.

Calculations for Infiltration BMPs

Infiltration area

The minimum infiltration area should be based on the following (according to the loading ratio):

Minimum Surface Infiltration Area = [Contributing impervious area] / 5*

*May be increased depending on soil infiltration capacity (e.g., where soils are Type A or rapidly draining). For carbonate, geologic areas may be decreased to three.

This actual infiltration area (Table 7.13) should be greater than the minimum infiltration area.

Protecting Groundwater Quality

The protection of groundwater quality is of utmost importance in any Michigan watershed. The potential to contaminate groundwater by infiltrating stormwater in properly designed and constructed BMPs with proper pretreatment is low.

Numerous studies have shown that stormwater infiltration BMPs have a minor risk of contaminating either groundwater or soil. The U.S. Environmental Protection Agency summarized in “Potential Groundwater Contamination from Intentional and Non-intentional Stormwater Infiltration” (Pitt et al., 1994) the potential of pollutants to contaminate groundwater as either low, low/moderate, moderate, or high. Of the 25 physical pollutants listed, one has a “high” potential (chloride), and two have “moderate” potential (fluoranthene and pyrene) for polluting groundwater through the use of shallow infiltration systems with some sediment pretreatment.

While chloride can be found in significant quantities due to winter salting, relatively high concentrations are generally safe for both humans and aquatic biota). Pentachlorophenol, cadmium, zinc, chromium, lead, and all the pesticides listed are classified as having a “low” contamination potential. Even nitrate which is soluble and mobile is only given a “low/moderate” potential.

Table 7.13
Definition of Infiltration Area for Infiltration BMPs

BMP	Infiltration Area Definition
Infiltration Berms	Total Infiltration Area (Ponding Area) = Length of Berm x Average Width of ponding behind berm.
Infiltration Basin	The Infiltration Area is the bottom area of the basin. This is the area to be considered when evaluating the Loading Ratio to the Infiltration basin.
Infiltration Trench	The Infiltration Area* is the bottom area of the trench. This is the area to be considered when evaluating the Loading Rate to the Infiltration basin. [Length of Trench] x [Width of Trench] = Infiltration Area (Bottom Area) * Some credit can be taken for the side area that is frequently inundated as appropriate.
Dry Well	A dry well may consider both bottom and side (lateral) infiltration according to design.
Subsurface Infiltration	The Infiltration Area is the bottom area of the bed. Some credit can be taken for the side area that is frequently inundated as appropriate.

Volume reduction

Infiltration BMPs can be used to reduce the volume of runoff and provide infiltration in accordance with LID stormwater goals. The volume reduction potential is a function of the storage provided (surface and subsurface, if applicable) and the infiltration that will occur. If a perforated pipe or underdrain is used in the design that discharges directly to surface water, the volume of water discharged must be subtracted from the volume reduction calculation.

Total Volume Reduced = Surface Storage Volume (if applicable) + Subsurface Volume (if applicable) + Infiltration Volume

Where,

Surface storage volume (ft^3) = Average bed area* (ft^2) x maximum design water depth (ft)

Subsurface storage/Infiltration bed volume (ft^3) = Infiltration area (ft^2) x Depth of underdrain material (ft) x Void ratio of storage material

*Depth is the depth of the water stored during a storm event, depending on the drainage area, conveyance to the bed, and outlet control.

Estimated Infiltration Volume (CF) = [Bed bottom area (SF)] x [Infiltration design rate (in/hr)] x [Infiltration period* (hr)] / 12 inches/ft.

*Infiltration Period is the time during the storm event when bed is receiving runoff and capable of infiltration at the design rate (typically 6 to 12 hours). See worksheet 5 in chapter 9.

Peak rate mitigation

The amount of peak rate control provided by infiltration practices is dependent on the cumulative runoff volume removed by all the infiltration practices applied to a site. Where sufficient infiltration is provided to control the runoff volume from any size storm, the corresponding peak runoff rate will also be restored and the peak runoff rate from larger, less frequent storms will be reduced. Where possible, reducing peak rate of runoff through volume control is generally more effective than fixed rate controls.

Some infiltration BMPs (e.g., infiltration basins) can manage peak rates better than others (e.g., infiltration berms). However, all infiltration BMPs provide some peak rate benefit (e.g., by removing direct connections from impervious surfaces and increasing time of travel). See Chapter 9 for more information.

Water quality improvement

Infiltration practices are effective in reducing pollutants such as total suspended solids, nutrients, metals, oil and grease. The vegetative surface and the underlying soils allow pollutant filtration and studies have shown that pollutants typically are bound to the soils and do not migrate deeply below the surface (i.e. greater than 30-inches). Infiltration practices should be used as part

Subsurface infiltration at Mid Towne Village at the City of Grand Rapids, MI

Source: Driesenga & Associates, Inc.

of a treatment train when capturing runoff from stormwater hot spots, such as industrial parking lots, due to the increased level of pollutants. Typical ranges of pollutant reduction efficiencies for infiltration practices are based on available literature data and listed below:

- TSS – 75 to 90 percent
- TP – 60 to 75 percent
- TN – 55 to 70 percent
- NO_3 – 30 percent

Construction Guidelines

The following guidelines apply for all infiltration BMPs.

- **Do not compact soil infiltration beds during construction**. Prohibit all heavy equipment from the infiltration area and absolutely minimize all other traffic. Equipment should be limited to vehicles that will cause the least compaction, such as low ground pressure (maximum four pounds per square inch) tracked vehicles. Areas for Infiltration areas should be clearly marked before any site work begins to avoid soil disturbance and compaction during construction.

- **Protect the infiltration area from sediment by ensuring erosion and sediment control practices are implemented until the surrounding site is completely stabilized**. Methods to prevent sediment from washing into BMPs should be clearly shown on plans. Where geo-textile is used as a bed bottom liner, this should be extended several feet beyond the bed and folded over the edge to protect from sediment wash into the bed during construction, and then trimmed.

  Runoff from construction areas should never be allowed to drain to infiltration BMPs. This can usually be accomplished by diversion berms and immediate vegetative stabilization. The infiltration area may be used as a temporary sediment trap or basin during earlier stages of construction. However, if an infiltration area is also to be utilized as a temporary sediment basin, excavation should be limited to within one foot of the final bottom invert of the infiltration BMP to prevent clogging and compacting the soil horizon, and final grade removed when the contributing site is fully stabilized.

  All infiltration BMPs should be finalized at the end of the construction process, when upstream soil areas have a dense vegetative cover. In addition, do not remove inlet protection or other erosion and sediment control measures until site is fully stabilized. Any sediment which enters inlets during construction is to be removed within 24 hours.
- **Provide thorough construction oversight**. Long-term performance of infiltration BMPs is dependent on the care taken during construction. Plans and specifications must generally be followed precisely. The designer is encouraged to meet with the contractor to review the plans and construction sequence prior to construction, and to inspect the construction at regular intervals and prior to final acceptance of the BMP.
- **Provide quality control of materials**. As with all BMPs, the final product is only as good as the materials and workmanship that went into it. The designer is encouraged to review and approve materials and workmanship, especially as related to aggregates, geotextiles, soil and topsoil, and vegetative materials.

Additional Construction Guidelines for Infiltration Berms

The following is a typical construction sequence for an infiltration berm without a subsurface infiltration trench, though alterations will be necessary depending on design variations.

- Lightly scarify (by hand) the soil in the area of the proposed berm before delivering soil to site (if required). Heavy equipment should not be used within the berm area.
- Bring in fill material to make up the major portion of the berm (as necessary) as soon as subgrade preparation is complete in order to avoid accumulation of debris. Soil should be added in eight-inch lifts and compacted after each addition according to design specifications. The slope and shape of the berm should graded out as soil is added.
- Protect the surface ponding area at the base of the berm from compaction. If compaction of this area does occur, scarify soil to a depth of at least 8 inches.
- After allowing for settlement, complete final grading within two inches of proposed design elevations. Tamp soil down lightly and smooth sides of the berm. The crest and base of the berm should be level along the contour.
- Seed and plant berm with turf, meadow plants, shrubs or trees, as desired. Water vegetation at the end of each day for two weeks after planting is completed. (Appendix C).
- Mulch planted and disturbed areas with compost to prevent erosion while plants become established.

Additional Construction Guidelines for Subsurface Infiltration

- Where erosion of subgrade has caused accumulation of fine materials and/or surface ponding, this material should be removed with light equipment and the underlying soils scarified to a minimum depth of six inches with a York rake (or equivalent) and light tractor. All fine grading should be done by hand. All bed bottoms are to be at level grade.
- Earthen berms (if used) between infiltration beds should be left in place during excavation.
- Geotextile and bed aggregate should be placed immediately after approval of subgrade preparation

and installation of structures. Adjacent strips of geotextile should overlap a minimum of 18 inches, and should also be secured at least four feet outside of the bed to prevent any runoff or sediment from entering the storage bed. This edge strip should remain in place until storage media is placed in the bed.

- Clean-washed, uniformly-graded aggregate should be placed in the bed in maximum eight-inch lifts. Each layer should be lightly compacted, with construction equipment kept off the bed bottom as much as possible.
- Once bed aggregate has been installed, geotextile can be folded over the top of the aggregate bed. Additional geotextile should be placed as needed to provide a minimum overlap of 18 inches between adjacent geotextile strips.
- Place approved engineered soil media over infiltration bed in maximum six-inch lifts.
- Seed and stabilize topsoil.

Additional Construction Guidelines for Infiltration Trenches

- Excavate infiltration trench bottom to a uniform, level uncompacted subgrade free from rocks and debris. Do NOT compact subgrade.
- Place nonwoven geotextile along bottom and sides of trench. Nonwoven geotextile rolls should overlap by a minimum of 16 inches within the trench. Fold back and secure excess geotextile during stone placement.
- Install upstream and downstream control structures, cleanouts, observation wells, etc.
- Place uniformly graded, clean-washed aggregate in 8-inch lifts, lightly compacting between lifts.
- Install continuously perforated pipe as indicated on plans. Backfill with uniformly graded, clean-washed aggregate in 8-inch lifts, lightly compacting between lifts.
- Fold and secure nonwoven geotextile over infiltration trench, with minimum overlap of 16-inches.
- If vegetated, place a minimum six-inch lift of approved topsoil over infiltration trench, as indicated on plans.
- Seed and stabilize topsoil.

Causes of Infiltration BMP Failure

With respect to stormwater infiltration BMPs, the result of "failure" is a reduction in the volume of runoff anticipated or the discharge of stormwater with excessive levels of some pollutants. Where the system includes built structures, such as porous pavements, failure may include loss of structural integrity for the wearing surface, whereas the infiltration function may continue uncompromised. For infiltration systems with vegetated surfaces, such as play fields or rain gardens, failure may include the inability to support surface vegetation, caused by too much or too little water.

The primary causes of reduced performance are:

- Poor construction techniques, especially soil compaction/smearing, which results in significantly reduced infiltration rates.
- A lack of site soil stabilization prior to the BMP receiving runoff, which greatly increases the potential for sediment clogging from contiguous land surfaces.
- Inadequate pretreatment, especially of sediment-laden runoff, which can cause a gradual reduction of infiltration rates.
- Lack of proper maintenance (erosion repair, re-vegetation, removal of detritus, catch basin cleaning, vacuuming of pervious pavement, etc.), which can reduce the longevity of infiltration BMPs.
- Inadequate design.
- Inappropriate use of geotextile.

Infiltration systems should always be designed such that failure of the infiltration component does not completely eliminate the peak rate attenuation capability of the BMP. Because infiltration BMPs are designed to infiltrate small, frequent storms, the loss or reduction of this capability may not significantly impact the storage and peak rate mitigation of the BMP during extreme events.

Additional Construction Guidelines for Infiltration Basins

- If necessary, excavate infiltration basin bottom to provide a level and uncompacted subgrade free from rocks and debris. Never compact subgrade.
- Install outlet control structures.
- Seed and stabilize topsoil (Planting with native species is preferred).

Additional Construction Guidelines for Dry Wells

- Excavate dry well bottom to a uniform, level uncompacted subgrade, free from rocks and debris. Do NOT compact subgrade. To the greatest extent possible, excavation should be performed with the lightest practical equipment. Excavation equipment should be placed outside the limits of the dry well.
- Completely wrap dry well with nonwoven geotextile. If sediment and/or debris have accumulated in dry well bottom, remove prior to geotextile placement. Geotextile rolls should overlap by a minimum of 18-24 inches within the trench. Fold back and secure excess geotextile during stone placement.
- Install continuously perforated pipe, observation wells, and all other dry well structures. Connect roof leaders to structures as indicated on plans.
- Place uniformly graded, clean-washed aggregate in 6-inch lifts, between lifts.
- Fold and secure nonwoven geotextile over trench, with minimum overlap of 12-inches.
- Place 12-inch lift of approved topsoil over trench, as indicated on plans.
- Seed and stabilize topsoil.
- Connect surcharge pipe to roof leader and position over splashboard.

Maintenance

There are a few general maintenance practices that should be followed for all infiltration BMPs. These include:

- All catch basins and inlets should be inspected and cleaned at least twice per year.
- The overlying vegetation of subsurface infiltration features should be maintained in good condition, and any bare spots revegetated as soon as possible.
- Vehicular access on subsurface infiltration areas should be prohibited (unless designed to allow vehicles), and care should be taken to avoid excessive compaction by mowers.

Additional Maintenance Information for Infiltration Berms

Infiltration berms have low to moderate maintenance requirements, depending on the design. Unless otherwise noted, the following maintenance actions are recommended on an as-needed basis.

Infiltration berms

- Regularly inspect to ensure they are infiltrating; monitor drawdown time after major storm events (total drawdown of the system should not exceed 72 hours; surface drawdown should not exceed 48 hours).
- Inspect any structural components, such as inlet structures to ensure proper functionality
- If planted in turf grass, maintain by mowing (maintain two to four-inch height); other vegetation will require less maintenance; trees and shrubs may require annual mulching, while meadow planting requires annual mowing and clippings removal
- Avoid running heavy equipment over the infiltration area at the base of the berms; the crest of the berm may be used as access for heavy equipment when necessary to limit disturbance.
- Do not apply pesticides or fertilizers in and around infiltration structures
- Routinely remove accumulated trash and debris
- Remove invasive plants as needed
- Inspect for signs of flow channelization and/or erosion; restore level spreading immediately after deficiencies are observed (monthly)

Diversion berms

- Regularly inspect for erosion or other failures (monthly)
- Regularly inspect structural components to ensure functionality
- Maintain turf grass and other vegetation by mowing and re-mulching
- Do not apply pesticides or fertilizers where stormwater will be conveyed
- Remove invasive plants as needed
- Routinely remove accumulated trash and debris

Additional Maintenance Information for Infiltration Basins

- Inspect the basin after major storm events and make sure that runoff drains down within 72 hours. Mosquito's should not be a problem if the water drains in 72 hours. Mosquitoes require a considerably long breeding period with relatively static water levels.
- Inspect for accumulation of sediment, damage to outlet control structures, erosion control measures, signs of water contamination/spills, and slope stability in the berms.
- Mow only as appropriate for vegetative cover species.
- Remove accumulated sediment from the sediment pretreatment device/forebay as needed. Inspect pretreatment forebay at least one time per year.
- If Infiltration basin bottom becomes clogged, scrape bottom and remove sediment and restore original cross section. Properly dispose of sediment.

Additional Maintenance Information for Dry Wells

- Inspect dry wells at least four times a year, as well as after every storm exceeding one inch.
- Remove sediment, debris/trash, and any other waste material from the dry well and dispose of at a suitable disposal/recycling site and in compliance with local, state, and federal waste regulations.
- Evaluate the drain-down time of the dry well to ensure the maximum time of 72 hours is not being exceeded. If drain down time exceeds the maximum, drain the dry well via pumping and clean out perforated piping, if included. If slow drainage persists, the system may need replacing.
- Regularly clean out gutters and ensure proper connections to facilitate the effectiveness of the dry well.
- Replace filter screen that intercepts roof runoff as necessary.
- If an intermediate sump box exists, clean it out at least once per year.

Winter Considerations

Most infiltration practices are typically located below the frost line and continue to function effectively throughout the winter. It is imperative to prevent salt, sand, cinder, and any other deicers from clogging the surface area of infiltration practices by avoiding piling snow in these areas. Sand and cinder deicers could clog infiltration devices and soluble deicers such as salt can damage the health of vegetation.

Cost

The construction cost of many infiltration BMPs can vary greatly depending on the configuration, location, site conditions, etc. Following is a summary of both construction and maintenance costs. This information should be strictly as guidance. More detailed cost information should be discerned for the specific site before assessing the applicability of the BMP.

	Construction Costs	Maintenance Costs
Dry well*	$4-9/ft3	5-10% of capital costs
Infiltration basin	Varies depending on excavation, plantings, and pipe configuration.	Disposal costs
Infiltration trench**	$20-30/ ft3	5-10% of capital costs
Subsurface infiltration bed	$13/ ft3	

*2003 dollars.
**City of Portland. 2006 dollars.

Designer/Reviewer Checklist for Infiltration Berms

ITEM	YES	NO	N/A	NOTES
Was the Soil Infiltration Testing Protocol followed?*				
Appropriate areas of the site evaluated?				
Infiltration rates measured?				
Was the Infiltration BMP followed?				
Two-foot separation from bedrock/SHWT?				
Soil permeability acceptable?				
Natural, uncompacted soils?				
Excavation in berm areas minimized?				
Loading ratio considered?				
Drawdown time less than 72 hours?				
Erosion and Sedimentation control?				
Feasible construction process and sequence?				
Entering flow velocities non-erosive?				
Berm height 6 to 24 inches?				
Berm designed for stability (temporary and permanent)?				
Acceptable berm side slopes?				
Are berm materials resistant to erosion?				
Located level, along contour?				
Acceptable soil for plants specified?				
Appropriate plants selected?				
Maintenance accounted for and plan provided?				

** In general, the protocol should be followed as much as possible (although there is more flexibility for berms than for other BMPs such as pervious pavement and subsurface infiltration that rely almost entirely on infiltration).*

Designer/Reviewer Checklist for Infiltration Trenches, Infiltration Basins, Dry Wells, and Subsurface Infiltration Beds

ITEM	YES	NO	N/A	NOTES
Was the Soil Infiltration Testing Protocol followed?				
Appropriate areas of the site evaluated?				
Infiltration rates measured?				
Was the Infiltration BMP followed?				
Two-foot separation between the bed bottom and bedrock/ SHWT?				
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?				
Loading ratio below 5:1?				
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?				

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BMP Fact Sheet

Level Spreaders

Level spreaders promote infiltration and improve water quality by evenly distributing flows over a stabilized, vegetated surface. This allows for better infiltration and treatment. There are several different types of level spreaders. Examples include concrete sills, earthen berms, and level perforated pipes.

LaVista Storm Drain Project Level Spreader
Source: City of Battle Creek

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Low
Commercial	Yes	**Groundwater Recharge**	Low
Ultra Urban	No	**Peak Rate**	Low
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	Low
Highway/Road	Yes	**TP**	Low
Recreational	Yes	**NO_3**	Low
		Temperature	Low

Additional Considerations	
Cost	Low
Maintenance	Low
Winter Performance	High

Variations
- Inflow
- Outflow

Key Design Features
- Ultimate outlet from structural BMPs
- Roof downspout connections (roof area > 500sf)
- Inlet connections (impervious area > 500sf)
- Inflow to structural BMP, such as filter strip, infiltration basin, vegetated swale

Site Factors
- Water table to bedrock depth – N/A
- Soils – Permeability not critical but should be considered for erodibility
- Slope – 1-8 percent max.
- Potential hotspots – Yes
- Maximum drainage area – Varies (five acres max.)

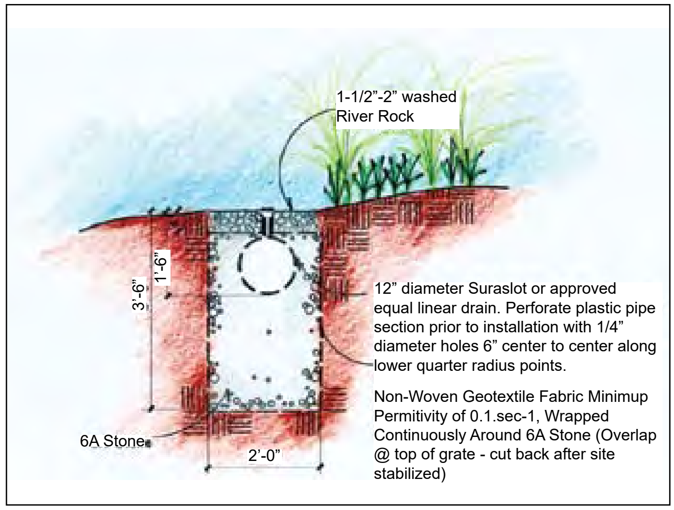
Benefits
- Low cost
- Wide applicability
- Ability to work with other BMPs in a treatment train
- Avoids concentrated discharges and their associated potential erosion

Limitations
- Low stormwater benefits by itself
- Careful design and construction required to function properly

Case Study: Washtenaw County West Service Center

Washtenaw County West Service Center civic buildings are located on sandy soils where infiltration is good, making the area an ideal location for a level spreader. Roof water is directed to the level spreaders, which are set in a gravel bed and are part of a series of stormwater treatment BMPs on site. On either end of the level spreader are structures with a sump that can be cleaned out. If the level spreader is overwhelmed because of a large storm, it fills and spills over into a detention area that is vegetated with native plants.

Washtenaw County West Service Center level spreader
Source: Insite Design Studio, Inc.

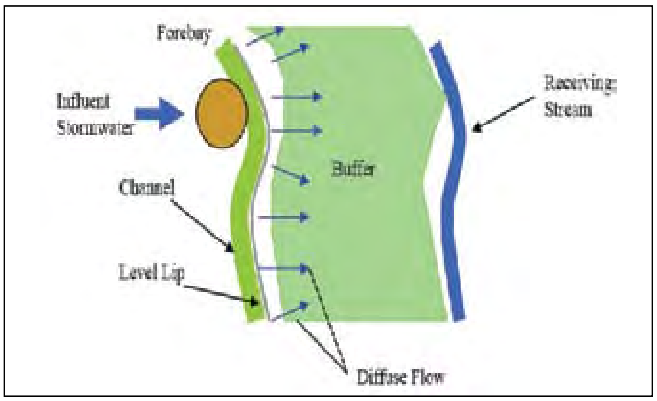


Level spreader schematic
Source: Insite Design Studio, Inc.

Case Study Site Considerations	
Project Type	Level spreader
Maintenance Responsibility	Washtenaw County
Project Contact	Andrea Kevrick, InSite Design Studio, akevrick@insite-studio.com 734-995-4194

Description and Function

Level spreaders are designed to disperse concentrated stormwater flows and are often used with other BMPs over a wide enough area to prevent erosion. Erosion can undermine a BMP, and can be a significant source of sediment pollution to streams and other natural water bodies. By dispersing flows, level spreaders assist vegetated BMPs in pollutant removal via filtration, infiltration, absorption, adsorption, and volatilization. Level spreaders also reduce the impact of a stormwater outlet to a receiving water body.



Level spreader located between a sediment forebay and a buffer

Source: NCSU-BAE requests acknowledgment for this image

Variations

Inflow

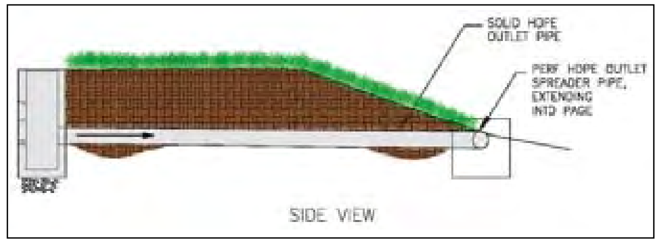
Inflow level spreaders are meant to evenly distribute flow entering into another structural BMP, such as a filter strip, infiltration basin, or vegetated swale. Examples of this type of level spreader include concrete sills and earthen berms.

Outflow

Outflow level spreaders are intended to reduce the erosive force of high flows while at the same time enhancing natural infiltration opportunities. Examples of this second type include earthen berms and a level, perforated pipe in a shallow aggregate trench (Figure 7.29). In this example, the flow is from the left (from an outlet control device from another BMP) and flow reaches the spreader via the solid pipe.

Figure 7.29

A level spreader with a perforated pipe



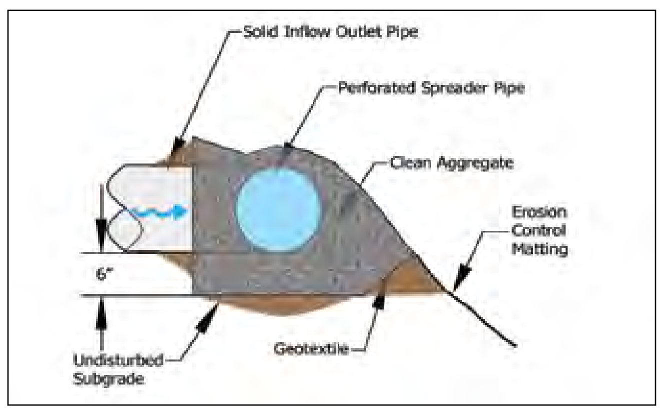
Applications

Level spreaders can be used in a variety of applications, from residential areas to highway/road projects. The primary requirement is that there must be adequate area with an acceptable slope to receive the outflow from the spreader. In ultra-urban settings, there is typically not adequate space for level spreaders.

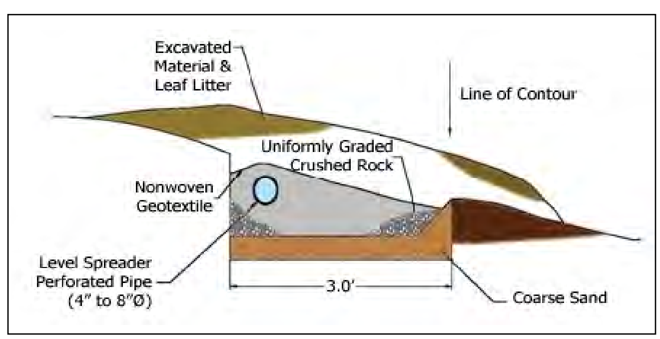
Figure 7.30, a close-up of Figure 7.29, shows an outlet pipe from an upstream BMP that serves as an inflow to the level spreader.

Figure 7.30

Level spreader with inflow pipe



Level spreader with geotextile surrounding the aggregate helping to create a sloped area.



Design Considerations

Level spreaders are considered a permanent part of a site's stormwater management system. Therefore, uphill development should be stabilized before any dispersing flow techniques are installed. If the level spreader is used as an erosion and sedimentation control measure, it must be reconfigured (flush perforated pipe, clean out all sediment) to its original state before use as a permanent stormwater feature.

All contributing stormwater elements (infiltration beds, inlets, outlet control structures, pipes, etc) should be installed first.

1. Provide as many outfalls as possible and avoid concentrating stormwater. This can reduce or even eliminate the need for engineered devices to provide even distribution of flow.
2. Level spreaders are not applicable in areas with easily erodible soils and/or little vegetation. The slope below the level spreader should be at a maximum eight percent in the direction of flow to discourage channelization. More gentle slopes (e.g., as low as one percent) are also acceptable.
3. The minimum length of flow after the level spreader (of the receiving area) should be 15 feet.
4. For design considerations of earthen berm level spreaders, refer to the Infiltration BMP.
5. Level spreaders should not be constructed in uncompacted fill. Undisturbed virgin soil and compacted fill is much more resistant to erosion and settlement than uncompacted fill.
6. Most variations of level spreaders should not be used alone for sediment removal. Significant sediment deposits in a level spreader will render it ineffective. A level spreader may be protected by adding a forebay to remove sediment from the influent. This can also make sediment cleanout easier.
7. Perforated pipe used in a level spreader may range in size from 4-12 inches in diameter. The pipe is typically laid in an aggregate envelope, the thickness of which is left to the discretion of the engineer. A deeper trench will provide additional volume reduction and should be included in such calculations (see Infiltration BMP). A layer of nonwoven geotextile filter fabric separates the aggregate from the adjacent soil layers, preventing migration of fines into the trench.
8. The length of level spreaders is primarily a function of the calculated influent flow rate. The level spreader should be long enough to freely discharge the desired flow rate. At a minimum, the desired flow rate should be that resulting from a 10-year design storm. This flow rate should be safely diffused without the threat of failure (i.e., creation of erosion, gullies, or rills). Diffusion of the storms greater than the 10-year storm is possible only if space permits. Generally, level spreaders should have a minimum length of 10 feet and a maximum length of 200 feet.
9. Conventional level spreaders designed to diffuse all flow rates should be sized based on the following:
   - For grass or thick ground cover vegetation:
     - 13 linear feet of level spreader for every one cubic feet per second (cfs)
     - Slopes of eight percent or less from level spreader to toe of slope
   - For forested areas with little or no ground cover vegetation:
     - 100 linear feet of level spreader for every one cfs flow
     - Slopes of six percent or less from level spreader to toe of slope

     For slopes up to 15 percent for forested areas and grass or thick ground cover, level spreaders may be installed in series. The above recommended lengths should be followed.
10. The length of a perforated pipe level spreader may be further refined by determining the discharge per linear foot of pipe. A level spreader pipe should safely discharge in a distributed manner at the same rate of inflow, or less. If the number of perforations per linear foot (based on pipe diameter) and average head above the perforations are known, then the flow can be determined by the following equation:

$$L = \frac{Q_P}{Q_L}$$

Where:
L = length of level spreader pipe (ft.)
QP = design inflow for level spreader (cfs)
QL = level spreader discharge per length (cfs/ft.)

AND

$$Q_L = Q_O \, x \, N$$

Where:
Q_L = level spreader discharge per length (cfs/ft.)

Q_o = perforation discharge rate (cfs.)
N = number of perforations per length of pipe, provided by manufacturer based on pipe diameter (#/ft)

AND

$$Q_o = C \ x A x \sqrt{2gH}$$

Where:
Q_o = perforation discharge rate (cfs)
C_d = Coefficient of discharge (typically 0.60)
A = Cross sectional area of one perforation (ft^2)
g = acceleration due to gravity, 32.2 $ft./sec^2$
H = head, average height of water above perforation (ft.) (provided by manufacturer)

11. Flows may bypass a level spreader in a variety of ways, including an overflow structure or upturned ends of pipe. Cleanouts/overflow structures with open grates can also be installed along longer lengths of perforated pipe. Bypass may be used to protect the level spreader from flows above a particular design storm.
12. Erosion control matting, compost blanketing, or riprap on top of filter fabric are recommended immediately downhill and along the entire length of the level spreader, particularly in areas that are unstable or have been recently disturbed by construction activities. Generally, low flows that are diffused by a level spreader do not require additional stabilization on an already stabilized and vegetated slope.

Stormwater Functions and Calculations

Volume reduction

In general, level spreaders do not substantially reduce runoff volume. However, if level spreaders are designed similarly to infiltration trenches, a volume reduction can be achieved. Furthermore, for outflow level spreaders, the amount of volume reduction will depend on the length of level spreader, the density of receiving vegetation, the downhill length and slope, the soil type of the receiving area, and the design runoff. Large areas with heavy, dense vegetation will absorb most flows, while barren or compacted areas will absorb limited runoff.

Peak rate mitigation

Level spreaders will not substantially decrease the overall discharge rate from a site.

Water quality improvement

While level spreaders are low in water quality pollutant removal, they are often an important BMP used in concert with other BMPs. For example, level spreaders can work effectively (and improve performance) with related BMPs such as filter strips and buffers. In addition, level spreaders can avoid erosion problems associated with concentrated discharges.

Construction Guidelines

The condition of the area downhill of a level spreader must be considered prior to installation. For instance, the slope, density and condition of vegetation, natural topography, and length (in the direction of flow) will all impact the effectiveness of a distributed flow measure. Areas immediately downhill from a level spreader may need to be stabilized, especially if they have been recently disturbed. Erosion control matting, compost blanketing, and/or riprap are the recommended measures for temporary and permanent downhill stabilization. Manufacturer's specifications should be followed for the chosen stabilization measure.

Maintenance

Compared with other BMPs, level spreaders require only minimal maintenance efforts, many of which may overlap with standard landscaping demands. The following recommendations represent the minimum routine inspection maintenance effort for level spreaders:

Once a month and after every heavy rainfall (greater than two inches):

1. Inspect the diverter box and clean and make repairs. Look for clogged inlet or outlet pipes and trash or debris in the box.
2. Inspect the forebay and level spreader. Clean and make repairs. Look for:
   - Sediment in forebay and along level spreader lip,
   - Trash and/or leaf buildup,
   - Scour, undercutting of level spreader,
   - Settlement of level spreader structure (no longer level; you see silt downhill below level spreader),
   - Fallen trees on level spreader, and
   - Stone from below the level spreader lip washing downhill.

3. Inspect the filter strip and the bypass swale and make repairs as needed. Look for:
    - Damaged turf reinforcement or riprap rolling downhill,
    - Erosion within the buffer or swale, and
    - Gullies or sediment flows from concentrated flows downhill of level spreader,

Once a year:

- Remove any weeds or shrubs growing on level spreader or in swale.

Cost

Level spreaders are relatively inexpensive and easy to construct. There are various types of level spreaders, so costs will vary. Per foot material and equipment cost will range from $5 to $20 depending on the type of level spreader desired. Concrete level spreaders may cost significantly more than perforated pipes or berms, but they provide a more sure level surface, are easier to maintain, and more reliable.

Designer/Reviewer Checklist for Level Spreaders

ITEM	YES	NO	N/A	NOTES
Avoidance of stormwater concentration as much as practical?				
Soil erodibility considered?				
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 level spreader?				
Level spreader length calculations performed?				
Erosion control matting, compost blankets, etc. provided?				
Appropriate vegetation selected for stabilization?				
Feasible construction process and sequence?				
Erosion and sedimentation control provided to protect spreader?				
Maintenance accounted for and plan provided?				
Soils stable or vegetation established before flows are directed to the level spreader?				
If used during construction, are accumulated soils removed?				

References

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BMP Fact Sheet

Native Revegetation

Native revegetation includes the restoration of forest savanna (scattered trees among prairie plants), and/or prairie. Revegetation should primarily use native vegetation due to the numerous benefits, including reduced maintenance needs.

Bennett Arboretum Wildflower Grow Zone Project, Wayne County, MI
Source: Wayne County Department of Environment

Potential Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Low/Med/High
Commercial	Yes	**Groundwater Recharge**	Low/Med/High
Ultra Urban	Limited	**Peak Rate**	Low/Med
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	High
Highway/Road	Limited	**TP**	High
Recreational	Yes	**TN**	Med/High
		Temperature	Med

Additional Considerations	
Cost	Low/Med
Maintenance	Low
Winter Performance	Medium

Variations
- Prairie
- No-mow lawn area
- Woodland
- Constructed wetlands
- Buffer areas
- Replacement lawn areas

Key Design Features
- Minimize traditional turf lawn area
- Develop landscape plan using native materials, determining the most appropriate
- Protect areas during construction
- Use integrated pest management (IPM) approach

Site Factors:
- Water table to bedrock depth: N/A
- Soils: Vegetation should match soil types
- Slope: Applicable on most slopes (up to 1H:1V)
- Potential hotspots: No
- Max. drainage area: Optimal is five times (max. 20 times) the revegetated area

Benefits
- Low long-term maintenance needs
- Improves water quality
- Reduces volume

Limitations
- Establishment period requires more intensive maintenance, such as weeding and watering

Case Study: Black River Heritage Trail and Waterfront Redevelopment

City of Bangor, MI

The South Branch of the Black River winds through the City of Bangor. The city owns significant frontage on the river, and undertook a restoration project to capitalize on this natural amenity. The project was funded through a section 319 Nonpoint Source Management Grant, a Michigan Natural Resources Trust Fund Grant, and the City of Bangor. Restoration activities focused on remediating streambank erosion and reducing stormwater runoff. Erosion and sedimentation of the river was reduced through regrading of the river banks and stabilizing with native plantings.

The city's stormwater, which previously flowed directly into the Black River, is now filtered through a rain garden in Lion's Park. Walking trails have been enhanced and expanded, fishing/viewing platforms were installed, and a canoe/kayak launch was added. This project not only improves water quality conditions directly, but provides opportunities for public education due to its location in a city park.

Native revegetation along a walkway
Source: City of Bangor, MI

Case Study Site Considerations	
Project Type	Native plant, rain garden, vegetated filter strips, enhanced riparian areas
Estimated Total Project Cost	$102,000
Maintenance Responsibility	City of Bangor
Project Contact	Erin Fuller, 269-657-4030

Description and Function

Using native plants to vegetate an area is an effective method of improving the quality and reducing the volume of site runoff. Native plants significantly change the soil medium by adding carbon, decreasing bulk density, and increasing infiltration rates by as much as a factor of 10 or more even in clay soils (see Bharati, et.al, 2002 and Fuentes, et.al, 2004).

Native revegetation of a prairie plant community

Source: JFNew

Native species are generally described as those existing in a given geographic area prior to European settlement. Over time, native vegetation does not typically require significant chemical maintenance by fertilizers and pesticides. This results in additional water quality benefits. Native species are typically more tolerant and resistant to pest, drought, and other local conditions than non-native species. Landscape architects and ecologists specializing in native plant species are usually able to identify a wide variety of plants that meet these criteria anywhere in the state. Appendix C provides lists of commercially available native species by ecoregion.

Whenever practical, native species should be from the same ecoregion as the project area. When necessary, species may be used from adjacent ecoregions for aesthetic or practical purposes. Additional information relating to native species and their use in landscaping is available from the Michigan Native Plant Producers Association (MNPPA), at www.mnppa.org.

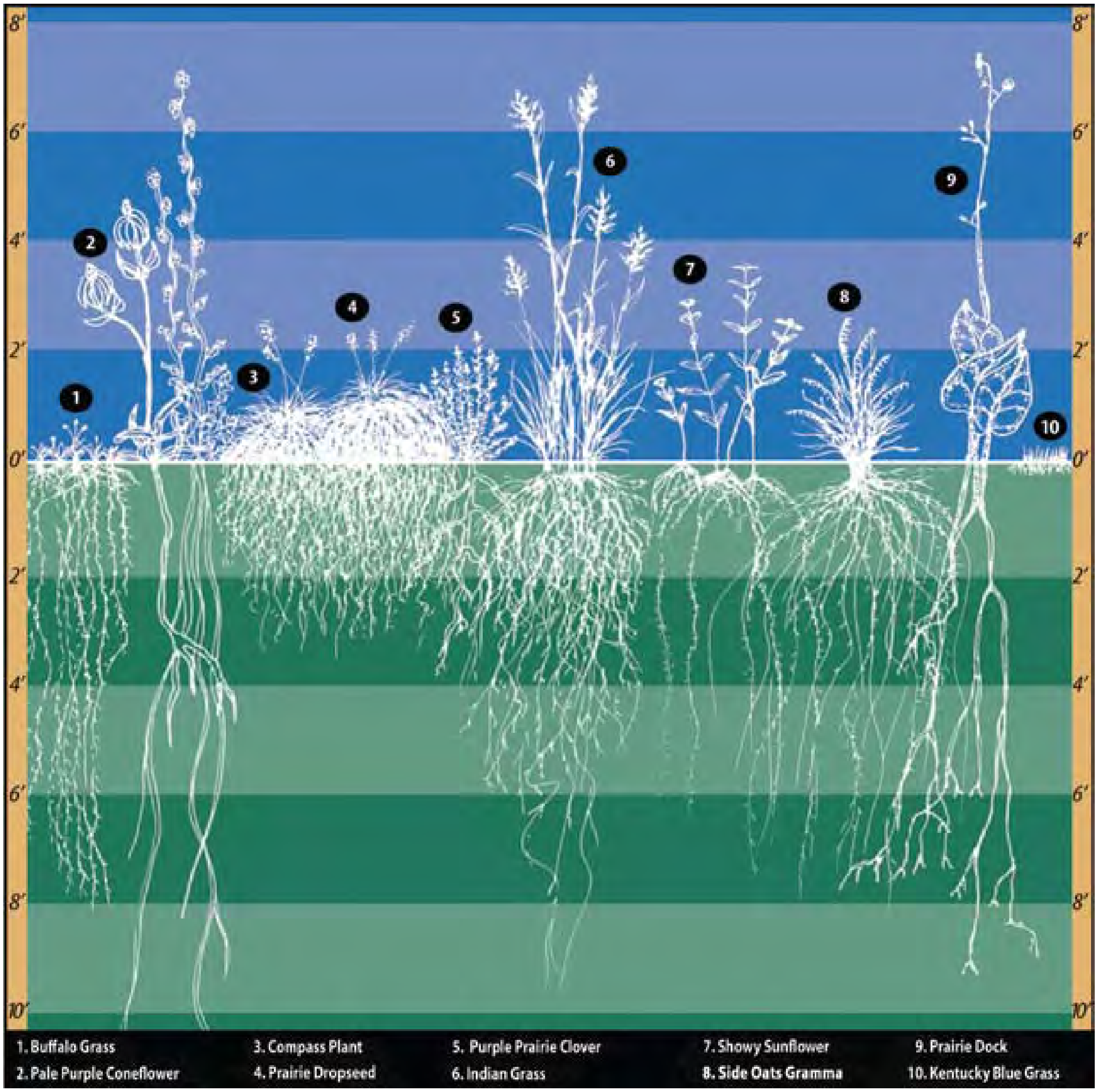
In addition to chemical applications, minimum maintenance also means minimal mowing and irrigation in established areas. Native grasses and other herbaceous materials that do not require mowing or intensive maintenance are preferred. Because selecting such materials begins at the concept design stage, this BMP can generally result in a site with reduced runoff volume and rate, as well as significant nonpoint source load reduction/ prevention.

A complete elimination of traditional lawns as a site design element can be a difficult BMP to implement, given the extent to which the lawn as an essential landscape design feature is embedded in current national culture. Instead, the landscape design should strategically incorporate areas of native plantings — surrounding limited turf grass areas — to act as buffers that will capture and filter stormwater flowing off of turf grasses or pavements.

Native species, being strong growers with denser root and stem systems than turf grass (Figure 7.31), result in:

- A greater volume of water uptake (evapotranspiration)
- Improved soil conditions through organic material and macropore formation
- Carbon sequestration
- Enhanced infiltration

Figure 7.31
Native meadow species compared to turf grass



Source: JFNew

If the objective is to revegetate an area with woodland species, the longer-term effect is a significant reduction in runoff volumes when contrasted with a conventional lawn planting. This decrease in runoff is caused by increases in interception, infiltration, evapotranspiration, and recharge. Peak runoff rate reduction also is achieved. Similarly, prairie reestablishment is also more beneficial than a conventional lawn planting. Again, these benefits are long term in nature and will not be apparent until the species have an opportunity to grow and mature (one advantage of the prairie planting is that this maturation process requires considerably less time than a woodland area).

In general, seeded prairie plantings grow roots in the first two years of planting, and by the third year, start to show substantial top growth. Therefore, a prairie planting may not be aesthetically pleasing during the first several years. Aesthetic expectations should therefore be adjusted accordingly. Posting signs explaining this fact to passersby can increase understanding and alleviate concerns about the look of the new planting. The signs can also explain the environmental benefits of planting native grasses.

Variations

Most newly-created native landscapes in Michigan fall under the category of either woodlands or prairies. Woodlands will provide shade, vertical structure, and a high level of rainfall interception in the long term. However, woodlands typically require a significant amount of time to mature. Prairies, on the other hand, have a tendency to establish and regain function rather quickly (3-10 years), and can provide lower-growing vegetation with highly attractive native grasses and wildflowers.

Species selection for any native landscape should be based on function, availability, and level of appropriateness for site conditions. Native species plantings can achieve variation in landscape across a variety of characteristics, such as texture, color, and habitat potential.

Properly selected mixes of flowering prairie species can provide seasonal color; native grasses offer seasonal variation in texture. Seed production is a food source for wildlife and reinforces habitat. In all cases, selection of native species should strive to achieve species variety and balance, avoiding creation of single-species or limited species "monocultures" which pose multiple problems. In sum, many different aspects of native species planting reinforce the value of native landscape restoration, typically increasing in their functional value as species grow and mature over time. Examples include:

- Prairie – Install forb/grass matrix that bears similarities to historic Michigan prairies and savannas.

Example of native woodland landscape restoration with Virginia bluebells

Source: JFNew

- No-mow lawn area – Install low-growing native grasses that are used as a substitute for lawn or cool-season grass plantings.
- Woodland – Install a balance of native trees, shrubs, forbs, grasses, and sedges that would historically be represented in Michigan woodlands.
- Constructed wetlands – Historic drained wetlands or existing artificial low areas may be planted with wetland species that will thrive in standing water or saturated conditions.
- Buffer areas – Bands of re-established native vegetation occurring between impermeable surfaces, lawns, or other non-native land uses and existing natural areas.
- Replacement lawn areas – Existing turf lawns may be converted to native prairies, wetlands, or woodlands to minimize maintenance while increasing stormwater benefits and wildlife habitat.

Example of a prairie restoration

Source: Veridian

Applications

- Residential – Native landscapes can be incorporated into common areas of residential developments. Additionally, individual homeowners may incorporate native landscapes into their own properties. Native revegetation should also be used to provide buffers around any existing natural areas that are undisturbed within the residential development.
- Commercial – Common areas and open spaces within commercial developments may be planted with native species, as well as any created detention/retention basins or artificial water ways. Native revegetation should also be used to provide buffers around any existing natural areas that are undisturbed within the commercial development.
- Ultra Urban – Use of native revegetation in limited in ultra-urban settings because of the lack of available green space. Wherever possible, however, native species should be incorporated.
- Industrial – Use of native revegetation in industrial settings is very similar to that in commercial settings.
- Retrofit – Established turf grass may be converted into prairie, woodland, or wetland.
- Highway/Road – Native plants may be established in rights-of-way to minimize long-term maintenance while establishing linear habitat corridors.

Design Considerations

The basis for native revegetation design scheme begins with assessing the site for:

- Existing native vegetation,
- Soil,
- Hydrologic regimes,
- Sun exposure, and
- Aesthetics

Existing native vegetation is a good starting point for determining what can thrive on a given site. However, the designer must also consider and balance various factors in developing a successful plant list. The hydrologic patterns set the stage for where along the moisture continuum plants will be most successful (easily found in native plant resource guides). The amount of sun

Native plantings surrounding detention facilities at South State Commons, Ann Arbor, MI

Source: InSite Design Studio, Inc.

Lawn replaced with native prairie mix at Scio Township Hall, MI

Source: InSite Design Studio, Inc.

Native vegetation at Harborside Office Center, City of Port Huron, MI

Source: St. Clair County Health Department and shade that a given species tolerates is also critical in successful plant selection (and is easy to find as well). Soil texture and pH (less often found in resources guides) will further narrow the plant choices. If soils are strongly acidic or basic, the pH will greatly influence and reduce plant choices. Once the potential plant list has run through the sieves of moisture, sun/shade, and soil characteristics, the designer will hopefully have a suite of loosely associated native plants that grow in similar conditions.

Besides the plants' physical requirements, there is the cultural issue of aesthetics to consider. Common issues that people have with native landscapes are the potential height and lack of cultivated appearance (tall and thin, smaller flowers, looser look, etc.). If the designed areas are highly visible, then these aesthetic issues can be addressed with good design principles and a solid understanding of native plants.

1. *Analyze site's physical conditions*

   The most important physical condition of the site is the topography, hydrology, and soil, each of which will guide protection activities and plant selection. Evaluate the soil using the USDA soil survey to determine important soil characteristics such as flooding potential, seasonal high water table, soil pH, soil moisture, and other characteristics. Evaluate the topography based on USGS maps or a topographical survey of the site.

2. *Analyze site's vegetative features*

   Existing vegetation present at the site should be examined to determine the overall strategy for vegetation restoration and establishment. Strategies will differ whether pre-existing conditions are pasture, overgrown abandoned field, mid-succession forest, or another type of setting. An effort to inventory existing vegetation for protection and to determine type of presettlement vegetation should be made to guide efforts.

   a. *Identify desirable species*: Use native tree and shrub species that thrive in local habitats in Michigan These species should be identified in the restoration site and protected. Several native vines and shrubs can provide an effective ground cover during establishment of the area, though they should be controlled to prevent herbaceous competition.

   b. *Identify undesirable species*: Control invasive plants prior to planting new vegetation.

   c. *Identify sensitive species*: Because many areas are rich in wildlife habitat and could potentially harbor wetland plant species, be aware of any rare, threatened, or endangered plant or animal species. Take care to protect sensitive species during restoration activities.

3. *Map the site*: Prepare an existing conditions sketch of the site that denotes important features, including stream width, length, stream bank condition, adjacent land uses, stream activities, desired width of buffer, discharge pipes, obstructions, etc.

4. *Create a design that meets multiple stakeholder objectives*

   a. *Landowner objectives*: Consider the current use of the existing vegetation, especially if the area will be protected by the landowner in perpetuity. Determine how the revegetated area will complement or conflict with existing and probable future uses of the property.

   b. *Community objectives:* Consider linking the revegetated area to an existing or planned green infrastructure system, which may include trails, parks, preserves, and wildlife habitat corridors. Evaluate how the new vegetation could help achieve local recreation goals.

   c. *Watershed objectives:* Examine the local watershed plan to identify goals related to establishing native plants. Have goals related to water quality been emphasized, or is wildlife habitat of primary concern? *If* no watershed plan has been prepared, examine other regional resource or recreation plans for reference to native plantings.

Native vegetation in a parking lot at Harborside Office Center, City of Port Huron, MI

Source: St. Clair County Health Department

5. *Amend soil*: In those sites where soils have been disturbed, restore compromised soils by subsoiling and/or adding a soil amendment, such as compost. This will help in reestablishing its long-term capacity for infiltration and pollution removal.
6. Limit the development footprint as much as possible, preserving natural site features, such as vegetation and topography. In contrast to turf, "natural forest soils with similar overall slopes can store up to 50 times more precipitation than neatly graded turf." (Arendt, *Growing Greener*, pg. 81) If lawns are desired in certain areas of a site, they should be confined to those areas with slopes less than six percent.
7. Prairie restoration can reduce turf or create a buffer between turf and forest. Meadow buffers along forests help reduce off-trail trampling and direct pedestrian traffic in order to avoid "desire-lines" which can further concentrate stormwater.

   Prepare the site for a prairie planting by weeding well before planting and during the first year. Perennial weeds may require year-long smothering, repeated sprayings with herbicides, or repeated tillage with equipment that can uproot and kill perennial weeds.

   The site should be sunny, open, and well-ventilated, as prairie plants require at least a half a day of full sun.

   Erosion prone sites should be planted with a nurse crop (such as annual rye or seed oats) for quick vegetation establishment to prevent seed and soil loss. Steep slopes (25 percent or steeper) and areas subject to water flow should be stabilized with erosion blankets, selected to mitigate expected runoff volumes and velocities. Hydro-seeding is generally not recommended for native species. There is tremendous variation among seed suppliers; choose seeds with a minimum percent of non-seed plant parts. Native seed should also be PLS (Pure Live Seed) tested by a third party to gauge seed viability.
8. Converting turf grass areas to prairie requires that all turf be killed or removed before planting, and care taken to control weeds prior to planting.
9. Forest restoration includes planting of tree species, 12-18 inches in height, and shrubs at 18-24 inches, with quick establishment of an appropriate ground cover to stabilize the soil and prevent colonization of invasive species. Trees and shrubs should be planted on eight-foot centers, with a total of approximately 430 trees per acre.

   Reforestation can be combined with other volume control BMPs such as retentive berming, vegetated filter strips and swales. Plant selection should mimic the surrounding native vegetation and expand on the native species already found on the site. A mixture of native trees and shrubs is recommended and should be planted once a ground cover is established.
10. Ensure adequate stabilization, since native grasses, meadow flowers, and woodlands establish more slowly than turf. Stabilization can be achieved for forest restoration by establishing a ground cover before planting of trees and shrubs. When creating meadows, it may be necessary to plant a fast growing nurse crop with meadow seeds for quick stabilization. Annual rye can be planted in the fall or spring with meadow seeds and will establish quickly and usually will not present a competitive problem. Erosion prone sites should be planted with a nurse crop and covered with weed-free straw mulch, while steep slopes and areas subject to runoff should be stabilized with erosion control blankets suitable for the expected volume and velocity of runoff.
11. Prepare a landscape maintenance plan that identifies weeding plans, mowing goals, irrigation needs, and trimming of herbaceous perennials or key tree specimens, as needed.

Example of native reforestation efforts
Source: JFNew

Maintenance

Local land conservancies are excellent resources when considering the long-term stewardship of the area. If a site has critical value, a local conservancy may be interested in holding a conservation easement on the area, or may be able to provide stewardship services and assistance. The following organizations may also provide resources:

- Stewardship Network (www.stewardshipnetwork.org), a statewide organization, provides informational and educational resources about stewardship in Michigan
- Wild Ones (www.wildones.org/) is a national organization with local chapters which may also provide stewardship resources.

Applying a carefully selected herbicide (Roundup or similar glyphosate herbicide) around the protective tree shelters/tubes may be necessary, reinforced by selective cutting/manual removal, if necessary. This initial maintenance routine is often necessary for the first two to three years of growth and may be needed for up to five years until tree growth and tree canopy form, naturally inhibiting weed growth (once shading is adequate, growth of invasives and other weeds will be naturally prevented, and the woodland becomes self-maintaining). Survey the new woodland intermittently to determine if replacement trees should be provided (some modest rate of planting failure is usual).

Prairie management is somewhat more straightforward. A seasonal mowing or burning may be required, although care must be taken to make sure that any management is coordinated with essential reseeding and other important aspects of meadow reestablishment. In addition, burning needs to be coordinated with the local fire marshall and follow local regulations. In the first year, weeds must be carefully controlled and consistently mowed back to four to six inches tall when they reach 12-18 inches in height.

In the second year, continue to monitor and mow weeds and hand-treat perennial or rhizomatous weeds with herbicide. Weeds should not be sprayed with herbicide if the drift from the spray may kill large patches of desirable plants, allowing weeds to move in to these new open areas. If necessary, controlled spot herbicide applications may be used to treat invasive plants if the treatments can be completed without damage to off-target vegetation.

A prescribed burn should be conducted at the end of the second or beginning of the third growing season. If burning is not possible, the prairie should be mowed very closely to the ground instead. If possible or practical, the mowed material should be removed from the site to expose the soil to the sun. This helps encourage rapid soil warming which favors the establishment of "warm season" plants over "cool season" weeds. Long-term maintenance should incorporate burning or mowing on a two to five year cycle to minimize woody species growth while encouraging development of the native prairie species.

Stormwater Functions and Calculations

Volume and peak rate

Native revegetation will lower runoff volume and peak rates by lowering the runoff coefficient (i.e., curve number). Designers can receive credit based on the square feet of trees or shrubs being added. Proposed trees and shrubs to be planted under the requirements of these BMPs can be assigned a curve number (CN) reflecting a woodlot in "good" condition for an area of 200 square feet per tree or the estimated tree canopy, whichever is greater. For shrubs, the area should be 25 square feet per shrub. Calculation methodology to account for this BMP is provided in Chapter 9.

Example of savanna restoration
Source: JFNew

Water quality improvement

Landscape restoration using native species, which includes minimizing disturbance and maintenance, improves water quality preventively by minimizing application of fertilizers and pesticides. Avoiding this nonpoint pollutant source is an important water quality objective. See Chapter 9 for Water Quality Improvement methodology, which addresses the pollutant removal effectiveness of this BMP.

Cost

Cost estimates in Michigan for various aspects of native landscaping, including material and installation costs, are the following:

- $1,000-$2,500/acre for prairie installation or woodland understory installation
- $1,800-$2,600/acre for bare-root tree installation (10-foot spacing)
- $10-$20/plant for gallon-potted native perennial
- $2.50-$3.50/plant for plug-sized native perennial
- $250-$400/tree for balled-and-burlap tree installation

Costs for meadow re-establishment are lower than those for woodland, largely due to the need for tree installation. Again, such costs can be expected to be greater than installing a conventional lawn (seeding and mulching), although installation cost differences diminish when conventional lawn seeding is redefined in terms of conventional planting beds.

Cost differentials grow greater when longer term operating and maintenance costs are taken into consideration. If lawn mowing can be eliminated, or even reduced significantly to a once per year requirement, substantial maintenance cost savings result, often in excess of $2,000-$3,000 per acre per year.

If chemical application (fertilization, pesticides, etc.) can be eliminated, substantial additional savings result with use of native species. These reductions in annual maintenance costs resulting from a native landscape re-establishment very quickly outweigh any increased installation costs that are required at project initiation. The aesthetic, water quality, and environmental protection benefits of native landscaping are clear. Nonetheless, implementation is often hindered because parties paying the higher up-front costs (usually the developer) are different than the parties reaping the benefits of reduced maintenance costs. Overcoming this impediment involves recognizing that native landscaping is another part of the "infrastructure" that communities must build into design in order to achieve the desired outcome of appearance and water quality protection.

Criteria to receive credits for Native Revegetation

To receive credit for native revegetation under a location regulation, the following criteria must be met:

- ☐ Area is protected by clearly showing the limits of disturbance on all construction drawings and delineated in the field.
- ☐ Area to receive credit for trees is 200 square feet per tree or the estimated tree canopy, whichever is greater.
- ☐ Area to receive credit for shrubs is 25 square feet per shrub.
- ☐ Area is located on the development project.
- ☐ Area has a maintenance plan that includes weeding and watering requirements from initial installation through ongoing maintenance.

Designer/Reviewer Checklist for Native Revegetation

ITEM	YES	NO	N/A	NOTES
Avoidance of stormwater concentration as much as practical?				
Soil erodibility considered?				
Slope considered and appropriate?				
Existing and surrounding vegetation assessed, including desirable, sensitive, and non-native species?				
Site mapped?				
Does the design meet all stakeholder objectives, including stormwater, habitat, aesthetics, and timeframe for establishment?				
Does the soil require amendment?				
Erosion control matting, compost blankets, etc. provided as needed?				
Feasible construction process and sequence?				
Short and long-term maintenance accounted for and plan provided?				

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Bowman's Hill Wildflower Preserve, Washington Crossing Historic Park, PO Box 685, New Hope, PA 18938-0685, Tel (215) 862-2924, Fax (215) 862-1846, Native plant reserve, plant sales, native seed, educational programs, www.bhwp.org

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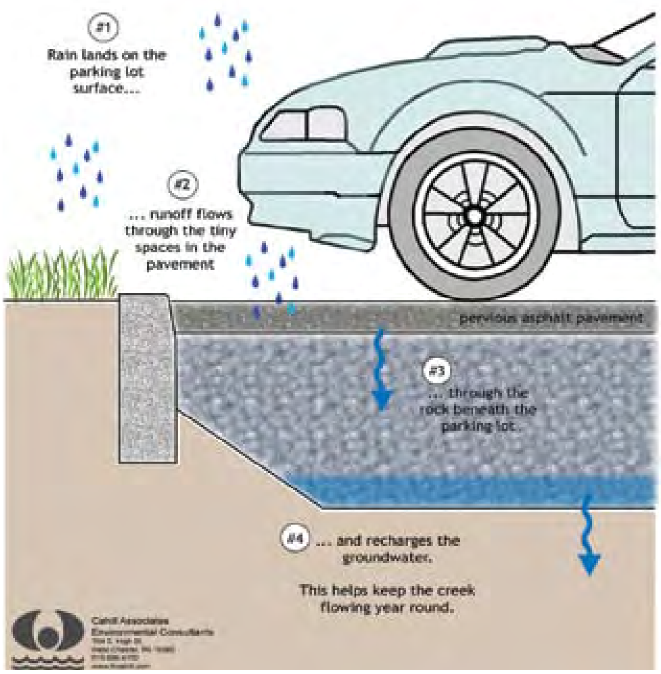
BMP Fact Sheet

Pervious Pavement with Infiltration

Pervious pavement is an infiltration technique that combines stormwater infiltration, storage, and structural pavement consisting of a permeable surface underlain by a storage reservoir. Pervious pavement is well suited for parking lots, walking paths, sidewalks, playgrounds, plazas, tennis courts, and other similar uses.



Pervious pavement with infiltration schematic

Applications		Stormwater Quantity Functions	
Residential	Yes**	**Volume**	High
Commercial	Yes	**Groundwater Recharge**	High
Ultra Urban	Yes	**Peak Rate**	Med/High
Industrial	Yes**	**Stormwater Quality Functions**	
Retrofit	Yes**	**TSS**	High***
Highway/Road	Limited	**TP**	Med/High
Recreational	Yes	**TN**	Medium
		Temperature	High

Additional Considerations	
Cost	Medium
Maintenance	High
Winter Performance	Medium

Variations

- Porous asphalt
- Pervious concrete
- Permeable paver blocks
- Reinforced turf/gravel

Key Design Features

- Follow soil infiltration testing protocol (Appendix E) and infiltration BMP guidelines
- Do not infiltrate on compacted soil
- Level storage bed bottoms
- Provide positive stormwater overflow from bed
- Surface permeability >20"/hr

Site Factors

- Water table/Bedrock separation: two-foot min*.
- Feasibility on steeper slopes: Low
- Potential hot spots: Not without design of pretreatment system

Benefits

- Volume control and groundwater recharge, moderate peak rate control
- Dual use for pavement structure and stormwater management

Limitations

- Pervious pavement not suitable for all uses
- High maintenance needs

* Four feet recommended, if possible

**Applicable with special design considerations.

***Pretreatment for TSS is recommended.

Case Study: Grand Valley State University Porous Pavement Parking Lots

A crucial project for Grand Valley State University (GVSU) to prevent the accelerated degradation of steep ravines, which had historically been used as a receptacle for untreated stormwater, was to construct two 180-car parking lots using porous asphalt pavement for student parking on the Allendale Campus. The site consists of heavy clay soils and, instead of using limited space for a detention basin, porous pavement was chosen to make the best use of available space. It is also one of the first best management practices adopted for campus use to move the university towards its goal of sustainable site design.

GVSU's clay soils don't allow for much infiltration so the goal of the porous pavement was primarily filtration and storage in the stone bed. Underdrains exist in the beds for just over half of one lot which outlet into a swale that has been planted with grasses. All other underdrains outlet directly to a storm sewer.

Project Highlights

The porous pavement has performed well, and there are no maintenance issues to date.

Since the project was completed in 2004, GVSU faculty has used the porous asphalt lots as an educational tool to demonstrate sustainable stormwater management concepts with students.

The pavement section consisted of 12 inches of MDOT 6A course aggregate over a nonwoven geotextile fabric, a four-inch underdrain, and three inches of porous asphalt.

Grand Valley State University Parking Lot
Source: Fishbeck, Thompson, Carr & Huber, Inc.

Water on Porous Asphalt
Source: Fishbeck, Thompson, Carr & Huber, Inc.

Case Study Site Considerations	
Project Type	Pervious pavement
Soil Conditions	Heavy clay soils
Estimated Total Project Cost	$240,000 per lot
Maintenance Responsibility	Grand Valley State University
Project Contact	Bob Brown, brownbo@gvsu.edu 616-331-3582, Kerri Miller, P.E., kamiller@ftch.com 616-464-3933

Description and Function

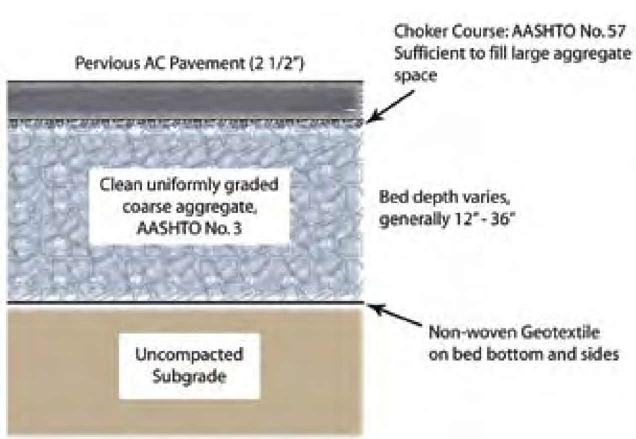
A pervious pavement system consists of a porous surface course underlain by a storage reservoir placed on uncompacted subgrade to facilitate stormwater infiltration (Figure 7.32). The storage reservoir may consist of a stone bed of uniformly graded, clean, and washed course aggregate with a void space of approximately 40 percent or other pre-manufactured structural storage units (see Infiltration BMP for detailed information on the use of structural storage units). The pervious pavement may consist of porous asphalt, pervious concrete, permeable paver blocks, or reinforced turf/gravel.

Stormwater drains through the surface course where it is temporarily held in the voids of the stone bed, and then slowly infiltrates into the underlying, uncompacted soil mantle (in some extreme cases, minimal compaction of the soil may be required). The stone bed can be designed with an overflow control structure so that during large storm events peak rates are controlled. At no time does the water level rise to the pavement level.

A layer of nonwoven geotextile filter fabric separates the aggregate from the underlying soil, preventing the migration of fines into the bed. The bed bottoms should be level and uncompacted to allow for even and distributed stormwater infiltration.

If new fill is required, it should consist of additional stone and not compacted soil. It is recommended that a fail safe be built into the system in the event that the pervious surface is adversely affected and suffers reduced performance. Many designs incorporate a riverstone/rock edge treatment (Figure 7.33) or inlets which are directly tied to the bed so that the stormwater system will continue to function despite the performance of the pervious pavement surface.

Figure 7.32
Example cross-section of porous asphalt system



Pervious pavement is well suited for parking lots, walking paths, sidewalks, playgrounds, plazas, tennis courts, and other similar uses. Pervious pavement can be used in driveways if the homeowner is aware of the stormwater functions of the pavement. Pervious pavement roadways have seen wider application in Europe and Japan than in the U.S., although at least one U.S. system has been constructed successfully. (In Japan and the U.S., applying an open-graded asphalt pavement of one inch or less on roadways has been used to provide lateral surface drainage and prevent hydroplaning, but these are applied over impervious pavement on compacted subgrade. This application is not considered a stormwater BMP.)

Properly installed and maintained pervious pavement has a significant life span. For example, existing systems that are more than 20 years old continue to function successfully. Because water drains through the surface course and into the subsurface bed, freeze-thaw cycles do not tend to adversely affect pervious pavement.

Pervious pavement is most susceptible to failure difficulties during construction and, therefore, it is important that construction be undertaken in such a way as to prevent:

- Compacted underlying soil (except in certain limited conditions),
- Contaminated stone subbase with sediment and fines,
- Tracking of sediment or any temporary storage of soil on the pavement surface, and
- Drainage of sediment-laden waters onto pervious surface or into constructed bed.

Figure 7.33
Riverstone edge serves as a backup inlet into the infiltration bed under the porous asphalt

Staging, construction practices, and erosion and sediment control must all be considered when using pervious pavements.

When properly designed, pervious pavement systems provide effective management of stormwater volume and peak rates. The storage reservoir below the pavement surface can be sized to manage both direct runoff and runoff generated by adjacent areas, such as rooftops. Because the stone bed provides storage, outlet structures can be designed to manage peak rates with the use of weir and orifice controls. A well-designed system can infiltrate the majority of frequent small storms on an annual basis while providing peak rate control for storms up to and including the 100-year frequency storm event.

Studies have shown that pervious systems have been very effective in reducing contaminants such as total suspended solids, metals, and oil and grease. Because pervious pavement systems often have zero net discharge of stormwater for small frequent storms, they provide effective water quality control. The pervious surface and underlying soils below the storage bed allow filtration of most pollutants.

However, care must be taken to prevent infiltration in areas where toxic/contaminated materials are present in the underlying soils or within the stormwater itself (see Infiltration Systems Guidelines for more information). When designed, constructed, and maintained according to the following guidelines, pervious pavement with underlying infiltration systems can dramatically reduce both the rate and volume of runoff, recharge the groundwater, and improve water quality.

In northern climates, pervious pavements have less of a tendency to form black ice and often require less plowing. Sand and other abrasives should never be used on pervious pavements, although salt may be used on pervious asphalt as long as it does not contain significant non-soluble particles. Commercial deicers may be used on pervious concrete. Pervious pavement surfaces often provide better traction for walking paths in rain or snow conditions.

Variations

Porous asphalt

Early work on porous asphalt pavement was conducted in the early 1970s by the Franklin Institute in Philadelphia. It consists of standard bituminous asphalt in which the fines have been screened and reduced, allowing water to pass through small voids. Pervious asphalt is typically placed directly on the stone subbase in a single 3½ to four-inch lift that is lightly rolled to a finished thickness of 2½ to three inches (Figures 7.34 and 7.35).

Because porous asphalt is standard asphalt with reduced fines, it is similar in appearance to standard asphalt. Newer open-graded mixes for highway application give improved performance through the use of additives and higher-grade binders. Porous asphalt is suitable for use in any climate where standard asphalt is appropriate.

Figure 7.34
Porous asphalt being placed at the University of Michigan in Ann Arbor

Figure 7.35
Porous asphalt on open-graded stone subbase

Pervious concrete

Pervious Portland Cement Concrete, or pervious concrete, was developed by the Florida Concrete Association. Like pervious asphalt, pervious concrete is produced by substantially reducing the number of fines in the mix in order to establish voids for drainage. In northern and mid-Atlantic climates such as Michigan, pervious concrete should always be underlain by a stone subbase designed for stormwater management and should never be placed directly onto a soil subbase.

While porous asphalt is very similar in appearance to standard asphalt, pervious concrete has a coarser appearance than conventional concrete. A clean, swept finish cannot be achieved. Care must be taken during placement to avoid working the surface and creating an impervious layer. Placement should be done by a contractor experienced with pervious concrete. Appropriately installed pervious concrete has proven to be an effective stormwater management BMP. Additional information pertaining to pervious concrete, including specifications, is available from the Michigan Concrete Association (www.miconcrete.org/).

Pervious and impervious concrete

Source: Michigan Department of Environmental Quality

Colored pervious concrete

Permeable paver blocks

Permeable paver blocks consist of interlocking units (often concrete) that provide some portion of surface area that may be filled with a pervious material such as gravel. These units are often very attractive and are especially well suited to plazas, patios, parking areas, and low-speed streets. As new products are always being developed, the designer is encouraged to evaluate the benefits of various products with respect to the specific application.

Permeable paver lot at Grand Rapids Environmental Services Building

Permeable paver blocks at Fairlane Green shopping center, Allen Park, MI

Reinforced turf/gravel

Reinforced turf consists of interlocking structural units that contain voids or areas for turf grass growth or gravel and suitable for traffic loads and parking. Reinforced turf units may consist of concrete or plastic and are underlain by a stone and/or sand drainage system for stormwater management.

Reinforced turf/gravel applications are excellent for fire access lanes, overflow parking (Figure 7.36), and occasional-use parking (such as at religious and athletic facilities). Reinforced turf is also an excellent application to reduce the required standard pavement width of paths and driveways that must occasionally provide for emergency vehicle access.

Figure 7.36
Reinforced turf used as overflow parking

Other

There are other proprietary products similar to pervious asphalt and concrete, but they use clear binders so that the beauty of the natural stone is visible. Material strength varies, so some of these products are not suitable for vehicular traffic Typical applications include tree pits, walkways, plazas, and playgrounds. There are also pervious pavements made using recycled tires.

Highly permeable paver
Source: Permapave

Applications

Pervious pavements have been widely applied in retrofit situations when existing standard pavements are being replaced. Care must be taken when using pervious pavements in industrial and commercial applications where pavement areas are used for material storage or the potential for surface clogging is high due to pavement use (see Infiltration BMP).

Parking areas

Porous asphalt lot with slow discharge to vegetated swale at Ford Motor Co., Dearborn, MI

Walkways

Pervious pavement, both asphalt and concrete, has been used in walkways and sidewalks. These installations typically consist of a shallow (eight-inch minimum) aggregate trench that is angled to follow the surface slope of the path. In the case of relatively mild surface slopes, the aggregate infiltration trench may be "terraced" into level reaches in order to maximize the infiltration capacity, at the expense of additional aggregate.

Porous asphalt pathway at Grey Towers National Historic Site, Milford, PA

Playgrounds/basketball/tennis

Porous asphalt street in Portland, OR

Streets and alleys

Permeable paver street in Dowagiac, MI
Source: Pokagon Band of Potawatomi Indians

Rooftop/impervious area connections

Pervious pavement systems are often used to provide total site stormwater management where rooftops and other impervious surfaces are tied into the infiltration bed below the pavement surface. This can be an effective means to manage stormwater for a development site, while reducing land disturbance for stormwater BMPs.

If pervious pavement systems receive runoff from adjacent areas, proper sediment pretreatment for that runoff must be considered to prevent clogging of the storage bed. Typical pretreatment can be achieved by the use of properly maintained cleanouts, inlet sediment traps, and water quality inserts or filter devices.

It is recommended that direct surface sheet flow conveyance of large impervious areas to the pervious pavement surface be avoided. High sheet flow loading to pervious pavement surfaces can lead to premature clogging of the pavement surface. To avoid this, it is recommended that adjacent impervious areas be drained and conveyed to the infiltration bed via inlets and trench drains with proper sediment pretreatment.

Design Considerations

While evaluating the following design considerations, there are also several additional resources to consider when implementing pervious pavement. These include the Site Design Process for LID (Chapter 5), Soil Infiltration Testing Protocol (Appendix E), the Recommendations for Materials are specific to porous asphalt and porous concrete (Appendix D), and additional steps set forth in the introduction to this chapter.

Siting

1. The overall site should be evaluated for potential pervious pavement/infiltration areas *early* in the design process because effective pervious pavement design requires consideration of grading.
2. A four foot clearance above the seasonally high water table and bedrock is recommended. A two foot clearance can be used but may reduce the performance of the infiltration BMP used.
3. Orientation of the parking bays along the existing contours will significantly reduce the need for cut and fill.

4. Pervious pavement and infiltration beds **should not be placed on areas of recent fill** or compacted fill. If fill is unavoidable, permeable stone subbase material should be used wherever possible (and applicable infiltration rates should be used in the design). Areas of historical fill (>5 years) may also be considered for pervious pavement.
5. In those areas where the threat of spills and groundwater contamination is likely, pretreatment systems, such as filters and wetlands, may be required before any infiltration occurs. In hot spot areas, such as truck stops and fueling stations, the appropriateness of pervious pavement must be carefully considered. A stone infiltration bed located beneath standard pavement, preceded by spill control and water quality treatment, may be more appropriate.
6. The use of pervious pavement must be carefully considered in areas where the pavement may be seal coated or paved over due to lack of awareness, such as individual home driveways. In those situations, a system that is not easily altered by the property owner may be more appropriate. An example would include an infiltration system constructed under a conventional driveway. Educational signage at pervious pavement installations can encourage proper maintenance and is recommended (Figure 7.34).
7. In areas with poorly draining soils, infiltration beds below pervious pavement may be designed to slowly discharge to adjacent swales, wetlands, or bioretention areas. Only in extreme cases (e.g., industrial sites with contaminated soils) will the aggregate bed need to be lined to prevent infiltration.

Design

1. Bed bottoms must be level (0 percent slope) or nearly level. Sloping bed bottoms will lead to areas of ponding and reduced stormwater distribution within the bed. However, beds may be placed on a slope by benching or terracing parking bays (Figure 7.37). Orienting parking bays along existing contours will reduce site disturbance and cut/fill requirements.
2. All systems should be designed with an overflow system. Water within the subsurface stone bed should typically never rise to the level of the pavement surface. Inlet boxes can be used for cost-effective overflow structures. All beds should empty within 72 hours, preferably within 48 hours.
3. While infiltration beds are typically sized to handle the increased volume from a two-year design storm, they must also be able to convey and mitigate the peak of the less-frequent, more-intense storms, such as the 100-year storm. Control in the beds is usually provided in the form of an outlet control structure. A modified inlet box with an internal weir and low-flow orifice is a common type of control structure (Figure 7.38). The specific design of these structures may vary, depending on factors such as rate and storage requirements, but it always must include positive overflow from the system to prevent surface ponding.
4. A weir plate or weir within an inlet or overflow control structure may be used to maximize the water level in the stone bed while providing sufficient cover for overflow pipes (Figure 7.38).
5. The subsurface bed and overflow may be designed and evaluated in the same manner as a detention basin to demonstrate the mitigation of peak flow rates. In this manner, the need for a detention basin may be eliminated or significantly reduced in size.
6. Pervious pavement installations should have a backup method for water to enter the stone storage bed in the event that the pavement fails or is altered. In uncurbed lots, this backup drainage may consist of an unpaved one-to-two foot wide stone edge drain connected directly to the bed (Figure 7.33). In curbed lots, inlets with sediment traps may be used at low spots. Backup drainage elements will ensure the functionality of the infiltration system if the pervious pavement is compromised.
7. Perforated pipes along the bottom of the bed may be used to evenly distribute runoff over the entire bed bottom (especially if runoff from adjacent areas is being brought into the bed). Continuously perforated pipes should connect structures (such as cleanouts and inlet boxes). Pipes may lay flat along the bed bottom and connect to the overflow structure (Figure 7.38). Depending on size, these pipes may provide additional storage volume.

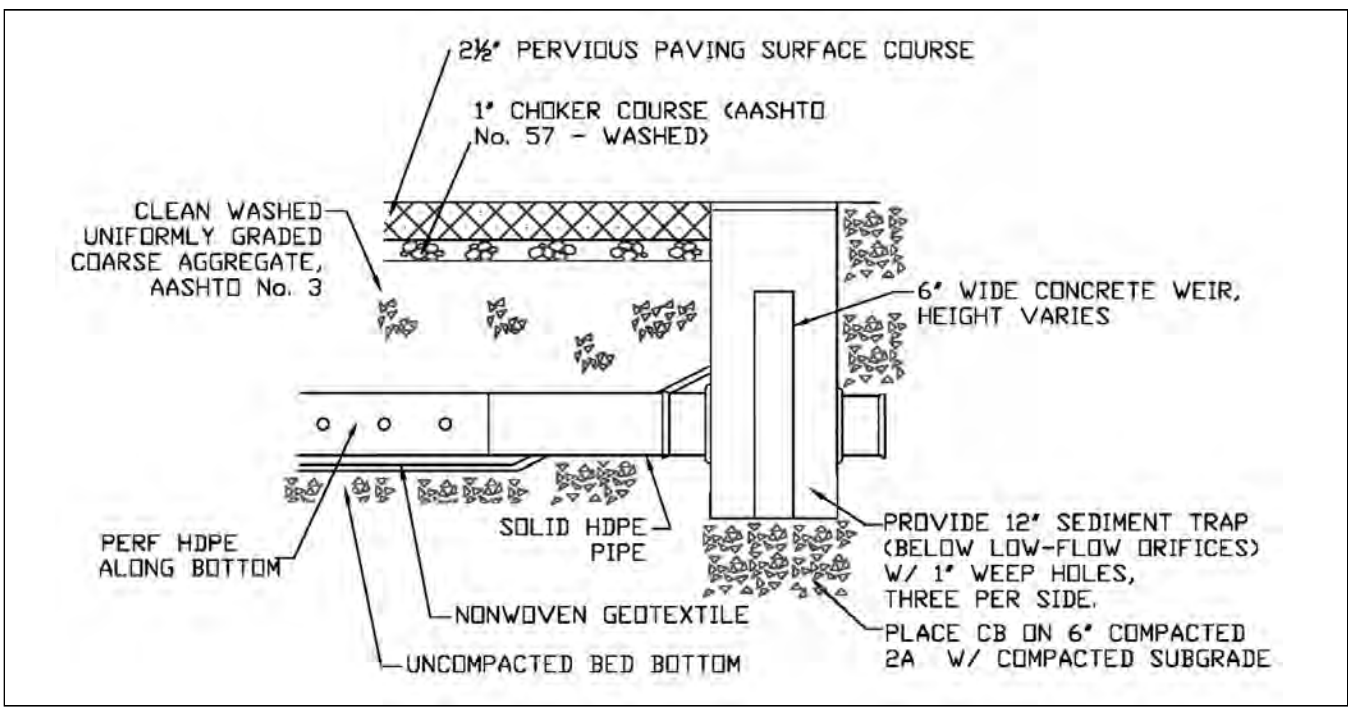
8. Perforated pipes can also be used as underdrains where necessary. Underdrains can ultimately discharge to daylight or to another stormwater system. They should be accessible for inspection and maintenance via cleanouts, overflow devices (Figure 7.38), or other structures.
9. Sediment transport to pervious systems should be minimized as much as possible to reduce maintenance requirements and extend the life of these systems. If roof leaders and area inlets convey water from adjacent areas to the bed, then native vegetation, water quality inserts, and/or sumped inlets should be used to prevent the conveyance of sediment and debris into the bed. Areas of impervious pavement draining directly onto pervious pavements should also be minimized as they can lead to clogging near the impervious-pervious boundary.
10. Infiltration areas should be located within the immediate project area in order to control runoff at its source. Expected use and traffic demands should also be considered in pervious pavement placement. An impervious water stop should be placed along infiltration bed edges where pervious pavement meets standard impervious pavements.

Figure 7.37
Slope stepping with berms

Source: Andropogon

11. The underlying infiltration bed is typically eight to 36 inches deep and comprised of clean, uniformly graded aggregate with approximately 40 percent void space. Local aggregate availability typically dictates the size of the aggregate used. The critical requirements are that the aggregate be uniformly graded, clean washed, and contain a significant void content. See the Specifications section for commonly used aggregates. The depth of the bed is a function of stormwater storage requirements, frost depth considerations, site grading, and structural needs.

Figure 7.38
Example detail of an overflow device from a pervious asphalt system



12. Proper pervious pavement applications are resistant to freeze-thaw problems because of their permeable and open-graded components (the pavement surface should not be saturated and the base has a high void content which allows for expansion). In somewhat frost susceptible soils, it may be necessary to increase the minimum bed depth to 14-22 inches (depending on loading and specific soil conditions). In extremely susceptible soils, the bed and/or improved soils can be placed down to the full frost depth (Smith, 2006).
13. While most pervious pavement installations are underlain by an aggregate bed, alternative subsurface storage products may also be used. These include a variety of proprietary plastic units that contain much greater storage capacity than aggregate, at an increased cost.

Stormwater Functions and Calculations

Infiltration area

The infiltration area is defined as the plan area of the storage reservoir under the pervious pavement. The minimum infiltration area should be based on the following equation:

Minimum infiltration area = Contributing impervious area (including pervious pavement) / 5*

*May be increased depending on soil infiltration capacity (where soils are Type A or rapidly draining).

Volume reduction

Pervious pavements with infiltration provide an excellent means of capturing and infiltrating runoff. The storage bed below the pavement provides runoff volume storage during storm events, while the undisturbed subgrade allows infiltration of runoff into the underlying soil mantle. The total volume reduction can be estimated by summing the storage and infiltration volumes described below.

Storage volume = Depth* (FT) x Area (SF) x Void space (i.e., 0.40 for aggregate)

*Depth is the depth of the water stored during a storm event, depending on the drainage area, conveyance to the bed, and outlet control.

Infiltration volume = Bed bottom area (SF) x Infiltration design rate (in/hr) x Infiltration period* (hr) x (1/12)

*Infiltration period is the time when bed is receiving runoff and capable of infiltrating at the design rate. Not to exceed 72 hours.

Peak rate mitigation

Properly designed pervious pavement systems provide effective management of peak rates. The infiltration bed below the pavement acts as a storage reservoir during large storm events, even while runoff exfiltrates through the soil mantle through the process of infiltration. Outlet structures can be designed to manage peak rates with the use of weir and orifice controls and carefully designed systems may be able to manage peak rates for storms up to and including the 100-year storm. For additional information relating to peak rate modeling and routing, refer to Chapter 9, LID Stormwater Calculations and Methodology.

Water quality improvement

Pervious pavement systems are effective in reducing pollutants such as total suspended solids, metals, and oil and grease. Both the pervious pavement surface and the underlying soils below the infiltration bed allow pollutant filtration.

When pervious pavement systems are designed to capture and infiltrate runoff volumes from small storm events, they provide very high pollutant reductions because there is little if any discharge of runoff carrying the highest pollutant loads. Pervious pavement systems require pretreatment of TSS when adjacent areas drain to them, resulting in a high reduction of TSS and other particulates. However, pervious pavement systems will provide limited treatment of dissolved pollutants, such as nitrates. Typical ranges of pollutant reduction efficiencies for pervious pavements are listed as follows:

- TSS* – 65-100%
- TP – 30-90%
- NO_3 – 30%

*Pretreatment for TSS is recommended if adjacent areas drain to pervious pavement

Construction Guidelines

1. Follow the Recommendations for Materials that are specific to porous asphalt and porous concrete in Appendix D.
2. Due to the nature of construction sites, pervious pavement and other infiltration measures should be installed toward the end of the construction

period, if possible. Infiltration beds under pervious pavement may be used as temporary sediment basins or traps provided that they are not excavated to within 12 inches of the designated bed bottom elevation. Once the site is stabilized and sediment storage is no longer required, the bed is excavated to its final grade and the pervious pavement system is installed.

3. The existing subgrade under the bed areas should **not** be compacted or subject to excessive construction equipment traffic prior to geotextile and stone bed placement. (Minor areas of unavoidable compaction can be partially remediated by scarifying the soil; see below.)

   Where erosion of subgrade has caused accumulation of fine materials and/or surface ponding, this material should be removed with light equipment and the underlying soils scarified to a minimum depth of six inches with a York rake (or equivalent) and light tractor. All fine grading should be done by hand. All bed bottoms are level grade.

4. Earthen berms (if used) between infiltration beds (Figure 7.39) may be left in place during excavation. These berms do not require compaction if proven stable during construction.

5. Geotextile and bed aggregate should be placed immediately after approval of subgrade preparation. Geotextile is to be placed in accordance with manufacturer's standards and recommendations.

   Adjacent strips of geotextile should overlap a minimum of 18 inches. It should also be secured at least four feet outside of bed in order to prevent any runoff or sediment from entering the storage 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 along bed edges can be cut back to bed edge.

6. Clean (washed) uniformly graded aggregate (Figure 7.40) is placed in the bed in eight-inch lifts. Each layer should be lightly compacted, with construction equipment kept off the bed bottom. Once bed aggregate is installed to the desired grade, approximately one inch of choker base course crushed aggregate should be installed uniformly over the surface in order to provide an even surface for paving (if required).

Figure 7.39
Earthen berms separating terraced infiltration beds

7. Cement mix time: Mixtures should be produced in central mixers or in truck mixers. When concrete is delivered in agitating or non-agitating units, the concrete should be mixed in the central mixer for a minimum of 1.5 minutes or until a homogenous mix is achieved. Concrete mixed in truck mixers should be mixed at the speed designated as mixing speed by the manufacturer for 75-100 revolutions.

8. The Portland Cement aggregate mixture may be transported or mixed onsite and should be used within one hour of the introduction of mix water, unless otherwise approved by an engineer. This time can be increased to 90 minutes when using the specified hydration stabilizer. Each truck should not haul more than two loads before being cycled to another type concrete. Prior to placing concrete, the subbase should be moistened and in a wet condition. Failure to provide a moist subbase will result in reduced strength of the pavement.

9. A minimum of 30 revolutions at the manufacturer's designated mixing speed is required following any water added to the mix. Discharge should be a continuous operation and completed as quickly as possible. Concrete should be deposited as close to its final position as practicable and such that fresh concrete enters the mass of previously placed concrete.

10. Placing and finishing concrete equipment: The contractor should provide mechanical equipment of either slipform or form riding with a following compactive unit that will provide a minimum of 10 psi vertical force. The pervious concrete pavement will be placed to the required cross section and should not deviate more than +/- 3/8 inch in 10 feet from profile grade.

Figure 7.40
Open-graded, clean, coarse aggregate for infiltration beds

Placement should be continuous and spreading and strikeoff should be rapid. It is recommended to strike off about ½ to ¾ inch above the forms to allow for compaction. This can be accomplished by attaching a temporary wood strip above the top of the form to bring it to the desired height. After strikeoff, the strips are removed and the concrete is consolidated to the height of the forms.

11. Consolidation should be accomplished by rolling over the concrete with a steel roller, compacting the concrete to the height of the forms. Consolidation should be completed within 10 minutes of placement to prevent problems associated with rapid hardening and evaporation. After mechanical or other approved strike-off and compaction operation, no other finishing operation is needed. The contractor will be restricted to pavement placement widths of a maximum of 15 feet.
12. Jointing: Control (contraction) joints should be installed at maximum 20-foot intervals. They should be installed at a depth of ¼ the thickness of the pavement. These joints can be installed in the plastic concrete or saw cut. However, installing in the plastic concrete is recommended. Joints installed in the plastic concrete should be constructed using a small roller (salt or joint roller) to which a beveled fin with a minimum depth of ¼ the thickness of the slab has been welded around the circumference of a steel roller. When this option is used it should be performed immediately after roller compaction and prior to curing. If saw cut, the procedure should begin as soon as the pavement has hardened sufficiently to prevent raveling and uncontrolled cracking (normally just after curing).

    Transverse construction joints should be installed whenever placing is suspended a sufficient length of time that concrete may begin to harden. In order to assure aggregate bond at construction joints, a bonding agent suitable for bonding fresh concrete should be brushed, tolled, or sprayed on the existing pavement surface edge. Isolation (expansion) joints will not be used except when pavement is abutting slabs or other adjoining structures.
13. Curing procedures should begin within 15 minutes after placement. The pavement surface should be covered with a minimum six millimeter thick polyethylene sheet or other approved covering material. Prior to covering, a fog or light mist should be sprayed on the surface. The cover should overlap all exposed edges and should be completely secured (without using dirt) to prevent dislocation due to winds or adjacent traffic conditions.
14. Porous asphalt should not be installed on wet surfaces or when the ambient air temperature is below 50 degrees Fahrenheit. The temperature of the bituminous mix should be determined by the results of the Draindown test (ASTM D6390) but typically ranges between 275 degrees Fahrenheit and 325 degrees Fahrenheit (as determined by the testing and recommendations of the asphalt supplier).

    Pervious pavement should be laid in one lift directly over the storage bed and stone base course to a 2.5- to 3-inch finished thickness. Compaction of the surface course should 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 course porosity.
15. Do not place Portland Cement pervious pavement mixtures when the ambient temperature is 40 degrees Fahrenheit or lower, unless otherwise permitted in writing by the engineer.
16. Mixing, placement, jointing, finishing, and curing doesn't apply to permeable paver systems. A manual on Permeable Interlocking Concrete Pavements from the Interlocking Concrete Pavement Institute (Smith, 2006) offers detailed guidance on the design and construction of permeable paver systems.
17. After final pervious asphalt or concrete installation, no vehicular traffic of any kind should be permitted on the pavement surface until cooling and

hardening or curing has taken place, and not within the first 72 hours (many permeable paver systems can be used right away). The full permeability of the pavement surface should be tested by applying clean water at the rate of at least five gallons per minute over the surface using a hose or other distribution devise (Figure 7.41). All water should infiltrate directly without puddle formation or surface runoff.

Maintenance

The primary goal of pervious pavement maintenance is to prevent the pavement surface and/or underlying infiltration bed from being clogged with fine sediments. To keep the system clean and prolong its life span, the pavement surface should be vacuumed twice per year with a commercial cleaning unit. Pavement washing systems or compressed air units are generally not recommended but may be acceptable for certain types of pavement. All inlet structures within or draining to the infiltration beds should also be cleaned out twice a year.

Planted areas adjacent to pervious pavement should be well maintained to prevent soil washout onto the pavement. If any washout does occur, immediately clean it off the pavement to prevent further clogging of the pores. Furthermore, if any bare spots or eroded areas are observed within the planted areas, they should be replanted and/or stabilized at once. Planted areas should be inspected twice a year. All trash and other litter should be removed during these inspections.

Superficial dirt does not necessarily clog the pavement voids. 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 pervious pavement lot.

Potholes in pervious pavement are unlikely, though settling might occur if a soft spot in the subgrade is not removed during construction. For damaged areas of less than 50 square feet, a depression could be patched by any means suitable with standard pavement, with the loss of porosity of that area being insignificant. The depression can also be filled with pervious mix.

If an area greater than 50 sq. ft. is in need of repair, approval of patch type must be sought from either the engineer or owner. If feasible, permeable pavers can be taken up and then simply re-installed (replacing damaged pavers if necessary). **Under no circumstance should the pavement surface ever be seal coated**. Any required repair of drainage structures should be done promptly to ensure continued proper functioning of the system.

Figure 7.41
Testing permeability with a high capacity hose

Pervious pavement maintenance considerations are summarized below:

Prevent clogging of pavement surface with sediment

- Vacuum pavement twice a year,
- Maintain planted areas adjacent to pavement,
- Immediately clean any soil deposited on pavement,
- Do not allow construction staging, soil/mulch storage, etc., on unprotected pavement surface, and
- Clean inlets draining to the subsurface bed twice a year.

Snow/Ice removal

- Pervious pavement systems generally perform better and require less treatment than standard pavements,
- Do not apply abrasives such as sand or cinders on or adjacent to pervious pavement,
- Snow plowing is fine but should be done carefully (i.e., set the blade slightly higher than usual), and
- Salt application is acceptable, although alternative deicers are preferable.

Repairs

- Surface should never be seal-coated,
- Damaged areas less than 50 sq. ft. can be patched with pervious or standard pavement,
- Larger areas should be patched with an approved pervious pavement,
- Permeable pavers should be repaired/replaced with similar permeable paver block material, and
- Permeable pavers and gravel pavers may require the addition of aggregate on an annual basis or as needed, in order to replenish material used to fill in the open areas of the pavers. Turf pavers may require reseeding if bare areas appear.

Winter Considerations

Pervious pavement systems should perform equally well in the winter, provided that infiltration bed design considers the soil frost line, and proper snow removal and deicing procedures are followed. Winter maintenance for pervious pavement may be necessary but is sometimes less intensive than that required for a standard pavement (especially for pervious asphalt). The underlying stone bed tends to absorb and retain heat so that freezing rain and snow melt faster on pervious pavement. Therefore, ice and light snow accumulation are generally not as problematic. However, snow will accumulate during heavier storms.

Abrasives such as sand or cinders should not be applied on or adjacent to the pervious pavement. Snow plowing is fine, provided it is done carefully (i.e., by setting the blade slightly higher than usual, about an inch). Salt with low non-soluble solids content is acceptable for use as a deicer on the pervious pavement. Non-toxic, organic deicers applied either as blended, magnesium chloride-based liquid products or as pretreated salt, are preferred.

Cost

The majority of added cost of a pervious pavement/infiltration system lies in the underlying stone bed, which is generally deeper than a conventional subbase and wrapped in geotextile. Costs may also be higher in areas where experienced contractors are not readily available. However, these additional costs are often offset by the significant reduction in the required number of inlets and pipes. Also, since pervious pavement areas are often incorporated into the natural topography of a site, there is generally less earthwork and/or deep excavations involved. Furthermore, pervious pavement areas with subsurface infiltration beds often eliminate the need (and associated costs, space, etc.) for detention basins. When all of these factors are considered, pervious pavement with infiltration has often proven itself less expensive than impervious pavement with associated stormwater management.

- Porous asphalt, with additives, is generally 15 percent to 25 percent higher in cost than standard asphalt on a unit area basis. Unit costs for pervious asphalt (without infiltration bed) range from about $4/SF to $5/SF.
- Pervious concrete as a material is generally more expensive than asphalt and requires more labor and expertise to install. Unit cost of a six-inch-thick pervious concrete (without infiltration bed) section is about $4/SF to $6/SF.
- Permeable paver blocks vary in cost depending on type and manufacturer.

NOTE: The data provided are based on average market costs. For greater accuracy, a site- and market-specific cost estimate should be developed.

Designer/Reviewer Checklist for Pervious Pavement with Infiltration Bed

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)?					
Was the Soil Infiltration Testing Protocol followed?					
	Appropriate areas of the site evaluated?				
	Infiltration rates measured?				
Was the Infiltration BMP followed?					
	Two-foot minimum separation between the bed bottom and bedrock/SHWT?				
	Soil permeability acceptable?				
	If not, appropriate underdrain provided?				
	Adequate separations from wells, structures, etc.?				
	Natural, uncompacted soils?				
	Level infiltration area (bed bottom)?				
	Excavation in pervious pavement areas minimized?				
	Hotspots/pretreatment considered?				
	Loading ratio below 5:1?				
	Storage depth limited to two feet?				
	Drawdown time less than 48 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?					

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BMP Fact Sheet

Planter Boxes

Planter boxes receive runoff from multiple impervious surfaces, which is used for irrigation of the vegetation in the planter box preventing stormwater from directly draining into nearby sewers. They also play an important role in urban areas by minimizing stormwater runoff, reducing water pollution, and creating a greener and healthier appearance of the built environment by providing space for plants and trees near buildings and along streets. There are three main types of planter boxes which can be used on sidewalks, plazas, rooftops, and other impervious areas: contained, infiltration, and flow-through.

Bioretention in planter box along Michigan Avenue, Lansing, Michigan
Source: Tetra Tech, Inc.

Potential Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Low/Med
Commercial	Yes	**Groundwater Recharge**	Low/Med
Ultra Urban	Yes	**Peak Rate**	Low
Industrial	Limited	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	Medium
Highway/Road	No	**TP**	Medium
Recreational	Yes	**TN**	Low/Med
		Temperature	Low/Med

Additional Considerations	
Cost	High
Maintenance	Medium
Winter Performance	Medium

Variations

- Contained
- Infiltration
- Flow-through

Key Design Features

- May be designed as pretreatment
- May be designed to infiltrate
- Captures runoff to drain out in three to four hours after a storm event
- Receives less than 15,000 square feet of impervious area runoff
- Planters should be made of stone, concrete, brick, or pressure-treated wood

Benefits

- Enhances the area where they are placed
- Potential air quality and climate benefits
- Can be used in a wide range of areas, including ultra-urban

Limitations

- Limited stormwater quantity/quality benefits
- Relatively high cost due to structural components

Case Study: Michigan Avenue Streetscape Bioretention Facilities

City of Lansing

The project consists of landscape planters and sidewalk paving improvements including new concrete sidewalks and accenting clay pavers, ornamental fences, rain garden plants, and site furnishings. In addition, a series of 27 bioretention facilities inside concrete planter boxes were designed as part of a Michigan Avenue corridor enhancement project. These infiltration bioretention facilities were developed in conjunction with the city's controlled sewer overflow work as a means to control, clean, and dispense stormwater in an urban environment. The planter boxes receive stormwater runoff from nearby roads and sidewalks which helps provide flooding protection for Michigan Avenue. The vegetation in the planter boxes is designed to remove sediment, nutrients, heavy metals, and other pollutants, as well as reduce water temperature, promote infiltration, evaporation, and transpiration of the stormwater runoff, thereby reducing the overall impact to the Grand River.

Michigan Avenue bioretention planter box
Source: Tetra Tech, Inc.

Case Study Site Considerations	
Project Type	Planter box, rain gardens
Estimated Total Project Cost	$500/linear foot
Maintenance Responsibility	City of Lansing, MDOT, MDEQ
Project Contact	Pat O'Meara, 866-454-3923

Description and Function

Planter boxes receive runoff from multiple impervious surfaces, including rooftops, sidewalks, and parking lots. Runoff is used for irrigation purposes, and the vegetation in the planter box absorbs stormwater and releases it back into the atmosphere through evapotranspiration. Boxes can take any form and can be made out of a variety of materials, although many are constructed from wood.

Construction specifications are critical to ensure that an appropriate volume of runoff from smaller storms "feeds" the carefully selected vegetation types in the boxes; however, consistent watering is necessary during dry periods.

In general, planter boxes must be carefully designed to accommodate the desired amount of runoff. In addition, plantings must be carefully selected, and boxes must be carefully maintained, to accomplish stormwater objectives, and perhaps, most importantly, to succeed in a landowner's overall landscaping objectives.

Stormwater benefits of planter boxes include reduction in runoff volumes and some reduction in peak rates of runoff. Boxes which overflow also effectively reduce peak rates of runoff. Depending on the type of box selected, evapotranspiration will increase along with infiltration and groundwater recharge. Water quality may benefit, depending upon how much runoff is directed into the ground and prevented from worsening erosive stream flows.

When well designed, installed, and maintained, planter boxes are extremely attractive additions to homes, commercial businesses, and office buildings. In fact, an essential objective in developing planter boxes is to enhance overall landscape aesthetics. Boxes are ideal for buffers around structures, foundation plantings, providing seat walls, and for defining walkways, patios, terraces, drives, and courtyards.

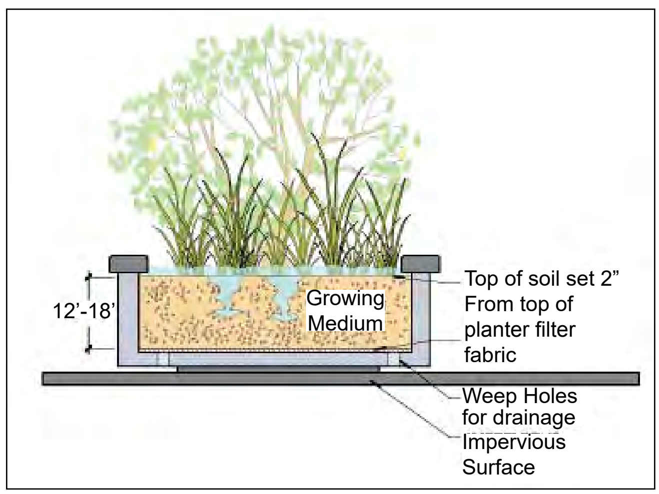
Variations

Of all the BMPs listed in this manual, planter boxes are probably the most adaptable to all types of sites with all types of site constraints. The infiltration variation is influenced by all factors which are limiting to any infiltration-oriented BMP (i.e., bedrock/seasonal high water table at or close to the surface, very poorly draining soils, etc., all of which are described in the Infiltration BMP of this manual). However, both the contained and flow through variations can be used on virtually every type of site — large or small, front yard or backyard, flat or sloping, shady or sunny.

Contained

Contained planter boxes (Figure 7.42) are generally traditional planters that have weep holes to drain excess water from the planter. They effectively reduce impervious area by retaining rainwater which slows stormwater runoff from draining into sewers. Contained planters are used for planting trees, shrubs, perennials, and annuals. The planter is either prefabricated or permanently constructed in a variety of shapes and sizes. Planters are typically placed on impervious surfaces like sidewalks, plazas, and rooftops. Contained planters may drain onto impervious surfaces through their base or into an overflow structure.

Figure 7.42
Schematic of Contained Planter Box



Source: City of Portland, OR Bureau of Environmental Services

Native vegetation should be used in contained planter boxes (Appendix C). They are hardy and self-sustaining with little need for fertilizers or pesticides. Irrigation needs to be monitored, since plants will need to be watered during dry periods. Sensors can help to regulate moisture in the planter box, ensuring consistent moisture. Smaller trees are highly encouraged because of the canopy and shade they will provide, reducing the urban heat island effect. Planters should be constructed of stone, concrete, brick, wood, or any other suitable material.

This type of planter box can be installed to retrofit an existing urban streetscape or large area of pavement, such as at an entryway to a building.

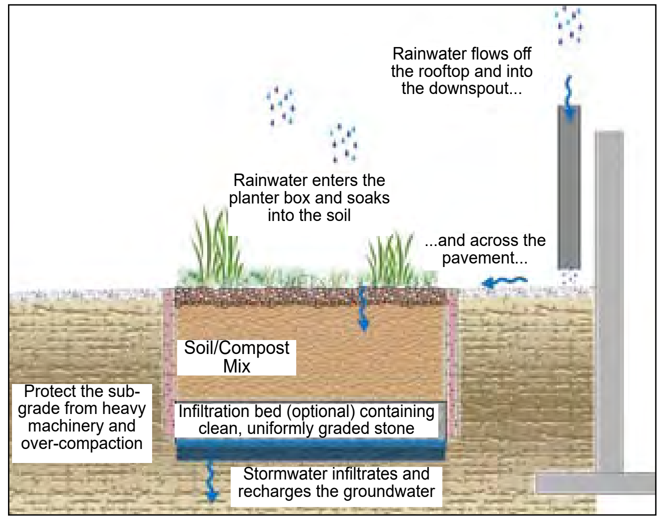
Infiltration

An infiltration planter box (Figure 7.43) is designed to allow runoff to filter through the planter soils (thus capturing pollutants) and then infiltrate into native soils below the planter. These planters are generally constructed to be flush with surrounding paved areas. The planter is sized to accept runoff and temporarily store the water in a reservoir on top of the soil. Different design variations are encouraged, but should allow a minimum delay in stormwater runoff capture of three to four hours after a wet weather event.

Recommended vegetation includes native rushes, reeds, sedges, irises, dogwoods, and currants. Also, the dimensions of the sand/gravel area used in these designs should be determined by an engineer and designed to receive less than approximately 15,000 square feet of impervious area runoff. The minimum planter width is typically 30 inches with no minimum length or required shape.

Suggested structural elements of infiltration planter boxes are stone, concrete, brick, or pressure-treated wood. In general, infiltration facilities should be greater than 10 feet from structures and at least five feet from an adjoining property line or as required by local ordinances.

Figure 7.43
Schematic of Infiltration Planter Box



Schematic of Infiltration Planter Box

Example of Infiltration Planter Box

Flow-through

The flow-through planter box (Figure 7.44) is completely contained and drains to a stormwater system. These planters are designed with an impervious bottom or are placed on an impervious surface. Pollutant reduction is achieved as the water filters through the soil/ growing medium. Flow control is obtained by ponding runoff above the soil and in a gravel layer beneath it. In most storm events, runoff flows through the soil into the gravel layer and is slowly discharged via the perforated pipe. In more extreme events, inflow may exceed the capacity of the soil and some runoff may be discharged through surface overflow. This type of planter can be used adjacent to a building if the planter box and/or building is adequately waterproofed to allow for saturated soil and temporary ponded runoff next to the building.

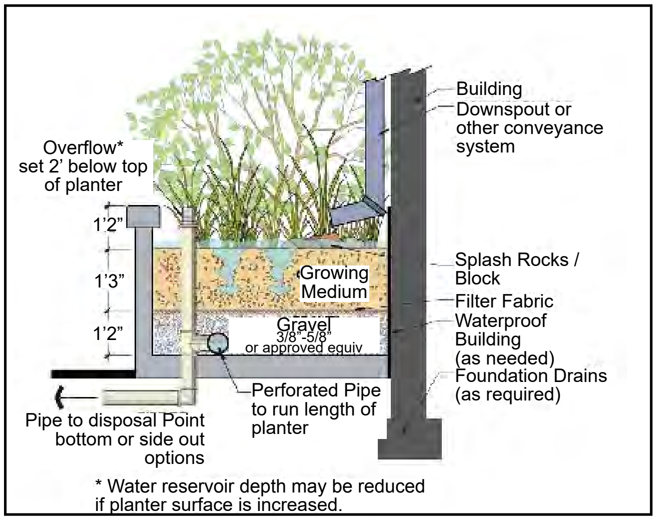
Flow-through planter boxes should be designed to retain water for no more than three to four hours after an average storm event. Recommended vegetation includes native rushes, reeds, sedges, irises, dogwoods, and currants. The minimum planter width is typically 18 inches with no minimum length or required shape. Planters should be designed to receive less than 15,000 square-feet of impervious area runoff.

Potential Applications

Planter boxes can be used in urbanized areas of high pollutant loads. They are especially applicable where there is limited area for construction of other BMPs. Planter boxes may be used as a pretreatment BMP for other BMPs such as wet ponds or infiltration systems. Areas that would benefit from using a planter box include:

- Parking garage
- Office building
- Residential building
- Other building use (commercial, light industrial, institutional, etc.)
- Transportation facilities
- Urban streetscapes

Figure 7.44
Schematic of Flow-through Planter Box



Source: City of Portland, Bureau of Environmental Services

Example of Flow-through Planter Box

Source: City of Portland, OR Bureau of Environmental Services

Design Considerations

- **Suggested structural elements** of planters are stone, concrete, brick, or pressure-treated wood. Flow-through planters are completely contained and, therefore, not designed to drain directly into the ground. Pipes can also be designed to transport water to an approved disposal point. It is recommended that planter boxes have setback distances of 10 feet from structures and five feet from property lines, unless the planter height is less than 30 inches or as required by local ordinances.
- The **flow entrance/inflow** must be designed to prevent erosion in the planter box. Some alternatives include gravel, splash blocks, perforated pipe, and erosion control mats.
- A **positive overflow system** should be designed to safely convey away excess runoff. The overflow can be routed to the surface in a nonerosive manner or to another stormwater system. Some alternatives include domed risers, inlet structures, weirs, and openings in the planter box wall.
- **Planting soil** should be capable of supporting a healthy vegetative cover and should generally be between 12 and 36 inches deep. Planting soil should be approximately four inches deeper than the bottom of the largest root ball.
- A subsurface **gravel layer**, if used, should be at least six inches thick and constructed of clean gravel with a significant void space for runoff storage (typically 40 percent) and wrapped in geotextile (filter) fabric.
- If used, **underdrains** are typically small diameter (4-12 inches) perforated pipes in a clean gravel trench wrapped in geotextile fabric (or in the gravel layer). Underdrains should have a flow capacity capable of draining the planter box system in approximately 12 hours. They can daylight to the surface or connect to another stormwater system. A way to inspect and clean underdrains should be provided (via cleanouts, inlet, overflow structure, etc.)
- **Native trees and shrubs** may require irrigation during dryer summer months to remain healthy. Monitoring vegetation in planter boxes is critical to the health of the plants, as they may need supplemental watering, in addition to the water received from storms.
- **Many planter box styles and sizes** are used to improve site aesthetics and stormwater management. Incorporating smaller planter boxes over the site adds visual appeal and a greater surface area.

Design variations:

- **Contained boxes**

  Plants should be relatively self-sustaining, with little need for fertilizers or pesticides. Irrigation is optional, although plant viability should be maintained. Trees are encouraged and will receive added credit for the canopy that will extend beyond the planter walls. Structural elements of the planters should be stone, concrete, brick, wood, or other durable material. Treated wood that may leach out any toxic chemicals should not be used.

- **Infiltration**

  Allow captured runoff to drain out in three to four hours after a storm event. The sand/gravel area width, depth, and length are to be determined by an engineer or a dry well may be required for complete onsite infiltration. Planters should be designed to receive less than 15,000 square-feet of impervious area runoff. Minimum planter width is 30 inches; there is no minimum length or required shape. The structural elements of the planters should be stone, concrete, brick, or pressure-treated wood. Treated wood that may leach out any toxic chemicals should not be used.

- **Flow-through**

  Allow captured runoff to drain out in three to four hours after a storm event. Minimum planter width is 18 inches; there is no minimum length or required shape. Planters should be designed to receive less than 15,000 square-feet of impervious area runoff. Structural elements of the planters should be stone, concrete, brick, or pressure-treated wood. Treated wood that may leach out any toxic chemicals should not be used. The flow-through planter box is contained and, thus, not designed to drain into the ground near a building. Irrigation is optional, although plant viability should be maintained.

- The plants within the **perimeter planter boxes** are designed to accept stormwater runoff from adjacent impervious areas. Plants and vegetation absorb most of the water volume. Overflow gradually drains to the surface, which slows the peak rates.
- Review the materials list in Appendix D for recommended planter box specifications.
- **Landscaping requirements**

The following quantities are recommended per 100 square feet of planter box area:

  - Four large shrubs/small trees in three-gallon containers or equivalent.
  - Six shrubs/large grass-like plants in one-gallon containers or equivalent
  - Ground cover plants (perennials/annuals) one per 12 inches on center, triangular spacing. Minimum container: four-inch pot. Spacing may vary according to plant type.

- Plantings can include rushes, reeds, sedges, iris, dogwood, currants, and numerous other shrubs, trees, and herbs/grasses (Appendix C).
- 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.
- **Tree planting** in planters is encouraged where practical. Tree planting is also encouraged near planters.
- Generally, plants requiring **moist-wet conditions** are preferred for flow-through planters.

Stormwater Functions and Calculations

Volume reduction

If a planter box is designed to infiltrate, the volume reduction is a function of the area of the filter and the infiltration rate. There is generally less volume reduction for planter boxes that are not designed to infiltrate.

Infiltration Volume* = Bottom Area (sf) x Infiltration Rate (in/hr) x Drawdown time** (hr)

*For filters with infiltration only
** Not to exceed 3-4 hours

Peak rate mitigation

Planter boxes generally provide little, if any, peak rate reduction. However, if the planter box is designed to infiltrate, then a modest level of peak rate attenuation can be expected (see Chapter 9, LID Stormwater Calculations and Methodology, for more information on peak rate mitigation).

Water Quality Improvement

Planter boxes are considered a moderate stormwater treatment practice with the primary pollutant removal mechanism being filtration and settling. Less significant processes can include evaporation, infiltration (if applicable), transpiration, biological and microbiological uptake, and soil adsorption. The extent to which planter boxes remove pollutants in runoff is primarily a function of their design, configuration, plant species/ density, and soil type.

For planter boxes that are also designed to infiltrate, see the water quality summary in the Subsurface Infiltration Bed section, or in the other infiltration BMP sections. For manufactured planters, see the manufacturer's information, as well as findings from independent studies. Also see Chapter 9, LID Stormwater Calculations and Methodology, which addresses the pollutant removal effectiveness of this BMP.

Construction Guidelines

Constructing or retrofitting planter boxes varies in difficulty at each site. Boxes may be ideal for inclusion in patio or walkway design and integrate easily with roof downspouts. In most cases, a landscape architect is essential, especially if the more complex infiltration and flow through variation is being constructed, and as the size/scale of the planter box grows larger.

1. Areas for planter boxes, especially the infiltration type, should be clearly marked before any site work begins to avoid soil disturbance and compaction during construction.
2. Planter boxes should generally be installed after the site is stabilized. Excessive sediment generated during construction can clog the planter and prevent or reduce the anticipated post-construction water quality benefits. Stabilize all contributing areas before runoff enters the filters.
3. Structures such as inlet boxes, reinforced concrete

boxes, etc. should be installed in accordance with the guidance of the manufacturers or design engineer.

4. Infiltration planter boxes should be excavated in such a manner as to avoid compaction of the subbase. Structures may be set on a layer of clean, lightly compacted gravel (such as AASHTO #57).
5. Infiltration planter boxes should be underlain by a layer of permeable nonwoven-geotextile.
6. Place underlying gravel/stone in minimum six-inch lifts and lightly compact. Place underdrain pipes in gravel.
7. Wrap and secure nonwoven geotextile to prevent gravel/stone from clogging with sediments.
8. Install planting soil per the recommendations of the landscape architect. Do not compact.
9. Install native vegetation (trees, shrubs, etc.) per the recommendations of the landscape architect.

Perforated pipe used for inflow/distribution in a stormwater planter box

Source: www.wsud.org

Maintenance

Planter boxes are relatively high maintenance, as is the case with any containerized garden. Property owners should be especially prepared for maintaining the vegetation itself, which will vary depending upon planting. In many cases, planter boxes may need additional watering during extremely dry periods. Selection of planter box construction material is also important (e.g., masonry construction is easier to maintain than wood construction).

Generally speaking, stormwater facilities need an adequate amount of space for proper maintenance. The minimum required width for maintenance is typically eight feet and the maximum slope is 10 percent. If structural surfaces need to support maintenance vehicles, access routes should be constructed of gravel or other permeable paving surface.

Winter Considerations

Michigan's winter temperatures can go below freezing for four or five months every year and surface filtration may not take place in the winter. Winterizing becomes an important issue in plant species selection, especially for larger hardy or nearly hardy species intended to winter over. In these cases, planter boxes must be designed and dimensioned so that plantings are adequately protected.

Depending on the composition of the planting soil, it may hold water, freeze, and become impervious on the surface. Design options that allow directly for subsurface discharge into the underlying infiltration bed, if applicable, during cold weather may overcome this condition, but at the possible expense of surface filtration.

Cost

Costs for planter boxes are quite modest. However, based on unit cost of cubic foot or gallons of runoff being managed, costs tend to be rather high. Because of the extreme variability of design and construction, costs will range based on the goals of the designer. Smaller boxes with smaller-scale vegetation will be less expensive than larger boxes with more mature vegetation.

Designer/Reviewer Checklist for Planter Boxes

ITEM	YES	NO	N/A	NOTES
For infiltration planters, was Soil Testing Infiltration Protocol (Appendix E) followed?*				
Appropriate areas of the site evaluated?				
Infiltration rates measured?				
For infiltration planters, was the Infiltration BMP followed?*				
Two-foot separation between the bed bottom and bedrock/seasonally high water table?				
Soil permeability acceptable?				
If not, appropriate underdrain provided?				
Natural, uncompacted soils?				
Excavation in infiltration areas minimized?				
Drawdown time less than 48 hours?				
Erosion and sedimentation control?				
Adequately stable inflow point(s)?				
Positive overflow from system?				
Waterproofing provided, as necessary?				
Acceptable soil/growing medium specified?				
Gravel layer specified properly?				
Underdrain positioned and sized?				
Appropriate native plants selected?				
Feasible construction process and sequence?				
Maintenance accounted for and plan provided?				

** In general, the Protocol and Infiltration BMP should be followed as much as possible (although there is more flexibility for infiltration planters than for other BMPs such as pervious pavement and subsurface infiltration that rely almost entirely on infiltration).*

References

Stormwater Management Guidance Manual, Version 2.0. Office of Watersheds, Philadelphia, PA: Water Department. www.pwdplanreview.org/manual-info/guidance-manual

Stormwater Management Manual, Revision 3. Portland, OR: Environmental Services, Clean River Works, September 2004. www.portlandoregon.gov/bes/64040

BMP Fact Sheet

Riparian Buffer Restoration

A riparian buffer is the area of land that exists between low, aquatic areas such as rivers, streams, lakes, and wetlands, and higher, dry upland areas such as forests, farms, cities, and suburbs. Unaltered riparian buffers may exist as various types of floodplain forest or wetland ecosystems. The Michigan Natural Features Inventory (MNFI) has identified multiple types of distinct natural communities which may occur in Michigan's riparian areas, such as southern floodplain forest, southern wet meadow, emergent marsh, and hardwood conifer swamp.

Suburban riparian buffer – Edward Drain, West Bloomfield, MI
Source: JFNew

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Low/Med
Commercial	Yes	**Groundwater Recharge**	Low/Med
Ultra Urban	Yes	**Peak Rate**	Low/Med
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	Med/High
Highway/Road	Limited	**TP**	Med/High
Recreational	Yes	**NO_3**	Med/High
		Temperature	Med/High

Additional Considerations	
Cost	Low/Med
Maintenance	Low
Winter Performance	High

Key Design Features

Riparian buffers consist of three distinct zones:

- **Zone 1**: Streamside zone extends a minimum distance of 25 feet.
- **Zone 2**: Middle zone extends immediately from the outer edge of Zone 1 for a minimum distance of 55 feet.
- **Zone 3**: Outer zone extends a minimum of 20 feet immediately from outer edge of Zone 2.

Site Factors

- Water table to bedrock depth: N/A
- Soils: Match vegetation to soils to maximize long-term viability of plantings.
- Slope: NA
- Potential hotspots: No
- Max. drainage area: 5-20 times the buffer area.

Benefits

- Water quality
- Ecological and aesthetic value
- Low cost

Limitations

- Reduced volume and peak rate control

Case Study: Nankin Mills Interpretive Center Grow Zone Project

Wayne County, MI

The grow zone demonstration along Edward Hines Park shows many benefits and opportunities that the use of native plants can create along a riparian buffer area. For this project, the turf grass was removed, the soil properly prepared, and native plantings installed and established to eliminate the maintenance required by turf grass and also, to improve water quality.

Wayne County received a grant through the Clean Michigan Initiative to convert 13 acres of turf grass into native landscape. This area is prone to flooding and soil erosion during storm events and has shallow rooted grass, which allows most of the stormwater to drain directly into the river with little or no infiltration. The existing turf grass was eliminated through use of herbicides and tilling. Areas of the grow zone were hand broadcast seeded and planted.

Materials Used

- Herbicide, tractor, and seed drill
- Shovels, rakes, landscape mulch
- 59 trees and shrubs and 52 lbs. of native plant seed
- 11 large grow zone signs w/ logo decal and 22 small grow zone boundary signs.

Riparian buffer grow zone around Nankin Mills Pond, Wayne County, MI

Source: Wayne County Department of Environment

Planting native trees and shrubs along with grow zone signage helps delineate the grow zone as a managed, important part of the Edward Hines Park. An interpretive kiosk explains the grow zone's purpose and function.

Occasional mowing and managing for invasive species is the only maintenance procedures anticipated. Research on native landscapes suggest the maintenance cost for 4.6 acres of grow zone will be approximately 80 percent less than managing the previous turf grass land cover.

Case Study Site Considerations	
Project Type	Riparian restoration, native revegetation
Estimated Total Project Cost	$18,119
Maintenance Responsibility	Wayne County Department of Environment
Project Contact	Noel Mullett, 734-326-4486

Description and Function

A riparian buffer is a permanent restoration area of trees, shrubs, and herbaceous vegetation adjacent to a waterbody that serves to protect water quality and provide critical wildlife habitat. A riparian buffer can be designed to intercept surface runoff and subsurface flow from upland sources for the purpose of removing or buffering the effects of associated nutrients, sediment, organic matter, pesticides, or other pollutants prior to entry into surface waters and groundwater recharge areas.

The riparian buffer is most effective when used as a component of a sound land management system including nutrient management and runoff and sediment and erosion control practices. Use of this practice without other runoff and sediment and erosion control practices can result in adverse impacts on riparian buffer vegetation and hydraulics including high maintenance costs, the need for periodic replanting, and the flow of excess nutrients and sediment through the buffer.

Riparian buffer restoration areas consist of three distinct zones and can be designed to filter surface runoff as sheet flow and down-slope subsurface flow, which occurs as shallow groundwater. For the purposes of these buffer strips, shallow groundwater is defined as saturated conditions which occur near or within the root zone of trees and other woody vegetation and at relatively shallow depths where bacteria, low oxygen concentrations, and soil temperature contribute to denitrification. Riparian buffers are designed to encourage sheet flow and infiltration and impede concentrated flow.

Buffer widths and vegetation types

When developing specific widths for riparian buffers (Figure 7.45), keep site specific factors in mind, and use exact measurements as a guide for each site. Various buffer widths and vegetation types may be appropriate depending on:

- Project goals,
- The natural features of the river valley, wetlands, lake, and floodplain, and
- Wildlife habitat requirements.

Buffer averaging and minimum distances

Buffer ordinances that set specific and minimum buffer dimensions allow the local government to accept buffer averaging in order to accommodate variability in terrain or development plans. For example, a wetland normally entitled by ordinance to a 75-foot minimum buffer may be able to tolerate a 50-foot buffer over part of its margin if a wider buffer is provided along another part. This depends upon such issues as water flow, topography, habitat, and species needs, and other factors that can best be assessed on a case-by-case basis.

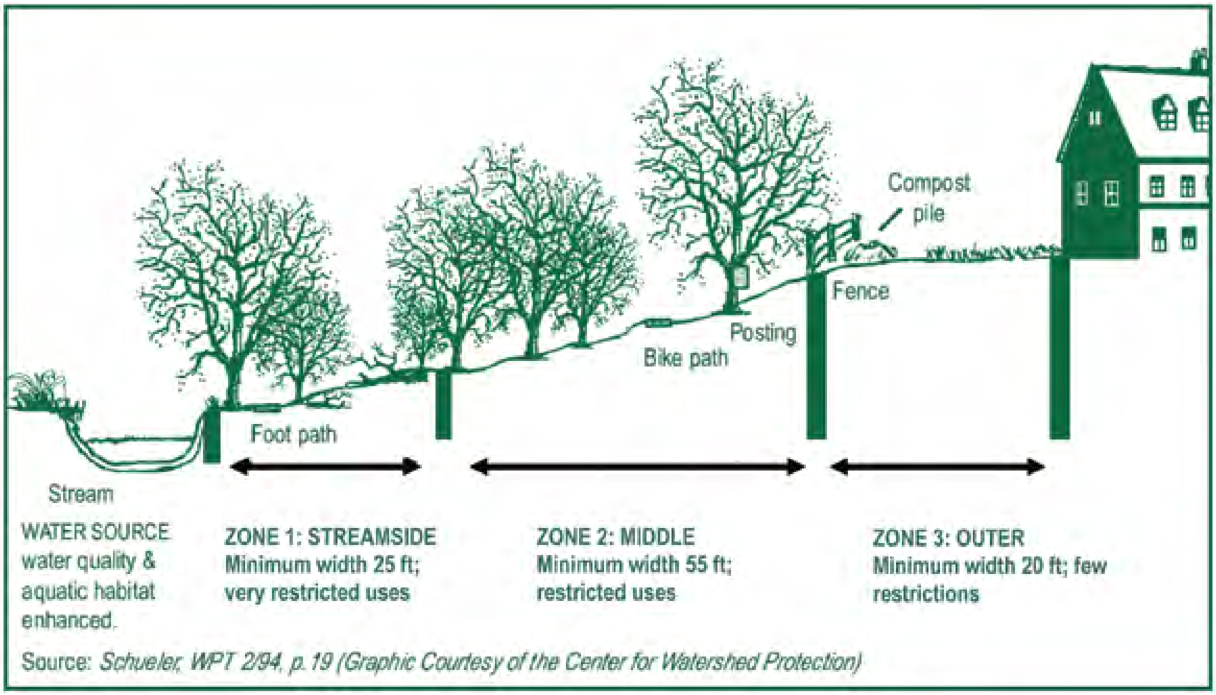
Port Townsend, Washington allows buffer averaging if the applicant demonstrates that the averaging will not adversely affect wetland functions and values, that the aggregate area within the buffer is not reduced, and that the buffer is not reduced in any location by more than 50 percent or to less than 25 feet.

Woodbury, Minnesota allows buffer averaging where averaging will provide additional protection to the wetland resource or to environmentally valuable adjacent uplands, provided that the total amount of buffer remains the same.

Source: Environmental Law Institute

Native pond edge
Source: JFNew

Figure 7.45
Schematic of a three-zone buffer



Source: Schueler, Watershed Protection Techniques, 1994 (Graphic courtesy of the Center for Watershed Protection)

Zone 1: Also termed the "streamside zone," begins at the edge of the stream bank of the active channel and extends a minimum distance of 25 feet; this is measured horizontally on a line perpendicular to the water body.

Undisturbed vegetated area helps protect the physical and ecological integrity of the stream ecosystem. The vegetative target for the streamside zone is undisturbed native woody species with native plants forming canopy, understory, and duff layer where such forest does not grow naturally; then native vegetative cover appropriate for the area (such as grasses, forbs, or shrubs) is the vegetative target. (*HRWC Model Ordinance*, p. 8)

Zone 2: Also termed the "middle zone," extends immediately from the outer edge of Zone 1 for a minimum distance of 55 feet.

This managed area of native vegetation protects key components of the stream ecosystem and provides distance between upland development and the streamside zone. The vegetative target for the middle zone is either undisturbed or managed native woody species or, in its absence, native vegetative cover of shrubs, grasses, or forbs. Undisturbed forest, as in Zone 1, is strongly encouraged to protect further water quality and the stream ecosystem. (*HRWC Model Ordinance* p. 8)

Zone 3: Also termed the "outer zone," it extends a minimum of 20 feet immediately from outer edge of Zone 2.

This zone prevents encroachment into the riparian buffer area, filters runoff from adjacent land, and encourages sheet flow of runoff into the buffer. The vegetative target for the outer zone is native woody and herbaceous vegetation to increase the total width of the buffer. Native grasses and forbs are acceptable. (*HRWC Model Ordinance* p. 8)

To maximize wildlife habitat, restoration buffers should reflect the type of riparian vegetation that was found at the site before alteration (presettlement vegetation maps available from MNFI are a good starting point for determining the presettlement ecosystem type). If water quality protection is the primary goal, greater emphasis may be placed on installing vegetation that enhances soil stability and absorbs pollutants. If the riparian area is very wet, wetland vegetation may be required.

In addition to installing vegetation, riparian buffer restoration may require physical restoration of soils, topography, or hydrology to achieve the desired result. Geographic factors such as the presence of steep slopes may necessitate an expanded buffer to achieve soil stability. If a river valley is very narrow, the buffer may be adjusted accordingly.

Applications

Riparian buffers are used adjacent to any wetland and bodies of water, such as lakes, streams, swales, and detention ponds. They are not typically applicable in upland areas where water bodies are not present. While riparian buffers provide significant water quality and ecological benefits, they have only very little benefit for volume control, unless they have some ability to trap and rapidly infiltrate water. Therefore, they should be used with other BMPs that will fulfill any volume control requirements.

Source: JFNew

Restoring riparian buffers can be applied in many stettings:

1. Adjacent to permanent or intermittent streams,
2. At the margins of lakes or ponds,
3. At the margin of intermittent or permanently flooded, environmentally sensitive, open water wetlands,
4. On karst formations at the margin of sinkholes and other small groundwater recharge areas, and
5. Between manicured lawns, cultivated areas or hardscape and swales, streams or rivers to help dissipate and treat runoff and help stabilize the tops of channel banks.

Design Considerations

Restoring riparian buffer areas requires a plan to ensure long-term success. Below is a summary of the steps that groups, designers, engineers, or volunteers should undertake during the planning stages of a riparian buffer project.

Rouge River streambank stabilization, City of Birmingham, MI
Source: Hubbell, Roth & Clark, Inc.

1. **Confirm suitability for restoration**

   If stream banks are extensively eroded, consider an alternative location for preparing the riparian buffer, or consider stream bank restoration first. Rapidly eroding stream banks may undermine top-of-bank restoration efforts.

2. **Analyze site's physical conditions**

   Consider site specific factors to determine the particular width of the individual zones:

   - Watershed condition,
   - Slope,
   - Stream order,
   - Soil depth and erodibility,
   - Hydrology,
   - Seasonal high water table,
   - Floodplains,
   - Wetlands,
   - Streambanks,
   - Soil type,
   - Vegetation type, and
   - Stormwater systems.

3. **Analyze site's vegetative features**

   Existing vegetation at the restoration site should be examined to determine the overall strategy for buffer protection and establishment. Strategies will differ whether pre-restoration conditions are pasture, overgrown abandoned field, mid-succession forest, predominantly invasive vegetation, or another type of setting. An effort to inventory existing vegetation for protection and to determine type of presettlement vegetation should be made to guide efforts.

   - *Identify desirable species*: Native tree and shrub species that thrive in riparian habitats in Michigan should be used. These species should be identified in the restoration site and protected. Several native vines and shrubs can provide an effective ground cover when establishing the buffer, though they should be controlled to prevent herbaceous competition.
   - *Identify non-native and invasive species*: Consider using undesirable species for shading during buffer establishment. Control invasive plants prior to buffer planting may be necessary.
   - *Identify sensitive species*: Because riparian zones are rich in wildlife habitat and wetland plant species, be aware of any rare, threatened, or endangered plant or animal species. Be sure to protect sensitive species during riparian buffer restoration.

4. **Map the site**

   Prepare an existing conditions sketch of the site noting important features such as stream width, length, stream bank condition, adjacent land uses, stream activities, desired width of buffer, discharge pipes, obstructions, etc.

5. **Create a design that accomplishes multiple stakeholder objectives**

   Ideally, the three-zone system should be incorporated into the design to meet landowner, community, and watershed objectives:

   - *Landowner objectives*: Consider the current use of the buffer by the landowner, especially if the buffer will be protected by the landowner in perpetuity. How will the riparian buffer complement or conflict with existing and probable future uses of the property?
   - *Community objectives*: Consider linking the buffer to an existing or planned green infrastructure system, which may include trails, parks, preserves, and wildlife habitat buffers. How can a buffer help achieve local recreation and green space goals?
   - *Watershed objectives*: Examine the local watershed plan to identify goals related to riparian buffers. Have goals related to water quality been emphasized. Is wildlife habitat a primary concern?

6. **Design measures**

   The following elements represent a menu of design measures for riparian and natural resource protection that communities may choose to encourage or require developers to incorporate during the site plan review process.

   - *Stream size* – A majority of Michigan's statewide stream system is comprised of small streams (first, second, and third order). It is important to reduce nutrient inputs to these streams.
   - *Availability of areas for continuous buffers* – Establishing continuous riparian buffers on the landscape should be given a priority over establishing fragmented buffers. Continuous buffers provide better shading and water quality protection as well as buffers for the wildlife movement.
   - *Degrees of degradation* – Urban streams have often been buried or piped as a result of previous development. Streams in areas without forestation may benefit the most from buffer restoration.
   - *Loading rate***s -** The potential for removing pollutants is generally highest where nutrient and sediment loading are the highest.
   - *Land uses* – Land uses adjacent to the riparian buffer may influence the required buffer width and vegetation types. While the three-zone riparian buffers described herein are ideal, the full widths of each zone may not always be feasible to establish, especially in urban areas.
   - *Habitats* – Establishing a buffer for habitat enhancement requires additional strategies beyond installing a buffer for increased water quality.

Aerial view of Quarton Lake remediation, Birmingham, MI
Source: Hubbell, Roth & Clark, Inc.

Green Development Standards

In 2007, the U.S. Green Building Council finalized pilot rating standards for the new Leadership in Energy and Environmental Design – Neighborhood Development (LEED –ND) certification program, which set standards for environmentally superior development practices.

Developers can earn certification credit for preserving a buffer around all wetlands and water bodies located on site in perpetuity. Local governments that adopt buffer ordinances encourage LEED-ND developments.

Source: Environmental Law Institute

7. **Determine the appropriate buffer width**

   Riparian buffer areas need not have a fixed linear boundary, but may vary in shape, width, and vegetative type and character, depending on the goals of the restoration and the natural geography of the water body and riparian area. The desired function of the buffer (habitat, water quality, etc.) determines buffer width (Figure 7.29). Many factors, including slope, soil type, adjacent land uses, floodplain, vegetative type, and watershed condition influence the design of the buffer. A rule of thumb is "the bigger, the better." Buffer widths for water quality and habitat maintenance should generally be 35 to100 feet. Buffers less than 35 feet generally do not protect aquatic resources in the long term.

- *Streamside buffers*

  The minimum width of streamside buffer areas can be determined by a number of methods suitable to the geographic area.

  Based on soil hydrologic groups as shown in the soil survey report, the width of Zone 2 should be increased to occupy any soils designated as Hydrologic Group D and those soils of Hydrologic Group C that are subject to frequent flooding. If soils of Hydrologic Groups A or B occur adjacent to intermittent or perennial streams, the combined width of Zones 1 and 2 may be limited to the 80-foot minimum.

  Based on area, the width of Zone 2 should be increased to provide a combined width of Zones 1 and 2 equal to one-third of the slope distance from the stream bank to the top of the pollutant source area. The effect is to create a buffer strip between field and stream that occupies approximately one-third of the source area.

- *Pond and lake-side buffers*

  The area of pond or lake-side buffer strips should be at least one-fifth the drainage area of the cropland and pastureland source area. The width of the buffer strip is determined by creating a uniform width buffer of the required area between field and pond. Hydrologic group determining width remains the same as for streamside buffers. Minimum widths apply in all cases.

Black River Heritage Trail and Waterfront Development
Source: Erin Fuller, Van Buren Conservation District

8. **Vegetation selection**

   Zone 1 and 2 vegetation should consist of native streamside species on soils of Hydrologic Groups C and D and native upland species on soils of Hydrologic Groups A and B.

   Deciduous species are important in Zone 2 due to the production of carbon leachate from leaf litter, which drives bacterial processes that remove nitrogen and sequester nutrients in growth processes. In warmer climates, evergreens are also important due to the potential for nutrient uptake during the winter months. In both cases, a variety of species is important to meet the habitat needs of insects important to the aquatic food chain.

   Zone 3 vegetation should consist of perennial grasses and forbs.

   Species recommendations for restoring riparian buffers depend on the geographic location of the buffer. Suggested species lists can be developed in collaboration with appropriate state and federal forestry agencies, the Natural Resources Conservation Service, and the USDA Fish and Wildlife Service. Species lists should include trees, shrubs, grasses, legumes, and forbs, as well as site preparation techniques. Please refer to the plant list in Appendix B for a recommended list of native trees and shrubs.

   The choice of planting stock (seeds, container seedling, bare-root seedlings, plugs, etc.) is often determined by cost. Larger plants usually cost more, though will generally establish more rapidly.

Many factors threaten the long-term viability of riparian plant protection or establishment. With proper foresight, these problems can be minimized. The following items should be considered during the planning stage:

- *Deer control*
  - Look for signs of high deer densities, including an overgrazed understory with a browse line five to six feet above the ground.
  - Select plants that deer do not prefer (e.g., paper birch, beech, common elderberry)
  - Apply homemade deer repellants
  - Install tree shelters
- *Tree shelters*
  - Tree shelters, such as plastic tubes that fit over newly planted trees, are extremely successful in protecting seedlings. They may be secured with a wooden stake and netting may be placed over top of the tree tube. They are recommended for riparian plantings where deer or human intrusion may be a problem. Tree shelters should be removed two to three years after the saplings emerge.
  - Tree shelters protect trees from accidental strikes from mowing or trimming.
  - Tree shelters create favorable microclimate for seedlings.
  - Tree shelters should be inspected at least four times per year. The following maintenance should be performed as necessary:

    – Repair broken stakes

    – Tighten stake lines

    – Straighten leaning tubes

    – Clean debris from tube

    – Remove netting as tree grows

    – Remove when tree trunk is approximately two inches wide
- *Stream buffer fencing*
  - Farm animals may cause great damage to stream banks. Consider permanent fencing such as high-tensile smooth wire fencing or barbed fencing.

    - The least expensive fencing is eight-foot plastic fencing, which is also effective against deer and is easily repaired
- *Vegetation*
    - Consider using plants that are able to survive frequent or prolonged flooding conditions. Plant trees that can withstand high water table conditions.
    - Soil disturbance can allow for unanticipated infestation by invasive plants.
- *Accidental or purposeful destruction by landowners*
    - Signage, posts, fencing, boulders, etc., may be required to alert adjacent landowners to the location, purpose, and management aims of riparian buffers. This is particularly important where actively managed landscaped areas abut native plant buffers. Signs that stress no mow/no pesticide and fertilizer zones may need to be in several languages, e.g., English and Spanish.

9. **Restoration design within your budget**

   The planting design (density and types) must ultimately conform to the financial constraints of the project. See discussion below for estimating direct costs of planting and maintenance.

10. **Draw a restoration planting plan**

    - *Planting layout*: The planting plan should be based on the plant types and density. The plan must show the site with areas denoted for trees and shrub species and plant spacing and buffer width.
    - *Planting density*: Trees should be planted at a density sufficient to provide 320 trees per acre at maturity. To achieve this density, approximately 436 (10 x 10 feet spacing) to 681 (8 x 8 feet spacing) trees per acre should be planted initially. Some rules of thumb for tree spacing and density based on plant size at installation follow:
        - Seedlings 6 to 10 feet spacing (~700 seedlings/acre)
        - Bare root stock 4 to 16 feet spacing (~200 plants/acre)
        - Larger & Container 16 to 18 feet spacing (~150 plants/acre)

    Formula for estimating number of trees and shrubs:

    Number of Plants = length x width of buffer (feet) / 50 square feet

    This formula assumes each tree will occupy an average of 50 square feet, random placement of plants approximately 10 feet apart, and a mortality rate of up to 40 percent.

    Alternatively, the table below can be used to estimate the number of trees per acre needed for various methods of spacing.

11. **Prepare site for restoration**

    Existing site conditions determine the degree of preparation needed prior to planting. Invasive plant infestation and vegetative competition are variable and must be considered in the planning stages. Site preparation should begin in the fall prior to planting. Determine whether the use of herbicides is necessary.

    Michigan State University County Extension offices can help identify pests and provide up-to-date herbicide recommendations. Michigan residents can use the URL listed below to find the location and phone number of their county's office: www.msue.anr.msu.edu/county

    Mark the site with flags, or marking paint, so that the plants are placed in the correct locations.

Table 7.14
Tree spacing per acre

Spacing (feet)	Trees (number)	Spacing (feet)	Trees (number)	Spacing (feet)	Trees (number)
2x2	10,890	7x9	691	12x15	242
3x3	4,840	7x10	622	12x18	202
4x4	2,722	7x12	519	12x20	182
4x5	2,178	7x15	415	12x25	145
4x6	1,815	8x8	681	13x13	258
4x7	1,556	8x9	605	13x15	223
4x8	1,361	8x10	544	13x20	168
4x9	1,210	8x12	454	13x25	134
4x10	1,089	8x15	363	14x14	222
5x5	1,742	8x25	218	14x15	207
5x6	1,452	9x9	538	14x20	156
5x7	1,245	9x10	484	14x25	124
5x8	1,089	9x12	403	15x15	194
5x9	968	9x15	323	15x20	145
5x10	871	10x10	436	15x25	116
6x6	1,210	10x12	363	16x16	170
6x7	1,037	10x15	290	16x20	136
6x8	908	10x18	242	16x25	109
6x9	807	11x11	360	18x18	134
6x10	726	11x12	330	18x20	121
6x12	605	11x15	264	18x25	97
6x15	484	11x20	198	20x20	109
7x7	889	11x25	158	20x25	87
7x8	778	12x12	302	25x25	70

Stormwater Functions and Calculations

Volume and peak rate

Restoration of the riparian buffer will lower runoff volume and peak rates through lowering the runoff coefficient (i.e., curve number). Designers can receive credit based on the square feet of trees or shrubs being added. Proposed trees and shrubs to be planted under the requirements of these BMPs can be assigned a curve number (CN) reflecting a woodlot in "good" condition for an area of 200 square feet per tree or the estimated tree canopy, whichever is greater. For shrubs, calculate based an area of 25 square feet per shrub. Calculation methodology to account for this BMP is provided in Chapter 9.

Water quality improvement

Water quality benefits of restoring riparian buffers are medium to high. The amount of benefit is based on flow characteristics and nutrient, sediment, and pollutant loadings of the runoff as well as the length, slope, type, and density of vegetation in the riparian buffer.

Runoff entering Zone 3 filters sediment, begins nutrient uptake, and converts concentrated flow to uniform, shallow sheet flow. Zone 2 provides contact time and carbon energy sources in which buffering processes can take place. It also provides long-term sequestering of nutrients. Zone 1 provides additional soil and water contact area to further facilitate nutrient buffering processes, provides shade to moderate and stabilize water temperature, and encourages production of beneficial algae.

Maintenance

An effective riparian buffer restoration project should include stewardship guidelines to manage and maintain the site in perpetuity. The most critical period of riparian buffer establishment is canopy closure, which is typically the first three to five years after saplings are planted. Buffer boundaries should be well defined with clear signs or markers. During this time, the riparian buffer should be monitored four times annually (February, May, August, and November are recommended) and inspected after any severe storm. Maintenance measures that should be performed regularly include:

1. **Watering**
   - Plantings need deep, regular watering during the first growing season, either natural watering via rainfall, or planned watering via caretaker.
   - Planting in the fall increases the likelihood of sufficient rain during planting establishment.
2. **Mulching**
   - Mulch provides moisture retention in the root zone of plantings, or potentially impacted vegetation from construction, moderate soil temperature, and some weed suppression.
   - Use coarse, organic mulch that is slow to decompose in order to reduce the need for repeat application.
   - Apply a two to four-inch layer, leaving air space around tree trunk to prevent fungus growth.
   - Use a combination of woodchips, leaves, and twigs that have been stockpiled for six months to a year.
3. **Weed and invasive plan control**
   - Invasive plants can overrun even a well-designed planting. It is essential that there is a plan in place to monitor and remove invasive vegetation as the planting matures. Use the Nature Conservancy's Global Invasive Species Team Web page as a resource for management techniques. (www.impainvasives.org/) Non-chemical weed control methods are preferred since chemicals can easily be washed into the stream.
   - *Herbicides*

     Using herbicides is a short-term maintenance technique (two to three years) that is generally considered less expensive and more flexible than mowing and will result in a quicker establishment of the buffer. Consider and evaluate the proximity of herbicide use to water features.
   - *Mowing*

     Mowing controls the height of the existing grasses, yet increases nutrient uptake. Therefore, competition for nutrients will persist until the canopy closure shades out lower layers of growth. A planting layout similar to a grid format will facilitate ease of mowing, but will yield an unnaturally spaced community. Mowing may result in strikes to tree trunks unless protective measures are used. Mowing should occur twice each growing season. Mower height should be set between eight and12 inches.
   - *Weed mats*

     Weed mats are geo-textile fabrics used to suppress weed growth around newly planted vegetation by blocking sunlight and preventing seed deposition. Weed mats are installed after planting, and should be removed once the trees have developed a canopy that will naturally shade out weeds.

4. **Stable debris**

   As Zone 1 reaches 60 years of age or is hit with pests or disease, it will begin to produce large debris. Large debris, such as logs, create small dams which trap and hold debris for processing by aquatic insects, thus adding energy to the stream ecosystem, strengthening the food chain, and improving aquatic habitat. Wherever possible, stable debris should be conserved.

   - Where debris dams must be removed, try to retain useful, stable portions which can provide storage. (A state permit may be required). For guidance on evaluating debris impacts on streams and methods for managing debris jams, refer to the "Primer on Large Woody Debris Management" developed by the City of Rochester Hills (see References).

   Deposit removed material a sufficient distance from the stream so that it will not be refloated by high water.

5. **Resources for assistance**

Local land conservancies are excellent resources when considering the long-term stewardship of the area. If a site has critical value, a local conservancy may be interested in holding a conservation easement on the area, or may be able to provide stewardship services and assistance. The following organizations may also provide resources:

- Stewardship Network (www.stewardshipnetwork.org) is a statewide organization that provides informational and educational resources about stewardship in Michigan.
- Wild Ones (www.wildones.org/) is a national organization with local chapters which may also provide stewardship resources.

Winter Considerations

Volume reduction, peak rate mitigation, and water quality benefits are not as pronounced in winter months compared to the rest of the year in riparian buffers because infiltration rates are generally lower during prolonged cold weather periods. In addition, evapotranspiration rates are lower in winter months because most vegetation is dormant. However, riparian buffers still provide stormwater management benefits even in winter.

Cost

Installing a riparian buffer involves site preparation, planting, second year reinforcement planting, and additional maintenance. Costs may fluctuate based on numerous variables including whether or not volunteer labor is used, and whether plantings and other supplies are donated or provided at a reduced cost. The following table presents an estimate of typical costs for riparian buffer restoration.

Criteria to receive credits for Riparian Buffer Restoration

To receive credit for riparian buffer restoration under a location regulation, the following criteria must be met:

- ☐ Area is protected by having the limits of disturbance clearly shown on all construction drawings and delineated in the field.
- ☐ Area to receive credit for trees is 200 square feet per tree or the estimated tree canopy, whichever is greater.
- ☐ Area to receive credit for shrubs is 25 square feet per shrub.
- ☐ Area is located on the development project.
- ☐ Area has a maintenance plan that includes weeding and watering requirements from initial installation throughout ongoing maintenance.

Designer/Reviewer Checklist for Riparian Buffer Restoration

ITEM	YES	NO	N/A	NOTES
Avoidance of stormwater concentration as much as practical?				
Appropriate buffer widths designed?				
Soil erodibility considered?				
Slope considered and appropriate?				
Appropriate vegetation selected based on soils, hydrology, and ecoregion?				
Appropriate vegetation selected based on budget and aesthetics?				
Appropriate plant spacing designed?				
Appropriate balance of woody to herbaceous species?				
Seasonality of planting/construction considered?				
Erosion and sedimentation control provided?				
Maintenance accounted for and plan provided?				

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BMP Fact Sheet

Soil Restoration

Soil is a key ingredient in effective stormwater and water quality management, making proper care of soils a key component of low impact development.

Soil restoration is a technique used to enhance and restore soils by physical treatment and/or mixture with additives – such as compost – in areas where soil has been compacted. Soil media restoration increases the water retention capacity of soil, reduces erosion, improves soil structure, immobilizes and degrades pollutants (depending on soil media makeup), supplies nutrients to plants, and provides organic matter. Soil restoration is also used to reestablish the soil's long term capacity for infiltration and to enhance the vitality of the soil as it hosts all manner of microbes and plant root systems in complex, symbiotic relationships.

The soil in the detention basin pictured above was amended with compost.

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Medium
Commercial	Yes	**Groundwater Recharge**	Low
Ultra Urban	Yes	**Peak Rate**	Medium
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Limited	**TSS**	High*
Highway/Road	Yes	**TP**	High*
Recreational	Yes	**NO_3**	Medium
		Temperature	Medium

Additional Considerations	
Cost	Medium
Maintenance	Low
Winter Performance	High

Key Design Features

- Follow nonstructural BMP to minimize soil compaction
- Evaluate existing soil conditions using methods referenced in Soil Infiltration Testing Protocol (Appendix E) before creating a soil restoration strategy
- Soil media used in restoration is either organic or inorganic (man-made) and is mixed into existing soil

Benefits

- Widely applicable
- Relatively low cost
- Additional benefits such as improved plant health and reduced erosion.

Limitations

- Relatively limited stormwater benefits on a unit area basis

*Newly amended soils are susceptible to erosion and release of TSS and phosphorus until stabilized with mulch, erosion blanket, sod, or some other covering.

Case Study: Ann Arbor District Library, Mallets Creek Branch

One of the goals of this project was to design a development aesthetically pleasing to both nearby residents and clients of the Mallets Creek Branch Library in Ann Arbor, MI, while managing stormwater onsite to help protect Mallets Creek. Bioswales were also installed in the Mallets Creek Library parking lot to slow and filter stormwater and increase infiltration prior its passage to the detention area. To help reach the library's goal of zero stormwater runoff, it shares its parking spaces with an adjacent public building to reduce the amount of impervious surface.

Soil restoration at Mallets Creek Library to enhance vegetation

InSite Design Studios

The existing site consisted of clay soils with a sand seam four feet down. The bioswales were designed to connect to the sand seam to help with the infiltration of stormwater.

A mix of topsoil, compost, and sand were added to the bioswales while the detention area had compost integrated into the parent soil. The bioswales had a four foot section of the special mix and the detention area had three inches of compost integrated into the top six inches of parent soil. Amending the soil resulted in an increased long-term capacity for infiltration in areas designed to handle stormwater runoff with a goal of zero runoff. In addition, the amended soil has the ability to support healthy native vegetation which helps to manage stormwater and reduce maintenance needs.

Case Study Site Considerations	
Project Type	Soil amendment, green roof, rain garden
Soil Conditions	Clay soils with sand seam
Estimated Total Project Cost	$70,000 (not including green roof) Bioswale mix was $60/cubic yard
Maintenance Responsibility	Mallets Creek Branch Library
Project Contact	Andrea Kevrick, 734-995-4194

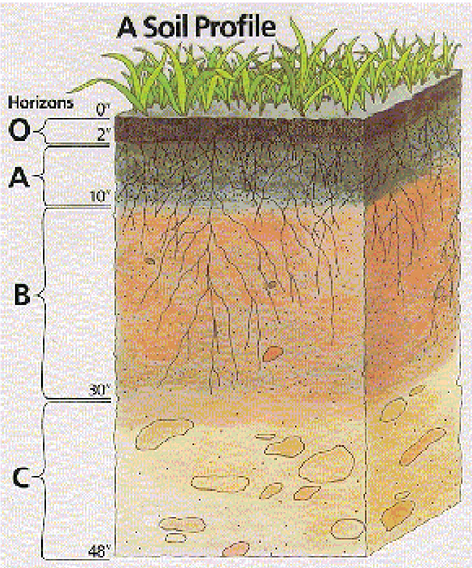
Description and Function

Soil can be restored after construction to partially recondition that which has been degraded by compaction. Bulk density field tests measure soil compaction and can be used to help determine if soil restoration is necessary. Restoring the soil improves its structure and function, increases infiltration potential, and supports healthy vegetative communities.

A healthy soil (Figure 7.46) provides a number of vital functions including water storage and nutrient storage, regulate the flow of water, and immobilize and degrade pollutants. Healthy soil contains a diverse community of beneficial microorganisms, a sufficient amount of plant nutrients (nitrogen and phosphorous), some trace elements (e.g., calcium and magnesium), and organic matter (generally five to 10 percent). Healthy soil typically has a neutral or slightly acidic pH and good structure which includes various sizes of pores to support water movement, oxygenation, and a variety of other soil processes.

Caring for soil is also a critical component of water management, especially during development activities, such as construction grading, which often result in erosion, sedimentation, and soil compaction. Proper protection and restoration of soil is a critical BMP to combat these issues. Soil restoration prevents and controls erosion by enhancing the soil surface to prevent the initial detachment and transport of soil particles.

Figure 7.46
A Healthy Soil Profile

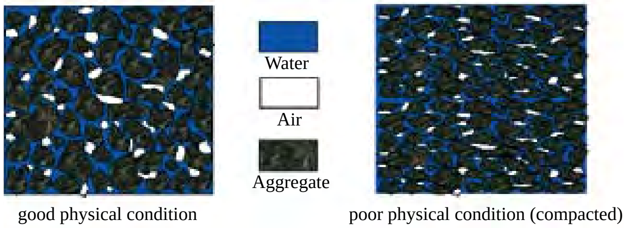


Source: USDA NRCS

Soil compaction

Soil compaction is the enemy of water quality protection. Soil compaction occurs when soil particles are pressed together, reducing the pore space necessary to allow for the movement of air and water throughout the soil (Figure 7.47). This decrease in porosity causes an increase in bulk density (weight of solids per unit volume of soil). The greater the bulk density of the soil, the lower the infiltration and, therefore, the larger the volume of runoff.

Figure 7.47
Compacted soil constrains movement of air and water



Source - USDA NRCS

Compaction limits vegetative root growth, restricting the health of plants as well as the biological diversity of the soil. Compaction also affects the infiltrating and water quality capacity of soils. Soil compaction can lead to increased erosion and stormwater runoff, low infiltration rates, increased flooding, and decreased water quality from polluted runoff. After compaction, a typical soil has strength of about 6,000 kilopascals (kPa), while studies have shown that root growth is not possible beyond 3,000 kPa. There are two types of compaction, minor and major, each of which requires a particular restoration technique (s) or method:

- **Minor compaction** – Surface compaction within 8-12 inches due to contact pressure and axle load <20 tons can compact through root zone up to one-foot deep. Soil restoration activities can include: subsoiling, organic matter amendment, and native landscaping. Tilling/scarifying is an option as long as it is deep enough (i.e., 8-12 inches) and the right equipment is used (should not be performed with common tillage tools such as a disk or chisel plow because they are too shallow and can compact the soil just beneath the tillage depth).

- **Major compaction** – Deep compaction, contact pressure and axle load > 20 tons can compact up to two-feet deep (usually large areas are compacted to increase strength for paving and foundation with overlap to "lawn" areas). Soil restoration activities can include: deep tillage, organic matter amendment, and native landscaping.

To evaluate the level of compaction in soils, bulk density field tests are conducted. Table 7.15 shows the ideal bulk densities for various textures of soils.

Amending media

Compacted soil can be amended by first tilling the soil, breaking apart the compaction, and then applying various soil media. For minor soil compaction, six inches of soil media (18.5 cubic yards per 1,000 square feet of soil) should be applied, and then tilled into the existing soil up to eight inches. For major soil compaction, 10 inches of soil media (31 cubic yards per 1,000 square feet of soil) should be applied and then tilled into the existing soil up to 20 inches.

Soil media used for amendment may be comprised of either organic or inorganic material. Organic media can increase soil organic matter content, which improves soil aeration, water infiltration, water and nutrient holding capacity, and is an important energy source for bacteria, fungi, and earthworms.

Organic media:

- Compost,*
- Aged manure,*
- Biosolids* (must be a Grade 1 biosolid),
- Sawdust, (can tie up nitrogen and cause deficiency in plants),
- Wood ash (can be high in pH or salt),
- Wood chips (can tie up nitrogen and cause deficiency in plants),
- Grass clippings,
- Straw, and
- Sphagnum peat (low pH;).

**Materials containing animal wastes can cause phosphorus to be exported from the amended soils.*

Inorganic media:

- Vermiculite,
- Perlite,
- Pea gravel, and
- Sand.

Table 7.15
Bulk Densities for Soil Textures

Soil Texture	Ideal Bulk densities, g/cm^3	Bulk densities that may afffect root growth, g/cm^3	Bulk densities that restrict root growth, g/cm^3
Sands, loamy sands	<1.60	1.69	1.8
Sandy loams, loams	<1.40	1.63	1.8
Sandy clay loams, loams, clay loams	<1.40	1.6	1.75
Slilt, silt loams	<1.30	1.6	1.75
Silt loams, silty clay loams	<1.10	1.55	1.65
Sandy clays, silty clays, some clay loams (35-45% clay)	<1.10	1.49	1.58
Clays (>45% clay)	<1.10	1.39	1.47

Source: Protecting Urban Soil Quality, USDA-NRCS

Applications

Soil restoration can occur anywhere to alleviate soil compaction. It can be specifically addressed in the following examples:

- **New development (residential, commercial, industrial)** – Heavily compacted soils can be restored prior to lawn establishment and/or landscaping to increase the porosity of the soils and aid in plant establishment.
- **Detention basin retrofits** – The inside face of detention basins is usually heavily compacted, and tilling the soil mantle will encourage infiltration to take place and aid in establishing vegetative cover.
- **Golf courses** – Using compost as part of landscaping upkeep on the greens has been shown to alleviate soil compaction, erosion, and turf disease problems.

Design Considerations

1. Tilling the soil (also referred to as scarification, ripping, or subsoiling)
   a. Effective when performed on dry soils.
   b. Should be performed where subsoil has become compacted by equipment operation, dried out, and crusted, or where necessary to obliterate erosion rills.
   c. Should be performed using a solid-shank ripper and to a depth of 20 inches, (eight inches for minor compaction).
   d. Should be performed before amending media is applied and after any excavation is completed.
   e. Should not be performed within the drip line of any existing trees, over underground utility installations within 30 inches of the surface, where trenching/drainage lines are installed, where compaction is by design, and on inaccessible slopes.
   f. The final pass should be parallel to slope contours to reduce runoff and erosion.
   g. Tilled areas should be loosened to less than 1,400 kPa (200 psi) to a depth of 20 inches below final topsoil grade.
   h. The subsoil should be in a loose, friable condition to a depth of 20 inches below final topsoil grade and there should be no erosion rills or washouts in the subsoil surface exceeding three inches in depth.
   i. Tilling should form a two-directional grid. Channels should be created by a commercially available, multi-shanked, parallelogram implement (solid-shank ripper), capable of exerting a penetration force necessary for the site.
   j. No disc cultivators, chisel plows, or spring-loaded equipment should be used for tilling. The grid channels should be spaced a minimum of 12 inches to a maximum of 36 inches apart, depending on equipment, site conditions, and the soil management plan.
   k. The channel depth should be a minimum of 20 inches or as specified in the soil management plan. If soils are saturated, delay operations until the soil, except for clay, will not hold a ball when squeezed.
   l. Only one pass should be performed on erodible slopes greater than one vertical to three horizontal.

2. Applying soil media for amendment
   a. Soil media should not be used on slopes greater than 30 percent. In these areas, deep-rooted vegetation can be used to increase stability.
   b. Soil restoration should not take place within the critical root zone of a tree to avoid damaging the root system. (Where one inch of tree trunk DBH is equal to one foot of soil area on the ground away from the tree trunk.)
   c. Onsite soils with an organic content of at least five percent can be stockpiled and reused to amend compacted soils, saving costs. Note: These soils must be properly stockpiled to maintain organic content.
   d. Soils should generally be amended at about a 2:1 ratio of native soil to media. If a proprietary product is used, follow the manufacturer's instructions for the mixing and application rate.

e. Add six inches compost or other media and till up to eight inches for minor compaction. (Six inches of compost equates to 18.5 cubic yards per 1,000 square feet of soil.)

f. Add 10 inches compost or other amendment and till up to 20 inches for major compaction. 10 inches of compost equates to approx. 30.9 cubic yard per 1,000 square feet.

g. Compost can be amended with bulking agents, such as aged crumb rubber from used tires, or wood chips. This can be a cost-effective alternative that reuses waste materials while increasing permeability of the soil.

Stormwater Functions and Calculations

Volume and peak rate reduction

Restored soils result in increased infiltration, decreased volume of runoff, and significantly delayed runoff.

Soil restoration will lower runoff volume and peak rates by lowering the runoff coefficient (i.e., curve number). Designers can receive credit based on areas (acres) complying with the requirements of these BMPs. These areas can be assigned a curve number (CN) reflecting a "good" condition instead of "fair" as required for other disturbed pervious areas. Chapter 9 and Worksheets 3 and 4 show how to calculate the runoff credit for this BMP.

Water quality improvement

Although either organic or inorganic materials may be used as soil media, only organic matter can improve water quality by increasing the nutrient holding capacity of soils. Soils rich in organic matter contain microorganisms that immobilize or degrade pollutants. See Chapter 9 for information on how to calculate the volume of runoff that needs treatment for water quality improvement.

Organic materials that include fecal matter or animal renderings should not be used where water may infiltrate though the soil and carry nutrients, primarily phosphorus, to surface waters (Hunt and Lord, 2006).

Maintenance

Soil restoration may need to be repeated over time, due to compaction by use and/or settling. Taking soil core samples will help to determine the degree of soil compaction and if additional media application is necessary.

Winter Considerations

Since soil restoration is performed in conjunction with plantings, this BMP should be undertaken in spring or autumn and during dry weather, so that plantings can establish.

Cost

Cost information has been compiled by Cahill Associates and reflects 2007 conditions:

- Tilling costs range from $800/acre to $1,000/acre
- Compost costs range from $860/acre to $1,000/acre. Costs of other soil media would vary greatly depending on their individual material costs and the amounts used.

Criteria to receive credits for Soil Restoration

To receive credit for soil restoration under a location regulation, the following criteria must be met:

- ☐ Area is clearly shown on all construction drawings and delineated in the field.
- ☐ Tilling the soil is required if subsoil is compacted; needs to occur before amending media is applied.
- ☐ Area is not located on slopes greater than 30 percent.
- ☐ Area is not within the critical root zone of any tree.
- ☐ Amendment consists of six inches for minor compaction; 10 inches of amendment for major compaction.
- ☐ Area is located on the development project.

Designer/Reviewer Checklist for Soil Restoration

Type of soil amendment(s) proposed: ______________________________

Amount of amendments(s) to be used: ______________________________

ITEM	YES	NO	N/A	NOTES
Appropriate soil amendment(s) for the site conditions?				
Adequate amount of amendment materials?				
Bulk density/degree of compaction considered?				
Appropriate decompaction techniques and equipment?				
Appropriate construction sequencing?				
Sensitive areas (e.g., near existing trees, shallow utilities, and steep slopes) accounted for?				
Appropriate vegetation selected?				
Seasonality of planting/construction considered?				
Erosion and sedimentation control provided?				
Maintenance accounted for and plan provided?				

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BMP Fact Sheet

Vegetated Filter Strip

A vegetated filter strip is a permanent, maintained strip of vegetation designed to slow runoff velocities and filter out sediment and other pollutants from urban stormwater. Filter strips require the presence of sheet flow across the strip, which can be achieved through the use of level spreaders. Frequently, filter strips are designed where runoff is directed from a parking lot into a stone trench, a grass strip, and a longer naturally vegetative strip.

Vegetated filter strip along roadway

Source: Wayne County Department of Environment

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Low
Commercial	Yes	**Groundwater Recharge**	Low
Ultra Urban	Limited*	**Peak Rate**	Low
Industrial	Limited*	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	Med/High
Highway/Road	Yes	**TP**	Med/High
Recreational	Yes	**NO_3**	Med/High
		Temperature	Med/High

Additional Considerations	
Cost	Low
Maintenance	Low/Medium Varies dependent on type of vegetation
Winter Performance	High

Variations

- Turf grasses
- Prairie grasses, shrubs, and groundcover vegetation, including trees
- Indigenous woods and dense vegetation

Key Design Features

- Use with level spreaders to promote sheet flow across strips
- Longitudinal slope from 1-6 percent
- Maintain dense vegetation
- See Appendix for recommended filter strip native vegetation

Site Factors

- Water table to bedrock depth – N/A
- Soils – N/A for permeability
- Slope – 2-5 percent preferred (1-10 percent if soils/vegetation allow)
- Potential hotspots – Yes with special design considerations
- Max. drainage area – 100 feet impervious or 150 feet pervious upgradient

Benefits

- Low cost
- Good water quality performance
- Aesthetic and habitat benefits

Limitations

- Generally should be coupled with other BMPs for comprehensive stormwater management

* According to site characteristics

Case Study: Wayne County, MI
Ford Road Outer Drive Vegetated Filter Strip

In 2006, Wayne County Parks eliminated the existing turf grass and seed bank on 5.3 acres of Hines Park along Ford Road and Outer Drive by applying herbicide and tilling the area. Preparation of the areas included shallow tilling and reseeding with native plant species to create a vegetated filter strip along a transportation corridor and to reduce maintenance costs of traditional turf grass. Occasional mowing and managing for invasive species are the only maintenance procedures anticipated.

Research on native landscapes suggest the maintenance cost for 5.3 acres of grow zone will be approximately 80 percent less than managing the previous turf grass land cover. A list of the 40-plus native plant species used for this project is available upon request. The species mix was specific to match the habitat of the planted area. Planted native trees and shrubs along with grow zone signage help to delineate the grow zone as a managed, important part of Edward Hines Park. This project has become a welcome addition to the park's natural environment.

Materials Used

- Herbicide, tractor, and seed drill
- Shovels, rakes, landscape mulch
- Design consultant services
- 55 trees and shrubs, 500 plugs and 59 lbs of native plant seed
- 10 large grow zone signs with logo decal and 30 small grow zone boundary signs.

The Ford Road/Outer Drive Grow Zone after the first growth

Source: Wayne County Department of Environment

Cost

The total cost of the project was $8,584. This cost covered the design, plant material, seed, signage, and herbicide. The site benefited by having Pheasants Forever, Ford Motor Company, and Wayne County provide in-kind service for the physical preparation and installation of the planting area. This project was part of a larger grow zone effort that took place across Edward Hines Park in the spring and summer of 2006.

Case Study Site Considerations	
Project Type	Vegetated filter strip
Estimated Total Project Cost	$8,584
Maintenance Responsibility	Wayne County Department of Environment
Project Contact	Noel Mullett, 734-326-4486

Description and Function

Filter strips (Figure 7.48) are gently sloping areas that combine a grass strip and dense vegetation to filter, slow, and infiltrate sheet flowing stormwater. Filter strips are best used to treat runoff from roads and highways, roof downspouts, small parking lots, and other impervious surfaces. They are generally not recommended as stand-alone features, but as pretreatment systems for other BMPs, such as infiltration trenches or bioretention areas. Therefore, filter strips generally should be combined with other BMPs as part of a treatment train so that water quality and quantity benefits are sufficient to meet recommended site design criteria.

Maintaining a dense growth pattern that includes turf-forming grasses and vegetation on a filter strip is critical for maximizing pollutant removal efficiency and erosion prevention.

The grass portion of the filter strip provides a pretreatment of the stormwater before it reaches the densely vegetated, or wooded area. In addition, a stone drop can be located at the edge of the impervious surface to prevent sediment from depositing at this critical entry point.

In addition to a stone drop, a pervious berm can reduce runoff velocity and increase volume reduction by providing a temporary, shallow ponded area for the runoff. The berm should have a height of not more than six to 12 inches and be constructed of sand, gravel, and sandy loam to encourage growth of a vegetative cover. An outlet pipe(s) or an overflow weir may be provided and sized to ensure that the area drains within 24 hours or to allow larger storm events to pass. The berm must be erosion resistant under the full range of storm events. Likewise, the ponded area should be planted with vegetation that is resistant to frequent inundation.

Filter strips are primarily designed to reduce total suspended solids (TSS) levels. However, pollutants such as hydrocarbons, heavy metals, and nutrients may also be reduced. Pollutant removal mechanisms include sedimentation, filtration, absorption, infiltration, biological uptake, and microbial activity. Depending on soil properties, vegetative cover type, slope, and length of the filter strip, a reduction in runoff volume may also be achieved by infiltration.

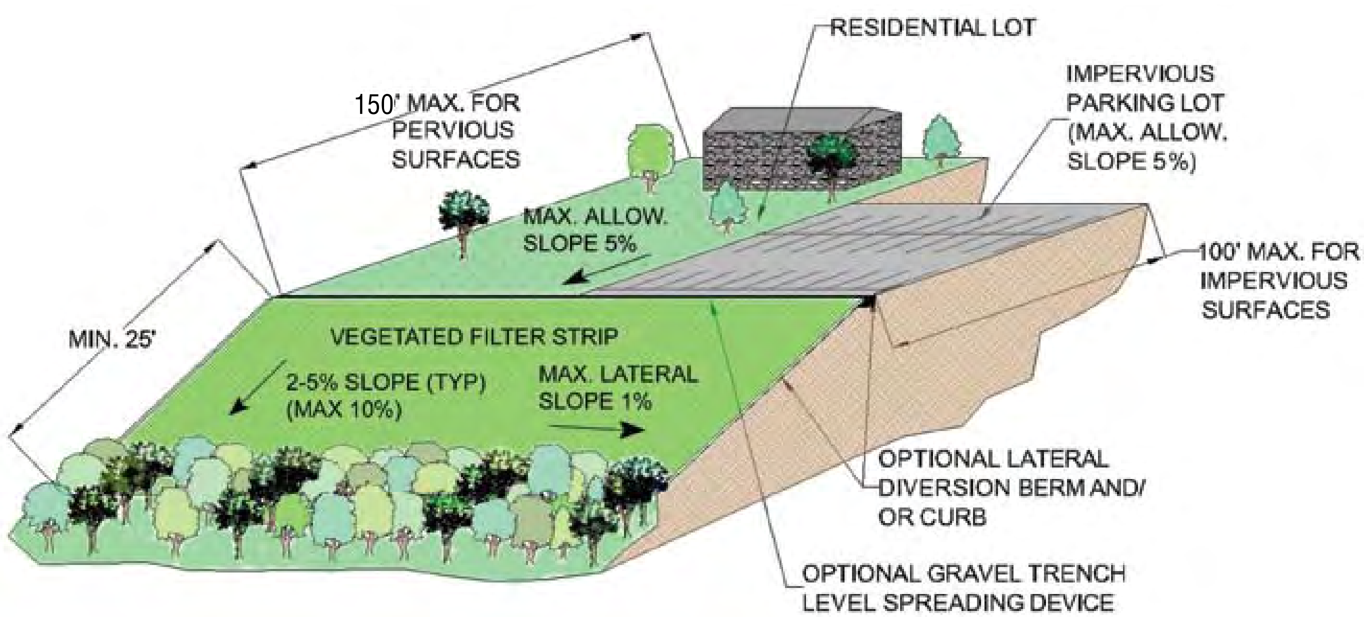
Applications

Vegetated filter strips can be used in a wide variety of applications from residential/commercial developments to industrial sites and even transportation projects where the required space is available. Lack of available space limits use in ultra urban areas and some redevelopment projects.

Design Considerations

1. The design of vegetated filter strips is determined by existing drainage area conditions including drainage area size, length, and slope. In addition, the filter strip soil group, proposed cover type, and

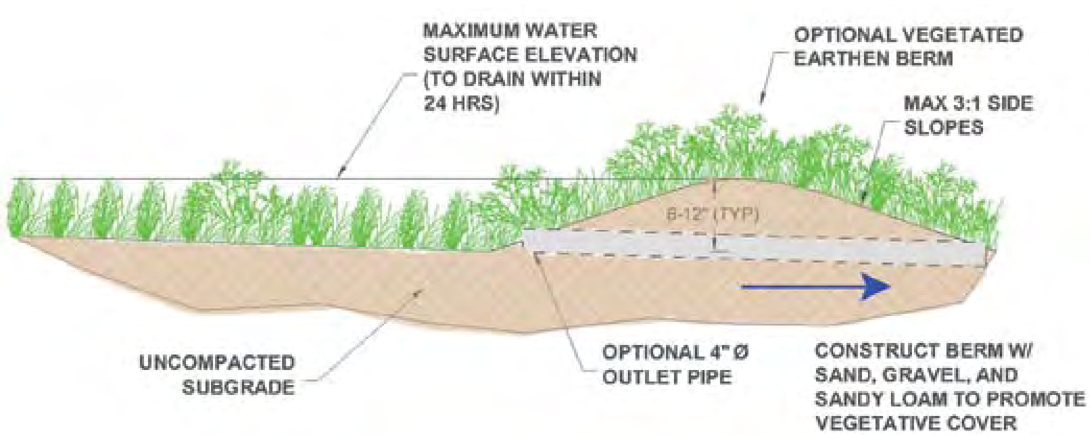
Figure 7.48
Diagram showing elements of a vegetated filter strip



slope needs to be determined. This information is used to determine the length of the filter strip using the appropriate graph (Figures 7.52 through 7.56).

2. Level spreading devices (see Level Spreader BMP for detailed information) are highly recommended to provide uniform sheet flow conditions at the interface of the adjacent site area and the filter strip. Concentrated flows should not be allowed to flow onto filter strips, as they can lead to erosion and, thus, failure of the system. Examples of level spreaders include:
   a. A gravel-filled trench (Figure 7.50), installed along the entire up-gradient edge of the strip. The gravel in the trenches may range from pea gravel (ASTM D 448 size no. 6, 1/8" to 3/8") for most cases to shoulder ballast for roadways. Trenches are typically 12" wide, 24-36" deep, and lined with a nonwoven geotextile. When placed directly adjacent to an impervious surface, a drop (between the pavement edge and the trench) of 1-2" is recommended, in order to inhibit the formation of the initial deposition barrier.
   b. A concrete curb stop with cutouts (Figure 7.51) can be used to provide uniform sheet flow across a vegetated filter strip.
   c. Concrete sill (or lip).
   d. An earthen berm (Figure 7.49) with optional perforated pipe.
3. Where possible, natural spreader designs and materials, such as earthen berms, are generally recommended, though they can be more susceptible to failure due to irregularities in berm elevation and density of vegetation. When it is desired to treat runoff from roofs or curbed impervious areas, a more structural approach, such as a gravel trench, is required. In this case, runoff should be directly conveyed, via pipe from downspout or inlet, into the subsurface gravel and uniformly distributed by a perforated pipe along the trench bottom.
4. The upstream edge of a filter strip should be level and directly abut the contributing drainage area.
5. In areas where the soil infiltration rate has been compromised (e.g., by excessive compaction), the filter strip should be tilled prior to establishing vegetation. However, tilling will only have an effect on the top 12-18 inches of the soil layer. Therefore, other measures, such as planting trees and shrubs, may be needed to provide deeper aeration. Deep root penetration will promote greater absorptive capacity of the soil.
6. The ratio of contributing drainage area to filter strip area should never exceed 6:1.
7. The filter strip area should be densely vegetated with a mix of salt-tolerant, drought-tolerant, and erosion-resistant plant species. Filter strip vegetation, whether planted or existing, may range from turf and native grasses to herbaceous and woody vegetation. The optimal vegetation strategy consists of plants with dense growth patterns, a fibrous root system for stability, good regrowth ability (following dormancy and cutting), and adaptability to local soil and climatic conditions. Native vegetation is always preferred. (See Appendix C for vegetation recommendations.)
8. Natural areas, such as forests and meadows, should never be unduly disturbed when creating a filter strip. If these areas are not already functional as natural filters, they may be enhanced by restorative methods or by constructing a level spreader.

Figure 7.49
Optional earthen berm at bottom of vegetated filter strip



9. The maximum lateral slope of a filter strip is one percent.
10. To prohibit runoff from laterally bypassing a strip, berms and/or curbs can be installed along the sides of the strip, parallel to the direction of flow.

As shown in Figures 7.52–7.56, the recommended filter strip length varies depending on the type of soil, the type of vegetation, and the filter strip slope. Generally, the more permeable the soil and/or the lower the slope, the shorter the filter strip may be for equivalent stormwater benefits.

Figure 7.50
A level spreading device (gravel-filled trench)

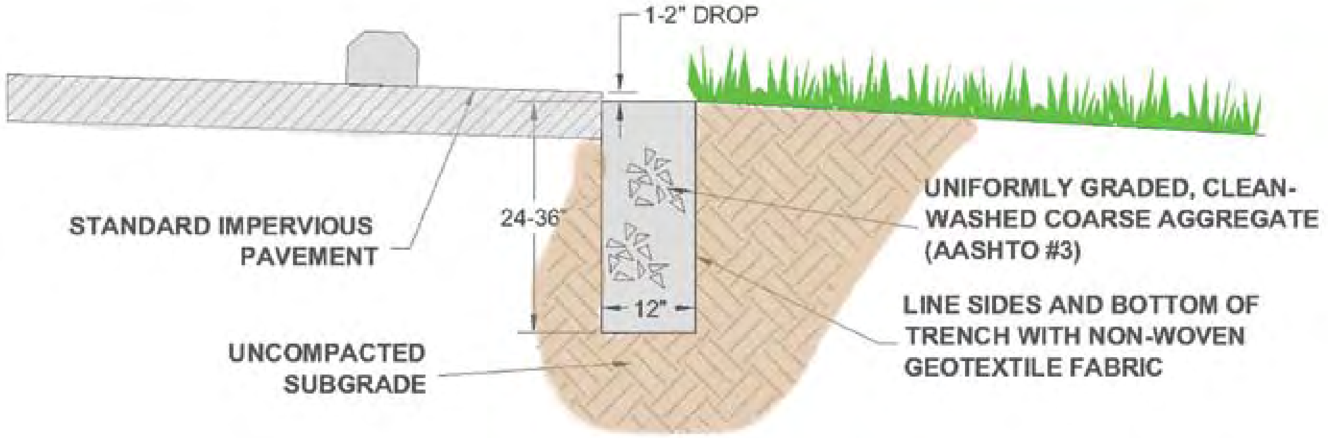


Figure 7.51
Concrete curb stop schematic

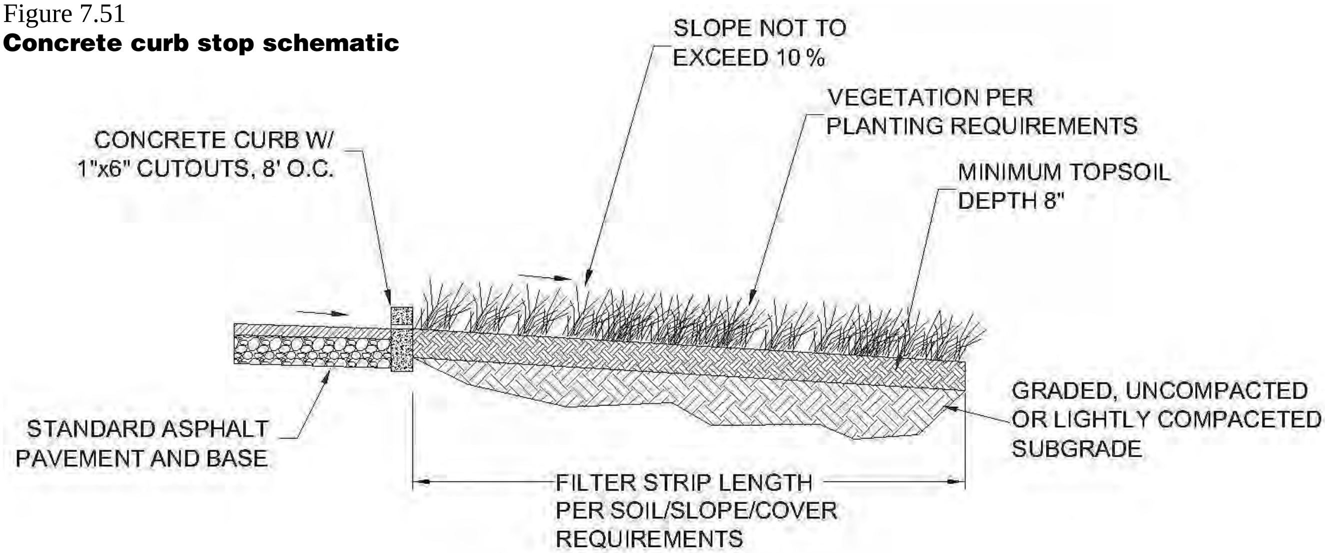
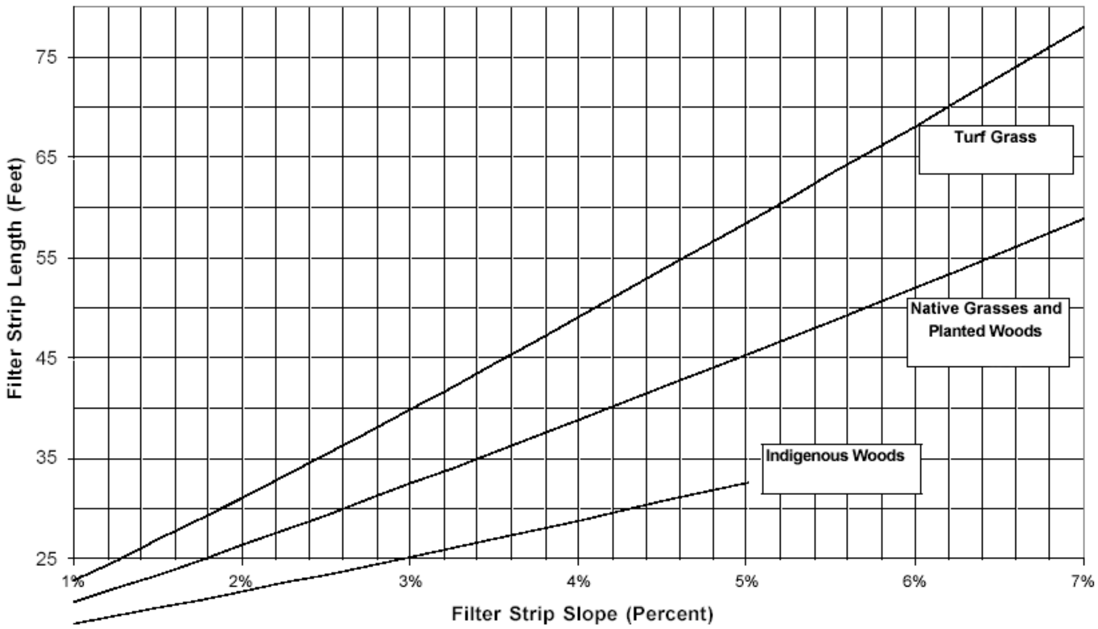


Table 7.15
Recommended Length as a Function of Slope, Soil Cover

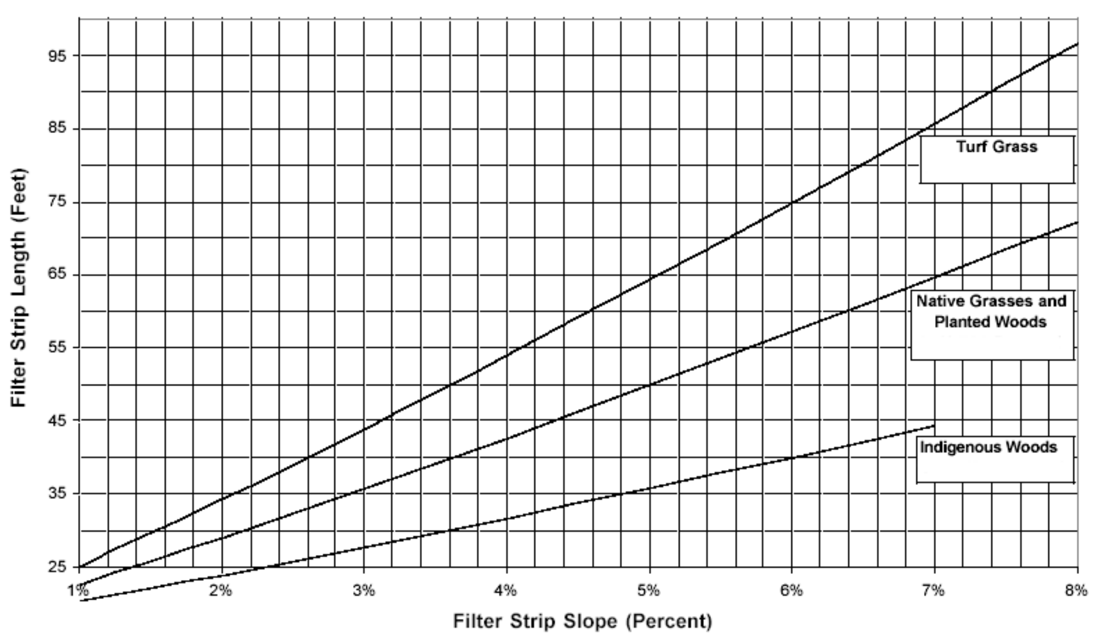
		Maximum Filter Strip Slope (Percent)	
Filter Strip Soil Type	**Hydrologic Soil Group**	**Turf Grass, Native Grasses and Meadows**	**Planted and Indigenous Woods**
Sand	A	7	5
Sandy Loam	B	8	7
Loam, Silt Loam	B	8	8
Sandy Clay Loam	C	8	8
Clay Loam, Silty Clay, Clay	D	8	8

Figure 7.52
Sandy soils with HSG Group A



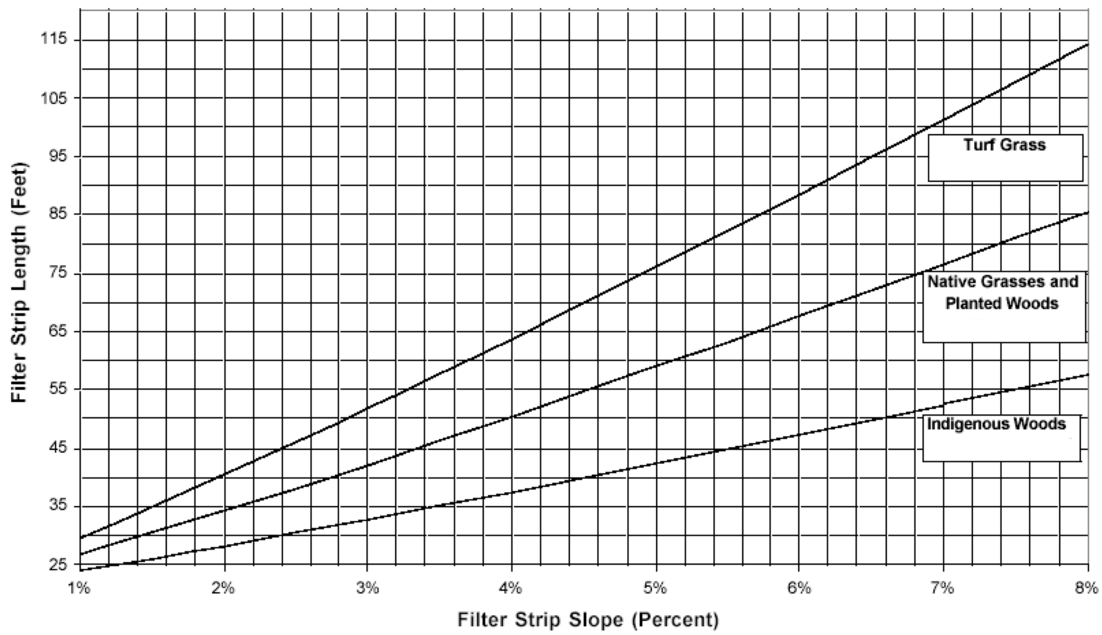
Source: New Jersey Stormwater Best Management Practices Manual; February 2004

Figure 7.53
Sandy Loam soils with HSG Group B



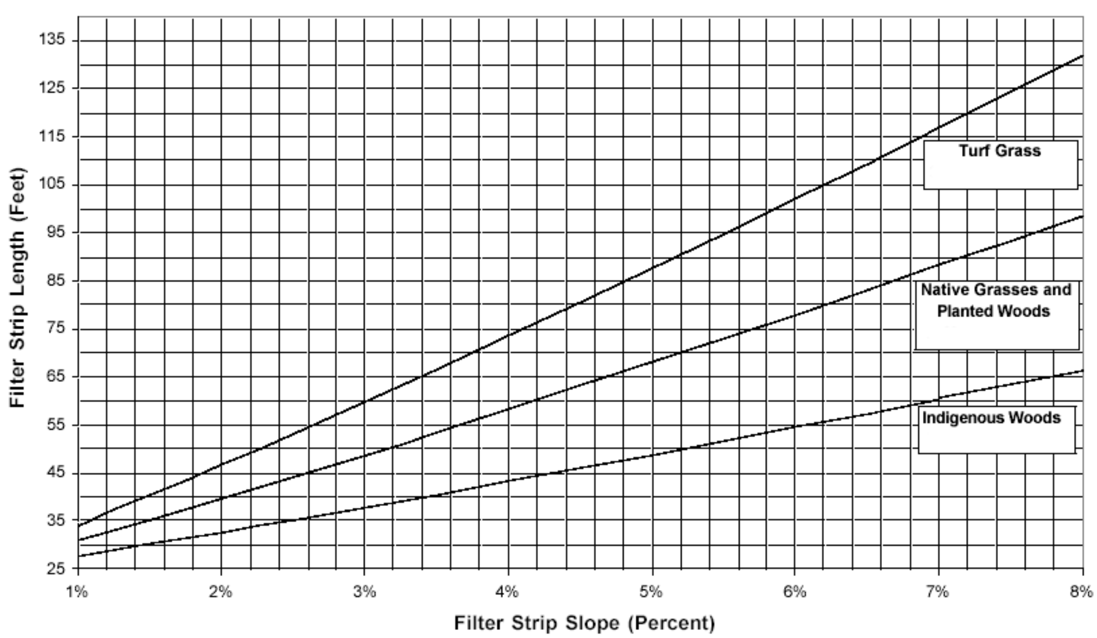
Source: New Jersey Stormwater Best Management Practices Manual, February 2004

Figure 7.54
Loam, Silt-Loam soils with HSG Group B



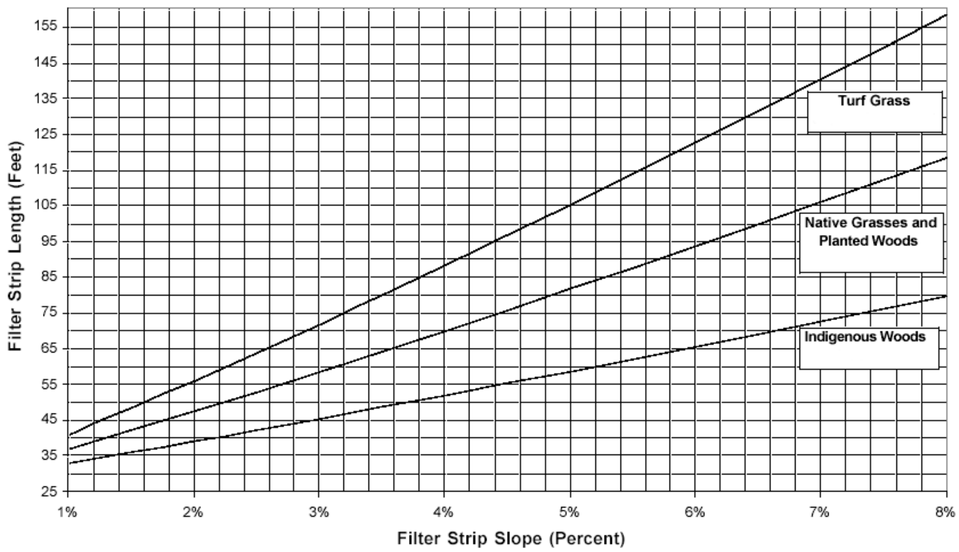
Source: New Jersey Stormwater Best Management Practices Manual; February 2004

Figure 7.55
Sandy Clay Loam soils with HSG Group C



Source: New Jersey Stormwater Best Management Practices Manual, February 2004

Figure 7.56
Clay Loam, Silty Clay or Clay soils with HSG Group D



Source: New Jersey Stormwater Best Management Practices Manual; February 2004

Stormwater Functions and Calculations

Volume reduction

Although not typically considered a volume-reducing BMP, vegetated filter strips can achieve some volume reduction through infiltration and evapotranspiration, especially during small storms (storms less than approximately one inch). The volume reduction benefit of a filter strip can be estimated through hydrologic calculations. Two recommended methods are weighting the curve number of the drainage area with that of the filter strip (see Chapter 9) or routing the runoff from the drainage area onto the filter strip area as inflow in addition to incident precipitation.

Large areas with dense vegetation may absorb unconcentrated flows that result from small storms, while areas covered by turf grass will absorb limited runoff. If a berm is constructed at the down-gradient end of the filter strip, an additional volume will be detained and may infiltrate the underlying soil.

Peak rate mitigation

Vegetated filter strips do not substantially reduce the peak rate of discharge. However, if a volume reduction is achieved through infiltration and evapotranspiration, a related reduction in peak rate will occur. If a berm is constructed at the down-gradient end of the filter strip, the rate of release of the detained volume may be controlled by an outlet structure.

Water quality improvement

Water quality benefits of vegetated filter strips are medium to high. The amount of benefit is based on flow characteristics and nutrient, sediment, and pollutant loadings of the runoff, as well as the length, slope, type, and density of vegetation in the filter strip.

Studies have shown 85 to 90 percent reductions in TSS and 40 to 65 percent reductions in nitrates (NO_2) from runoff being treated by vegetated filter strips. In these studies, the vegetated filter strips were between 25 and 29 feet wide with mild (0.7 percent to 1.7 percent) slopes, with grass and mixed vegetation.

Other studies have shown that suspended solids and metals are reduced to steady state amounts within several meters of the edge of the filter strip. (Note: If a filter strip is used for temporary sediment control, it should be regraded and reseeded immediately after construction and stabilization has occurred.)

Construction Guidelines

1. Follow the recommendations for materials in Appendix D.
2. Begin filter strip construction only when the up-gradient site has been sufficiently stabilized and temporary erosion and sediment control measures are in place. The strip should be installed 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.
3. For non-indigenous filter strips, clear and grade site as needed. Care should be taken to disturb as little existing vegetation as possible, whether in the designated filter strip area or in adjacent areas, and to avoid soil compaction. Grading a level slope may require removing existing vegetation.
4. Grade the filter strip area, including the berm at the toe of the slope. Pressure applied by construction equipment should be limited to four pounds per square inch to avoid excessive compaction or land disturbance.
5. Construct level spreader device at the upgradient edge of the filter strip. For gravel trenches, do not compact the subgrade. (Follow construction sequence for Infiltration Trench.)
6. Fine grade the filter strip area. Accurate grading is crucial for filter strips. Even the smallest irregularities may compromise sheet flow conditions.
7. Seed, sod, or plant more substantial vegetation, as proposed. If sod is proposed, place tiles tightly to avoid gaps, and stagger the ends to prevent channelization along the strip. Use a roller on sod to prevent air pockets from forming between the sod and soil.
8. Stabilize seeded filter strips with appropriate permanent soil stabilization methods, such as erosion control matting or blankets. Erosion control for seeded filter strips should be required for at least the first 75 days following the first storm event of the season.
9. Once the filter strip is sufficiently stabilized after one full growing season, remove temporary erosion and sediment controls.

Maintenance

As with other vegetated BMPs, filter strips must be properly maintained to ensure their effectiveness. In particular, it is critical that sheet flow conditions are sustained throughout the life of the filter strip. Field observations of strips in urban settings show that their effectiveness can deteriorate due to lack of maintenance, inadequate design or location, and poor vegetative cover. Compared with other vegetated BMPs, filter strips require only minimal maintenance efforts, many of which may overlap with standard landscaping demands.

- Inspect sediment devices quarterly for clogging, excessive accumulations, and channelization for the first two years following installation, and then twice a year thereafter. Inspections should also be made after every storm event greater than one inch during the establishment period.
- Sediment and debris should be removed when buildup exceeds two inches in depth in either the filter strip or the level spreader. Improve the level spreader if erosion is observed. Rills and gullies observed along the strip may be filled with topsoil, stabilized with erosion control matting, and either seeded or sodded. For channels less than 12 inches wide, filling with crushed gravel, which allows grass to creep in over time, is acceptable. For wider channels (greater than 12 inches), regrading and reseeding may be necessary. Small bare areas may only require overseeding. Regrading may also be required when pools of standing water are observed along the slope. In no case should standing water be tolerated for longer than 48 to 72 hours.
- If check dams are proposed, inspect for cracks, rot, structural damage, obstructions, or any other factors that cause altered flow patterns or channelization. Inlets or sediment sumps that drain to filter strips should be cleaned periodically or as needed.
- Remove sediment when the filter strip is thoroughly dry. Dispose of sediment and debris at a suitable disposal or recycling site that complies with applicable local, state, and federal waste regulations.
- When a filter strip is used for sediment control, it should be regraded and reseeded immediately after construction.

- Guidance information, usually in written manual form, for operating and maintaining filter strips, should be provided to all facility owners and tenants. Facility owners are encouraged to keep an inspection log, for recording all inspection dates, observations, and maintenance activities.
- Grass cover should be mowed to maintain a height of 4-6 inches.
- Invasive plants should be removed on an annual basis. Vegetative cover should be sustained at 85 percent and reestablished if damage greater than 50 percent is observed.
- If a filter strip exhibits signs of poor drainage, periodic soil aeration or liming may help to improve infiltration.

Winter Considerations

Filter strips often make convenient areas for snow storage. Thus, vegetation should be salt-tolerant and the maintenance schedule should include removing sand buildup at the toe of the slope.

The bottom of the gravel trench (if used as the level spreader) should be placed below the frost line to prohibit water from freezing in the trench. The perforated pipe in the trench should be at least eight inches in diameter to further discourage freezing.

Other water quality options may be explored to provide backup to filter strips during the winter, when pollutant removal ability is reduced.

Cost

The cost of constructing filter strips includes grading, sodding (when applicable), installing vegetation, constructing a level spreader, and constructing a pervious berm, if proposed. Depending on whether seed or sod is applied, enhanced vegetation use or design variations such as check dams, construction costs may range anywhere from no cost (assuming the area was to be grassed regardless of use as treatment) to $50,000 per acre. The annual cost of maintaining filter strips (mowing, weeding, inspecting, litter removal, etc.) generally runs from $100 to $1,400 per acre and may overlap with standard landscape maintenance costs. Maintenance costs are highly variable, as they are a function of frequency and local labor rates.

Designer/Reviewer Checklist for Vegetated Filter Strips

Soil type and HSG category: ______________________________

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 during construction?				
Maintenance accounted for and plan provided?				

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BMP Fact Sheet

Vegetated Roof

Vegetated roofs, or green roofs, are conventional rooftops that include a thin covering of vegetation allowing the roof to function more like a vegetated surface. The overall thickness of the vegetated roof may range from 2 to 6 inches, typically containing multiple layers consisting of waterproofing, synthetic insulation, non-soil engineered growth media, fabrics, synthetic components, and foliage.

Green roof with sedum at Lawrence Technological University's Taubman Student Services Center

Source: Lawrence Technological University

Applications		Stormwater Quantity Functions	
Residential	Limited	**Volume**	Med/High
Commercial	Yes	**Groundwater Recharge**	Low*
Ultra Urban	Yes	**Peak Rate**	Medium
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	Medium
Highway/Road	N/A	**TP**	Medium
Recreational	Yes	**TN**	Medium
		Temperature	High

Additional Considerations	
Cost	High
Maintenance	Medium
Winter Performance	Medium

Variations
- Intensive
- Semi-intensive
- Extensive

Key Design Features
- Extensive roofs are most commonly used for rainfall runoff mitigation
- Roofs with pitches steeper than 2:12 (9.5 degrees) must incorporate supplemental measures

Benefits
- Good stormwater volume control
- Heating and cooling energy benefits
- Increased lifespan of roof
- Heat island reduction
- Enhance habitat value

Limitations
- Cost (intensive systems)
- Careful design and construction required
- Maintenance requirements until plants established
- Can't store or treat stormwater from other parts of the property

* Although vegetated roofs can be used very successfully in combination with infiltration systems.

Case Study: City of Battle Creek City Hall Runoff Project

City of Battle Creek, MI

The City of Battle Creek City Hall Runoff Project was designed to treat stormwater runoff from a municipal complex adjacent to the Battle Creek River, a tributary of the Kalamazoo River. The goal of the project was to treat one-half inch of rainstorm runoff by incorporating several best management techniques (BMPs) that promote infiltration and low impact development. The BMPs included a vegetated roof system on the Police Department roof; infiltration of runoff water from the impervious walkway in front of the Police Department building; and infiltration from the parking lots behind and adjacent to City Hall and the Police Department buildings.

Green roof on City of Battle Creek Police Department building
Source: City of Battle Creek

The green roof is primarily an extensive system with the exception of a band around the perimeter of the roof which is intensive. The load reductions on the roof have been revised to accommodate the additional system. The City of Battle Creek is responsible for the light maintenance needed for the vegetated roof. Keeping the native plants, mainly sedum, properly watered during establishment did pose a challenge. Replanting was required in some areas.

Case Study Site Considerations	
Project Type	Extensive Green Roof
Estimated Total Project Cost	$520,252 for roof reconstruction plus green roof; green roof materials alone were $121,635
Maintenance Responsibility	City of Battle Creek
Project Contact	Christine Kosmowski, 269-966-0712

Estimated Annual Pollutant Load Reductions:

- Sediment – 3.8 tons
- Nitrogen – 101 lbs.
- Phosphorous – 16 lbs.
- Volume – 68 percent

Another goal of the City of Battle Creek City Hall Runoff Project was to increase community awareness of low impact development techniques and their water quality protection benefits. The City is promoting the area as a demonstration site for local builders and homeowners.

Description and Function

Vegetated roofs involve growing plants on rooftops, thus replacing the vegetated footprint that was removed when the building was constructed. Vegetated roof covers are an "at source" measure for reducing the rate and volume of runoff released during rainfall events. The water retention and detention properties of vegetated roof covers can be enhanced through selection of the engineered media and plants. Depending on the plant material and planned usage for the roof area, modern vegetated roofs can be categorized as systems that are intensive, semi-intensive, or extensive (Table 7.16).

Intensive vegetated roofs utilize a wide variety of plant species that may include trees and shrubs, require deeper substrate layers (usually > four inches), are generally limited to flat roofs, require 'intense' maintenance, and are often park-like areas accessible to the general public.

Extensive vegetated roofs are limited to herbs, grasses, mosses, and drought tolerant succulents such as sedum, can be sustained in a shallow substrate layer (<four inches), require minimal maintenance once established, and are generally not designed for access by the public. These vegetated roofs are typically intended to achieve a specific environmental benefit, such as rainfall runoff mitigation. Extensive roofs are well suited to rooftops with little load bearing capacity and sites which are not meant to be used as roof gardens. The mineral substrate layer, containing little nutrients, is not very deep but suitable for less demanding and low-growing plant communities.

Semi-intensive vegetated roofs fall between intensive and extensive vegetated roof systems. More maintenance, higher costs and more weight are the characteristics for this intermediate system compared to that of the extensive vegetated roof.

Vegetated system layers

A proprietary system provides a growing environment on the roof which adequately compensates for the plant's natural environment. It ensures reliable technical and ecological functionality for decades. Vegetated roof systems contain the following functional layers (from bottom to top):

Root barrier: The root barrier protects the roof construction from being damaged by roots. If the waterproofing is not root resistant a separate root barrier has to be installed.

Extensive vegetated roof at Kresge Foundation Headquarters in Troy, MI

Source: Conservation Design Forum

Waterproof membrane: This layer protects the roof structure from moisture and can include a unique root-resistant compound to prevent roots from penetrating.

Protection layer: A specially designed perforation resistant protection mat prevents mechanical damage of the root barrier and roof construction during the installation phase. Depending on the thickness and the material the protection layer can also retain water and nutrients.

Drainage Layer: The drainage layer allows for excess water to run-off into the water outlets. Depending on the design and the material the drainage layer has additional functions such as water storage, enlargement of the root zone, space for aeration of the system and protection for the layers below it. Due to the weight constraints of the roof, the drainage layer is made of light-weight materials. Molded drainage elements made of rubber or plastic are used quite often. Other drainage layers are made of gravel, lava, expanded clay or clay tiles.

Filter layer: The filter layer separates the plant and substrate layers from the drainage layer below. Especially small particles, humic and organic materials, are retained by the filter sheet and are therefore available for the plants. In addition, the filter sheet ensures that the drainage layer and the water outlet are not clogged with silt. Filter layers are preferably made of geo-textiles such as fleece or other woven materials.

Table 7.16
Vegetated roof types

	Extensive Vegetated Roof	Semi-Intensive Vegetated Roof	Intensive Vegetated Roof
Maintenance	Low	Periodically	High
Irrigation (after plants are established)*	No	Periodically	Regularly
Plant Communities	Moss, Sedum, Herbs, and Grasses	Grass, Herbs, and Shrubs	Perennials, Shrubs, and Trees
System build-up height	60-200 mm	120-250 mm	150-400 mm Underground garages = > 1000 mm
Weight	60 - 150 kg/m2 13-30 lbs/sqft	120 - 200 kg/m2 25-40 lbs/sqft	180 - 500 kg/m2 35-100 lbs/sqft
Construction costs	Low	Medium	High
Desired use	Ecological protection layer	Designed vegetated roof	Park-like garden

*Irrigation is required regularly to establish plant communities, especially during the first season.

Source: Adapted from International Green Roof Association

Growing medium: The growing medium is the basis of the vegetated roof. A sufficient depth for the root zone has to be ensured as well as an adequate nutrient supply and a well balanced water-air relation. Depending on the type of vegetated roof and the construction requirements, a variety of different system substrates are available.

Light-weight mineral materials, with high water retention capacity and good water permeability, such as lava, pumice, expanded clay, expanded schist, and clay tiles, have proven to be reliable for many years. Untreated organic material and top soil have disadvantages in terms of weight and drainage function; they are only used as additions to mineral substrates.

Plant level: The plant selection depends on the growing medium as well as local conditions, available maintenance and the desired appearance. Low maintenance, durable and drought resistant plants are used for extensive vegetated roofs, versus, a nearly limitless plant selection for intensive vegetated roofs.

Variations

Some specialized vegetated roof companies offer installation using vegetated blankets/mats or trays. Pre-vegetated blankets/mats are grown off-site and brought to the site for installation (similar to the concept of sod for grass). They can provide an immediate vegetative coverage which can prevent erosion, reduce installation times, and reduce maintenance during what would otherwise be the establishment period for vegetation.

Frasier School District is testing both the tray system (foreground) and mat system (background} on their operations and maintenance building.

Modular systems are manufactured trays filled with various vegetated roof layers (often pre-vegetated as well) that are delivered to the site and installed on a prepared roof. Manufacturers of these systems claim that benefits include faster installation and easier access to the roof if maintenance or leak repairs are necessary (in addition to the potential benefits of a pre-vegetated system). Others argue that these benefits are not significant and that trays can have drawbacks such as increased cost, poor aesthetics (module edges being visible), and reduced performance (wet and dry spots resulting from the barriers between modules in the system).

Extensive vegetated roofs

Extensive vegetated roofs are the most commonly used systems due to their higher mitigation of stormwater runoff as well as their lower cost compared to the other systems. Extensive systems have three variations of assemblies that can be considered in design.

Single media assemblies

Single media assemblies (Figure 7.57) are commonly used for pitched roof applications and for thin and lightweight installations. These systems typically incorporate very drought tolerant plants and utilize coarse engineered media with high permeability. A typical profile would include the following layers:

1. Waterproofing membrane
2. Protection layer
3. Root barrier (optional, depending on the root-fastness of the waterproofing)

Installation of green roof at the Ford Rouge Plant in Dearborn, MI

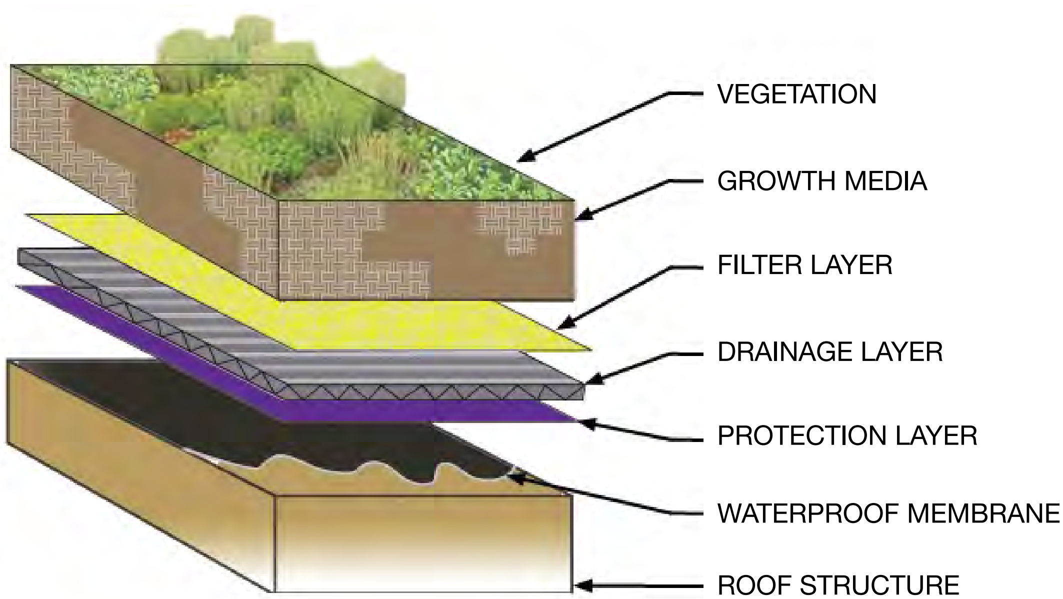
Source: Rouge River National Wet Weather Demonstration Project

4. Drainage layer
5. Filter layer
6. Growth media
7. Vegetation

Pitched roof applications may require the addition of slope bars, rigid slope stabilization panels, cribbing, reinforcing mesh, or similar method of preventing sliding instability.

Flat roof applications with mats as foundations typically require a network of perforated internal drainage conduit to enhance drainage of percolated rainfall to the deck drains or scuppers.

Figure 7.57
Single media assembly



Dual media assemblies
Dual media (Figure 7.58) assemblies utilize two types of non-soil growth media. In this case a finer-grained media with some organic content is placed over a base layer of coarse lightweight mineral aggregate. They do not include a geocomposite drain.

The objective is to improve drought resistance by replicating a natural alpine growing environment in which sandy topsoil overlies gravelly subsoil. These assemblies are typically 4 to 6 inches thick and include the following layers:

1. Waterproofing membrane
2. Root barrier/ protection layer
3. Coarse-grained drainage media
4. Filter layer
5. Growth media
6. Vegetation

These assemblies are suitable for roofs with pitches less than, or equal to about 1.5:12 (7.1 degrees). Large vegetated covers will generally incorporate a network of perforated internal drainage conduit located within the coarse grained drainage layer.

Dual media with synthetic retention/detention layer
These assemblies introduce impervious plastic panels with cup-like receptacles on their upper surface (i.e., a modified geocomposite drain sheet). The panels are in-filled with coarse lightweight mineral aggregate. The cups trap and retain water. They also introduce an air layer at the bottom of the assembly. A typical profile would include:

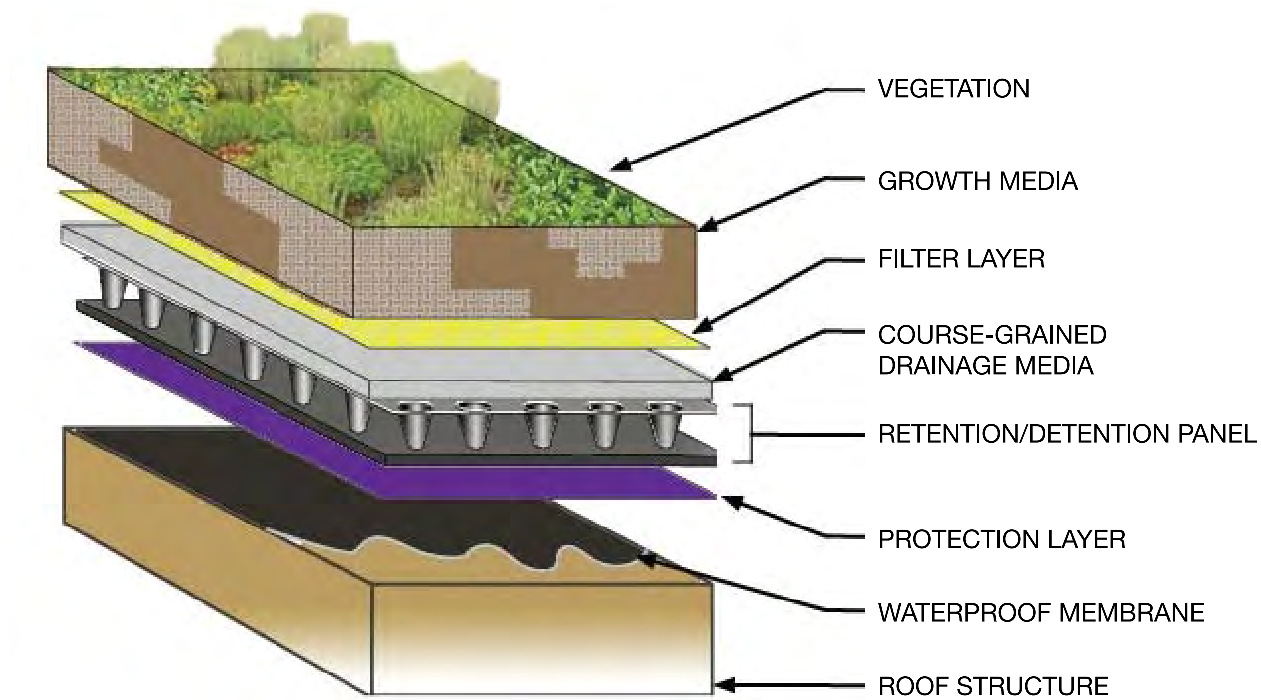
1. Waterproof membrane
2. Protection layer
3. Retention/detention panel
4. Coarse-grained drainage media
5. Filter layer
6. Growth media
7. Vegetation

These assemblies are suitable on roof with pitches less than or equal to 1:12 (4.8 degrees). Due to their complexity, these systems are usually a minimum of five inches deep. If required, irrigation can be provided via surface spray or mid-level drip.

Treatment Train

Vegetated roof covers are frequently combined with ground infiltration measures. This combination can be extremely effective for stormwater management and is one of the best ways to replicate the natural hydrologic cycle. Vegetated roofs evapotranspirate a significant fraction of annual rainfall and typically discharge larger

Figure 7.58
Dual media assembly



storm events relatively slowly. If overflow is directed to an infiltration system, the discharge can be infiltrated efficiently as the system has more time to absorb water as it is slowly released from the roof. Vegetated roof covers improve the efficiency of infiltration devices by:

- Reducing the peak runoff rate,
- Prolonging the runoff, and
- Filtering runoff to produce a cleaner effluent.

Benefits

Establishing plant material on rooftops provides numerous ecological and economic benefits including stormwater management, energy conservation, mitigation of the urban heat island effect, increased longevity of roofing membranes, as well as providing a more aesthetically pleasing environment to work and live. A major benefit of green roofs is their ability to absorb stormwater and release it slowly over a period of several hours, retaining 60-100 percent of the stormwater they receive, depending on the duration and the intensity of the storm.

In addition, green roofs have a longer life-span than standard roofs because they are protected from ultraviolet radiation and the extreme fluctuations in temperature that cause roof membranes to deteriorate. A vegetated roof has a life expectancy of 60 years — three times as long as a traditional roof.

As pervious surfaces are replaced with impervious surfaces due to urban development, the need to recover green space is becoming increasingly critical for the health of our environment. Vegetated roof covers have been used to create functional meadows and wetlands to mitigate the development of open space. This can be accomplished with assemblies as thin as six inches.

Design Considerations

Roof substructure

Wooden constructions, metal sheeting as well as reinforced concrete decks can be considered as appropriate roof substructures. The base for the vegetated roof is a waterproof roof construction with appropriate load bearing capacity.

Root barrier

Root barriers should be thermoplastic membranes with a thickness of at least 30 mils. Thermoplastic sheets can be bonded using hot-air fusion methods, rendering the seams safe from root penetration. Membranes that have been certified for use as root-barriers are recommended.

Green roof at the Ford Rouge Plant in Dearborn, MI

Recognized in 2004 by Guinness World Records as the largest green roof in the world, this green roof covers 454,000 square feet atop Ford's truck assembly plant in Dearborn, MI. The green roof is part of a comprehensive effort to revitalize the historic Ford Rouge complex as a model for 21st Century sustainable manufacturing and is a significant component of a site-wide 600-acre stormwater management system.

Over a period of time roots can damage the waterproofing and roof construction if there have been no corresponding protection measures taken. The root resistance of the waterproofing is determined from the "Procedure for investigating resistance to root penetration at green-roof sites" by the FLL (The Landscaping and Landscape Development Research Society). Over 70 different waterproofing products meet the requirements of this test. If the waterproofing is not root resistant, an additional root barrier has to be installed. Aside from the roof surface, the upstands, perimeters, joints and roof edges also have to be protected against root penetration.

Growth media

Growth media should be a soil-like mixture containing not more than 15 percent organic content. The appropriate grain-size distribution is essential for achieving the proper moisture content, permeability, nutrient management, and non-capillary porosity, and 'soil' structure. The grain-size guidelines vary for single and dual media vegetated cover assemblies.

Blowing media onto Mallet's Creek Library Roof, Ann Arbor, MI
Source: Mallet's Creek Library, Ann Arbor, MI

Separation fabric

Separation fabric should be readily penetrated by roots, but provide a durable separation between the drainage and growth media layers. (Only lightweight nonwoven geotextiles are recommended for this function.)

Roof penetrations

For vegetated roofs, the following upstand and perimeter heights have to be considered:

- Upstand height for adjacent building parts and penetrations: minimum of six inches.
- Upstand height for roof edges: minimum of four inches.

> Even though it is possible to build pitched green roofs with a slope of 45° it is not recommended to exceed 10° due to significant limited accessibility for upkeep and maintenance.

Important: The upstand height is always measured from the upper surface of the vegetated roof system build up or gravel strip. Clamping profiles guarantee reliable protection and a tight connection of the upstand areas. Roof penetrations (e.g. water connections, building parts for the usage of the roof area, etc.), when possible, should be grouped in order to keep roof penetration to a minimum.

Roof slope

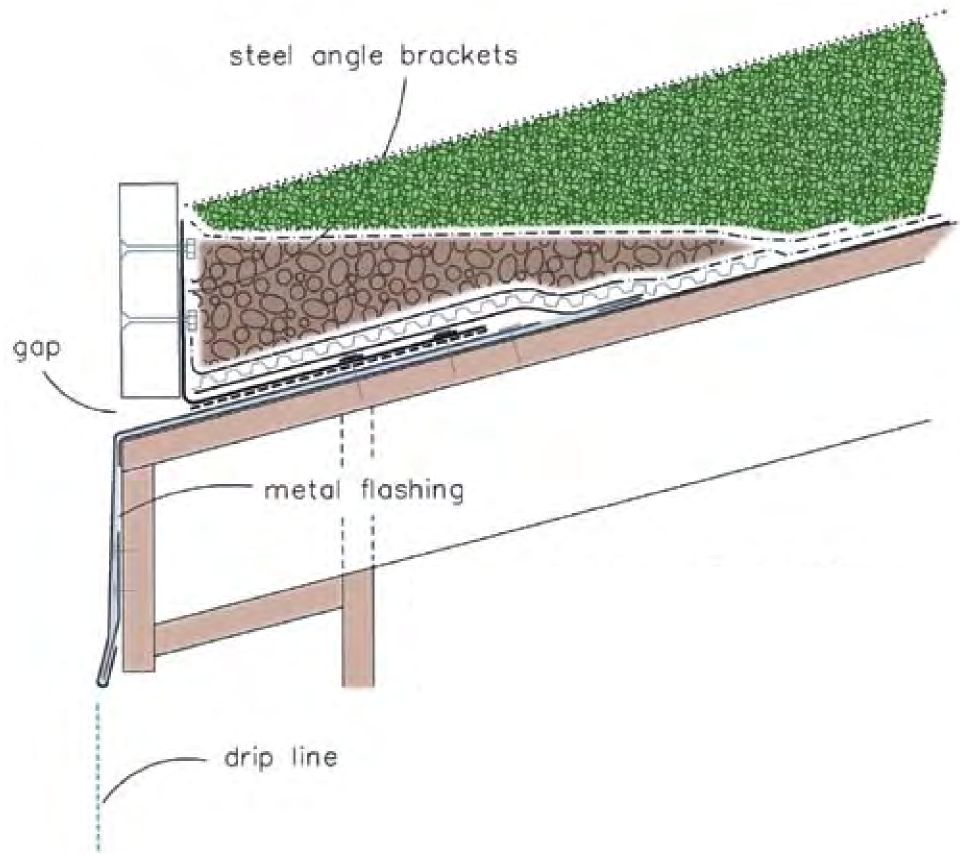
Using modern technologies it is possible to install a reliable vegetated roof system not only on conventional flat roofs, but also on saddle roofs, shed roofs and barrel roofs. Special technical precautions for the mitigation of existing shear forces and erosion are only necessary for a roof slope over 10°.

Roofs with a slope of more than 45° are normally not suitable for a vegetated roof system. Roofs with a slope of less than two percent are special roof constructions on which puddles often develop.

In order to avoid damage to extensive vegetated roofs by water retention, specific arrangements for the roof drainage are necessary. In contrast, it can be beneficial for intensive vegetated roofs to design the roof construction without slope to allow for dam up irrigation.

Load calculations

The maximum load bearing capacity of the roof construction must be considered when installing vegetated roofs. Therefore, the water saturated weight of



Example eave detail for sloped roof
Source: Roofscapes, Inc.

the green roof system, including vegetation must be calculated as permanent load. Extensive vegetated roofs weigh between 60-150 kg/m2 (13.0-30.0 lb/sq.ft.) depending on the thickness of the vegetated roof system build-up. Trees, shrubs, and construction elements such as pergolas and walkways cause high point loads and, therefore, have to be calculated accordingly.

Wind uplift

A vegetated roof must be tight to the roof, especially in cases of strong wind. When designing and installing the vegetated roof, safety measures against wind uplift are to be considered.

This is especially important when the vegetated roof provides the load for a loose laid waterproofing and root barrier. The actual influence from the wind depends on the local wind zone, height of the building, roof type, slope, and area (whether corner, middle or edge) and the substructure.

Roof drainage

Vegetated roof systems store a major part of the annual precipitation and release it to the atmosphere by transpiration. Depending on the thickness of the vegetated roof system build-up and rain intensity, surplus water may accumulate at certain times and must be drained off the roof area. The number of roof outlets and the penetrability factor, or more precisely, the water retaining capacity of the vegetated roof system build-up, has to be adjusted to the average local precipitation.

Roof outlets are to be kept free of substrate and vegetation and have to be controllable at all times. For this purpose "inspection chambers" are installed over the roof outlets. Due to safety precautions, roof areas with inlayed drainage must always have two drainage outlets or one outlet and one safety overflow. For facades and roof areas, gravel strips, gullies and grids provide fast drainage of rainwater into the drainage system.

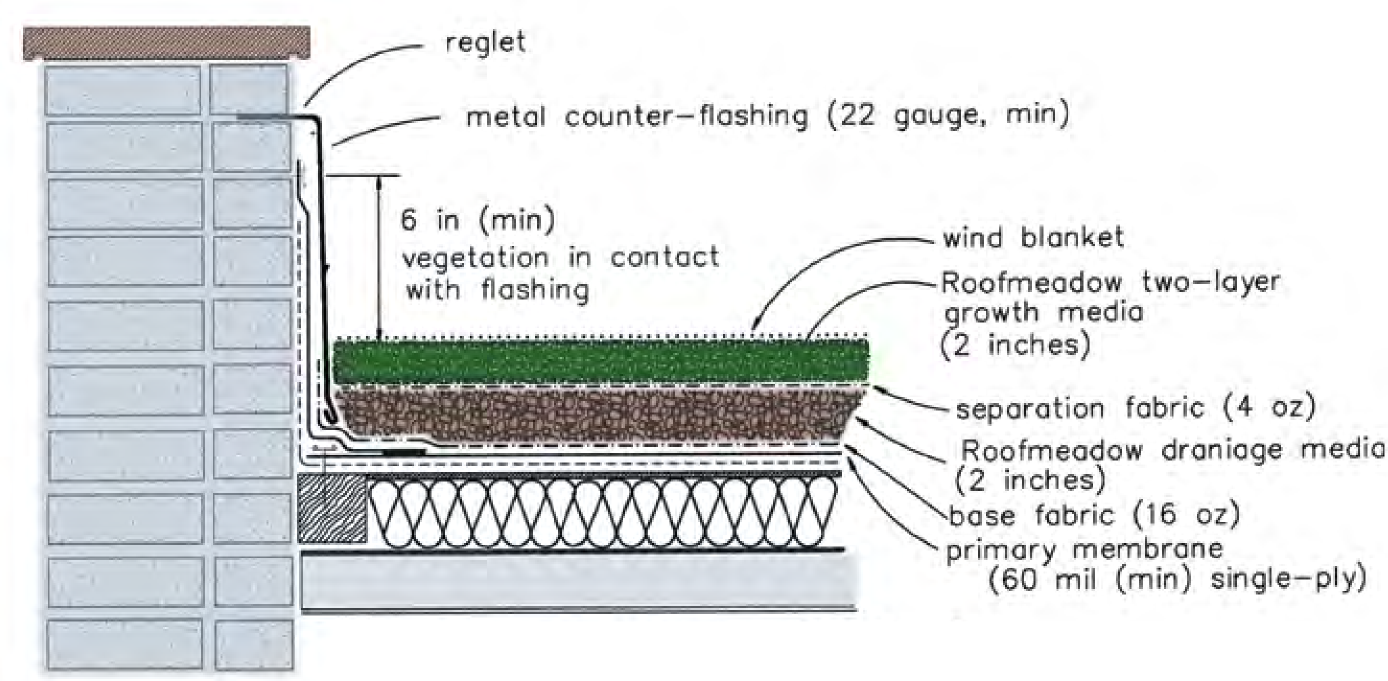
Pitched Vegetated Roofs

Technical requirements

Root resistant waterproofing is necessary for pitched vegetated roofs; installing an additional root barrier, requires much effort and increases the risk of slippage. Stable abutments have to be installed on the eaves edges to transfer shear forces from the vegetated roof system build-up and the additional snow load into the roof construction. Additional shear barriers may be necessary to transfer the shear forces depending on the roof slope and the roof length. It is recommended the design for the shear barriers and the eaves profiles be done by a structural engineer. With increasing slope, the vegetated roof system build-up is more complicated and the substrate has to be protected from erosion; plastic grid elements can be used for this purpose.

Plant selection

The success of the landscaping on pitched roofs depends on the plants. Fast surface coverage is the highest priority. A dense planting of root ball plants or pre-cultivated vegetation mats are used in cases of steep slopes and allow for rapid coverage. It is also important to consider the exposure of the roof area, the slope and the location of the building when selecting plants. Perennials and grasses can be used whereas Sedum is the most suitable for pitched roofs, due to the species' high water retention capacity and erosion protection. The water run-off is much faster on pitched roofs compared to a flat roof. It is advisable to plan for an additional irrigation system to provide water during dry periods. The irrigation can be provided either by drip irrigation or by sprinkler systems.



Example parapet flashing detail for a flat roof
Source: Roofscapes, Inc.

Irrigation

Extensive vegetated roofs with drought resistant plant species have to be irrigated only during planting and installation maintenance over the first two years. After its establishment, the annual rainfall is sufficient to sustain the vegetation. In contrast, the requirements are more involved for intensive vegetated roofs with lawn, shrubs, or trees. An adequate number of precisely dimensioned hoses with automatic irrigation units make plant maintenance during drought periods more manageable. The water supply for roof gardens with no slope can be increased through additional dam-up irrigation. Vegetated roofs can also be irrigated with cistern water.

Fire prevention

As a part of the "hard roof" classification, intensive vegetated roofs provide preventative fire protection in the case of sparks and radiating heat. The criteria that extensive vegetated roofs must meet in order to be considered fire resistant, are already met by most vegetated roof systems that are offered by suppliers. Openings within the vegetated roof (e.g. skylights) need to be installed with a vegetation free zone (approx. 20 in). On larger roof areas a vegetation free zone (e.g. gravel strip or concrete slabs) are to be installed at least every 130 feet.

Vegetation Considerations

Extensive vegetated roofs

Plants for extensive vegetated roofs have to survive intense solar radiation, wind exposure, drought, low nutrient supply, freezing temperatures and limited root area. Suitable plant varieties are those growing in severe locations with little moisture and nutrient supply, such as dry meadows. The main varieties are sedum, and delosperma. The plants are able to store high amounts of water in the leaves, are stress resistant and recover easily from periods of drought. Other varieties such as dianthus species, asteraceae and ornamental grasses are also suitable for these conditions.

Plugs prior to planting extensive vegetated roof

Source: Mallet's Creek Library, Ann Arbor, MI

Intensive green roofs

Having an appropriate vegetated roof system and sufficient growing medium (with higher root penetration volume, nutrients and water supply) growth of sophisticated plant varieties on the roof is possible. The selected plants need to be resistant to intense solar radiation and strong winds. Vegetation with various plant varieties such as perennials, herbs, grasses and trees allow for a natural character on the roof. Having a broader plant community increases the amount of maintenance required.

Conventional roof prior to retrofit

Extensive vegetated roof cover retrofit incorporating a patio for viewing

Stormwater Functions and Calculations

The performance of vegetated roof covers as stormwater best management practices cannot be represented by simple algebraic expressions used for surface runoff. In the analysis of vegetated roof covers, the water that is discharged from the roof is not surface runoff, but rather underflow, i.e., percolated water. The rate and quantity of water released during a particular storm can be predicted based on knowledge of key physical properties, including:

- Maximum media water retention
- Field capacity
- Plant cover type
- Saturated hydraulic conductivity
- Non-capillary porosity

The maximum media water retention is the maximum quantity of water that can be held against gravity under drained conditions. Standards that have been developed specifically for measuring this quantity in roof media are available from FLL and ASTM (E2399).

Conventional runoff coefficients, such as the NRCS **runoff curve number**, CN, can be back-calculated from computer simulation or measurements of vegetated roof cover assemblies. However, these coefficients will only apply for the specific design storm for which they have been determined.

Volume reduction

All vegetated roof covers have both a retention and a detention volume component. Benchmarks for these volumes can be developed from the physical properties described above.

Peak rate mitigation

Vegetated roof covers can exert a large influence on peak rate, especially in less extreme storms such as the 1-, 2-, and 5-year storms. Because volume is reduced, there is some peak rate reduction achieved for all storms. An evaluation of peak runoff rates requires either computer simulation or measurements made using prototype assemblies.

A general rule for vegetated roof covers is that rate of runoff from the covered roof surface will be less than or equal to that of open space (i.e., NRCS curve number of about 65) for storm events with total rainfall volumes up to three times the maximum media water retention of the assembly. For example, a representative vegetated roof cover with maximum moisture retention of one inch will react like open space for storms up to and including the three-inch magnitude storm.

Using computer simulations, municipalities could generate a table of CN values for specific design storms and green roof types. The table would relate maximum moisture capacity to the CN coefficients

Water quality improvement

Direct runoff from roofs is a contributor to pollutants in stormwater runoff. Vegetated roof covers can significantly reduce this source of pollution. Assemblies intended to produce water quality benefits will employ engineered media with almost 100 percent mineral content. Furthermore, following the plant establishment period (usually about 18 months), on-going fertilization of the cover is no longer needed. Experience indicates that it may take five or more years for a water quality vegetated cover to attain its maximum pollutant removal efficiency.

Dam-up Irrigation in Vegetated Roof

Intensive Vegetated Roofs depend mainly on additional irrigation. To install an irrigation system which does not use fresh water, a water dam-up irrigation unit is recommended.

Requirements of a dam-up irrigation unit:

- flat roof
- dam-up elements above roof outlets
- an appropriate drainage layer with the necessary height

In case of heavy rain the reservoir is filled primarily and any excess water is collected in the cistern. During dry periods the water on the roof is used first, then water is pumped from the cistern onto the roof and supplied to the plants.

This process can be carried out either manually or electronically. The water in the cistern can also be used for other purposes, provided the reservoir is big enough.

Maintenance

- Irrigation will be required as necessary during the plant establishment period and in times of drought.
- During the plant establishment period, three to four visits to conduct basic weeding, fertilization, and infill planting is recommended.
- The soluble nitrogen content (nitrate plus ammonium ion) of the soil should be adjusted to between one and five parts per million, based on soil test.
- Once plants are established, it is crucial to maintain the roof once or twice a year. Weeds and other unwanted plants on the entire roof, at the perimeters and at the upstands need to be removed. For grass and herb vegetation the organic buildup has to be removed once a year. Intensive vegetated roofs require higher maintenance and service throughout the year.

Winter Considerations

Applicable snow load must be considered in the design of the roof structure.

Cost

The construction cost of vegetated roof covers varies greatly, depending on factors such as:

- Height of the building
- Accessibility to the structure by large equipment such as cranes and trailers
- Depth and complexity of the assembly
- Remoteness of the project from sources of material supply
- Size of the project

Active growth on Fraser public school maintenance green roof during winter in Fraser, MI

However, under 2007 market conditions, extensive vegetated covers for roof will typically range between $8 and $16 per square foot, including design, installation, and warranty service (not including waterproofing). Basic maintenance for extensive vegetated covers typically requires about 2-3 person-hours per 1,000 square feet, annually.

Although vegetated roofs are relatively expensive compared to other BMPs in terms of stormwater management, they can have other significant benefits which serve to reduce their life-cycle costs. For example, the longevity of the roof system may be greatly increased. In addition, heating and cooling costs can be significantly reduced.

Designer/Reviewer Checklist for Vegetated Roofs

Type of vegetated roof(s) proposed: ____

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?				
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?				
Plant establishment (temporary irrigation/fertilization) procedures provided?				
Erosion control / wind protection provided?				
Maintenance accounted for and plan provided?				

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BMP Fact Sheet

Vegetated Swale

A vegetated swale (or bioswale) is a shallow stormwater channel that is densely planted with a variety of grasses, shrubs, and/or trees designed to slow, filter, and infiltrate stormwater runoff. Check dams can be used to improve performance and maximize infiltration, especially in steeper areas.

Vegetated swale at the Pokagonek Edawat Housing Development in Dowagiac, MI.
Source: Pokagon Band of Potawatomi Indians

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	Low/Med
Commercial	Yes	**Groundwater Recharge**	Low/Med
Ultra Urban	Limited	**Peak Rate**	Low/Med
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Limited	**TSS**	Med/High
Highway/Road	Yes	**TP**	Low/High
Recreational	Yes	**TN**	Medium
		Temperature	Medium

Additional Considerations	
Cost	Low/Med
Maintenance	Low/Med
Winter Performance	Medium

Variations

- Vegetated swale with infiltration trench
- Linear wetland swale
- Grass swale

Key Design Features

- Handles the 10-year storm event with some freeboard
- Two-year storm flows do not cause erosion
- Maximum size is five acres
- Bottom width of two to eight feet
- Side slopes from 3:1 (H:V) to 5:1
- Longitudinal slope from one to six percent
- Check dams can provide additional storage and infiltration.

Site Factors

- Water table to bedrock depth – two-foot minimum.*
- Soils – A, B preferred; C & D may require an underdrain (see infiltration BMP)
- Slope –one to six percent. (< one percent can be used w/ infiltration)
- Potential hotspots – No
- Maximum drainage area – five acres

Benefits

- Can replace curb and gutter for site drainage and provide significant cost savings
- Water quality
- Peak and volume control with infiltration

Limitations

- Limited application in areas where space is a concern
- Unless designed for infiltration, there is limited peak and volume control

* four feet recommended, if possible.

Case Study: Meadowlake Farms Bioswale

Bloomfield Township, MI

Meadow Lake is a 50-acre lake in a residential area in Bloomfield Township. It is tributary to the Franklin Branch of the Rouge River. A 30-inch storm sewer serves a large area north of the lake and discharges into the lake via the roadside ditch at its north end. The storm sewer carries runoff from residential and commercial areas as well as a golf course and a school. Historically, the stormwater discharged from the sewer has been a source of significant amounts of sediment, nutrients, and other pollutants. The discharges have been the subject of frequent concern and complaints from the residents of the lake.

To improve the quality of the stormwater reaching the lake, enhance habitat for wildlife, and provide a visual amenity, a bioswale was created by converting a roadside ditch to a wetland. This was done by land balancing and establishing wetland plants native to Michigan. The main design of the bioswale includes four distinct planting zones each consisting of a monoculture of plants with similar flowering color. This provides a landscaped appearance without sacrificing the water quality benefit of the bioswale.

The design features infiltration trenches filled with one-inch x three-inch crushed aggregate. The space constraints of the site prevent the use of inline detention for water storage so the infiltration trenches will provide an area where stormwater will be detained and allowed to seep into the soil profile. In addition to the infiltration trenches, the current swale will be widened from six feet to 12 feet which will aid in reducing flow velocities and encourage uptake and infiltration of the stormwater.

Meadowlake Farms Bioswale

Case Study Site Considerations	
Project Type	Bioswale
Estimated Total Project Cost	$63,000
Maintenance Responsibility	Bloomfield Township
Project Contact	Meghan Bonfiglio 248-594-2802

Description and Function

Vegetated swales are broad, shallow, earthen channels designed to slow runoff, promote infiltration, and filter pollutants and sediments in the process of conveying runoff. Water is filtered through the soil to under drains and the swale is quickly dewatered, preventing standing water. Vegetated swales are an excellent alternative to conventional curb and gutter conveyance systems, because they provide pretreatment and can distribute stormwater flows to subsequent BMPs.

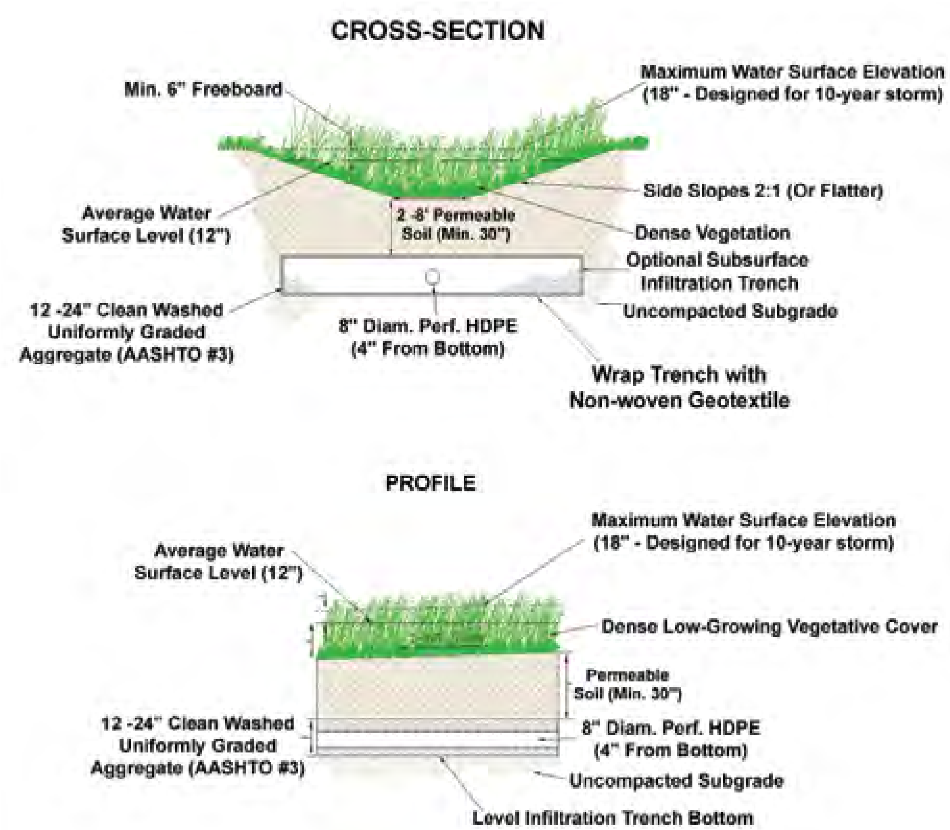
A vegetated swale typically consists of a band of dense vegetation, underlain by at least 12 inches of permeable soil (> 0.5 inches/hour). Swales constructed with an underlying aggregate layer (Figure 7.59) can provide significant volume and peak rate reductions. The permeable soil media should have a minimum infiltration rate of 0.5 inches per hour.

Vegetated swales are sometimes used as pretreatment devices for other structural BMPs, especially from roadway runoff. While swales themselves are intended to effectively treat runoff from highly impervious surfaces, pretreatment measures are recommended to enhance swale performance. Pretreatment can dramatically extend the functional life of any BMP, as well as increase its pollutant removal efficiency by settling out some of the coarser sediments. This treatment volume is typically obtained by installing check dams at pipe inlets and/or driveway crossings. Other pretreatment options include a vegetated filter strip, a sediment forebay (or plunge pool) for concentrated flows, or a pea gravel diaphragm (or alternative) with a six-inch drop where parking lot sheet flow is directed into a swale.

Check dams made of wood, stone, or concrete are often employed to enhance infiltration capacity, decrease runoff volume, rate, and velocity. They also promote additional filtering and settling of nutrients and other pollutants. Check-dams create a series of small, temporary pools along the length of the swale, which drain down within a maximum of 48 hours.

Weep holes may be added to a wood or concrete check dam to allow the retained volume to slowly drain out. Care should be taken to ensure that the weep holes are not subject to clogging. For stone check dams, allow

Figure 7.59
Schematics of Vegetated Swale with an underlying aggregate layer



Source: Pennsylvania Stormwater BMP Manual, 2006 lower flows (two-year storm) to drain through the stone, while allowing higher flows (10-year storm) to drain through a lower section in the center (thereby reducing the potential erosion from water flowing around the sides of the check dam). Flows through a stone check dam are a function of stone size, flow depth, flow width, and flow path length through the dam.

Conveyance

It is highly recommended that a flow splitter or diversion structure be provided to allow larger flows to bypass this practice as needed. Contributing drainage areas should be limited to five acres and an overflow should be provided within the practice to pass the excess flows to a stabilized water course or storm drain. Weirs are common overflow systems with media filters and can control velocities so that they are non-erosive at the outlet point to prevent downstream erosion.

Figure 7.60
Large Swale with subsurface storage

Source: Hubbell, Roth & Clark, Inc.

Media filters should be equipped with a minimum eight-inch diameter underdrain in a one-foot gravel bed. Increasing the size of the underdrain makes freezing less likely. The porous gravel bed prevents standing water in the system by promoting drainage. Gravel is also less susceptible to frost heaving than finer grained media. It is also highly recommended that a permeable filter fabric be placed between the underdrain and gravel layer but not extend laterally from the pipe more than two feet on either side (Figure 7.59).

Variations

Vegetated swale with infiltration trench

This option includes a six to 24-inch aggregate bed or trench, wrapped in a nonwoven geotextile (See Infiltration BMP for further design guidelines). The addition of an aggregate bed or trench can substantially increase volume control and water quality performance although cost is also increased.

Residential grass swale

Source: Pennsylvania Stormwater BMP Manual, 2006

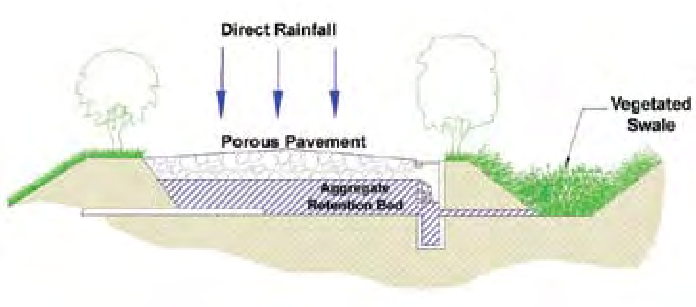
Figure 7.60 shows a regraded area with a series of infiltration trenches (geotextile fabric, crushed aggregate, topsoil, and planting mixes). Additional stone energy dissipaters were installed along the width of the swale. A combination of plant plugs and seed mixes were then installed.

Wet swale

Source: Hubbell, Roth & Clark, Inc.

Vegetated swales with infiltration trenches are best fitted for milder sloped swales (< 1 percent) or poorly-drained soils where the addition of the aggregated bed system can help to make sure that the maximum allowable ponding time of 48 hours is not exceeded. Ideally, the subsurface system should be designed like an infiltration trench (see Infiltration BMP). The subsurface trench should be comprised of terraced levels, though sloping trench bottoms may also be acceptable. The storage capacity of the infiltration trench may be added to the surface storage volume to achieve the desired storage.

Figure 7.61
Slow discharge from porous pavement bed to vegetated swales



Source: Pennsylvania Stormwater BMP Manual, 2006

Grass swale

Grass swales are essentially conventional drainage ditches. They typically have milder side and longitudinal slopes than their vegetated counterparts. Grass swales are usually less expensive than vegetated swales. However, they provide far less infiltration and pollutant removal opportunities and should be used only as pretreatment for other structural BMPs. Grassed swales, where appropriate, are preferred over catch basins and pipes because of their ability to increase travel time and reduce peak flow rates from a site.

Linear wetland swale

Wetland swales occur when the water table is located very close to the surface, incorporating long, shallow, permanent pools or marshy conditions that can sustain wetland vegetation. Like the dry swale, the entire water quality treatment volume is stored within a series of cells created by check dams.

Potential Applications

- Residential – Swales can be used along road rights of ways and for side yard and backyard drainage.
- Commercial/Industrial – Swales can provide site drainage around a site, within a site and can help take/slow discharge from other BMPs that outlet to the swale (Figure 7.61).
- Ultra urban – There may be some opportunity for swales in ultra urban areas. However, swales are usually no less than two feet deep. With horizontal to vertical side slopes between 3:1 to 5:1 horizontal to vertical, the top width of the swale can prohibit its use in this setting where space is usually at a premium.
- Retrofit – Potential application in retrofit situations will depend strongly on space and topographic limitations. On sites with little to no slope, swales may not be the best drainage option. In these areas, swales may end up not moving water fast enough or may be prone to long periods of flooding or inundation in areas meant to be mostly dry.
- Highway/Road – Vegetated swales are an excellent alternative to curb and gutter systems. Appropriately sized roadside swales should be able to handle all the runoff from the roadway and may also be able to handle runoff from areas outside the road surface.

Design Considerations

1. Sizing
   a. Convey the calculated peak discharge from a 10-year storm event. Calculate the peak discharge for a 10 year storm event using methods from Chapter 9. Use Manning's equation (see stormwater calculations section) to calculate the velocity associated with the flow and compare to Table 7.19.
   b. Temporarily store and infiltrate the one-inch storm event, while providing capacity for up to the 10-year storm with 12 inches of freeboard.
   c. Flows for up to the two-year storm should be conveyed without causing erosion.
   d. Maintain a maximum ponding depth of 18 inches at the end point of the channel, with a 12-inch average maintained throughout.

Stone check dams

Source: Road Commission for Oakland County

   e. The maximum ponding time should be 24 hours. It is critical that swale vegetation not be submerged during smaller storms, because it could cause the vegetation to bend over with the flow. This leads to reduced roughness of the swale, higher flow velocities, and reduced contact filtering opportunities.
   f. Bottom widths typically range from two to eight feet. The maximum bottom width to depth ratio for a trapezoidal swale should be 12:1.
2. Longitudinal slopes between one and six percent are recommended.
3. Swale side slopes are best within a range of 3:1 to 5:1 and should never be greater than 2:1 for ease of maintenance and side inflow from sheet flow.
4. Check dams
   a. Recommended for vegetated swales with longitudinal slopes greater than three percent or when additional detention or infiltration is desired.
   b. Should be constructed to a height of six to 18 inches and regularly spaced.
   c. Should be keyed into the bottom and sides of the swale, usually at least one to two feet on all sides. The height of the key on both sides should exceed the water surface elevation of the 10-year event by at least six inches.
   d. The middle of the check dam crest should be below the sides of the check dam to help focus flow over the check dam and away from the channel sides.
5. Maximum drainage area is five acres.
6. Soil testing is required when infiltration is planned (Appendix E).
7. Runoff can be directed as concentrated flows or as lateral sheet flow drainage. Both are acceptable provided sufficient stabilization or energy dissipation is included. If flow is to be directed into a swale via curb cuts, provide a two- to three-inch drop at the interface of pavement and swale. Curb cuts should be at least 12 inches wide to prevent clogging and should be spaced appropriately to minimize the number of cuts but maximize area drained.
8. Soil should be at least 12 inches of loamy or sand with an infiltration rate of at least 0.5 inches per hour.
9. Inundation time is 24 hours. Rototill and replant swale if draw down time is more than 24 hours.
10. Prior to establishment of vegetation, a swale is particularly vulnerable to scour and erosion and therefore its seed bed must be protected with temporary erosion control, such as straw matting, straw-coconut matting, compost blankets, or fiberglass roving. Most vendors will provide information about the Manning's 'n' value and will specify the maximum permissible velocity. It is critical that the selected erosion control measure is adequate to prevent scour (see calculation section for more information on Manning's equation).

Table 7.17
Values of Manning's Roughness Coefficient n (Uniform Flow)

Type of Channel and Description	Minimum	Normal	Maximum
Excavated or Dredged			
A. Earth, straight and uniform:			
1. Clean, recently completed	0.016	0.018	0.02
2. Clean, after weathering	0.018	0.022	0.025
3. Gravel, uniform section, clean	0.022	0.025	0.03
4. With short grass, few weeds	0.022	0.027	0.033
B. Earth, winding and sluggish:			
1. No vegetation	0.023	0.025	0.03
2. Grass, some weeds	0.025	0.03	0.033
3. Dense weeds or aquatic plants in deep channels	0.03	0.035	0.04
4. Earth bottom and rubble sides	0.025	0.03	0.035
5. Stony bottom and weedy sides	0.025	0.035	0.045
6. Cobble bottom and clean sides	0.03	0.04	0.05
C. Dragline - excavated or dredged:			
1. No vegetation:	0.025	0.028	0.033
2. Light brush on banks:	0.030	0.050	0.060
D. Rock cuts:			
1. Smooth and uniform:	0.025	0.035	0.040
2. Jagged and irregular:	0.035	0.040	0.050
E. Channels not maintained, weeds and brush uncut:			
1. Dense weeds, high as flow depth:	0.050	0.080	0.120
2. Clean bottom, brush on sides:	0.040	0.050	0.080
3. Same, highest stage of flow:	0.045	0.070	0.110
4. Dense brush, high stage:	0.080	0.100	0.140

Source: Michigan Department of Transportation Drainage Manual, 2006

Table 7.18
Permanent stabilization treatments for various ditch grades

Ditch Bottom Treatment	Ditch Grades
Seed and Mulch *	0.3% to 0.5%
Standard Mulch Blanket *	0.5% to 1.5%
High Velocity Mulch Blanket or Sod *	1.5% to 3.0%
Turf Reinforcement Mat or Cobble Ditch	3.0% to 6.0%
Specific Design Required **	6.0% +

** When within 200 feet of a stream, the permanent ditch treatment will be a mulch blanket for ditch grades 0.5 or less and sod for ditch grades between 0.5 and 3.0 percent. The designer should set up a miscellaneous quantity of mulch blanket media (if not already set up) and high velocity mulch blanket media to use in case sod is not immediately available or it is outside of seasonal sodding limits.*

*** Downspouts, see Standard Plan R-32-Series; paved ditches, see Standard Plan R-46-Series; for spillways consult with the Design Engineer - Hydraulics/ Hydrology.*

Source: Michigan Department of Transportation Drainage Manual, 2006

Table 7.19
Permissible flow velocities to minimize erosion

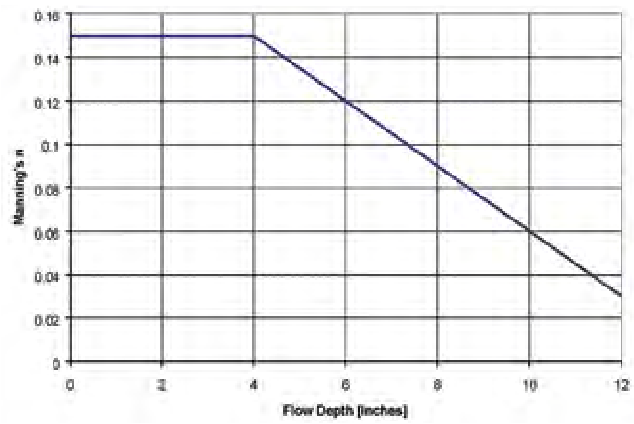
Permissible velocity – (fps)

SOIL TEXTURE	Channel Vegetation		
	Retardance	Fair (V_1)	Good (V_2)
Loam, Sand, Silt Sandy Loam and Silty Loam	B C D	3.0 2.5 2.0	4.0 3.5 3.0
Silty Clay Loam Sandy Clay Loam	B C D	4.0 3.5 3.0	5.0 4.5 4.0
Clay	B C D	5.0 4.5 4.0	6.0 5.5 5.0

Source: Michigan Department of Environmental Quality, Surface Water Quality Division *Guidebook of Best Management Practices for Michigan Watersheds*, Reprinted 1998

Note: Retardance (Vegetation Cover Classification by height of vegetation): B = 30-60cm: C = 15-30 cm and D = 5-15 cm.

Figure 7.62
Example of decreasing roughness (“n” value) with increasing flow depth



Source: Schueler and Claytor, 1996

Stormwater Functions and Calculations

Utilize Manning’s equation to calculate the velocity associated with the flow from the peak discharge of the 10 year storm or local standard. Maintain velocity of the 10 year and water quality criteria at non-erosive rates (Table 7.19).

Manning’s Equation

$$Q = VA = \frac{1.49}{n}\left(\frac{A}{WP}\right)^{2/3} S^{1/2}$$

Where;

Q = Flow in cfs

V = Velocity in ft/sec

A = Area in ft^2

n = Manning’s roughness coefficient

WP = Wetted Perimeter in ft

S = Slope in ft/ft

Manning’s roughness coefficient, or ‘n’ value in the equation, varies with the type of vegetative cover and design flow depth. As a conservative approach, the lower value between design depth (Figure 7.62) and vegetative cover/swale configuration (Table 7.17) should be used in design to determine flow velocities.

If driveways or roads cross a swale, culvert capacity may supersede Manning’s equation for determination of design flow depth. In these cases, use standard culvert calculations to establish that the backwater elevation would not exceed the banks of the swale. If the maximum permissible velocity is exceeded at the culvert outlet, energy dissipation measures must be implemented. Table 7.18 provides stabilization methods and Table 7.19 provides recommended velocities for various swale configurations.

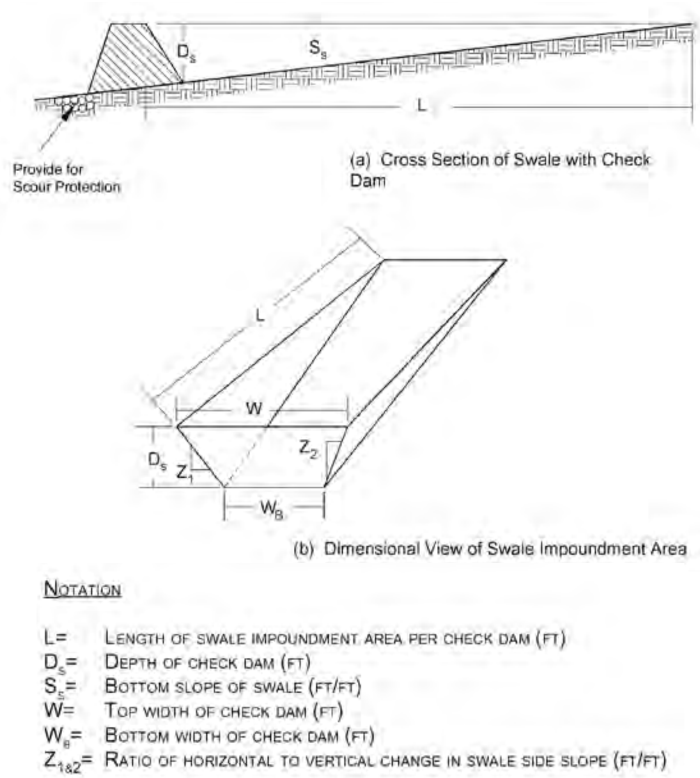
Volume calculations (as it relates to the use of check dams)

The volume stored behind each check-dam (Figure 7.63) can be approximated from the following equation:

Storage Volume = 0.5 x (Length of Swale Impoundment Area per Check Dam) x (Depth of Check Dam) x[(Top Width of Check Dam) + (Bottom Width of Check Dam)] / 2

Active infiltration during the storm should also be accounted for when appropriate according to guidance provided in the Infiltration BMP and Chapter 9.

Figure 7.63
Storage behind check dam



Source: Northern Virginia Planning District Commission, 1992

Peak rate mitigation

Vegetated swales can help reduce peak flows by increasing travel times, reducing volume through infiltration, and storing runoff behind check dams, culverts, etc. See Chapter 9 for Peak Rate Mitigation methodology, which addresses the link between volume reduction and peak rate control.

Water quality improvement

Although the reported water quality benefits of vegetated swales vary widely, they can be expected to remove a high amount of total suspended solids (typically 70 percent to 90 percent), a low-to-medium amount of total phosphorus (approximately 10 percent to 50 percent), and a medium amount of total nitrogen (often 40 percent to 75 percent). There is some research to suggest that longer swales provide additional treatment. Vegetated swales can be used effectively for pretreatment prior to discharge to other BMPs (see Chapter 9 for water quality criteria and calculations).

Construction Guidelines

1. Begin vegetated swale construction only when the upgradient 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.
2. Rough grade the vegetated swale. Equipment should 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), the compacted soils should be removed and replaced with a blend of topsoil and sand to promote infiltration and biological growth. At the very least, topsoil should be thoroughly deep plowed 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.
3. After rough grading, fine grade the vegetated swale. Accurate grading is crucial for swales. Even the smallest non-conformities may compromise flow capacity or soil stability.
4. Vegetation should consist of a dense and diverse selection of close-growing, water-tolerant plants (See Appendix C for complete list). Common species used in vegetated swales in Michigan include Canada Bluejoint (Calamagrostis canadensis), Virginia Wild Rye (Elymus virginicus), Switch Grass (Panicum virgatum), and Prairie Cord Grass (Spartina pectinata). Additionally, a cover crop of seed oats (Avena sativa) and Annual Rye (Lolium multiforum) should be used for quick germination and stability.

Installing bioswale vegetation at Macomb County Public Works Office.

Maintenance

1. Irrigation will be necessary during plant establishment and may be needed in periods of little rain or drought. Vegetation should be established as soon as possible to prevent erosion and scour.
2. Stabilize freshly seeded swales with appropriate temporary or permanent soil stabilization methods, such as erosion control matting or blankets. Erosion control for seeded swales should be required for at least the first 75 days following the first storm event after planting. If runoff velocities are high, consider sodding the swale or diverting runoff until vegetation is fully established.
3. Annually inspect and correct erosion problems, damage to vegetation, and sediment and debris accumulation (address when > three inches at any spot or covering vegetation).
4. Annually mow and trim vegetation to ensure safety, aesthetics, proper swale operation, or to suppress

weeds and invasive vegetation. Dispose of cuttings in a local composting facility; mow only when swale is dry to avoid rutting.

5. Annually inspect for uniformity in cross-section and longitudinal slope; correct as needed.
6. Inspect and correctly check dams when signs of altered water flow (channelization, obstructions, etc.) are identified.

Winter Considerations

Plowing snow into swales will help insulate the bottom of the swale. However, snow that has accumulated salt or sand from de-icing operations should not be pushed into swales. Winter conditions also necessitate additional maintenance concerns, which include the following:

- Inspect swale immediately after the spring melt, remove residuals (e.g., sand) and replace damaged vegetation without disturbing remaining vegetation.
- If roadside or parking lot runoff is directed to the swale, mulching and/or soil aeration/manipulation may be required in the spring to restore soil structure and moisture capacity and to reduce the impacts of de-icing agents.
- Use nontoxic, organic de-icing agents, applied either as blended, magnesium chloride-based liquid products or as pretreated salt.
- Consider the use of salt-tolerant vegetation in swales.

Cost

Vegetated swales provide a cost-effective alternative to traditional curbs and gutters, including associated underground storm sewers (Table 7.20). The following table compares the cost of a typical vegetated swale (15-foot top width) with the cost of traditional conveyance elements.

It is important to note that the costs listed are strictly estimates and should be used for rough estimating purposes only. Also, these costs do not include the cost of activities such as clearing, grubbing, leveling, filling, and sodding of vegetated swale (if required). When all construction, operation, and maintenance activities are considered, the cost of vegetated swale installation and maintenance is far less than that of traditional conveyance elements.

Table 7.20
Cost comparison showing vegetated swale to pipe, curb, and gutter

	SWALE	Underground Pipe	Curb & Gutter
Construction Cost (per linear foot)	$4.50 - $8.50 (from seed)	$2 per foot per inch of diameter	$13 - $15
	$15 - $20 (from sod)	(e.g. a 12” pipe would cost $24 per linear foot)	
Annual O & M Cost (per linear foot)	$0.75	No Data	No Data
Total annual cost (per linear foot)	$1 from seed $2 from sod	No Data	No Data
Lifetime (years)	50		20

Source: Bay Area Stormwater Management Agencies Association, June 1997.

Designer/Reviewer Checklist for Vegetated Swales

Type of vegetated swale proposed: ______________________________

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 and ten-year flows 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?				
Underdrain provided for infiltration swales?				
Vegetation and Mannings coefficient selected?				
Non-erosive inflow condition(s)?				
Erosion control provided during construction?				
Maintenance accounted for and plan provided?				

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BMP Fact Sheet

Water Quality Devices

Various proprietary, commercially available BMPs have been designed to remove non-point source pollutants from the conveyance system for stormwater runoff. These structural BMPs vary in size and function, but all utilize some form of filtration, settling, or hydrodynamic separation to remove particulate pollutants from overland or piped flow. The devices are generally configured to remove pollutants including coarse sediment, oil and grease, litter, and debris. Some filtration devices employ additional absorbent/adsorbent material for removal of toxic pollutants. Pollutants attached to sediment such as phosphorus, nitrates, and metals may be removed from stormwater by effective filtration or settling of suspended solids. Regular maintenance is critical for the continued proper functioning of water quality devices.

Filtration insert with debris in St. Clair Shores, MI

Source: Environmental Consulting & Technology, Inc.

Applications		Stormwater Quantity Functions	
Residential	Yes	**Volume**	None
Commercial	Yes	**Groundwater Recharge**	None
Ultra Urban	Yes	**Peak Rate**	None
Industrial	Yes	**Stormwater Quality Functions**	
Retrofit	Yes	**TSS**	Varies
Highway/Road	Yes	**TP**	Varies
Recreational	Yes	**TN**	Varies
		Temperature	None

Additional Considerations	
Cost	Varies
Maintenance	Varies, but no less than two inspections and cleanings per year
Winter Performance	High

Variations

- Filtration
- Settling
- Hydrodynamic separation

Key Design Features

- Located below ground, as part of the stormwater conveyance system
- Devices may be internal to the conveyance system
- Devices may be installed in an offline configuration, so that a certain flow will be treated while allowing a surcharge flow to bypass the treatment.

Benefits

- Can be used in a variety of applications including retrofitting existing stormwater systems

Limitations

- Virtually no water quantity benefits
- Potentially high costs
- Typically require frequent maintenance

Case Study: LaVista Storm Drain Project

City of Battle Creek, MI

The LaVista Storm Drain Project was undertaken by the City of Battle Creek, MI to help improve stormwater runoff quality to its largest lake, Goguac Lake. The City applied several LID techniques, including a small bioretention basin, perforated piping, a grass swale, a large bioretention basin, and a structural vortex device to control runoff from three separate storm sewer systems in the project area. Native plantings were also incorporated to promote phosphorus removal and water infiltration. The largest drainage area, LaVista at 150 acres, had the most LID techniques employed. The two other drainage areas, Meno at four acres and Hulbert at 14 acres, utilized structural vortex devices only.

The primary goals of the project were to reduce stormwater runoff volume and phosphorus pollutant loadings to the lake by 50 percent. Another aspect of the project was to promote the use of the LID in the Battle Creek area.

Non-blocking and non-mechanical screening vortex devices were installed at the outlets of all three drainage areas to Goguac Lake. They were used because portions of the stormwater sewer system could not geographically be diverted to any of the natural treatment areas.

Estimated Annual Pollutant Load Reductions for entire site:

- Sediment – 57.3 tons
- Nitrogen – 744 lbs.
- Phosphorous – 105 lbs.
- Volume Reduction – 80 percent

Screening vortex device with floating debris

Source: City of Battle Creek

Case Study Site Considerations	
Project Type	Water Quality Devices
Estimated Total Project Cost	$932,911
Maintenance Responsibility	City of Battle Creek
Project Contact	Christine Kosmowski, 269-966-0712

Description and Function

Water quality devices are generally proprietary, commercially available units designed to improve the quality of stormwater by removing pollutants as the stormwater flows through the system. Devices designed to reduce particulate solids may also reduce pollutants since pollutants can be bound to solid particles.

Water quality devices are often employed in areas with high concentrations of pollutants in runoff and may effectively reduce sediment particles in stormwater runoff before they reach other BMPs, such as infiltration systems. Manufacturers of the devices usually provide the internal design specifications and installation instructions. Most are designed to treat a "first flush" of stormwater and provide an overflow or bypass route for large storm events. The first flush is generally measured as a volume of runoff from a specified storm.

The advantage of the manufactured devices is their adaptability to ultra urban and retrofit situations, where they can be installed beneath most surface infrastructure such as roads and parking lots.

Variations

Water quality devices may be separated into three categories: filtration (including absorption and adsorption), settling, and hydrodynamic separation.

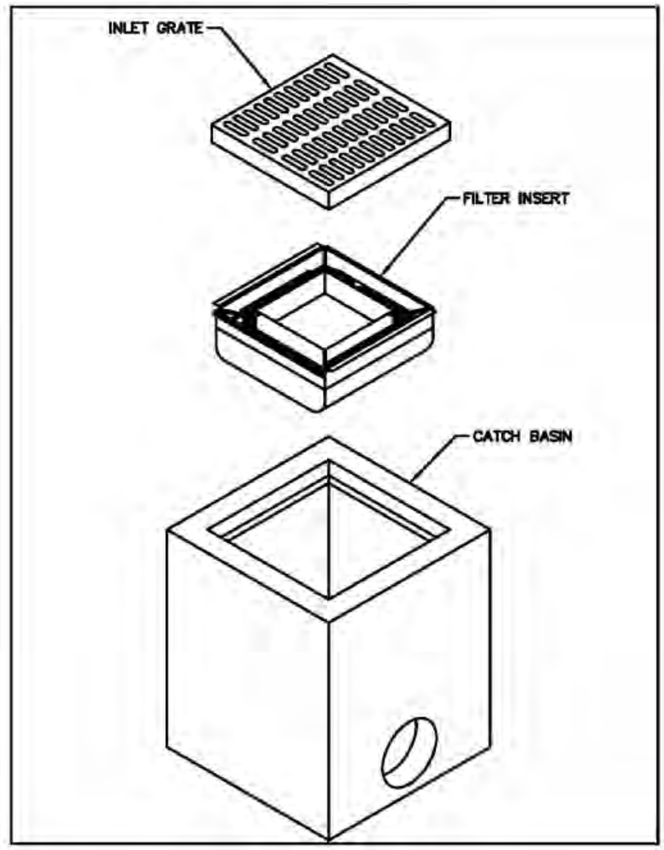
Filtration devices

These devices usually take the form of catch basin inserts. They are installed within catch basins directly below the grates, and may be tray, bag, or basket types. Runoff passes through the device before discharging into the outlet pipe. Some modification of the catch basin inlet is sometimes necessary to accommodate and support the insert, and to allow bypass from large storms. Trays, baskets and bag type inserts perform similar functions – removing debris and sediment.

Tray type inserts
Tray type inserts (Figure 7.64) allow flow to pass through filtration media contained in a tray around the perimeter of the catch basin. High flows pass over the tray and into the catch basin directly.

Bag type inserts
Bag type inserts are made of fabric that hangs down below the catch basin grate. Overflow holes are usually provided to allow larger flows to pass without causing flooding at the grate. Certain manufactured products include polymer textiles that are intended to increase pollutant removal effectiveness.

Figure 7.64
Tray type insert



Source: Pennsylvania Stormwater BMP Manual, 2004

Installing a bag type catch basin insert
When filled with sediment, a machine such as a bobcat or backhoe may be needed to lift the bag from the catch basin.
Source: Pennsylvania Stormwater BMP Manual, 2004

Basket type inserts

Basket type inserts (Figure 7.65) are also installed in catch basins. Most have a handle to remove the basket for maintenance. Tray and basket inserts can be fitted with packets of absorbent or adsorbent material to aid with removal of oil, grease, or toxic pollutants. Small orifices allow small storm events to weep through, while larger storms overflow the basket. Tray and basket inserts are generally useful for debris and large sediment, and require consistent maintenance.

Figure 7.65
Catch basin insert showing basket frame

Source: Stormwater 360

Settling devices

Settling devices provide sump areas where stormwater can collect within the conveyance system. Stormwater pools in the sump area, where velocity decreases and suspended solids settle out. Cleaner water pours over the top to the next link in the conveyance system. An example of a settling water quality device is a sumped catch basin.

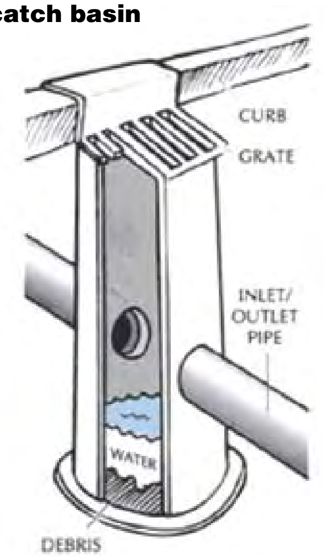
Sumped catch basins

Sumped catch basins (Figure 7.66) are constructed in the same way as standard catch basins, but are constructed with approximately 12 to 24 inches of storage depth below the invert of the outlet pipe. Where suitable soils exist and groundwater is not a concern, weep holes should be drilled into the bottom of the inlet to prevent standing water from remaining in the inlet for long periods of time.

Hydrodynamic devices

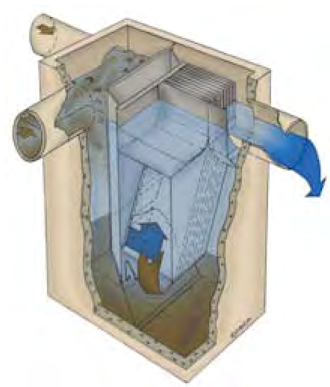
Hydrodynamic devices (Figure 7.67) are flow-through devices designed to serve within the stormwater conveyance system. Many products available from various manufacturers employ various mechanical methods to remove sediment, debris, and pollutants from stormwater. These methods include inclined plane settlement plates, vortexes, baffle systems, tubular settlement chambers, or combinations of these. Sediment, debris, and pollutant removal efficiencies vary widely among devices and according to the rate, quantity, and quality characteristics of the flow reaching the device. These devices work most effectively in combination with other BMPs.

Figure 7.66
Sumped catch basin



Source: City of Farmington Hills, MI

Figure 7.67
Example Hydrodynamic Devices



Vortex Hydrodynamic Separator
Source: Stormwater Solutions

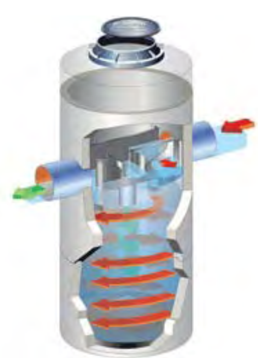


Plate Hydrodynamic Separator
Source: Terre Hill Stormwater Solutions

Applications

The wide variety of commercially available water quality devices allows for them to be used in many different applications. However, their use in low-density residential projects is likely to be limited by their maintenance burden and the fact that other BMPs are more cost effective for stormwater management in residential projects (they are generally used for areas with high impervious cover).

Water quality devices are useful in any existing or proposed conveyance systems that have or are expected to have significant levels of sediment or debris, or in areas that have pollutant hot spots. Such areas include, but are not limited to: parking lots, gas stations, golf courses, streets, driveways, and material handling at industrial or commercial sites.

Water quality devices are commonly used as pre-treatment before other structural BMPs. Long term functionality of these devices is dependent on regular long term inspection and cleaning. Long term maintenance must be considered when specifying these devices.

Design Considerations

1. Consider the requirements of the site including anticipated sediment loading and the components of each water quality device. The proposed land use should determine specific pollutants to be removed from runoff.
2. Design to ensure easy access to the device for people and also the necessary tools for maintenance. Frequent inspection and maintenance is required. To avoid re-suspension of pollutants, perform maintenance well before sediment or debris has filled the device to capacity.
3. Consider the head requirements for the device to work properly, especially when determining the total head requirements for a treatment train. Catch basin inserts have the advantage of fitting into existing drainage systems at points where head loss already occurs.
4. The stormwater management system for the site should be designed to provide treatment for bypassed water. This occurs when storms in excess of the device's hydraulic capacity bypass the device and fail to achieve the designed runoff treatment standard for the site.
5. Properly design and select water quality devices to prevent re-suspension of captured sediments during storm events that exceed the system capacity.

Stormwater Functions and Calculations

Volume reduction

Water quality devices do not provide volume reduction.

Peak rate mitigation

Water quality devices do not provide peak rate reduction.

Water quality improvement

Water quality benefits may be quantified according to a third party review and testing of the technology, such as the U.S. EPA which offers a searchable clearinghouse of approximately 220 independent tests of BMP performance at: www.epa.gov/npdes/npdes-stormwater -program

If third party test results are not available for a device, the manufacturers' specifications and tests for removal efficiencies of a device may be considered.

Winter Considerations

A limited amount of data is available concerning cold weather effects on water quality insert effectiveness. Freezing may result in runoff bypassing the treatment system. Salt stratification may also reduce detention time. Colder temperatures reduce the settling velocity of particles, which can result in fewer particles being "trapped". Salt and sand loadings may significantly increase in the winter and may warrant more frequent maintenance.

Water quality inserts (tray, bag, or basket types) as well as hydrodynamic devices should be inspected and maintained during winter months. Application of sand, ash, cinders, or other anti-skid materials may cause water quality devices to fill more quickly. Clogged inserts in cold weather can be especially problematic if flow is restricted and ponded water freezes over to create a safety hazard or render a portion of the site unusable.

Maintenance

Follow the manufacturer's guidelines for maintenance taking into account expected sediment and pollutant load and site conditions.

Inspect each water quality device at least twice per year and after all major storm events if possible. Post-construction, they should be emptied when full of sediment (and trash) and cleaned at least twice a year.

Vactor trucks may be an efficient cleaning mechanism for devices with firm or solid floors or sumps. Vactors should not be use for bag type filters or other devices where they could damage filter membranes or absorptive/adsorptive materials.

Maintenance is crucial to the effectiveness of water quality devices. The more frequent a water quality insert is cleaned, the more effective it will be. One study (Pitt, 1985) found that water quality inserts can effectively store sediment up to 60 percent of their sump volumes. Once the stored volume exceeds 60 percent, the inflow re-suspends the sediments into the stormwater. Keeping a maintenance log of sediment amounts and dates removed is helpful in planning a maintenance schedule.

Michigan law classifies wastes removed from storm sewers as liquid industrial waste. There are specific requirements for the proper transport and disposal of these wastes, which may include proper permitting and registration if the transporter is a private entity. Guidance for proper disposal, registration, and permitting is available from the Michigan Department of Environmental Quality at:

http://www.michigan.gov/documents/deq/wb-stormwater-CatchBasinGuidance_216198_7.pdf

Cost

Costs vary widely according to manufacturer, type, and size of water quality devices. Contact manufacturers to determine current costs.

Installation and maintenance costs for in-line or off-line devices installed below ground can run significantly higher than for vegetative filters and infiltration devices that provide similar levels of treatment.

Designer/Reviewer Checklist for Water Quality Devices

Type of water quality device(s) proposed: ______________________________

Manufacturer(s) & model(s) proposed: ______________________________

Independent Verifications (ETV, TARP, etc.): ______________________________

ITEM	YES	NO	N/A	NOTES
If system is off-line, adequate flow diversion system?				
If system is on-line, adequate bypass/overflow that minimizes release of captured pollutants?				
Adequate hydraulic head available for device to operate?				
Properly sized for drainage area, flow, pollutant capture?				
Has device been independently verified for adequate pollutant removal for appropriate particle sizes (especially if it is the primary water quality BMP)?				
Manufacturer's recommendations followed?				
Details provided for device and connections?				
Erosion control provided, if necessary?				
Easy access/visibility for maintenance?				
Maintenance accounted for and a detailed plan provided (including the amount sediment/debris accumulation that triggers the need for cleaning)?				

References

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Chapter 8

Implementing LID in Special Areas

For LID to be successful in as many places as possible, special areas need special considerations. This chapter summarizes some of these special areas and identifies how LID can be incorporated into the design and development process. By recognizing that LID may not be practical in all places, we help facilitate the local discussion and decision-making process that must occur to determine how these special issues will be addressed.

These special areas include:

- Transportation corridors,
- CSO and SSO issues,
- Brownfield sites,
- High risk areas such as wellhead protection areas, karst areas, and special water designations.

Bioswale and porous pavers in Ann Arbor, MI.

East Street reconstruction consisting of 26-foot asphalt section converted to 18 feet of asphalt with two 3.5-foot concrete porous paver strips (and ribbon curb) that infiltrates all road runoff and some rooftop and sidewalk runoff.

Source: JFNew

Transportation corridors. Highways and roads comprise a significant portion of total impervious surface, especially in more urban areas. Emphasis to date has been to remove stormwater from the roadway as swiftly as possible to ensure public safety and the integrity of the road system. This presents a challenge to incorporating LID practices.

CSO and SSO issues. The impact of stormwater on the local sewer system is extremely important in several Michigan communities where the excess flow produced by adding runoff to a sewer flow, directly or indirectly, results in a hydraulically overloaded system.

Brownfield sites. Redevelopment of Brownfields is a policy priority of Michigan and numerous communities. Typically these sites were highly disturbed or degraded during prior land development. To date, the goal is usually to minimize permeation of rainfall to the subsurface to minimize contact and movement of onsite pollutants.

High-risk areas. High-risk areas include sites such as wellhead protection areas, source water protection areas, sensitive streams, and areas of porous limestone bedrock known as karst. In certain communities, LID will need to be tailored to complement programs in place to address high risk areas.

These special areas are discussed in this chapter. To tailor these special issues to local situations, both LID techniques and policy issues are described below.

Transportation Corridors

Using LID in transportation corridors, especially heavily traveled highways, is somewhat constrained. By design, much of the right-of-way (ROW) is paved with impervious materials built over compacted subgrade. While normal highway design may allow some portion of the corridor to be landscaped, standard earthwork practices result in these corridors being constructed using a soil mantle that has been excavated, filled, and totally altered from its natural form and function.

Also, the linear dimensions of this land use further constrain the type and capacity of LID measures that might be applied within the ROW.

Roadway design, construction, and maintenance must all be considered when selecting measures that effectively manage the quality, rate, and volume of roadway runoff. (For communities that have a stormwater permit, certain practices and procedures are a matter of compliance.)

LID technologies, including both nonstructural and structural, can help meet these requirements and can also be applied in a variety of other settings. Nonetheless, roads must recognize and address these specific challenges in managing stormwater.

- The need to manage stormwater while maintaining safe road conditions.
- Uncompacted soils, trees, and tall vegetation present safety hazards.
- Limited available space and the need to locate BMPs within the right-of-way, if possible.

Construction of Meadowlake Farms bioswale with infiltration, Bloomfield Township, MI.
Source: Hubbell, Roth, & Clark

- Drainage area imperviousness greater than 50 percent, and sometimes near 100 percent.
- Areas of extensive disturbance and compaction of soils (cut and fill).
- Potential for spills of hazardous materials (runoff containment).
- Use of deicing chemicals and salts, and the need to dispose of removed snow.
- Higher concentration of pollutants as compared to many other land uses.
- Thermal impacts to receiving streams in both summer and winter.

Despite these limitations, there are numerous opportunities to incorporate LID practices in the transportation system. These opportunities include:

- Design of new construction,
- Reconstruction projects,
- Maintenance activities, and
- As part of a community redesign process.

Examples of these opportunities can be found in the case studies.

Transportation and stormwater pollution

Stormwater runoff from roads is a significant source of stormwater pollutants, as well as a significant source of thermal pollution to receiving waterways. The chemical constituents of roadway runoff are highly variable. The Federal Highway Administration identifies a number of roadway runoff pollutants and possible sources (Table 8.1).

Compared to other land uses and impervious surfaces, roadway runoff tends to have higher levels of sediment and suspended solids, which must be considered when selecting BMPs. In addition, roadway runoff may also contain salts, deicing materials, and metals that can affect both receiving waters and vegetation and must be considered in BMP selection.

In addition to the water quality issues associated with roadway runoff, temperature impacts can also affect water quality. Roadway systems can deliver large amounts of warm or cold water directly and rapidly to receiving streams and wetlands, resulting in significant temperature impacts for aquatic species. Studies have shown that the runoff from summer storm events may exceed 90 degrees F, and winter runoff may be 37 degrees F colder than the receiving stream ambient temperature (Galli, 1990, Pluhowski, 1970). These temperature impacts can have profound impacts on the aquatic systems of a receiving stream, and significantly alter and reduce the aquatic diversity.

Table 8.1
Pollutants and Sources in Highway Runoff

Pollutents	Source
Particulates	Pavement wear, vehicles, atmospheric deposition, maintenance activities
Nitrogen, Phosphorus	Atmospheric deposition and fertilizer application
Lead	Leaded gasoline from auto exhausts and tire wear
Zinc	Tire wear, motor oil and grease
Iron	Auto body rust, steel highway structures such as bridges and guardrails, and moving engine parts
Copper	Metal plating, bearing and bushing wear, moving engine parts, brake lining wear, fungicides and insecticides
Cadmium	Tire wear and insecticide application
Chromium	Metal plating, moving engine parts, and brake lining wear
Nickel	Diesel fuel and gasoline, lubricating oil, metal plating, bushing wear, brake lining wear, and asphalt paving
Manganese	Moving engine parts
Cyanide	Anti-caking compounds used to keep deicing salts granular
Sodium, Calcium Chloride	Deicing salts
Sulphates	Roadway beds, fuel, and deicing salts

Source: FHWA Stormwater Best Management Practices in an Ultra-Urban Setting

General considerations for implementing LID along transportation corridors

Not all transportation elements offer the same opportunities for LID. In general, the greater the traffic volume and mix of vehicles using the roadway, the fewer measures can be accommodated within the right-of-way (ROW). However, locations such as park-and-ride lots and recreational pathways can use numerous LID BMPs with few constraints.

While many of the LID measures discussed in this manual are appropriate for use in managing roadway runoff, these measures should be designed and implemented with consideration of the nature of runoff from road surfaces. Specifically:

High levels of total suspended solids. Roadway runoff has higher levels of suspended solids compared to many other urban land uses. Roadway runoff should not be discharged directly to many BMPs, specifically infiltration systems without measures to reduce sediment loads. The following pretreatment BMPs can be used to reduce sediment loads:

The City of Battle Creek Willard Beach Park Project showcases LID practices to the community by installing rain gardens and porous asphalt throughout the park roadway system. During a rainstorm, notice the amount of runoff from the traditional asphalt (top) versus the porous asphalt at the start of the park (bottom). These BMPs address both stormwater quantity and temperature concerns that are often associated with roadway runoff.

Source: City of Battle Creek

- Vegetated systems such as grassed swales and filter strips.
- Structural elements such as catch basin inserts, filters, and manufactured treatment units.
- Maintenance measures such as street sweeping and vacuuming.

Proper design of vegetative BMPs. Vegetative BMPs such as grassed swales and filter strips can be highly effective in reducing pollutant loads from roadways, but must be properly designed in terms of slope, flow velocity, flow length, and vegetative cover. (Chapter 7 provides detailed design information on vegetative BMPs).

Vegetated BMPs are most effective for water quality treatment when the vegetation growth is lush and not frequently cut. Concerns with the increase of friction losses, through completely vegetated swales can be addressed with proper plant selection. Typically, there is a direct relationship between height and thickness of vegetation and friction losses in vegetated swales. The higher the friction losses in a watercourse the higher the water depth at a given flow. For appropriate herbaceous plant species with flexible stems (such as Fowl Manna Grass, Bottlebrush Sedge, Brown Fox Sedge, etc.), flows that result in water depths just above plant submergence will actually result in the plants laying down in the flow and significantly decreasing friction losses for high flows. Improperly designed or maintained systems may increase rather than reduce pollutant load.

Consider the issue of spills. It is cost prohibitive to design for spill containment on all sections of roadway, but the designer should consider the potential for spills and the necessary action should a spill occur. Subsurface systems, infiltration systems, or vegetative systems may have to be replaced should a spill occur. While this may seem to be a limiting factor in the use of such systems, many existing storm sewers from roadways discharge directly to receiving streams with no opportunity to contain or mitigate a spill before discharge to a receiving stream. Therefore, while BMP restoration may be required after a spill, a stream discharge of a spill may be prevented. Consider the materials that are carried in vehicles when selecting BMPs. For example, some highways restrict certain hazardous materials so those highways may be more apt to use infiltration BMPs vs. highways that allow all vehicles.

Deicing materials. Use of deicing materials and salts may affect vegetation, soil conditions, and water quality. Consider the types of vegetation used in vegetative BMPs, as chloride levels may adversely affect some vegetation as well as the soil microbial community. Proximity to water supply sources should also be considered when designing infiltration BMPs as well as the potential for groundwater chloride levels to be impacted by roadway runoff.

Disposing of snow removed from roadways must also be considered. This snow may ultimately be deposited in BMP areas and may contain higher concentrations of roadway salts and sediments. The potential impacts of this material on the BMP should be addressed in the design process (See Appendix C for a list of salt tolerant plants).

Temperature impacts. The temperature impacts of runoff from roadways can significantly affect receiving stream aquatic habitat. Roadways, especially asphalt roadways, tend to absorb heat and lack cooling vegetation in the ROW that can help cool runoff. Many existing storm sewers from roads discharge directly and immediately to receiving waters. New discharges should mitigate temperature impacts prior to discharge to the receiving water. This may involve:

- Vegetated systems and buffers to replace sections of concrete swales or pipes that impart heat to runoff. Multiple small drainage elements that use vegetated swales for conveyance will help reduce the temperature impacts from roadway runoff.
- If extended detention systems, wet ponds, or constructed wetlands are used for peak rate mitigation, the discharge from these systems could be further mitigated by using vegetated swales or buffers, as these impoundments may also create adverse temperature impacts. The discharge from an extended detention system could be conveyed via a vegetated swale, or dispersed through a level spreader. Discharges should not be piped directly into receiving streams or wetlands.
- Extended detention systems should include design elements to reduce temperature impacts. Recommended techniques include:
  - Design system with minimal permanent pool.
  - Preserve existing shade trees; plant trees

along shoreline (where feasible and still allowing for proper maintenance access).
  - Avoid excessive riprap and concrete channels that impart heat to runoff.

LID BMPs: Small Steps to Full Integration

The following LID implementation guide provides simple, low effort LID application concepts up to full integration of LID into new road construction, road reconstruction, and maintenance activities.

Easy to implement strategies

The first and foremost strategy is to avoid or minimize impacts. This includes limiting clearing and grubbing, minimizing site compaction, reducing impervious areas, and using native vegetation wherever possible. These strategies are detailed below and described in more detail in Chapters 6 and 7.

- **Minimize clearing and grubbing and soil compaction as feasible**. Existing vegetation, including tree canopy, understory, prairies, pastures, etc., along with root structure and litter on the ground can capture and evapotranspire significant amounts of annual rainfall before it ever has a chance to become runoff. In these landscapes, even when rainfall does reach the ground, it has a much higher likelihood of infiltrating into the soil than in cleared and compacted areas.

  As the traffic volume and travel speeds decrease, this measure becomes more easily implementable. For instance, for low volume, low speed roads – residential streets, gravel roads, etc. — removal of existing vegetation should be limited only to the actual corridor of the pavement surface and subsurface materials. The rhizosphere (plant rooting zone) is the area of the landscape where the most significant water quality treatment benefits are achieved. Leaving as much of the existing rhizosphere in place as possible is the first, best and least cost BMP for road projects. (This may require working with local community to discuss vegetation height requirements in the ROW).

- **Reduce compaction on non-load bearing areas.** Compaction beyond 85 percent of maximum dry bulk density can inhibit root growth. Compaction requirements for non-load bearing areas should be limited to 80 to 85 percent. This lowered compaction requirement ensures that the basic soil pore structure is mostly left intact. For more information on compaction, plant needs and structural stability see www.foresternetwork.com/daily/construction/optimizing-soil-compaction-and-other-strategies

- **Consider reducing impervious surfaces**. Where feasible and safe, consider impervious area reduction strategies for reducing road widths, particularly on residential streets. Changes in road widths will clearly reduce the cost of road construction and reconstruction. The rationale for existing road widths should be systematically re-examined for opportunities to reduce impervious surfaces, particularly for low-service roads.

- **Re-evaluate roadside ditch cleaning and or/ mowing practices**. Efforts should be made to retain existing vegetation during maintenance. For example, consider excavating or clean out of the up-gradient section of the ditch only (e.g., approximately top three quarters of ditches) and retaining vegetation in the down-gradient.

  Washington State DOT assessed routine highway ditch cleaning alternatives or service levels for water quality benefits, surveyed bioswales to evaluate conditions promoting water quality benefits, and assessed restabilization and revegetation options for use after ditch cleaning and for restoring bioswale vegetation.

Evaluate roadside ditching operations to retain existing vegetation where possible.

Source: Bloomfield Township

Of the options explored, the study found the greatest water quality benefits when the first three quarters of the ditch were excavated and vegetation was retained in the remainder. The ditch treated in this manner was capable of reducing TSS by approximately 40 percent, total phosphorus by about 50 percent, and total and dissolved copper and zinc each by roughly 20 to 25 percent. Analysis of survey data also showed that bioswales with broad side slopes, wide bases, and total storage volumes equivalent to three inches of runoff from the impervious drainage area consistently supported good vegetation cover and showed few signs of damage. Refer to henvironment.transportation.org/environmental_issues/construct_maint_prac/compendium/manual/10_11.aspx#tooltip. This approach may not be feasible for highways or other roadways with safety specifications for maximum depth of standing water in roadside ditches.

- **Incorporate native Michigan plants more comprehensively into roadside and median planting plans**. MDOT has experimented with native plantings with mixed success (See www.foresternetwork.com/). Some of the issues cited in the past - problems with seed availability and invasives control - can be better addressed now because of increased expertise of local native plant nurseries and companies devoted to landscape restoration.
- **Limit the use of curb and gutter and storm sewer wherever possible**. Where practical, particularly in areas with either well-draining soils or where there is sufficient fall to move water into swales and channels, runoff can be directed via sheet flow or to appropriately protected drainage features for storage and enhanced evapotranspiration and infiltration. Unprotected road edges are notoriously prone to cracking and crumbling. Where sheet flow moves over pavement edges, ribbon/flush curbing can be used to protect the pavement and help control drainage off the road surface.
- **Avoid discharging directly into a waterbody**. Traditional approaches to stream channel and water quality protection include ending the pipe well uphill of the stream bank and lining the area between the end of the pipe and the stream bank with well-graded stone and/or a high velocity mulch blanket. LID approaches can accomplish better water quality and even some volume reduction by discharging storm sewer and underdrains into vegetated areas, including constructed wetlands, bioretention/detention basins, and vegetated swales. These controls may sometimes be accomplished by acquiring land outside of the standard right of way.

> California Department of Transportation (CalTrans) developed a roadside management toolbox, which is a Web-based decision making tool for improving the safety and maintenance requirements of roadsides. CalTrans formally adopted an integrated vegetative management strategy to reduce the need for ongoing vegetation management. The most inexpensive "tool" for minimizing long-term roadside vegetative maintenance is native landscaping at $2 to $10 per square yard.

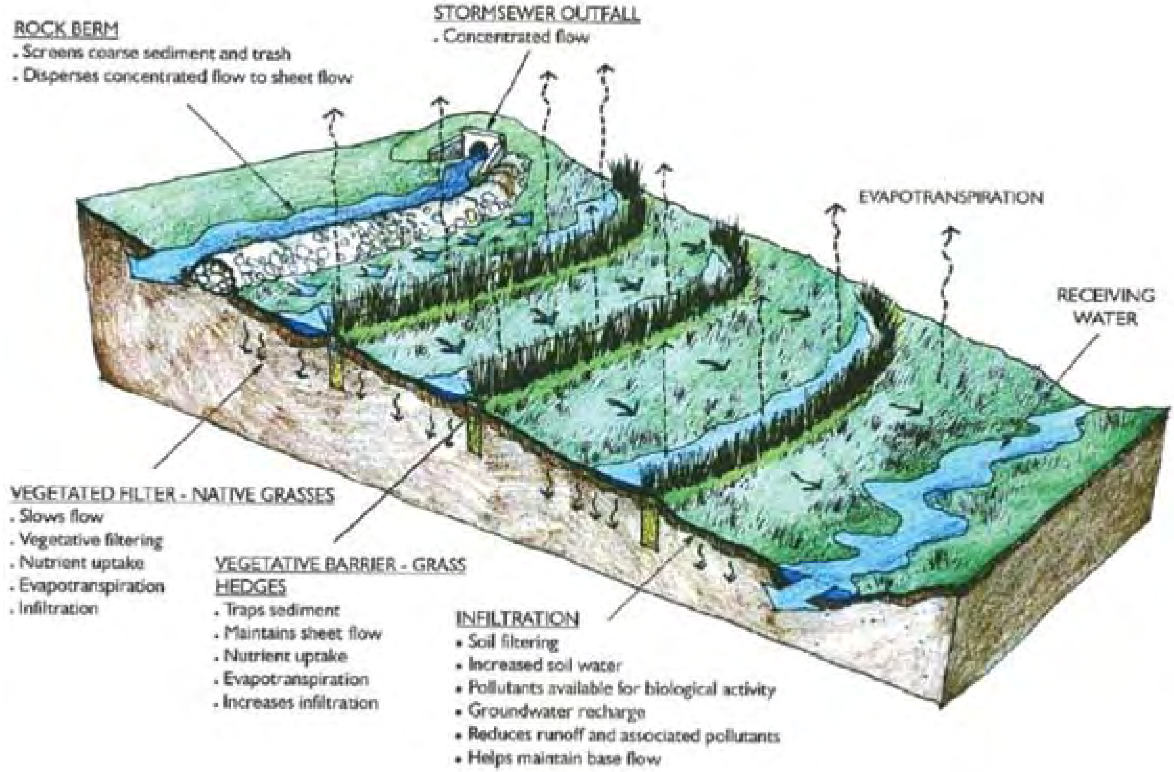
- **Consider alternative methods of energy dissipation where existing land allows** (in lieu of concrete or supplement rock pads). This can include tall, thick native plantings that act as a porous, "green" weir. (Figure 8.1)
- **Consider the use of infiltration berms** and retentive grading in areas that slope down from the roadway (Figure 8.1 and Figure 8.2).

Moderate-to high-level LID implementation

- **Incorporate street trees**. Wherever possible, integrate street trees, particularly in urban and suburban areas. The use of structural soils in these areas allows for street side tree plantings that can thrive and also provide significant structural stability. These areas can accept sidewalk/rooftop and road drainage and provide an overstory for shading and rainfall capture.

  Structural soil is a designed planting medium which can meet pavement design and installation requirements, while remaining root penetrable. The Cornell Urban Horticultural Institute has developed the structural soil system. This system includes gap-graded gravels made of crushed stone, clay loam, and a hydrogel stabilizing agent. This system creates a rigid stone lattice with the voids partially filled by soil (Figure 8.3).
- **Use pervious pavement**. Reducing impervious surfaces can also be accomplished by mixing impervious and pervious pavement types, textures, and colors. This juxtaposition of paving surfaces, textures, and colors can provide other benefits such as traffic calming or easy access to utilities.

Figure 8.1
Alternative outfall BMP using rock berm and alternating strips of native vegetation

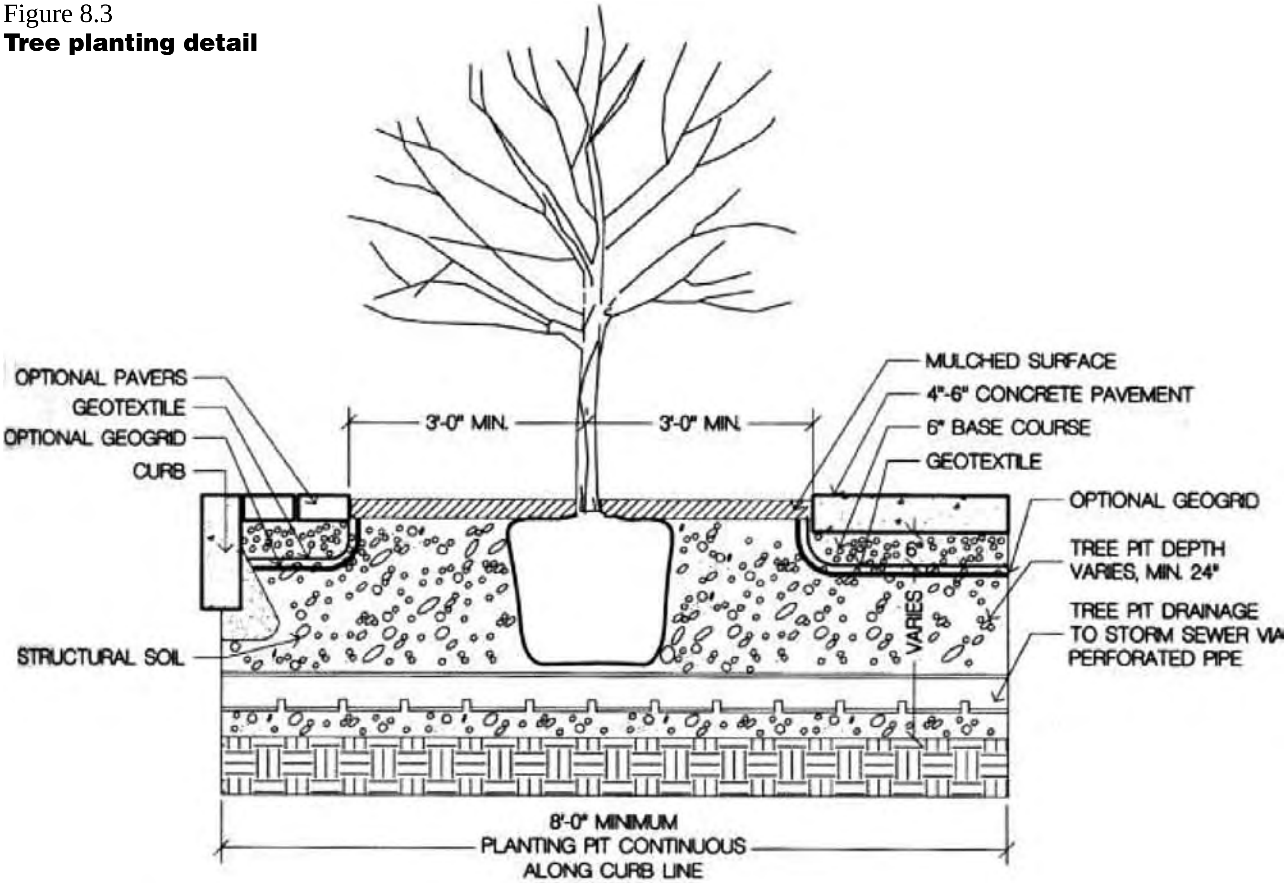


Source: Scaief, J. and Murphee, G., 2004

Figure 8.2
Mature rock berm and native vegetation filter berms

Source: Scaief, J. and Murphee, G., 2004

Figure 8.3
Tree planting detail



Source: Cornell Urban Horticultural Institute

The Easy Street case study shows 3.5-foot porous concrete paver block strips on either side of an 18-foot conventionally paved surface. The paver blocks can easily be lifted off their subbase in order to reach water pipes beneath the street. In addition, in the driver's eye these strips make the street look narrower, even though the pavers can handle the same loads as the asphalt. This perception of a narrower street has resulted in significantly slower speeds through what once was a "cut-through" street.

- **Take advantage of planted areas surrounded by impervious surfaces**. For instance, cul-de-sac interior circles and boulevard medians are typically planted areas. These areas are usually mounded at or above the road surface (convex topography). These areas could just as easily be depressions (concave topography) that capture drainage from the road, either over ribbon curb or through curb cuts in mountable or standard curb around the island or boulevard.

The Pokagonek Edawat Housing Development located in Dowagiac, MI includes the use of 25,000 square feet of interlocking pavers for the primary driving surface.

Source: Pokagon Band of Ptawatomi Indians

- **Require bioretention capability in the design of dry detention basins**. This can include replacing existing soils with engineered soil. Replacing existing soils with well-drained, organic soils can provide valuable water quality benefits, some storage, enhanced evapotranspiration opportunities, and an excellent growth medium for plantings even in areas with poor, fine-grained soils. These basins can be fitted with underdrains and overflows to facilitate drying out and eliminate flooding.
- **Incorporate LID into park-and-ride and other parking lots**. Consider using porous pavement, underground storage, and other subsurface infiltration practices on park- and- ride sites and parking lots.

Complete integration of LID design

Complete integration of LID is more likely possible on suburban or urban street settings, where other considerations, such as pedestrian access, commercial establishment visibility, aesthetics, recreation opportunities, and traffic calming can also impact design elements. This can be best accomplished by including various stakeholders in the process (e.g., transportation agencies, local planners and elected officials, and the public).

Complete integration of LID design would include such elements as conserved or planted trees, vegetated swales with amended soils, and subsurface aggregate storage:

- Incorporate swales into curb extensions mid-block and/or at intersections.
- Use permeable pavement materials for on- or off-street parking areas and sidewalk or bike lanes.
- Create underground storage under parking areas that can also receive rooftop runoff.

The City of Portland, Oregon is in the midst of re-defining how urban streets look and perform hydrologically. The figure below, taken from the Gateway Green Streets Master Plan for Portland, vividly demonstrates the look and suggests the effectiveness of this design on mitigating street runoff impacts.

Opportunities for moving LID forward

Local leadership is needed to move LID implementation forward in Michigan. This leadership needs to occur within transportation agencies as well. Numerous opportunities exist for agencies with transportation responsibility to encourage LID implementation.

Portland Gateway Green Streets Master Plan

Source: City of Portland, OR, Bureau of Environmental Services

Wayne County Miller Road Revitalization Project

The Miller Road Revitalization Project, located near the Ford Rouge Complex, implemented LID techniques to make the busy transportation corridor safer, more attractive, and more environmentally effective.

A 1.5-mile greenbelt promenade was developed on both sides of Miller Road with hundreds of trees and 20,000 shrubs. In addition, over 22 acres of sustainable landscaping was planted along the road. Irrigation is provided by mill water from the Detroit River, using pipes originally installed by Henry Ford. Swales are used along the road to filter stormwater before flowing to the Rouge River.

Swale along Miller Road in Dearborn, MI

Source: Atwell Hicks

Opportunities for MPOs

Metropolitan Planning Organizations (MPOs) designated under the Safe, Accountable, Flexible, Efficient, Transportation Equity Act: A Legacy for Users (SAFETEA-LU), have mandated responsibilities for developing long-range transportation plans and transportation improvement programs. Typically, MPOs work closely with road implementing agencies in their jurisdiction. And often, the MPO is also the council of governments representing a variety of local governments. Such is the case for SEMCOG. Thus, MPOs can play a major role in advocating for implementation of LID techniques.

Vegetation within right-of-way on Miller Road in Dearborn, MI
Source: Atwell Hicks

Furthermore, an emerging trend in federal transportation legislation and regulations is to integrate environmental protection issues early in the transportation planning process. This transportation planning institutional structure and policy trend presents an opportunity to promote LID in the process of implementing roadway plans and projects. SEMCOG, for example, has developed a procedure for ensuring that transportation agencies in Southeast Michigan consider a variety of potential environmental concerns when proposing a project for the transportation plan and transportation improvement program.

Several suggested action steps are proposed for consideration by MPOs:

- MPOs should become familiar with the content of this manual and the Best Management Practices that can apply to road projects.
- MPOs should incorporate policies into the transportation plan that advance LID implementation. Coordinating with watershed management plans or Total Maximum Daily Loads (where they exist) will result in policies that are unique for the needs of the waterway.
- MPOs should help educate road implementing agencies on LID techniques, including operational and maintenance practices.
- MPOs should convene representatives of road agencies in the area to discuss policy options and to identify opportunities and impediments in supporting LID. For areas under a stormwater permit program, the benefits of achieving compliance through use of LID should be considered.
- MPOs should use this manual to develop a checklist of actions for road agencies to use in project design and as part of operation and maintenance. Also, MPOs should develop prototype language for contractor specifications that include LID.
- Finally, MPOs should consider giving priority to projects that incorporate LID techniques.

LID policies incorporated into transportation plan

SEMCOG includes LID policies in their long-range transportation plan, specifically through a document, *Integrating Environmental Issues in the Transportation Planning Process: Guidelines for Road and Transit Agencies.*

One policy specifically stated in the SEMCOG process is to "Integrate stormwater management into the design of the site. If appropriate, utilize low impact development practices that infiltrate stormwater into the ground (e.g., swales, rain gardens, native plantings)."

Opportunities for implementers

Incorporating LID into roadway projects is not a minor undertaking. It involves a shift in perspective where the value of water quality and stream channel protection is reflected during different phases of a project — conception, design, construction, and maintenance. In areas where the MPO chooses to take many of the actions suggested above, the process will be more seamless.

Regardless of the MPO's level of activity, there are a number of actions that road agencies should do to be a proactive part of state and local government efforts to restore and protect water resources.

- Land use planning is a primary function of local government. Local plans and policies reflect community desires. Road agencies should be familiar with local water issues and the community's efforts to address them, including whether the community is covered by a stormwater permit, as well as the extent to which LID is applied in site development.
- More county drain commissioners and/or offices of public works have developed or are developing programs to protect water quality. Many of these programs have implications for roadway design or maintenance, including limitations on stormwater runoff.
- It is critical to consider the potential for applying LID techniques as early in the process as possible. Once designers are committed to the project design, it is hard to change course for what would likely be perceived as a secondary consideration, i.e., using LID techniques. Early meetings, at the project conception phase, with the local unit of government are encouraged.
- Many road agencies have written guidelines, procedures, and manuals. Consider revisions to existing manuals and procedures that incorporate LID supportive practices and policies.
- Include language in contractor specifications that spell out expectations during design and construction.

Michigan Avenue Streetscape Bioretention Facilities

City of Lansing

In 2004, the City of Lansing formed the Mayoral Task Force to address future infrastructure needs and improvements along four blocks of Michigan Avenue. The committee recommended the following elements be addressed in redeveloping the streetscape:

- Create more welcoming gathering places,
- Highlight pedestrian crosswalks,
- Make the corridor more environmentally friendly, and
- Add streetscape improvements such as kiosks, benches, and signage.

Michigan Avenue rain gardens in planter boxes in Lansing, MI.
Source: Tetra Tech

Street view of rain gardens in planter boxes in Lansing, MI.
Source: Tetra Tech

Construction on the project began in spring 2006 and incorporated landscape planters and sidewalk paving improvements, including new concrete sidewalk and accenting clay pavers, ornamental fencing, and site furnishings. In addition, a series of concrete, under-drained bioretention facilities (i.e., rain gardens) were designed as part of the enhancement project. The rain gardens were developed in conjunction with the city's controlled sewer overflow work as a means to control, clean, and dispense stormwater in an urban environment.

The rain gardens are designed to remove sediment, nutrients, heavy metals, and other pollutants, as well as reduce water temperature, and promote evaporation and transpiration of stormwater runoff, thereby reducing the overall impact to the Grand River. The project budget was $1.8 million.

Soil testing was required to address the numerous plant challenges such as impacts of road salt, drought, shade, height, and beauty, as well as soil challenges such as permeability, compaction, longevity, and available nutrients. The engineered soil specification was a mix of 30 percent sand, 30 percent topsoil, 10 percent coir fiber, and 30 percent municipal compost. The plants include Southern Blue Flag, Tall Tickseed, Nodding Wild Orchid, Rough Blazing Star, Switch Grass, Sweet Flag, Marsh Blazing Star, Swamp Milkweed, St. John's Wort, Rose Mallow, Boneset, Joe-Pye Weed, Beard-tongue, and Ironweed.

Maintenance and monitoring is provided by the City of Lansing Public Services Department and through an Adopt a Rain Garden program. Estimated maintenance costs are $30,000 per year for weeding, cleanup, plant replacement, mulching, and underdrain cleaning. In the future, interpretive educational signage will be posted in the gardens, providing information about stormwater pollution to pedestrians.

Easy Street

City of Ann Arbor

The Easy Street pavement rehabilitation project evolved into a re-envisioning of an overall street design. Easy Street drains via storm sewers to Mallets Creek, which is one of six creeks that drain to the Huron River through the city. Easy Street is a major asphalt thoroughfare through the City of Ann Arbor that had been resurfaced in over 10 years.

Over several years, residents of Easy Street initiated various design efforts to achieve a more integrated street design. The goal was a road design that would assist in stormwater management, along with addressing traffic calming, pedestrian access, and landscaping.

Easy Street in Ann Arbor, MI before LID implementation
Source: JFNew

Easy Street in Ann Arbor, MI after LID implementation
Source: JFNew

The project plan resulted in the installation of three-foot wide porous pavers on both sides of the street. Infiltration rates in the pavers can be maintained between four and eight inches per hour. In one hour, the pavers can infiltrate almost two times the depth of a 100-year rain event. Because the pavers' infiltration rate is approximately 16 to 32 times higher than the surrounding soil, it can take the runoff from an area at least 16 times its own size and still exceed the soil's infiltration capacity. The City of Ann Arbor has an annual maintenance program in place to take care of porous pavement.

The project includes an evaluation plan with pre- and post-construction flow and water quality monitoring, along with hydrologic and hydraulic modeling of conditions before and after construction.

Addressing CSO and SSO Issues

A significant source of water quality impairment comes from stormwater runoff that has been mixed with untreated sewage or wastewater. Some Sanitary Sewer Overflows (SSOs) and all Combined Sewer Overflows (CSOs) are discharges of mixed stormwater and untreated wastewater directly to lakes and streams, and even into basements. CSOs result from excessive stormwater entering a sewer system. SSOs can be caused by precipitation or failure of the sewer system (blockage, breakage, etc.). In the case of an SSO, the sanitary sewer system is designed to collect and transport sanitary wastes only and stormwater is transported by a storm sewer system, whereas CSOs come from sewer systems designed to transport both stormwater and sanitary wastes in one pipe. Correction of CSOs and precipitation-related SSOs can be difficult and costly because of the size of the systems involved and the large areas they serve, resulting in huge volumes of stormwater to the systems.

Protecting Michigan's vast surface waters is important to the state's citizens. Therefore, Michigan implemented its current CSO control program around 1988. Appropriate controls for each community were chosen, and most are in place or under construction. Michigan's CSO program requires either separation of the combined sewer system or retention of all flows from storms up to the one-year, one-hour storm and treatment of the discharges above that size storm (including skimming, settling, and disinfection).

In Michigan, LID controls are not expected to be a benefit in terms of replacing or allowing a downsizing of end-of-pipe treatment. However, managing stormwater runoff by implementing LID through techniques such as infiltration, green roofs, and capture reuse reduces the volume of stormwater entering the sewer system. For combined sewers, volume reduction reduces the size or frequency of overflow events from the treatment basins. The cost of implementing LID for CSO control needs to be weighed against the needs of the receiving stream and the expected benefit. Where water quality concerns exist such as Total Maximum Daily Loads for nutrients, reduction of loadings from treated CSOs may be important.

CSO Retention Treatment Basin in the City of Birmingham
Source: Rouge River National Wet Weather Demonstration Project.

LID BMPs in CSO and SSO areas
CSO communities are generally older and heavily urbanized. Redeveloping and reclaiming older inner-city properties presents an opportunity to plant trees, increase open space, and decrease impervious surfaces. In addition, stormwater from roads and other impervious surfaces can be directed to these expanded open areas using methods like curb cuts in place of traditional catch basins and pipes.

For newly developing areas that discharge stormwater into combined sewers, LID methods prevent volume increases to these systems and avoid additional overflows. Traditional stormwater control methods can make problems worse if the volume of stormwater discharges increase.

For SSOs, Michigan law does not allow for the discharge of raw sewage. If the sewer system's excessive stormwater inputs can be partially addressed through LID, it may provide some benefit and should be considered in determining a final solution. SSOs can result when excessive stormwater enters the sanitary sewer either through direct inflow from manholes and improper connections or from infiltration of groundwater into pipes. Where excessive inflow is the concern, LID provides numerous opportunities for capturing stormwater and transporting it away from the sanitary sewer. If infiltration into the system is also of concern, LID infiltration techniques may need to be limited in the proximity of the sanitary system.

The following are examples of implementing LID techniques in an urban area as part of a CSO/SSO reduction strategy.

- Use rain gardens on residential property.
- Integrate cisterns into redevelopment projects.
- Use subsurface infiltration when renovating public parking lots.
- Create community-wide tree planting initiatives, especially where canopy extends over impervious surfaces.
- Integrate porous pavement in appropriate street and parking lots during renovation.
- Create community gardens and open space for areas cleared of unused structures that are not planned for new buildings.
- Plant vegetated roofs on redeveloped commercial and institutional buildings.
- Restore the riparian corridor during redevelopment and on public property.

Tollgate Drain Wetlands

City of Lansing

Source: Fishbeck, Thompson, Carr & Huber

The Tollgate Drain Drainage District is served by a county drain established in the late 1800s, but which no longer provided an adequate outlet for the densely developed residential neighborhoods served by a combined sewer system built in the 1950s. Frequent flooding was problematic. A CSO separation project was completed for the 210-acre Groesbeck neighborhood. The new Tollgate Drain was then designed to divert stormwater through a state-of-the-art stormwater treatment wetland located in Fairview Park with overflows to the Groesbeck Golf Course where the stormwater could be used for irrigation.

An entire Michigan ecosystem was conceived and designed into the Tollgate Wetlands, which is the focal piece of Fairview Park. This stormwater treatment system uses limestone cascades to aerate and neutralize the pH of the urban stormwater runoff, a peat filter for ion-exchange and removal of pollutants associated with urban runoff, level spreaders to disperse concentrated flows and allow for a wide-variety of native Michigan plants for water uptake and pollutant breakdown. A wet pond is also incorporated into the design to settle particulates before excess stormwater is recharged into the ground through irrigation at the Groesbeck Municipal Golf Course. The design results in a “zero discharge” stormwater system with a proven track record of water quality improvements and flood prevention.

The estimated cost to construct a traditional drain outlet to the Red Cedar River was about $20 million. This approach was rejected in favor of the innovative Tollgate Wetlands “zero discharge” approach. The final cost of the Tollgate Wetland project cost $6.2 million.

Implementing LID on Brownfield Sites

Every community in Michigan is in some stage of redevelopment. In many locations where redevelopment is underway, the previous use of the parcel has left behind a residue of pollution, which may constrain the types and extent of LID solutions for stormwater management. The general term used to describe such sites is “brownfields,” to distinguish them from the undeveloped fields of suburban development (or “greenfields) where only cultivation has taken place. Brownfields and the residual contaminants they contain are from a host of different uses including commercial, industrial, municipal waste handling, demolition, and even military.

Unlike many conventional developments, impervious footprints on brownfields cannot always be minimized through site designs that incorporate more porous surfaces to allow for infiltration. Direct infiltration on a brownfield site may introduce additional pollutant loads to groundwater and nearby surface waters. However, green infrastructure practices exist that can retain, treat, and then reuse or release stormwater without it ever coming in contact with contaminated soils.

Bioswale at Macomb County Administration Building, Mt. Clemens, MI.

Understand the contamination on the site

Well-planned stormwater management associated with brownfield redevelopment requires a thorough knowledge of the site's contamination. The extent of the location(s) of contamination, the maximum concentrations of the contaminants, and the risks associated with the contamination remaining in place are critical pieces of information in determining whether LID BMPs are appropriate.

Stormwater management associated with redevelopment of a brownfield site, when done without sufficient knowledge of site conditions, frequently results in increased loadings of contaminants to the stormwater system. Actions that cause contamination to migrate beyond the source property boundaries at levels above cleanup criteria are considered "exacerbation." Consequences associated with exacerbation of existing conditions exist under Michigan's cleanup programs. Increased infiltration that results in loadings to the local storm sewer systems may be exacerbation. The cleanup programs allow contamination to remain in place when the current and reasonably foreseeable site conditions would not result in any unacceptable risk. If the redevelopment of the site changes site conditions so that stormwater drainage patterns are changed, the risks must be further evaluated to ensure the conditions at the site remain protective and that the proposed stormwater management design will prevent exacerbation of the existing contamination.

When the contaminants on a site pose a threat to human health and the environment, the development proposal must first go through a due care review process mandated by the Michigan Department of Environmental Quality. Developers can take advantage of that process to discuss with the state methods for handling stormwater runoff, identifying areas and methods to avoid; and setting the groundwork for proper approaches.

General design considerations for brownfield sites

Once sufficient knowledge is available about the contamination on the site, brownfield redevelopment and LID techniques can be discussed. Brownfield redevelopment and LID both produce economic and environmental benefits by improving urban areas, protecting open space, and preventing further pollution of our water. However, in order to prevent further environmental damage by infiltrating precipitation through contaminated soil, onsite stormwater management must be done carefully, using particular design guidelines. Projects have been implemented across the country incorporating effective solutions to the challenge of developing a brownfield site with residual contamination, by incorporating appropriate natural systems for stormwater management.

The University of Michigan's School of Natural Resources and Environment developed the following design guidelines as part of a planning project that use low impact development techniques on contaminated sites. The following guidelines have been reviewed and adapted by the Michigan Department of Environmental Quality for this manual.

- **Avoid infiltration practices in contaminated area**. If infiltration is proposed and contaminated areas cannot be avoided, additional testing could demonstrate that residual contamination will not leach from the percolation of rainfall through the contaminated soils to groundwater in concentrations that present an unacceptable risk. If leach testing demonstrates infiltration would result

Horizontal grates can be added to a site as one way to separate stormwater from contaminated and non-contaminated areas. This was a measure employed at the Macomb County Public Administration Building to ensure that runoff from the site did not enter the storm drainage system in the older section of the parking lot, which directly drains to the Clinton River.

in additional unacceptable concentrations reaching the groundwater, design considerations to separate contaminated soils from contact with stormwater must be included.

LID practices on brownfield sites may include treatment and storage with reuse of stormwater rather than complete infiltration. Most brownfields that have residual contamination need caps, so vegetated areas need to be located above caps and fitted with underdrain systems to remove stormwater or reservoirs to capture it for later use.

Detention, retention, and biofiltration are suitable for contaminated sites when designed to prevent exfiltration to underlying soils and allow adequate time for water to be in contact with plants and trees for bioremediation. Infiltration trenches and basins collect stormwater and infiltrate or attenuate runoff. If fitted with filter devices for pre-treatment of contaminated water, these become wastewater treatment systems subject to requirements of National Pollutant Discharge Elimination System (NPDES) permits.

Permeable pavement and rain gardens are not usually suitable for sites with residual contamination that could be mobilized to groundwater, or to the storm sewer system in cases where these BMPs are underdrained. Additional features including impermeable liners and underdrains to storm sewers can be coupled with modified LID practices to safely filter stormwater without exposing the water to contaminated soils .

- **Retain/revegetate trees and vegetation**. Retaining and revegetating helps evapotranspirate stormwater runoff while intercepting large amounts of rainfall that would otherwise enter waterways as runoff.
- **Use impervious surfaces as additional caps**. When siting the development, consider locating buildings and other impervious surfaces over contaminated areas as long as escaping vapors or other contaminants are not present or are controlled to prevent health risks. The Macomb County case study strategically located the parking area over the small, contaminated area.
- **Implement practices that encourage evapotranspiration and capture/reuse**. Green roofs are an ideal way to reduce runoff from building roofs by encouraging evapotranspiration of rainwater. The redevelopment project at East Hills Center in Grand Rapids used a green roof for this purpose.

  Another option for brownfield sites is to capture and reuse stormwater for non-potable uses. This can include runoff storage in rain barrels for irrigation of green roofs or landscaped areas, or in cisterns that store rainwater for toilet flushing and other uses.
- **Include LID techniques in sites around brownfield areas**. New and redeveloped sites near brownfields should use green infrastructure practices to prevent additional runoff from flowing onto potentially contaminated areas.

The principle of separation

Keep clean stormwater separate from contaminated soils and water to prevent leaching and/or spread of contaminants.

LID uses soil and plants to clean and detain stormwater. This is an effective strategy on a wide range of sites, but it becomes more complicated when contaminants from historical uses are present. On brownfield sites, encouraging interaction between relatively clean stormwater and contaminated soil of contaminated groundwater can cause leaching of contaminants to groundwater, erosion of contaminated sediments, and lateral movement of contamination onto neighboring properties. In planners' and designers' enthusiasm to use LID, it is crucial that they avoid situations that could spread contamination from brownfield sites.

Redevelopment of a landfill: Fairlane Green

City of Allen Park

Fairlane Green, developed by Ford Land, is a one million-square-foot retail/recreational center with parks and trails on the 243-acre closed Allen Park Clay Mine Landfill. It is the largest landfill redevelopment project in Michigan and the largest in the country for retail use. The project incorporates environmentally friendly features including a 43-acre park, 3.5 miles of trails, and a three-phase retail development. In all, nearly two-thirds of the site is reestablished as natural green space.

Retail center that incorporated a cistern and rain garden.

Due to the potential for contamination, infiltration was not allowed on the site. The rain garden and detention basin BMPs did use liners to ensure infiltration did not occur.

In addition, redeveloping the industrial site required innovative methods to protect the landfill's integrity. Stress on the underlying landfill was reduced through a preloading soil fill program and lightweight geofoam fill. Geofoam was used in place of additional fill under buildings to eliminate additional weight on the landfill. These features allowed developers to reduce settlement levels and create shallow foundations.

Retail center with cistern for greywater needs

Developers maintained side slope stability with a soil buttress. The soil buttress helped stabilize one million cubic yards of fill on a 40-foot high slope. It was monitored to ensure safety during the construction process.

Utilities and foundations were placed in a landfill cap within an engineered fill layer. Nearly 17,000 feet of utilities were installed with utility corridor trenches lined with a combination geosynthetic clay liner and high density polyethylene (HDPE) liner. This liner prevented exfiltration and leakage from site utilities.

The Fairlane Green retail center includes prairie landscape and retention ponds which create natural habitat for wildlife that can flourish in an area that was previously unable to support them. A surprise bonus; the habitat attracted a snowy owl, the first in this area.

East Hills Center

City of Grand Rapids

The East Hills Center (EHC) project is a direct result of a 10-year organizing effort by the East Hills Association. The goal for the neighborhood was to revitalize a vacant, contaminated brownfield located within a mixed-use central corridor. The project redeveloped a former contaminated gas station into a net-zero stormwater discharge.

Vegetated roof on East Hills Center

Source: Fishbeck, Thompson, Carr, and Huber

The EHC effort began in 1994 when a neighborhood business was denied a building rehabilitation loan due to the contamination of the EHC site. For the next seven years, the neighborhood association campaigned for remediation of the site. The redeveloped East Hills Retail Center has become a LID example for urban infill projects.

Other green features

This project was selected by the U.S. Green Building Council (USGBC) as a pilot project for the LEED-CS rating system and received a gold level certification. The building was designed to have a highly insulated shell for maximum energy efficiency. The exterior walls were constructed with insulated concrete forms. Interior slabs are isolated from exterior surfaces to act as a heat sink for the sun's warming energy in the winter. An exterior and interior lightshelf was designed to control direct sunlight in the summer, while allowing the sun's warmth in the winter. The lightshelf bounces natural daylight into the spaces without direct sun glare.

Title: Rain garden at East Hills Center

Source: Fishbeck, Thompson, Carr, and Huber

Redevelopment using bioswales and rain gardens

Macomb County, City of Mt. Clemens

The Macomb County Department of Planning and Economic Development led an effort to transform an old gas station and automobile dealership, located in the City of Mt. Clemens, into a parking lot with numerous LID features. The contaminated section of the parking lot was capped and the parking lot and LID practices were designed to allow for infiltration BMPs only in areas not directly impacting the contaminated area.

Rain garden at Macomb County building in Mt. Clemens, MI

Source: Macomb County Planning and Economic Development

Four rain gardens and approximately 400 linear feet of bioswales were constructed on the site, which uses native plant materials that are very effective at holding stormwater in deep root systems and filtering out negative pathogens and pollutants.

The development also contains horizontal grates so runoff from the parking lot is completely captured and conveyed to the rain gardens and swales. This measure ensured that runoff from the site did not enter the storm drainage system in the older section of the parking lot, which directly drains to the Clinton River.

The price of the project was very similar in cost to a conventional development ($507,000), but less maintenance over the lifetime of this site will realize a more significant savings. The estimated maintenance costs for weeding, mowing, edging, and removing debris is $4,000 to $5,000 per year for the first two years and $2,000 to $4,000 after that.

From Model A to a model of redevelopment in Dearborn, MI

Ford Rouge Plant

Built by Henry Ford in the 1920s, the Rouge Truck Manufacturing Complex was a marvel of industrial efficiency. Raw materials went into one end of the plant and completed vehicles came out the other.

Native vegetation for stormwater infiltration at the Ford Rouge Center
Source: Atwell Hicks

Over time, the area devolved into a brownfield. In 2000, Ford Motor Company began a project to redevelop the plant as a model of sustainable manufacturing.

The centerpiece of stormwater management at this industrial area is a 10-acre green roof that can retain approximately 50 percent of the precipitation falling onto it. Additionally, it decreases the building's heating and cooling costs and will likely double the roof's lifespan.

World's largest green roof covering 454,000 square feet atop Ford's truck assembly plant in Dearborn, MI.

Other stormwater features include collecting excess runoff and reusing it throughout the plant. Porous pavement is used where new vehicles are parked; this allows water to drain through to a filter system that improves quality before it is used elsewhere. Due to the potential for contamination, infiltration was not allowed on the site. The BMPs (e.g., porous pavers) did use liners to ensure infiltration did not occur.

Landscaped swales and wetlands containing native plants, bushes, and trees remediate the soils surrounding the building by taking up, sequestering, and even treating pollutants that accumulated during more than 80 years of manufacturing. This vegetation also provides valuable habitat for wildlife and helps to clean water before it enters the nearby Rouge River. Water quality monitoring data show increased levels of dissolved oxygen necessary for fish and other species to thrive. Harmful bacteria levels are declining, which is beneficial not only to fish, but to the increasing numbers of people who enjoy spending time on the river.

Implementing LID in High Risk Areas

LID implementation can be an essential component of protecting high risk areas, such as sensitive streams and lakes. In addition, LID can be an important component in areas with public waters supply (e.g., wellhead protection areas) and karst areas; however, specific considerations to prevent pollution should be implemented.

LID BMPs for high risk areas

Use nonstructural BMPs as much as possible. High risk areas are areas where preventive nonstructural BMPs should be emphasized. These nonstructural BMPs work to prevent stormwater generation from the outset. In addition, certain structural BMPs (e.g., riparian corridor restoration and native revegetation) can also be used to prevent stormwater generation.

Consider additional requirements for "hotspot" land uses. A useful first step toward protecting high risk areas and implementing LID is to require special requirements for any and all land uses known to be especially pollutant-producing (either to surface water or to groundwater), the so-called "hot spots." In the Model Ordinance (Appendix H), specific provisions are included which target these "hot spot" land uses, requiring that specific pretreatment measures designed to manage the specific types of pollutants being generated are implemented at each development site. Tables 8.2 and 8.3 summarize the land uses and pretreatment options for these "hot spot" land uses.

Table 8.2
Pre-Treatment Options for Stormwater Hot Spots

Stormwater Hot Spots	Minimum Pre-Treatment Options
Vehicle Maintenance and Repair Facilities	A, E, F, G
Vehicle Fueling Stations	A, D, G
"Fast Food" Restaurants	B, C, D, I, K
Convenience Stores	B, C, D, I, K
Storage Areas for Public Works	A, B, D, E, F, G, H
Outdoor Storage of Liquids	G
Commercial Nursery Operations	I, J, L
Salvage Yards and Recycling Facilities*	M
Fleet Storage Yards and Vehicle Cleaning Facilities*	M
Facilities that Store or Generate Regulated Substances*	M
Marinas*	M
Certain Industrial Uses (listed under NPDES)*	M
Other Uses or Activities Designated by Appropriate Authority	As Required

**Regulated under the NPDES Stormwater Program*

Note: As used in this list, the term "Regulated Substances" shall mean any substances regulated under federal, state, or county environmental, pollution control, hazardous substance, and drinking water laws and regulations.

Table 8.3
Minimum Pre-Treatment Options

Minimum Pre-Treatment Options	
A	Oil/Water Separators/Hydrodynamic Devices
B	Sediment Traps/Catch Basin Sumps
C	Trash/Debris Collectors in Catch Basins
D	Water Quality Inserts for Inlets
E	Use of Drip Pans and/or Dry Sweep Material under Vehicles/Equipment
F	Use of Absorbent Devices to Reduce Liquid Releases
G	Spill Prevention and Response Program
H	Diversion of Stormwater away from Potential Contamination Areas
I	Vegetated Swales/Filter Strips
J	Constructed Wetlands
K	Stormwater Filters (Sand, Peat, Compost, etc.)
L	Stormwater Collection and Reuse (especially for irrigation)
M	BMPs that are a part of a Stormwater Pollution Prevention Plan (SWPPP) under a NPDES Permit

Use BMPs that protect water temperature. Sensitive streams and lakes, such as trout stream and trout lake designations, should consider the issue of temperature when selecting BMPs. In selecting a BMP, the goal is ensuring that runoff discharged from land development in warm weather months does not increase stream and lake temperatures which can result in harmful impacts to fish and other aquatic life. Michigan's trout species can't survive for more than brief periods in water temperatures above 70 degrees F (and lower temperatures for some species).

The following BMPs should be considered to manage temperatures:

- Protect or restore the riparian corridor.
- Protect or revegetate sensitive areas.
- Stormwater disconnection.
- Implement structural BMPs that control volume through infiltration.

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Chapter 9

Calculations and Methodology

This chapter describes design methods to calculate the level of control needed using LID techniques and how to select BMPs to meet those conditions. Chapters 6 and 7 provide detailed design criteria for each BMP. As described previously, LID designs are based on mimicking the presettlement hydrology as defined by groundwater recharge, stream channel stability, and flooding. LID methodology also provides treatment of pollutants carried in stormwater runoff.

Several methods of analysis may be used to produce a LID based site design. This manual will discuss many of them and the conditions where each may be most useful. The Curve Number method is widely used and is recommended for typical LID design calculations. The Curve Number (CN) method will be used throughout this chapter and on the associated worksheets to illustrate the design process.

The design process described here takes the user through full implementation of LID on a site. Users may choose to partially implement LID or implement some LID practices for specific purposes or to meet unusual site conditions. Some site conditions requiring special attention are addressed in Chapter 8 as well as modifications to the LID design process for those site conditions.

Throughout this document, the term "presettlement" is used to describe the initial condition of a site before development occurs. Defining the initial condition is important to determine the appropriate level of LID controls needed. Defining precisely what the appropriate initial condition was can be difficult. The term "predevelopment" is used routinely in other LID guidance documents as a generic statement referring to the site condition before development. "Presettlement" is a specific reference to that time period before significant human change to the landscape. For the purpose of LID design, this chapter defines presettlement as the presettlement site condition. To simplify LID design calculations, presettlement is further defined as either woods or meadow in good condition. This definition will not represent the actual presettlement condition of all land in Michigan. It does provide a simple, conservative value to use in site design that meets common LID objectives. Predevelopment may be defined in other ways based on site specific or watershed-specific study.

However, care should be given to apply consistent criteria throughout any given watershed in order to maintain a stable storm runoff response from the watershed.

Implementing a Community Stormwater Regulation

Stormwater management is a necessary component of water quality improvement and protection in a growing number of communities. Some communities may chose to adopt standards (e.g., through ordinance, engineering standards, rules) that would be implemented throughout the community. Appendix H contains a model stormwater ordinance that incorporates various elements of LID, including standards.

In developing a stormwater regulation, the following steps should be considered:

Step 1: Discuss and decide on water quality and quantity outcomes. Local communities need to consider the importance of achieving certain outcomes, including water quality protection, groundwater recharge, stream channel protection, and flood control. LID is a means of achieving all of these outcomes by mimicking presettlement hydrology.

Step 2: Adopt design standards that achieve desired outcomes. After determining the applicable outcomes, the next step is developing standards for the community. The recommended criteria presented in this chapter are designed to meet comprehensive water quantity (total volume and peak rate) and water quality objectives. Other factors that should be discussed include waivers for certain site considerations, how to address redevelopment, and the need to address flooding concerns.

Step 3: Select the stormwater methodologies to meet the design standards. A final decision is determining the acceptable calculation methodologies that can be used to meet the standards.

LID Design Criteria

Defining the hydrology of the site is based on three criteria — groundwater recharge, stream channel protection, and flood control. A fourth criterion — water quality protection — is used to determine the level of treatment necessary to remove pollutants from stormwater runoff. Each is defined in the following ways.

Groundwater recharge

According to U.S. Geological Survey and others, over 90 percent of annual precipitation infiltrates into the soil in Michigan watersheds under natural (presettlement) conditions. More than half of this infiltration volume is taken up by vegetation and transpired or evaporated. The rest of this infiltrated water moves down gradient to feed local wetlands, lakes, springs and seeps, and surface streams as base flow, and/or enters the deeper aquifers that supply drinking water wells.

Although groundwater recharge volumes and percentages vary around the state, recharge remains a vitally important element of the water cycle in most areas. Without the continuous recharge of groundwater aquifers from precipitation, surface stream flows and groundwater in wells would be reduced or even disappear during drought periods and would be impacted year-round.

Groundwater design criteria: Instead of developing a separate groundwater recharge criteria, this can be accomplished by implementing a volume control criteria and maximizing the use of infiltration BMPs.

Stream channel protection

Stream channels develop their shape in response to the volume and rate of runoff that they receive from their contributing watersheds. Research has shown that in hydrologically stable watersheds, the stream flow responsible for most of the shaping of the channel (called the bankfull flow) occurs between every one to two years. When land is developed, the volume and rate of runoff from that land increases and the stream channel will adapt by changing its shape. As the stream channel works to reach a new stable shape, excess erosion occurs.

Channel protection is achieved by matching the post construction runoff volume and rate to the presettlement condition for all runoff events up to the bankfull flow. In a stable stream channel, the channel-forming flow would often correspond to the rain event of the same frequency. So a 1.5 year flow would roughly correspond to a 1.5 year rain event. Site specific channel forming flows could be determined through a morphological analysis of the stream channel receiving the stormwater runoff. Nearly all channel forming flows in hydrologically stable watersheds occur with a frequency of between one and two years. The return frequency for channel forming flow for most streams in Michigan is 1.5 years. To choose design condition for stream channel protection it would be best to have a site specific morphological study identifying the most accurate return frequency for the channel forming flow.

Channel protection criteria: Without a site specific study or analysis, LID site design based on no increase of the presettlement runoff condition for all storms up to the two-year, 24-hour return frequency storm provides the most assurance that the stream channel will be protected.

In addition to channel protection, this criterion provides the following LID design benefits:

- The two-year event encompasses about 95 percent of the annual rainfall volume (Figure 9.1) across the state and equals or exceeds presettlement groundwater recharge volumes.
- Volume reduction BMPs based on this standard provide a storage capacity to substantially reduce the increase in peak flow rates for larger runoff events (most out-of-bank events and many so-called extreme events).
- If this volume control is accomplished through infiltration/vegetative BMPs, water quality criteria, including temperature control, is achieved as well.
- The two-year, 24-hour storm is well defined and data ares readily accessible for use in stormwater management calculations.

In waterbodies that are so large that the added volume from localized stormwater runoff is insignificant, or where channel erosion will not occur for other reasons, channel protection criteria become unnecessary. These waterbodies include the Great Lakes and their connecting channels and lakes with rock or concrete-lined channels leading to the Great Lakes (e.g., Muskegon Lake). Implementing the channel protection criteria may still be desired in these situations to maintain groundwater recharge or control localized flooding.

As stated previously, maintaining the presettlement runoff volume is most often accomplished using infiltration BMPs. There are a number of site conditions that will either limit infiltration or eliminate it as an option altogether. Volume reduction can still be accomplished in these circumstances through the use of BMPs that provide significant interception and evapotransporation such as vegetated roofs and bioretention, and capture and reuse of stormwater. Off-site or nearby regional volume control consistent with LID concepts may also be appropriate.

However, on some sites maintaining the presettlement runoff volume may not be possible within a reasonable cost. When this occurs, volume reduction should still be maximized to the extent practicable, and the one-year, 24-hour storm event should be detained and released over at least a 24-hour period (i.e., extended detention of the one-year, 24-hour storm must be provided). Simply maintaining the presettlement peak rate of runoff is not protective of stream channels in many cases and, therefore, extended detention **greater than is needed to maintain the predevelopement peak rate should be provided at a minimum** (see Center for Watershed Protection's "Manual Builder" at www.stormwatercenter.net/Manual_Builder/Sizing_Criteria/Channel%20Protection/Stream%20Channel%20Protection%20Volume%20Requirements.htm).

Whenever possible, this detention should be provided using infiltration practices that are lined, underdrained, and ultimately discharge. In this way, detention lowers the peak rate of multiple storms up to the design runoff condition, is not subject to the same clogging concerns, and provides better water quality treatment.

Maximizing volume reduction to the extent possible, even if less than the two-year volume, will reduce the size of peak runoff rate controls and water quality controls and are recommended for any LID site design. Similarly, maintaining time of concentration in new development and lengthening time of concentration in site redevelopment will assist in peak runoff rate control and should also be pursued.

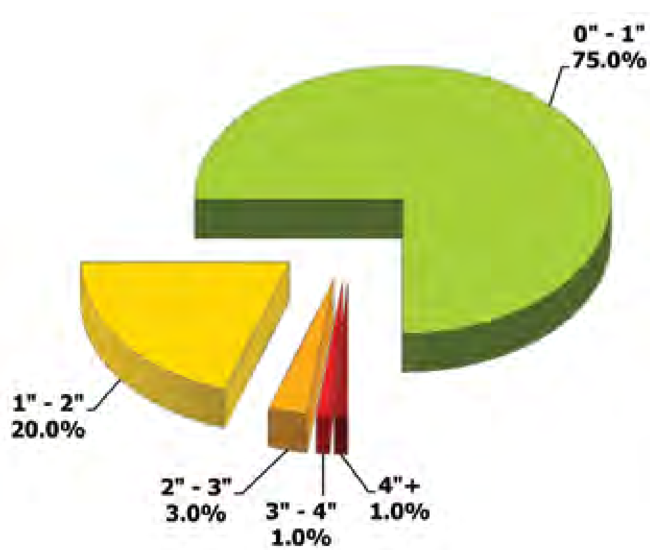
Including waivers in your stormwater regulation

Communities implementing a volume control standard based on this manual need to provide for alternatives from the standard to account for constraints on certain sites. Site constraints include but aren't limited to: poor draining soils, contaminated soils, bedrock, karst geology, highwater table, or other constraints where commonly used LID BMPs would either be impractical, pose a threat of groundwater contamination, and stormwater reuse is not feasible. Communities should require documentation of the reason an alternative design standard is being used such as site infiltration testing, evaluation of reuse alternatives or potential for evapotransporation mechanisms such as green roofs. A community may wish to identify an alternative standard to areas which have specific, known design limitations.

At a minimum for qualifying sites, an alternative standard should be applied that requires detention of the one-year, 24-hour storm with release at the pre-settlement peak runoff rate. A water quality treatment volume should also be specified.

The model ordinance (Appendix H) provides language that includes these exemptions.

Figure 9.1.
Rainfall Distribution by Storm Size for Lansing, MI based on Daily Precipitation Values from 1948-2007. The two-year, 24-hour storm is 2.42 inches.



Flood control

Flood control is based on protecting life and property. Mimicking the presettlement hydrology with respect to flooding will reduce the frequency and intensity of flooding, but out-of-bank flows are a natural process and will still occur. Flood control criteria are ultimately determined locally based on drainage needs and flood risk of any particular area and may go beyond LID design criteria to achieve the necessary level of flood protection.

Where runoff volume is maintained to the presettlement value for any given storm, the presettlement peak runoff rate will also be maintained up to the same storm. Additionally, runoff volume controls implemented for small storms but not larger, less frequent storms will reduce the size of peak runoff rate control for larger storms. Where peak rate runoff control is used alone with a fixed rate of release, runoff from storms smaller than the design storm receive limited or no peak rate reduction.

Maintaining the presettlement runoff volume by implementing LID-based site designs for the entire range of design runoff events has several benefits. However, as storms increase in size the incremental benefit of volume control for each larger storm becomes less significant and, at some larger storm event, the control of peak runoff rate becomes the only critical basis for design. When additional flood protection is needed beyond maintaining the presettlement hydrology, additional peak runoff rate control is applied.

Flood protection criteria: Maintain presettlement runoff volume and rate for all storms up to the two-year event. Maintain presettlement runoff volume for additional storms as practicable for the site conditions up to the 100-year event or the event determined by local standard. Maintain the presettlement peak runoff rate for all storms up to the 100-year event or the event determined by local standard.

Water quality protection

Impervious (and some pervious) surfaces associated with land development are known to generate a wide range of potentially harmful loads of nonpoint source pollutants. These surfaces accumulate pollutants that are picked up by stormwater runoff and carried to our lakes and streams. Examples of these pollutants include:

- Bacteria from pet waste, goose droppings, and other wildlife.
- Nutrients from excessive fertilizer left on streets, sidewalks, and lawns.
- Suspended solids from erosive stream banks, roadways, and construction sites.
- Hydrocarbons and trace metals from leaky vehicles.
- Chlorides from road salt.

Runoff picks up or washes off pollutants during the course of a storm event. After some time during an event most of the pollutants are carried away and the remainder of the runoff is relatively clean. This concentration of pollutants in the initial stormwater runoff is often called a “first flush” and is particularly true of impervious surfaces. Exposed soil, however, could wash off soil particles for the entire duration of an event.

Additional flood information for your stormwater regulation

Community stormwater standards for flood control are based on protecting life and property above all else. When developing flood protection standards, a community must first identify the level of flood protection needed. Many factors will determine the level of flood control needed such as location in a watershed, proximity to a waterbody, and type of current drainage. It is not cost effective to require or provide flood protection above a certain size, infrequent storm. In Michigan, many communities provide some level of control up to the 100-year storm.

Computer simulations are used to determine the effect of controls on the extent or frequency of flooding for the storms of interest.

Many existing flood control standards are based on maintaining some fixed rate of runoff from an area or site for a given storm. Using the LID design criteria described in this manual will often meet or exceed these criteria. However, there are some areas where LID controls may not be sufficient to reduce the risk of flooding necessary to offer the level of protection identified by the local community. Additional control may be provided through additional volume control for larger less frequent storms or fixed-rate control.

Local standards should define the level of flood control needed and provide that appropriate controls are applied as necessary in addition to LID controls to meet the flood criteria when LID controls alone are insufficient.

A community may also allow exemptions from the flood standard for such issues as small sites or direct discharge to a major river or lake.

The model ordinance (Appendix H) provides language that includes additional considerations.

The nature of stormwater runoff makes it difficult to sample actual runoff quality and treatment efficiency for individual practices on a routine basis. An acceptable alternative to determine if adequate treatment is provided is to calculate the volume of water expected to carry the majority of pollutants at the beginning of a rain event and treat that volume with BMPs that will remove the pollutants expected from that source of runoff. An accepted quantitative goal to determine adequate water quality protection is to achieve an 80 percent reduction in post-development particulate associated pollutant load as represented by Total Suspended Solids based on post-development land use.

The expected treatment of many BMPs applied to LID designs is based on removing solids. Many pollutants are attached to solids or are removed by similar treatment mechanisms. Therefore, removing solids can act as a surrogate for the expected removal of other particulate pollutants. Often multiple BMPs will be necessary to remove successively smaller particle sizes to achieve the highest level of treatment.

The water quality volume is normally, but not always less than the channel protection volume. Where infiltration BMPs are used to fully obtain the channel protection volume, the water quality volume should be automatically addressed. There are a number of ways to determine the volume of runoff necessary to treat for water quality.

- **0.5 inch of runoff** from a single impervious area. This criterion was one of the first to define the "first flush" phenomenon by studying runoff from parking lots. It was been widely used as the design water quality volume. Additional research has found that this criterion for water quality volume only applies to runoff from a single impervious area, such as the parking lot to a single development. It is the minimum value that could be expected to capture the runoff containing the most pollutants. It is not appropriate for a mixture of impervious areas and pervious areas. It is also not appropriate to use for multiple impervious areas treated by a single BMP or multiple BMPs. Although it may have applications in some limited circumstances, it is not recommended that this method be used to calculate water quality volume.
- **One inch of runoff from all impervious areas and 0.25 inches of runoff from all disturbed pervious areas**. This method provides reasonable certainty that the runoff containing the majority of pollutants from impervious areas is captured and treated by applying a simple calculation. It assumes that disturbed pervious areas contribute less runoff and therefore less pollutant to the BMPs selected. This method is recommended when the percentage of impervious area on a site is small and both pervious and impervious areas are treated by the same BMP.
- **One inch of runoff from disturbed pervious and impervious areas**. This is the most conservative water quality volume calculated with a simple formula. It virtually assures that all of the first flush from any site will be captured and treated. However, when calculated this way the water quality volume may exceed the channel protection volume. The volume determined using this method should always be compared to the channel protection volume to determine if additional water quality treatment is necessary. This method is an appropriate way for any site to calculate a simple yet rigorous water quality volume. It eliminates the need for detailed soil/land cover descriptions, choosing an appropriate storm, and rainfall-runoff calculations. The resulting volume will typically be less than the "one inch of runoff from disturbed pervious and impervious areas" and slightly more than the "90 percent of runoff producing storms" method listed below.
- **90 percent of runoff producing storms**. This method determines the water quality volume by calculating the runoff generated from the 10 percent exceedence rain event for the entire site. In Michigan, that event varies from 0.77 to 1.00 inch. This method provides a more rigorous analysis based on the response of the land type of the site. In order to accurately represent the pervious portion of runoff needing treatment, the runoff calculation for this method must use the small storm hydrology method described later in this chapter. The water quality volume calculated in this way produces a lower volume than using one inch of runoff but still ensures treatment of the first flush. The 10 percent exceedance storm values for 13 climatic regions of the state can be found in Table 9.1. This method is recommended when a precise estimate of water quality volume is desired or for multiple distributed sites treated by one BMP.

Table 9.1
90 Percent Nonexceedance Storm Values

Weather Station	Kenton	Champion Van Riper	Newberry	Kalkaska	Mio	Baldwin	Alma	Saginaw Airport	Cass City	Gull Lake	Lansing	East Lansing	Detroit Metro
Station Number	4328	1439	5816	4257	5531	0446	0146	7227	1361	3504	4641	2395	2103
Zone*	1		2	3	4	5	6	7		8	9		10
90 percent nonexceedance storm	0.95	0.87	0.84	0.77	0.78	0.93	0.93	0.92	0.87	1.00	0.90	0.91	0.90

Source: Dave Fongers, Hydrologic Studies Unit, Michigan Department of Environmental Quality. Memo: 90 Percent Annual Nonexceedance Storms. March 24, 2006. http://www.michigan.gov/documents/deq/lwm-hsu-nps-ninety-percent_198401_7.pdf

*See Figure 9.2 Climatic Zones for Michigan

Other water quality issues. Additional issues must be considered when protecting water quality, including soluable pollutants and high risk areas.

- **Soluble pollutants**. Materials that dissolve in stormwater are of special concern in those areas where soils are rapidly draining (e.g., Hydrologic Soil Group A) with cation exchange capacity values of less than 10 milliequivalents per 100 grams. In these cases, groundwater protection requires that volume control BMPs that are infiltrating provide additional measures, such as inclusion of organic filtering layers, in their design. Additionally, the use of soluble substances such as road salt (chlorides) and fertilizers (nitrates) on areas treated by infiltration BMPs should be limited or less soluble alternatives found.
- **Hot spot and high risk areas**. Some areas of a site, such as karst topography or proximity to drinking water wells may be particularly susceptible to stormwater contaminants. Conversely, sites may be contaminated with pollutants that should not be transported off site in storm runoff. When development is planned for these sites, specific BMPs or design modifications should be included in the overall stormwater plan to ensure protection of both surface and groundwater systems.

Evapotranspiration (ET) and the natural hydrologic/water cycle

The previous design criteria are often quantified in terms of the water cycle factors of runoff and infiltration, but the additional cycle variables of evaporation and transpiration also are critical. Development that results in clearing the existing vegetation from a site removes the single largest component of the hydrologic regime — evapotranspiration (ET). The post-development loss in ET can significantly increase not only runoff, but also groundwater recharge that may have impacts on existing developments (i.e., basement flooding) and certain groundwater dominant rivers and streams. Vegetated swales and filter strips, tree planting, vegetated roof systems, rain gardens, and other "green" BMPs help replace a portion of lost ET.

Evapotransporation is difficult to quantify. The design criteria recommended here is to minimize the loss of ET by protecting existing vegetated areas and replacing vegetation lost or removed with vegetation exhibiting similar ET qualities as much as possible.

Selecting design criteria

LID design is based on reproducing the presettlement hydrology of a site. Specific selection of design criteria should be based on achieving this goal while meeting local, state, and federal regulations. The criteria described here will apply to the majority of situations in Michigan. However, site specific or watershed studies may provide suitable alternative design criteria to achieve the same result. Additionally, some sites will be constrained by conditions that either limit the use of LID or require design and implementation of additional or alternative measures to meet LID goals.

Reducing disturbed areas and protecting sensitive areas

The first step of any LID site design is to minimize the area of disturbance for a site. Any portion of a site that can be maintained in its presettlement state will not contribute increased stormwater runoff and will reduce the amount of treatment necessary. This manual includes nonstructural BMPs that describe methods to protect sensitive areas. Any area that is protected as described in those BMPs may be subtracted from site development for purposes of designing LID-based treatments.

Credits

Credits are used in the design process to emphasize the use of BMPs that, when applied, alter the disturbed area in a way that reduces the volume of runoff from that area. Credits are given for five BMPs because they enhance the response of a piece of land to a storm event rather than treat the runoff that is generated. These BMPs are encouraged because they are relatively easy to implement over structural controls, require little if any maintenance, and the land they are applied to remains open to other uses. The credit only works with designs based on the Curve Number or CN method of analysis described later in this chapter. Credit is applied by modifying the CN variable so that the amount of runoff generated from an event is reduced.

The BMPs that generate a design credit are:

- Minimize Soil Compaction
- Protection of Existing Trees (part of Minimize Disturbed Area)
- Soil Restoration
- Native Revegetation
- Riparian Buffer Restoration

Calculating runoff

Many methodologies have been developed to estimate the total runoff volume, the peak rate of runoff, and the runoff hydrograph from land surfaces under a variety of conditions. This section describes some of the methods that are most widely used in Michigan and throughout the country. This is not a complete list of procedures nor is it intended to discourage using alternative methods as they become available.

The runoff Curve Number (CN) method is widely applied for LID designs around the country and is applicable for most site designs in Michigan. This manual recommends the use of the CN method for LID design and applies that method in design guidance and examples. The other methods discussed here may be equally as applicable within the limitations of each method. The ultimate selection of the method used should be determined on the applicability of the method to the site design, the preference of the user, and local requirements.

There are also a wide variety of public and private domain computer models available for performing stormwater runoff calculations. The computer models use one or more calculation methodologies to estimate runoff characteristics. The procedures most commonly used in computer models are the same as those discussed below.

In order to facilitate a consistent and organized presentation of information throughout the state, assist design engineers in meeting the recommended site design criteria, and help reviewers analyze project data, a series of worksheets are included in this chapter for design professionals to complete and submit with their development applications.

Methodologies for runoff volume calculations

Numerous methodologies available for calculating runoff volumes. Runoff curve number, small storm hydrology method, and infiltration models are described below.

Runoff Curve Number (CN) Method (Recommended)

The Runoff Curve Number Method, sometimes referred to as TR55 and developed by the Soil Conservation Service (now the Natural Resources Conservation Service), is perhaps the most commonly used tool in the country for estimating runoff volumes. In this method, runoff is calculated using the following formula:

$$Q_v = \frac{(P - I_a)^2}{(P - I_a) + S}$$

where:

Q = runoff volume (in.)

P = rainfall (in.)

I_a=initial abstraction (in.)

S=potential maximum retention after runoff begins (in.)

Initial abstraction (I_a) includes all losses before the start of surface runoff: depression storage, interception, evaporation, and infiltration. SCS has found that I_a can be empirically approximated for typical land uses by:

$$I_a = 0.2S$$

Therefore, the runoff equation becomes:

$$Q_v = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

Finally, S is a function of the watershed soil and cover conditions as represented by the runoff curve number (CN):

$$S = \frac{1000}{CN} - 10$$

Therefore, runoff can be calculated using only the curve number and rainfall.

Curve numbers are determined by land cover type, hydrologic condition, antecedent runoff condition (ARC), and hydrologic soil group (HSG). Curve numbers for various land covers based on an average ARC for annual floods and $I_a = 0.2S$ can be found in *Urban Hydrology for Small Watersheds* (Soil Conservation Service, 1986) and various other references. Table 9.2 includes some of the more commonly used curve numbers from *Urban Hydrology for Small Watersheds*.

Note that the hydrologic soil group is sometimes mapped with a dual specification such as A/D, B/D, etc. This refers to soils that are specified as D soils in an undrained state and a specification with higher infiltration capacity when they are drained. For designing LID controls, it is important to use the same hydrologic soil group to calculate presettlement runoff as the post-development runoff. The user must pick the most appropriate hydrologic soil group to apply to both conditions.

Often a single, area-weighted curve number is used to represent a watershed consisting of subareas with different curve numbers. This approach is acceptable only if the curve numbers are similar. When curve numbers differ by a significant margin, the use of a weighted curve number significantly reduces the estimated amount of runoff from the watershed. This is especially problematic with pervious/impervious combinations "combination of impervious areas with pervious areas can imply a significant initial loss that may not take place." (Soil Conservation Service, 1986) Therefore, the runoff from different subareas should be calculated separately and then combined or weighted appropriately. At a minimum, runoff volume from pervious and directly connected impervious areas should be estimated separately for storms less than approximately four inches. (NJDEP, 2004 and PADEP, 2006)

Table 9.2
Commonly used curve numbers (CNs) from TR-55

Runoff curve numbers for urban areas[1]				
Cover Description	**Curve numbers for hydrologic soil group**			
Cover Type and hydrologic condition*	A	B	C	D
Open spaces (parks, golf courses, cemeteries, etc.)[2]				
Poor condition (grass cover < 50%)	68	79	86	89
Fair condition (grass cover 50% to 75%)*	49	69	79	84
Good condition (grass cover > 75%)*	39	61	74	80
Impervious Areas:				
Paved parking lots, roofs, driveways, etc. (excluding right of way)	98	98	98	98
Streets and Roads				
Paved; curbs and storm sewers (excluding right of way)	98	98	98	98
Paved, open ditches (including right of way)	83	89	92	93
Gravel (including right of way)	76	85	89	91

1 Average runoff condition, and $I_a = 0.2S$.
2 CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

Table 9.2 Contiuned

Runoff curve numbers for other agricultural lands[1]					
Cover Description		**Curve numbers for hydrologic soil group**			
Cover Type*	**Hydrologic condition**	A	B	C	D
Pasture, grassland, or range – continuous forage for grazing.[2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow – continuous grass, protected from grazing and generally mowed for hay.		30	58	71	78
Brush – brush-weed-grass mixture with brush the major element.[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30[4]	48	65	73
Woods-grass combination (orchard or tree farm).[5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods.[6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30[4]	55	70	77
Farmsteads – buildings, lanes, driveways, and surrounding lots.		59	74	82	86

1 Average runoff condition, and $I_a = 0.2S$.

2 Poor: <50% ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.

3 Poor: <50% ground cover.
Fair: 50 to 75% ground cover.*
Good: >75% ground cover.*

4 Actual curve number is less than 30; use CN = 30 for runoff computations.

5 CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

6 Poor: Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

* To account for the land development process, all disturbed pervious areas that are not restored using one of the techniques in Chapter 7 should be assigned a curve number that reflects a "fair" hydrologic condition as opposed to a "good" condition for post-development volume calculations. For example, lawns should be assigned curve numbers of 49, 69, 79, and 84 for soil groups A, B, C, and D respectively.

The Curve Number Method is less accurate for storms that generate less than 0.5 inch of runoff; the Soil Conservation Service (1986) recommends using another procedure as a check for these situations. For example, the storm depth that results in 0.5 inch of runoff varies according to the CN. For impervious areas (CN of 98) it is a 0.7-inch storm; for "open space" in good condition on C soils (CN of 74) it is 2.3 inches; for woods in good condition on B soils (CN of 55) it is over 3.9 inches. The CN methodology can also significantly underestimate the runoff generated from smaller storm events. (Claytor and Schueler, 1996 and Pitt, 2003) An alternate method for calculating runoff from small storms is described below.

Recently, some researchers have suggested that the assumption that $I_a = 0.2S$ does not fit the observed rainfall-runoff data nearly as well as $I_a = 0.05S$. Incorporating this assumption into the Curve Number Method results in a new runoff equation and new curve numbers. Woodward et al. (2003) describe the new runoff equation and a procedure to convert traditional CNs to new values based on $I_a = 0.05S$. They also describe a plan to implement these changes into all appropriate NRCS documents and computer programs. The most notable differences in runoff modeling with these changes occur at lower curve numbers and lower rainfalls (using the traditional curve number assumption of $I_a = 0.2S$ results in higher initial abstractions and lower runoff volumes under these conditions). When used to predict runoff from developed sites in Michigan during typical design storms, the difference is likely to be insignificant. It is recommended that the traditional relationship of $I_a = 0.2S$ be used until additional research supports the new method.

The Curve Number Method, applied with appropriate CNs and the above considerations in mind, is recommended for typical runoff volume calculations and is used in the design worksheets at the end of this chapter.

Small Storm Hydrology Method

The Small Storm Hydrology Method (SSHM) was developed to estimate the runoff volume from urban and suburban land uses for relatively small storm events. (Other common procedures, such as the Runoff Curve Number Method, are less accurate for small storms as described previously.) The SSHM is a straightforward procedure in which runoff is calculated using volumetric runoff coefficients. The runoff coefficients, R_v, are based on extensive field research from the Midwest, the Southeastern U.S., and Ontario, Canada, over a wide range of land uses and storm events. The coefficients have also been tested and verified for numerous other U.S. locations. Runoff coefficients for individual land uses generally vary with the rainfall amount – larger storms have higher coefficients. Table 9.3 lists SSHM runoff coefficients for seven land use scenarios for 0.5 and 1.5-inch storms.

Runoff is calculated by multiplying the rainfall amount by the appropriate runoff coefficient (it is important to note that these volumetric runoff coefficients are not equivalent to the peak rate runoff coefficient used in the Rational Method, discussed below). Since the runoff relationship is linear for a given storm (unlike the Curve Number Method), a single weighted runoff coefficient can be used for an area consisting of multiple land uses. Therefore, runoff is given by:

$$Q = P \times R_v$$

Where: Q = runoff (in.)

P = rainfall (in.)

R_v = area-weighted volumetric runoff coefficient

Table 9.3
Runoff Coefficients for the Small Storm Hydrology Method

Rainfall (in.)	Volumetric Runoff Coefficients, R_v						
	Impervious Areas				Pervious Areas		
	Flat Roofs/ Large Unpaved Parking Areas	Pitched Roofs	Large Imperv. Areas	Small Imperv. Areas and Uncurbed Roads	Sandy Soils (HSG A)	Silty Soils (HSG B)	Clayey Soils (HSG C & D)
0.5	0.75	0.94	0.97	0.62	0.02	0.09	0.17
1.5	0.88	0.99	0.99	0.77	0.05	0.15	0.24

Source: Adapted from Pitt, 2003.

Infiltration models for runoff calculations

Several computer packages offer the choice of using soil infiltration models as the basis of runoff volume and rate calculations. Horton developed perhaps the best-known infiltration equation – an empirical model that predicts an exponential decay in the infiltration capacity of soil towards an equilibrium value as a storm progresses over time (Horton, 1940). Green and Ampt (1911) derived another equation describing infiltration based on physical soil parameters. As the original model applied only to infiltration after surface saturation, Mein and Larson (1973) expanded it to predict the infiltration that occurs up until saturation (James, et al., 2003). These infiltration models estimate the amount of precipitation excess occurring over time. Excess precipitation must then be transformed to runoff with other procedures to predict runoff volumes and hydrographs.

Methodologies for peak rate/hydrograph estimations

There are numerous methods for estimating peak rate, including the Rational Method, NRCS Unit Hydrograph method, and Modified Unit Hydrograph Method. This manual recommends the use of the NRCS (SCS) Unit Hydrograph method to calculate peak runoff rate for LID design and applies that method in design guidance and examples. The other methods discussed here may be equally as applicable within the limitations of each method. The ultimate selection of the method used should be determined on the applicability of the method to the site design, the preference of the user, and local requirements.

Regardless of the method of analysis selected, the same method must be used to calculate pre- and post-development runoff.

NRCS (SCS) Unit Hydrograph Method (Recommended)

In combination with the Curve Number Method for calculating runoff volume, the Soil Conservation Service (now NRCS) also developed a system to estimate peak runoff rates and runoff hydrographs using a dimensionless unit hydrograph (UH) derived from many natural unit hydrographs from diverse watersheds throughout the country (NRCS Chapter 16, 1972). As discussed below, the SCS methodologies are available in several public domain computer models including the TR-55 computer model (WinTR-55, 2005), TR-20 Computer Program (WinTR-20, 2005), and is an option in the U.S. Army Corps of Engineers' Hydrologic Modeling System (HEC-HMS, 2006).

Modified Unit Hydrograph Method for Michigan

The Michigan Department of Environmental Quality has developed a modified unit hydrograph method that better represents conditions in Michigan and addresses the fact that the traditional NRCS UH "consistently overestimates discharges when compared to recorded gage flows for Michigan streams." (*Computing Flood Discharges For Small Ungaged Watersheds*, MDEQ 2008, available online at www.michigan.gov/documents/deq/lwm-scs_198408_7.pdf.

The result is a relatively simple equation for calculating the unit peak flow rate from the time of concentration:

$$Q_{up} = 238.6 \times T_c^{-0.82}$$

Where:

Q_{up}= unit peak discharge (cfs per inch of runoff per square mile of drainage area)

T_c= time of concentration (hours) Note: Tc must be at least one hour. If Tc is less than one hour, use TR-55 or HEC-HMS.

The unit peak discharge (cfs/in./mi^2) calculated above can be converted to the peak runoff rate (cfs) by multiplying by the drainage area in square miles and by the runoff in inches (calculated by the Runoff Curve Number Method described in section 9.2.1):

$$Q_p = Q_{up} \times A \times Q_v$$

Where:

Q_p= peak runoff rate (cfs)

A = drainage area (square miles)

Q_v= total runoff volume from CN method (in.)

The Modified UH Method for Michigan is recommended for calculating the peak rate of runoff for presettlement conditions and undisturbed areas.

The Rational Method

The Rational Method has been used for over 100 years to estimate peak runoff rates from relatively small, highly developed drainage areas. The peak runoff rate from a given drainage area is given by:

$$Q_p = C \times I \times A$$

Where:

Q_p= peak runoff rate (cubic feet per second, cfs)

C = the runoff coefficient of the area (assumed to dimensionless)

I = the average rainfall intensity (in./hr) for a storm with a duration equal to the time of concentration of the area

A= the size of the drainage area (acres)

The runoff coefficient is usually assumed to be dimensionless because one acre-inch per hour is very close to one cubic foot per second (1 ac-in./hr = 1.008 cfs). Although it is a simple and straightforward method, estimating both the time of concentration and the runoff coefficient introduce considerable uncertainty in the calculated peak runoff rate. In addition, the method was developed for relatively frequent events so the peak rate as calculated above should be increased for more extreme events. (Viessman and Lewis, 2003) Because of these and other serious deficiencies, the Rational Method should only be used to predict the peak runoff rate for very small (e.g., 1 acre) highly impervious areas. (Linsley et. al, 1992)

Although this method has been adapted to include estimations of runoff hydrographs and volumes through the Modified Rational Method, the Universal Rational Hydrograph, the DeKalb Rational Hydrograph, etc., these are further compromised by assumptions about the total storm duration and therefore should not be used to calculate volumes related to water quality, infiltration, or capture/reuse.

Computer models for calculating runoff

Numerous models are available that assist in estimating runoff from a site. These include:

- HEC Hydrologic Modeling System (HEC-HMS)
- SCS/NRCS Models: WinTR-20 and WinTR-55
- Storm Water Management Model (SWMM)
- Source Loading and Management Model (SLAMM)

HEC Hydrologic Modeling System (HEC-HMS)

The U.S. Army Corps of Engineers' Hydrologic Modeling System (HEC-HMS, 2006) supersedes HEC-1 as "new-generation" rainfall-runoff simulation software.

HEC-HMS was designed for use in a "wide range of geographic areas for solving the widest possible range of problems." The model incorporates several options for simulating precipitation excess (runoff curve number, Green & Ampt, etc.), transforming precipitation excess to runoff (SCS unit hydrograph, kinematic wave, etc.), and routing runoff (continuity, lag, Muskingum-Cunge, modified Puls, kinematic wave).

SCS/NRCS Models: WinTR-20 and WinTR-55

WinTR-20 model is a storm event surface water hydrologic model. It can be used to analyze current watershed conditions as well as assess the impact of proposed changes (alternates) made within the watershed. Direct runoff is computed from watershed land areas resulting from synthetic or natural rain events. The runoff is routed through channels and/or impoundments to the watershed outlet. TR-20 applies the methodologies found in the Hydrology section of the National Engineering Handbook (NRCS, 1969-2001), specifically the runoff Curve Number Method and the dimensionless unit hydrograph. (SCS, 1992) .

Technical Release 55 (TR-55) generates hydrographs from urban and agricultural areas and routes them downstream through channels and/or reservoirs. WinTR-55 uses the TR-20 model for all of its hydrograph procedures. (NRCS, 2002).

Storm Water Management Model (SWMM)

The EPA Storm Water Management Model (SWMM) is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each subcatchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps.

Source Loading and Management Model (SLAMM)

The Source Loading and Management Model (SLAMM) is designed to provide information about the sources of critical pollutants in urban runoff and the effectiveness of stormwater BMPs for controlling these pollutants. SLAMM was primarily developed as a planning level model to predict flow and pollutant discharges from a wide variety of development conditions using many combinations of common stormwater BMPs. Because of their importance for pollutant loading, SLAMM places special emphasis on small storms and uses the Small Storm Hydrology Method to calculate surface runoff (Pitt and Voorhees 2000).

Continuous modeling

The methodology included in this chapter is based on single-event calculations using hypothetical design storms (e.g., the two-year, 24-hour NRCS Type II storm) because they are relatively simple and widely accepted, have been used historically, and are the basis of many of the local standards throughout Michigan. However, the advent of better computer models and faster processors has made the continuous simulation of long periods of recorded climate data quite feasible. While continuous simulations require extensive precipitation data and generally require much more time to develop, they offer the benefit of analyzing actual long-term conditions rather than one or more hypothetical storms. Legitimate continuous modeling may be a more accurate simulation of performance to the site design criteria listed in this chapter. In fact, some jurisdictions in the country are beginning to require continuous simulation to demonstrate compliance with stormwater standards. That being said, the single-event methodology recommended here - with the appropriate assumptions included - is a cost-effective, defensible approach for most Michigan projects.

Calculating peak rate by utilizing volume control

The use of volume reduction BMPs and LID practices reduces or eliminates the amount of storage required for peak rate mitigation because less runoff is discharged. However, quantifying the peak rate mitigation benefits of LID can be difficult and cumbersome with common stormwater models/methodologies. This section discusses some available tools for quantifying the benefits of LID (see also Worksheet 7).

In its Surface Water and Storm Water Rules Guidance Manual (available at www.mmsd.com/rulesandregs/manuals), the Milwaukee Metropolitan Sewerage District (MMSD) describes five methods of accounting for "distributed retention" or LID, based on the NRCS Unit Hydrograph Method. MMSD developed a spreadsheet model called LID Quicksheet 1.2: "Quicksheet allows the user to quickly evaluate various LID features on a development site to reduce … detention requirements…LID features included in the Quicksheet include rain gardens, rain barrels, green roofs, cisterns, and permeable pavement."

While Quicksheet seems to be a useful tool, the current version does not appear to directly account for ongoing infiltration during the storm event and, therefore, may not fully credit LID practices that achieve significant infiltration. (The ongoing infiltration volume could be added to the capacity of the LID Retention Features to make up for this.)

Some other resources on LID calculations include:

BMP Modeling Concepts and Simulation (USEPA, 2006): https://www.epa.gov/

Stormwater Best Management Practice Design Guide, Vol. 2 (USEPA, 2004): https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=99759

Mecklenburg County BMP Design Manual, Chapter 4 (2007): charlottenc.gov/

The Delaware Urban Runoff Management Model - DURMM (Lucas, 2004): www.dnrec.state.de.us/

Low-Impact Development Hydrologic Analysis (Prince George's County, MD, Dept. of Environmental Resources, 1999): www.princegeorgescountymd.gov/

Precipitation data for application in stormwater calculations

Accurate rainfall frequency data are necessary to determine a reliable design. At the time of this writing, the most reliable source of rainfall frequency data is the *Rainfall Frequency Atlas of the Midwest* (Huff and Angel, 1992); available for free download at www.sws.uiuc.edu/pubdoc/B/ISWSB-71.pdf. Table 9.4 includes selected 24-hour event data for the entire state.

In terms of measured precipitation data, long-term daily and monthly precipitation data for about 25 stations throughout Michigan are available free from the United States Historical Climatology Network (USHCN) at cdiac.ornl.gov/epubs/ndp/ushcn/ushcn_map_interface. If local rainfall data are used, the period of record must be of sufficient length to provide a statistically valid result.

Table 9.4
Rainfall Events of 24-Hour Duration in Michigan

Zone*	Rainfall frequencies, 24-hour duration (rainfall in inches)						
	1-year	2-year	5-year	10-year	25-year	50-year	100-year
1	1.95	2.39	3.00	3.48	4.17	4.73	5.32
2	1.66	2.09	2.71	3.19	3.87	4.44	5.03
3	1.62	2.09	2.70	3.21	3.89	4.47	5.08
4	1.71	2.11	2.62	3.04	3.60	4.06	4.53
5	1.77	2.28	3.00	3.60	4.48	5.24	6.07
6	1.86	2.27	2.85	3.34	4.15	4.84	5.62
7	1.75	2.14	2.65	3.05	3.56	3.97	4.40
8	1.95	2.37	3.00	3.52	4.45	5.27	6.15
9	2.03	2.42	2.98	3.43	4.09	4.63	5.20
10	1.87	2.26	2.75	3.13	3.60	3.98	4.36

Source: Huff and Angel, 1992. *Rainfall Frequency Atlas of the Midwest*

*See Figure 9.2 Climatic Zones for Michigan

Design calculation process

The design calculations detailed below provide the steps necessary to perform a site analysis and complete a LID-based site design. Users should also refer to Chapter 5 "Incorporating LID into the Site Design Process" for additional steps.

Credits

Design credits are identified for several nonstructural BMPs. When these BMPs are implemented according to the guidance provided, they may generate credits that affect the design calculations by reducing the value of the CN of a portion of contributing area. These credits may only be applied when using a calculation based on the CN Method.

Those BMPs that generate a design credit are listed below at the appropriate step in the design process. CN changes due to design credits are determined in Worksheet 3.

Flow Chart A (*Stormwater Calculation Process*) is provided to guide the user through the first steps of the stormwater calculation process and can be thought of as a series of steps executed through a series of worksheets.

Figure 9.2
Climatic Zones for Michigan

Source: Sorrell, Richard C., Computing Flood Discharges for Small Ungaged Watersheds

Step 1: Provide general site information (Worksheet 1)

- This is basic identifying information, e.g., name, location, and waterways. It also includes information about the watershed from a number of state resources.

Step 2: Map the existing features of the site

- More than one map may be necessary. Collect any necessary design information.
- Identify waterbodies, floodplains, and natural flow paths. Identify existing structures and infrastructure. Identify hydrologic soil types. Show elevations and identify critical slopes of 15 percent to 25 percent and above 25 percent. Show areas of known contamination. Identify karst topography and bedrock outcroppings.
- Identify the total area of impervious surface existing prior to development.
- Note the seasonal high groundwater level.
- Identify type and area of existing sensitive resource areas on Worksheet 2. Identify the area of sensitive resource areas to be protected. The following nonstructural BMPs identify how to properly protect sensitive areas so they maintain their presettlement state and runoff characteristics.
    - Protect Sensitive Areas
    - Protect Riparian Buffers
    - Minimize Total Disturbed Area
    - Protect Natural Flow Pathways
    - Cluster Development
- Record the sum of the protected sensitive areas from Worksheet 2 on the space provided for it on Worksheet 3.

Step 3: Lay out the proposed development avoiding the protected areas

- If after the development is sited, additional sensitive areas are impacted, modify Worksheet 2.

Step 4: Determining the disturbed area size

- On Worksheet 3 subtract the sum of the Protected Sensitive Areas on Worksheet 2 from the total site area. Use this as the new disturbed or modified area requiring LID controls. Apply the following BMPs, as appropriate, to determine runoff reduction credits.
    - Minimize Soil Compaction
    - Protection of Existing Trees (part of Minimize Total Disturbed Area)
    - Soil Restoration
    - Native Revegetation
    - Riparian Buffer Restoration
- Continue on Worksheet 3 to record the area, soil type, existing CN and modified CN for each Runoff Reduction Credit generated.

Step 5: Calculate the level of volume control needed for channel protection

- On Worksheet 4 record the two-year 24-hour rainfall for your area from Table 9.4 as well as the Total Site Area, Protected Site Area, and the Area to be Managed from Worksheets 2 and 3 in the spaces provided. Record the presettlement condition by filling in the area of each soil type and cover type.
- Calculate the runoff volume for the presettlement condition of each soil type and cover type using this formula:

  Runoff Volume (ft^3) = Q_v x 1/12 x Area

  Where

  Q_v = Runoff (in) = $(P - 0.2S)^2/(P + 0.8S)$

  P = 2 Year, 24 Hr Rainfall (in)

  $S = 1000/CN - 10$
- Sum the individual volumes to obtain the total presettlement runoff volume.
- Continue on Worksheet 4 to record the post-development area of each soil type and cover type. Use the same formulas to calculate the post-development runoff volume for the site and record in the space provided.
- Subtract the presettlement runoff volume from the post-development runoff volume and record the result in the space for "2 Year Volume Increase." This is the volume that must be removed by infiltration, interception, evaporation, transpiration or capture and reuse.

Step 6: Select volume control BMPs

- Worksheet 5 includes a list of the BMPs from this manual that provide volume removal and tracks the volume removed of each practice and total sum of volume removed for all practices. Select and Design Structural BMPs that provide volume control for the applicable stream channel protection volume increase indicated on Worksheet 4. Indicate the volume reduction provided by the proposed BMPs.

- Proceed to Flow Chart B, Peak Rate Calculations.

Step 7: Peak rate exemption for small sites

- The peak rate calculation for channel protection is not necessary for sites that have a small proportion of imperviousness and can maintain the presettlement runoff volume. Worksheet 6 provides a checklist of criteria that if met, would eliminate the need for most peak rate conditions. Peak rate calculations may still be necessary for larger storms to address flooding in some areas. If peak rate calculations for channel control are necessary, follow step 8 and Worksheet 7 to provide the necessary peak rate control.

Step 8: Calculate peak rate control

- Use Worksheet 7 and the NRCS Unit Hydrograph Method (or other appropriate runoff model) and determine peak rate control for all storms up to the 100-year storm or according to local requirements.
- List the design criteria used (local requirement, LID guidance or other) and what it specified.
- List the presettlement and post-development peaks for each design storm in the space provided.
- If time of concentration is more than one hour, the following formula can be used.

  $Q_p = Q_v * A * 238.6 * Tc^{-0.82}$

  Where;

  Q_p = Peak flow rate in cfs

  Q_v = surface runoff in inches

  A = Drainage area in square miles

  Tc = Time of concentration in hours. If Tc is less than one hour, use TR-55 or HEC-HMS.
- Time of concentration in the case of LID design is the time it takes a drop of water to move from the furthest point in the disturbed area to its discharge from the disturbed area. Time of concentration can be affected by adjusting the length or roughness of natural flow paths and routing through BMPs.

  If time of concentration is kept constant for the presettlement and post development condition, the peak rate is completely dependent on the volume of surface runoff and can be completely controlled by implementing additional volume control. Repeat steps 5 and 6 for the larger storms and determine if additional volume control can be implemented to control the peak rate.

Other recommended methods of determining the effects of volume control on peak rate mitigation are listed below.

- **Simple Volume Diversion**. This is a very simple way to partially account for the effect of volume control BMPs on peak runoff rates. Many computer models have components that allow a "diversion" or "abstraction." The total volume reduction provided by the applicable structural and nonstructural BMPs can be diverted or abstracted from the modeled runoff before it is routed to the detention system (if detention is needed). This approach is very conservative because it does not give any credit to the increased time of travel, fully account for ongoing infiltration, etc. associated with the BMPs. Even this conservative approach can reduce the detention storage requirements significantly. This method can and should be used in conjunction with Travel Time/Time of Concentration Adjustment explained below.
- **Travel Time/ Time of Concentration Adjustment**. The use of widely distributed, volume-reducing BMPs can significantly increase the post-development runoff travel time and therefore decrease the peak rate of discharge. The Delaware Urban Runoff Management Model (DURMM) discussed previously calculates the extended travel time through storage elements, even at flooded depths, to adjust peak flow rates (Lucas, 2001). The extended travel time is essentially the residence time of the storage elements, found by dividing the total storage by the 10-year peak flow rate. This increased travel time can be added to the time of concentration of the area to account for the slowing effect of the volume-reducing BMPs. This can significantly reduce or even eliminate the detention storage required for peak rate control. This method can and should be used with Simple Volume Diversion explained above.
- **Composite BMPs w/Routing**. For optimal stormwater management, this manual suggests widely distributed BMPs for volume, rate, and quality control. This approach, however, can be very cumbersome to evaluate in detail with common computer models. To facilitate modeling, similar types of BMPs with similar outlet configurations can be combined within the model. For modeling purposes, the storage of the combined BMP is simply the sum of the BMP capacities that it represents. A stage-storage-discharge relationship

(including ongoing infiltration) can be developed for the combined BMP based on the configuration of the individual systems. The combined BMP(s) can then be routed normally and the results submitted. BMPs that are grouped together in this manner should have similar drainage area to storage volume ratios to ensure the individual BMPs function properly. This method should not be used in conjunction with Travel Time / Time of Concentration Adjustment method described above.

- **Full BMP Routing including ongoing infiltration**. For storms where additional volume control is not possible or where the post-development Tc is shortened, select and design BMPs that detain storm runoff and release at the presettlement rate. See the Detention BMP and Infiltration BMPs that are underdrained to a storm collection system or waterway.
- Proceed to Flow Chart C, Water Quality Process.

Step 9: If Needed– Determine water quality volume and select appropriate BMPs.

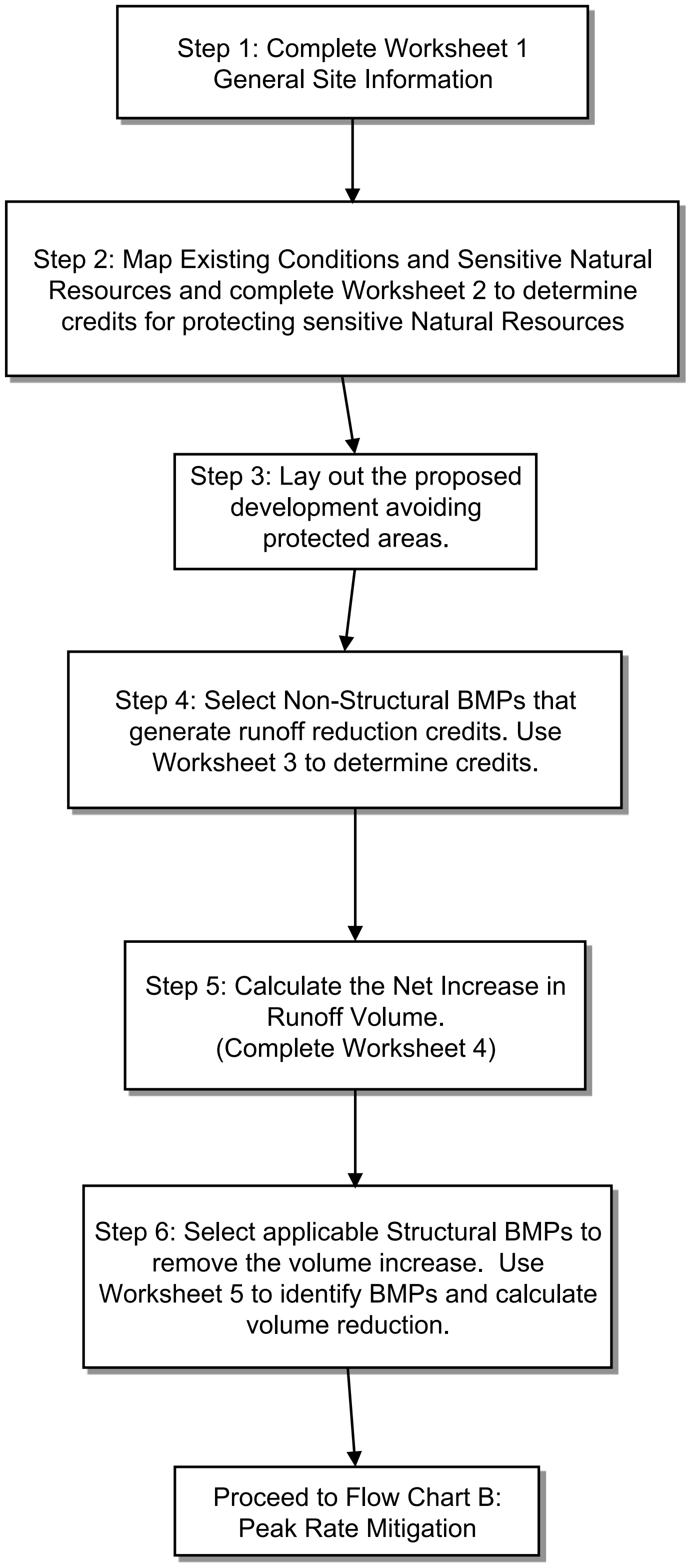
- When the channel-forming volume is controlled with BMPs that also remove expected pollutants, often no additional calculation or BMP implementation is necessary. If the channel-forming volume is not controlled, calculate the water quality volume that provides for the most reasonable amount of control of the volume carrying the most pollutants. This manual recommends using one inch of runoff from the entire site as the channel-control volume. The other methods of calculating water quality volumes described above may be appropriate for your site.
- The water quality volume calculation is necessary if the one-inch runoff method is used or the channel protection volume is not controlled. Use Worksheet 8 and record each contributing area needing treatment and calculate the water quality volume. Select BMPs that will remove the expected pollutants for the land use type. Often, multiple types of BMPs used in series will be required to provide adequate treatment. Design the BMPs in conjunction with any detention control if possible. As a guide, use a series of BMPs that will achieve 80 percent removal of solids or better (Table 9.5).

Table 9.5
Pollutant removal efficiencies for various stormwater BMPs

Pollutant	Infiltration Practices	Stormwater Wetlands	Stormwater Ponds Wet	Filtering Practices	Water Quality Swales	Stormwater Dry Ponds
Total Phosphorus	70	49	51	59	34	19
Soluable Phosphorus	85	35	66	3	38	-6
Total Nitrogen	51	30	33	38	84	25
Nitrate	82	67	43	-14	31	4
Copper	N/A	40	57	49	51	26
Zinc	99	44	66	88	71	26
TSS	95	76	80	86	81	47

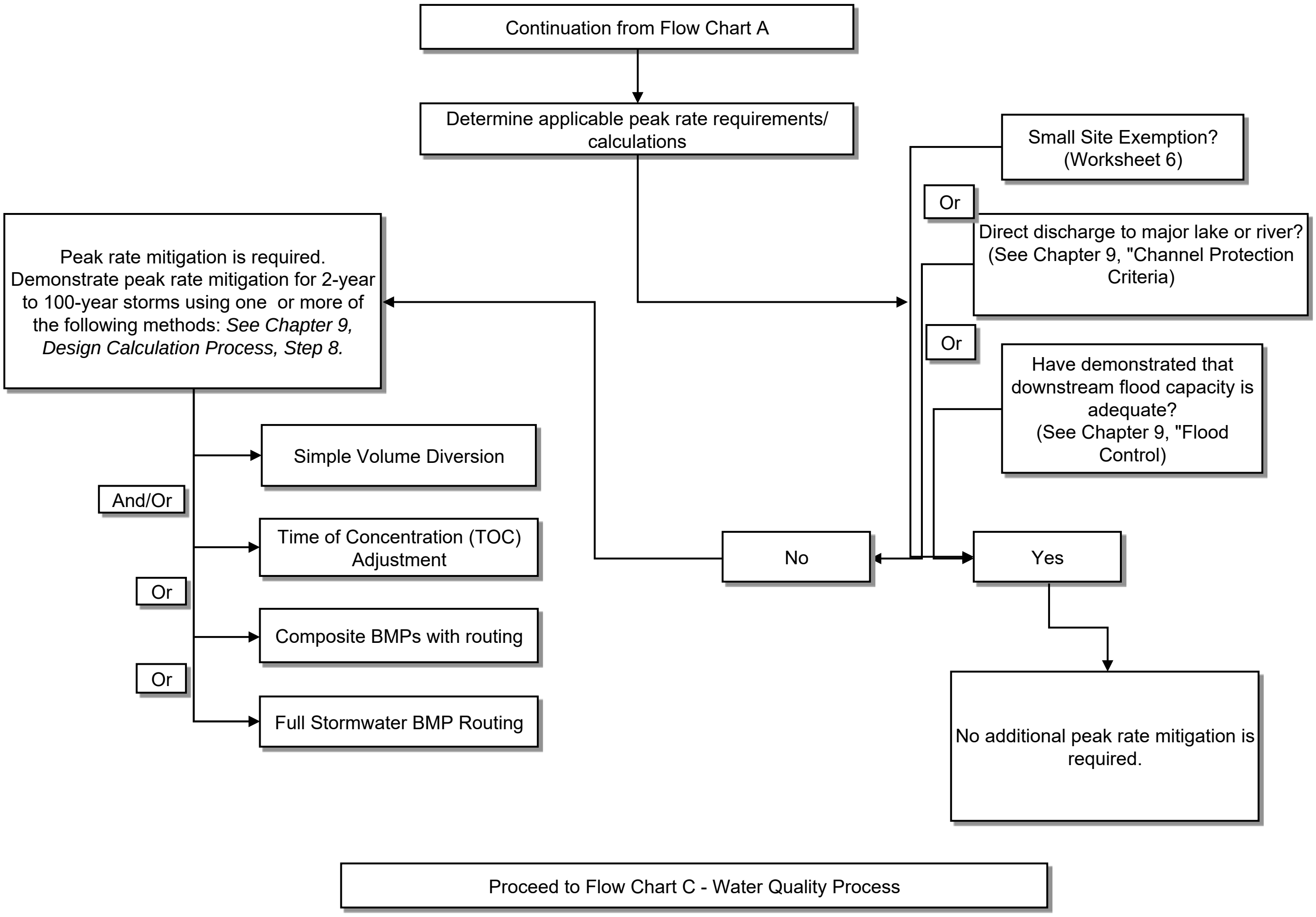
Source: "National Pollutant Removal Performance Database for Stormwater Treatment practices" Center for Watershed Protection, June 2000

FLOW CHART A
Stormwater Calculation Process

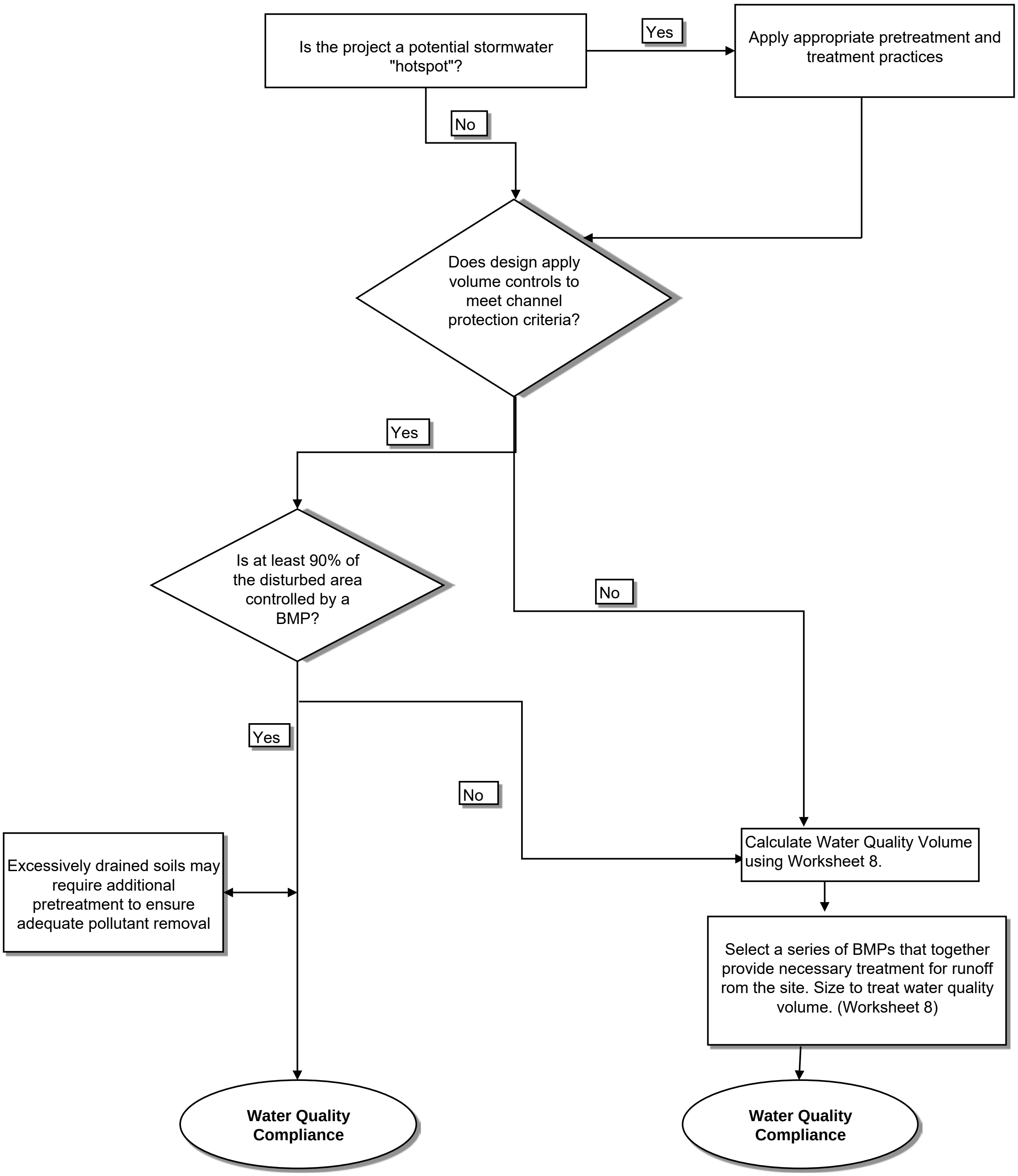


Flow Chart B

Peak Rate Mitigation



Flow Chart C
Water Quality Process



Worksheet 1. General Watershed/ Site Information

NOTE: If the project extends over more than 1 Watershed, fill out Worksheet 1 for each Watershed

Date: ______________________

Project Name: ______________________

Municipality: ______________________

County: ______________________

Total Area (acres): ______________________

Major Watershed: ______________________

https://cfpub.epa.gov/surf/state.cfm?statepostal=MI

Subwatershed: ______________________

Nearest Surface Water(s) to Receive Runoff: ______________

Part 4 - Designated Water Use: (OSRWS, Cold water, etc.) __________

http://w3.lara.state.mi.us/orr/AdminCode.aspx?admincode=Department&Dpt=EQ

Michigan Natural Rivers watershed? Yes ☐ No ☐

http://www.michigan.gov/dnr/0,4570,7-153-10364_52259_31442-95823--,00.html

Impaired according to Chapter 303(d) List? Yes ☐ No ☐

http://www.michigan.gov/deq/0,4561,7-135-3313_3681_3686_3728-12711--00.html

List Causes of Impairment:

Is project subject to, or part of:

Phase I or Phase II Municipal Separate Storm Sewer System (MS4) Requirements? Yes ☐ No ☐

http://www.michigan.gov/deq/0,4561,7-135-3313_71618_3682_3716-24366--,00.html

Existing or planned drinking water supply? Yes ☐ No ☐

If yes, distance from proposed discharge (miles): __________

Approved Watershed Management Plan? Yes ☐ No ☐

http://www.michigan.gov/deq/0,4561,7-135-3313_71618_3682_3714-69714--,00.html

Worksheet 2. Sensitive Natural Resources

INSTRUCTIONS:

1. Provide Sensitive Resources Map for the site. This map should identify waterbodies, floodplains, riparian areas, wetlands, woodlands, natural drainage ways, steep slopes, and other sensitive natural features.

2. Summarize the existing extent of each sensitive resource in the Existing Sensitive Resources Table (below, using Acres).

3. Summarize total proposed Protected/Undisturbed Area. Use the following BMPs to define Protected/Undisturbed Area; protect sensitive areas, protect riparian buffers, protect natural flow pathways, cluster development, and minimize disturbed area.

4. Do not count any area twice. For example, an area that is both a floodplain and a wetland may only be considered once (include as either floodplain or wetland, not both).

EXISTING NATURAL SENSITIVE RESOURCE	MAPPED? (yes, no, n/a)	TOTAL AREA (Ac.)	PROTECTED/ UNDISTURBED AREA (Ac.)
Waterbodies			
Floodplains			
Riparian Areas			
Wetlands			
Woodlands			
Natural Drainage Ways			
Steep Slopes, 15% - 25%			
Steep Slopes, over 25%			
Special Habitat Areas			
Other:			
TOTAL EXISTING:			

Worksheet 3. Runoff Reduction Credits

PROTECTED/ UNDISTURBED AREA

Protected/Undisturbed Area* (from WS 2) ________ **Ac.**

TOTAL PROPOSED PROTECTED/UNDISTURBED AREA ________ **Ac.**

Total Site Area	*minus*	Protected/ Undisturbed Area	*equals*	Disturbed Area (To be managed)
[ ]	-	[ ]	=	[ ]

This is the area that requires stormwater management

Transfer to WS 4

NON STRUCTURAL BMP CREDITS**

BMP: Minimize Soil Compaction Area: ________ **Ac.**

Soil Type ________ Existing CN ________ Credited CN ________

BMP: Soil Amendment and Restoration Area: ________ **Ac.**

Soil Type ________ Existing CN ________ Credited CN ________

Areas complying with the requirements of these BMPs can be assigned a Curve Number (CN) reflecting a "Good" condition instead of "Fair" as required for other disturbed pervious areas. For example, lawn areas with B soils would be given a CN of 61 instead of 69; lawns with C soils a CN of 74 instead of 79.

Protect Existing Trees within Disturbed Area (part of Minimize Disturbed Area)

Number of Trees: ________

Total Area: ________ **Ac.**

Soil Type ________ Existing CN ________ Credited CN ________

Trees protected under the requirements of this BMP can be assigned a Curve Number (CN) reflecting a Woods in "Good" condition for an area of 800 SF per tree or the entire area of the tree canopies protected, whichever is greater.

BMPS: Native Revegetation and Riparian Corridor Restoration

Number of Trees: ________

Number of Shrubs: ________

Total Area: ________ **Ac.**

Soil Type ________ Existing CN ________ Credited CN ________

Proposed trees and shrubs to be planted under the requirements of these BMPs can be assigned a Curve Number (CN) reflecting a Woods in "Good" condition for an area of 200 SF per tree or the estimated tree canopy, whichever is greater. For shrubs, an area of 25 SF per shrub.

ˆˆ *A checklist is provided for each BMP in chapter 6 and 7 to ensure certain criteria is being met and credit can be given.*

WORKSHEET 4. Calculations for Volume Criteria

PROJECT NAME: ______________________ **Sub-basin:** ______________

2-Year, 24-Hour Rainfall): ________ **in**

(Site specific rainfall event may be substituted if applicable)

Total Site Area: ________ **acres**

Disturbed Area to be managed: ________ **acres**

Pre-Development Conditions

Cover Type	Soil Type	Area (sf)	Area (ac)	CN (from TR-55)	S	Q Runoff[1] (in)	Runoff Volume[2] (ft^3)
Woods / Meadow	A			30	23.3		
Woods	B			55	8.2		
Meadow	B			58	7.2		
Woods	C			70	4.3		
Meadow	C			71	4.1		
Woods	D			77	3.0		
Meadow	D			78	2.8		
Impervious	N/A			98	0.20		
Other:							
TOTAL:	**N/A**			**N/A**	**N/A**	**N/A**	

Post-Development Conditions

Cover Type	Soil Type	Area (sf)	Area (ac)	CN*	S	Q Runoff[1] (in)	Runoff Volume[2] (ft^3)
TOTAL:	**N/A**			**N/A**	**N/A**	**N/A**	

Runoff Volume Increase (ft^3):	

Transfer to WS 5

Runoff Volume Increase = (Post-Dev. Runoff Volume) MINUS (Pre-Dev. Runoff Volume)

1. **Runoff (in)** = $Q = (P - 0.2S)^2 / (P + 0.8S)$ where:
   - P = 2-Year, 24-Hour Rainfall (in)
   - S = 1000/ CN - 10
   - CN = Curve Number
   - Q = Runoff (in)
2. **Runoff Volume (ft^3)** = Q x 1/12 x Area
   - Area = Area of specific land cover (ft^2)

* Runoff Volume must be calculated separately for pervious and impervious areas (without using a weighted CN), unless Non-Structural BMP Rooftop/Downspout Disconnection is applied.

WORKSHEET 5. STRUCTURAL BMP VOLUME REDUCTION*

PROJECT: ______________________________

Subwatershed: ______________________________

Runoff Volume Increase (cubic feet) *from Worksheet 4*: ____________

Proposed BMP[A]	**Area (ft^2)**	**Permanently Removed Storage Volume**[B] **(ft^3)**	**Ave. Design Infiltration Rate (in./hr.)**	**Infiltration Volume During Storm**[C] **(ft^3)**	**Total Volume Reduction**[D] **(ft^3)**
Porous Pavement					
Infiltration Basin					
Subsurface Infiltration Bed					
Infiltration Trench					
Bioretention					
Dry Well					
Vegetated Swale					
Retentive Grading					
Vegetated Roof			N/A	N/A	
Capture and Re-use			N/A	N/A	

Total Volume Reduction Credit by Proposed Structural BMPs (ft^3): ____________

Runoff Volume Increase (cubic feet) *from Worksheet 4*: ____________

*** FOR PERMANENTLY REMOVED VOLUME ONLY, TEMPORARY DETENTION VOLUMES ARE NOT INCLUDED HERE.**

[A] Follow design guidance and Protocols from Manual for each Structural BMP type

[B] Storage volume as defined in individual BMP writeups - this represents permanently removed volume, not detention storage

[C] Can be approximated as the average design infiltration rate over 6 hours multiplied by the BMP area:
Design Infiltration Rate x 6 hours x BMP Area x Unit Conversions = Infiltration Volume (ft^3)

[D] Total Volume Reduction is sum of Storage Volume and Infiltration Volume During Storm.

Other Proposed BMPs *Not Volume Reducing*	**Area (ft^2)**
Constructed Filter	
Constructed Wetlands	
Wet Detention Pond	
Dry Extended Detention Basin	
Water Quality Devices	
Level Spreader	

WORKSHEET 6. SMALL SITE / SMALL IMPERVIOUS AREA EXEMPTION FOR PEAK RATE MITIGATION CALCULATIONS

NOTE: This does not exempt small projects from stormwater management, only the peak rate mitigation calculations.

The following conditions must be met for exemption from peak rate analysis for small sites:

_______ The 2-Year, 24-hour Runoff Volume increase must be controlled in BMPs designed in accordance with manual guidance.

_______ Total project impervious area may not exceed **1 acre**.

_______ Maximum proposed disturbed area is **10 acres**.

_______ Maximum proposed impervious cover is 50%.

_______ Project shall not be a part of a larger phased project.

_______ Infiltration BMPs must have a design infiltration rate of at least 0.25 in/hr.*

Example project configurations that may be eligible for exemption:

Porposed Disturbed Area	Percent Impervious	Total Impervious
10 acre	10%	1 acre
5 acre	20%	1 acre
2 acre	50%	1 acre
1 acre	50%	0.5 acre
0.5 acre	50%	0.25 acre

*Although this infiltration rate is higher than the minimum recommended in the manual, for site seeking a peak rate exemption a higher infiltration rate is warrented.

WORKSHEET 7. PEAK RATE MITIGATION SUMMARY SHEET

PROJECT: ______________________

Subwatershed: ______________________

Applicable Peak Rate Criteria (e.g. pre- vs. post, release rate): ______________________

Additional Flood Control Criteria (if applicable): ______________________

Storm Event	Storm Duration (hr)	Are criteria applicable to this storm? (Yes / No)	Post-Settlement Peak Discharge Rate[1] (cfs)	Pre-Settlement Peak Discharge Rate[1,2] (cfs)	Other peak rate criteria, if applicable (cfs)	Are the criteria met? (Yes / No)
1-year	24					
2-year	24					
5-year	24					
10-year	24					
25-year	24					
50-year	24					
100-year	24					

1 - As determined by computer simulation, acceptable calculation methods, etc.

2 - If applicable to the peak rate criteria.

Notes, Special Conditions, etc.: ______________________

WORKSHEET 8. WATER QUALITY WORKSHEET

PROJECT: ______________________________

Subwatershed: ______________________________

This worksheet calculates water quality volume based on the criteria of 1 inch of runoff from impervious areas and 0.25 inch of runoff from disturbed pervious areas.

A	B	C	D	E	F
Total Disturbed Area (ft^2)	**Impervious Area (ft^2)**	**Disturbed Pervious Area (ft^2)**	**Water Quality Volume for Impervious Area (ft^3)** **Col B x 1 inch/12**	**Water Quality Volume for Pervious (ft^3)[B]** **Col C x 0.25 inch/12**	**Total Water Quality Volume to BMPs (ft^3)[C]** **Col D + Col E**

If 2 or more water quality BMPs are proposed in series, any that are rated "Low/Medium" or better for TSS Removal are acceptable. List proposed BMPs here:

____

If only 1 water quality BMP is proposed for a given area, then it must be rated "High" for TSS Removal. Check off the proposed BMP here:**

- ________ **Bioretention**
- ________ **Capture/Reuse**
- ________ **Constructed Wetlands**
- ________ **Wet Ponds**
- ________ **Constructed Filters**
- ________ **Porous Pavement (with appropriate pretreatment to prevent clogging)**
- ________ **Infiltration Systems (with appropriate pretreatment to prevent clogging)**

*** Proprietary, manufactured water quality devices are not acceptable unless they have been field tested by a third-party according to approved testing protocols.*

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Chapter 10

Michigan LID Case Studies

This chapter highlights several developments that have incorporated numerous LID best management practices into their designs. These best management practices help communities meet their land use planning goals of protecting public health, safety, and welfare, as well as preserving community character, and making desirable places for people to live and work.

The following case studies showcase the implementation of numerous best management practices working together through integrated systems. Almost all components of the urban environment have the potential to serve as elements of an integrated stormwater management system. This includes using open space, as well as rooftops, streetscapes, parking lots, sidewalks, and medians.

In addition, these case studies represent various size developments as well as a diverse range of land use types and property ownership. LID is a versatile approach that can be applied equally well to new development, urban redevelopment, and in limited space applications such as along transportation corridors.

Pokagonek Edawat Housing Development

The Pokagonek Edawat Housing Development is located in Dowagiac, MI in Cass County. The Dowagiac River Watershed Management Plan was used as the basis for the design principles in this project, which led to integrating LID techniques into the development.

The Pokagon Band of Potawatomi Indians Tribal Development used nine LID BMPs to arrive at an overall strategy that protects and uses natural flow pathways and preserves natural features in overall stormwater planning and design. This development also maximized stormwater infiltration to ground water through:

- Rain gardens and bioswales,
- Sensitive area preservation,
- Cluster development, and
- Porous pavers.

Rain gardens and bioswales

The first phase, or neighborhood, of the development includes 17 homes. Each home has at least one rain garden that accepts roof-top drainage. During the design process, the native topography of the site was retained as much as possible to preserve the natural drainage. Any stormwater runoff generated from the neighborhood is managed by the depressions where infiltration capacities have been augmented by native vegetation to create bioswales.

Bioswale

Source: Pokagon Band of Potawatomi Indians

The rain gardens and bioswales required approximately two growing seasons to become established. The General Land Office survey notes indicate that the development location was a Mixed Oak Savanna circa 1800s. Thus, plant species associated with savanna and prairie settings were selected. Initial maintenance largely included watering and weeding, and infill planting, as needed. Currently, periodic weeding is the main maintenance activity related to this BMP.

For the bioswales, a combination of plug placement and seeding with a warm season grass drill was used, along with an initial fertilizer application. A mixture of warm season grasses and forbs were selected for the bioswale vegetation. Initial maintenance largely included watering and weeding. Weed management during the first year included mowing. Current maintenance activities include prescribed burns and selective mowing. All maintenance is performed by the Pokagon Band Housing Department. Most maintenance costs involve the care of limited turf grass that surrounds each home. Watering of the rain gardens is conducted as needed during prolonged dry spells.

Natural flow path and sensitive area preservation

The site was formerly agricultural fields mixed with woodlots. The woodlots and native topography of the site was retained as much as possible to preserve the natural drainage, and the lots and streets were designed around these depressions. Land between these depressions that is not included as a lot and spared via clustered design is scheduled to remain as open space.

Plant species associated with savanna and prairie settings were selected to mimic the presettlement ecosystem. Native vegetation was established by seeding the open space areas with a warm season grass and forb mixture. This was enhanced with selective placement of plugs.

Turf grass was established in small, select locales within the open space to create social gathering areas. Additionally, groomed walking trails were designed into the open spaces and woodlots. Walking trails will connect to subsequent phases of development to create a walkable community.

Annual maintenance costs are chiefly associated with prescribed burns, followed by lesser costs to maintain the limited areas of turf grass. However, the frequency of prescribed burns may be reduced in the future as the landscape matures.

Cluster development

The housing units have been clustered in loops following the site topography with 17 units in the first phase and 16 units scheduled for the second phase. Clustering reduced development costs by shortening roads and utility runs. Smaller lots have reduced lawn and yard maintenance. Clustering also allows for shared bioswales to be established among the buildings, helping to manage runoff. The footprints of the homes were minimized, through smaller hallway space and eliminating foyers, while still providing for maximum usable space.

Porous pavers

The street design for the first phase of the development is 1,800 linear feet long with approximately 25,000 square feet of interlocking pavers for the primary driv-

Clustering homes

Source: Pokagon Band of Potawatomi Indians

Reduced imperviousness

Source: Pokagon Band of Potawatomi Indians

ing surface. The street's three-foot depth subbase is composed of a bottom layer of road-grade gravel and crushed concrete overlain by coarse grained sand to help facilitate stormwater infiltration. The earth at the bottom of the subbase is graded with a slight slope toward the central bioswale to assist with drainage during very heavy precipitation events.

Additionally, the sidewalk was constructed using six inches of reinforced concrete and is actually part of the roadway. It is designed to accommodate the weight of heavier emergency vehicles and allow passage in the presence of street traffic and parked vehicles, if needed. This approach also limits impermeable surfaces through the use of pavers and a narrower streetscape, encouraging slower traffic flow while promoting the walkability of the neighborhood.

Curb and gutters were not used in the street design, since the permeable nature of the pavers and subbase made it unnecessary to collect and divert stormwater. However, a concrete border was constructed to anchor the interlocking pavers into place at the outer edges of the street.

The tribal maintenance department is responsible for maintaining the streets. Placing sand between the pavers is conducted as needed, along with periodic weeding.

Additional information

The pre-existing use of the land was agricultural and covered with large areas of wooded open space. Woodlots were maintained and treated with a tree management plan to open the canopy as well as to remove invasive tree species. Invasive underbrush was removed to assist propagation of remnant native vegetation. Half of the Phase I development was integrated into a wooded portion of the parcel for aesthetics and variation. Soil types within the property range from sandy loams to gravelly sands.

Additionally, the wooded areas have been identified as potential conservation areas in a study conducted by the Michigan Natural Features Inventory for a regional green infrastructure project within Cass, Van Buren, and Berrien Counties. The restoration-based concept for the Pokagonek Edawat development demonstrates that conservation and development can be compatible.

Lawrence Technological University – A. Alfred Taubman Student Services Center

The 42,000 square-foot A. Alfred Taubman Student Services Center, located on the Lawrence Technological University Campus in Southfield, MI, in Oakland County not only meets the requirements of the important student services functions it is designed to house, but is also a "living laboratory" of sustainable design and engineering. Built to U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) specifications, the Taubman Student Services Center addresses the criteria of sustainable site development and construction, recycled materials selection, indoor environmental quality, and water and energy efficiency. Specifically related to stormwater management, the Taubman Student Services Center uses the following best management practices:

- Vegetated roof,
- Bioswale, and
- Soil restoration.

Vegetated roof

The building's 10,000 square-foot living vegetated roof is created with layers of insulation, roof membrane, drainage fabric, and a four-inch granular composition that supports nine different species of sedum ground cover. About nine inches thick, the roof offers more effective insulation than traditional roofs and expands and contracts with seasonal changes. It is expected to last about 40 years, more than twice the lifespan of traditional materials.

The vegetated roof also controls and reduces stormwater runoff. With normal rainfall, about 60 percent of the water will be absorbed by the roof while the remainder drains into a 10,000-gallon underground cistern to be used as "gray" water for flushing toilets and for irrigating the campus quadrangle. The weight of the roof is estimated to be 10 to 12 pounds per square foot with a saturated weight of 15 pounds per square foot.

Vegetated Roof at Lawrence Technological University
Source: Lawrence Technological University

The Hydrotech Garden Roof Assembly is an extensive roof that includes the following vegetation:

- Dianthus plumarius
- Koeleria glauca
- Seven varieties of Sedum:
  - Sedum album
  - Sedum floriferum 'Weihenstephaner Gold'
  - Sedum kamtschaticum
  - Sedum spurium
  - Sedum spurium 'Fuldaglut'
  - Sedum spurium 'Summer Glory
  - Sedum middendorffianum 'Diffusum'

Maintenance activities included a minor amount of watering (permitted by LEED) in the first two years to develop the roots of the sedum plugs. After the two-year establishment period, watering was cut off. Additionally, the first two years required several weedings due to the spacing between the plugs. Now that the roof has fully filled in, the weeding effort is reduced to almost nothing. These intermittent maintenance activities are performed by the Campus Facilities Department.

Bioswale

A circular bioswale, approximately 725 linear feet was installed around the campus quadrangle. The width of the bioswale varies from eight to 15 feet. The preexisting soil consisted of clay with minimal topsoil. A system of weirs, tile fields (composed of material made of volcanic ash), and long-rooted grasses and trees will prevent 60 percent of the rainwater that falls on the adjacent campus quadrangle from running into the Rouge River as part of a regional effort to control stormwater drainage and improve the water quality and biodiversity of this portion of the Rouge watershed. This bioswale of vegetation will naturally purify the water by filtering out pollutants commonly found in snow and rain.

The capacity for the bioswale to capture stormwater runoff was designed for the 10+-year storm event — designed to flood with holding capacity exceeding 10-year event by backing up into the bioswale — essentially a long detention pond. Plants evapotranspiring coupled with free draining soils drain off surface water within 24 to 36 hours. Check dams positioned approximately 30 feet on center through more sloping zones create additional stormwater holding capacity.

Maintenance activities are conducted by the Lawrence Technological University's Campus Facilities Department. Grasses are cut down in the spring to encourage new growth, along with periodic weeding.

Soil restoration

The upper 18 inches of soil within the bioswale is loamy sand amended with sphagnum peat moss for organic content and pH, covered with shredded hardwood bark mulch. All site subgrade soils were decompacted to a depth of 24 inches following construction operations, including in the bioswale, and prior to finishing landscape soil placement. The operation was performed in order to maximize porosity of subsoils for stormwater infiltration and to foster plant and tree health in the bioswale and all general landscape areas.

Bioswale at Taubman Center, LTU Campus

Source: LTU

Mid Towne Village

Mid Towne Village is a mixed-use urban redevelopment project located in Grand Rapids, MI in Kent County, designed to provide a unique setting that contains a walkable community of residential, retail, and office uses (182,000 sq ft.).

The site was previously an older residential neighborhood consisting of 40 homes. Mid Towne Village is unprecedented in the City of Grand Rapids as it is the first project approved under the new Planned Redevelopment District zoning law passed in the fall of 2003 and uses the following LID BMPs:

- Reduce imperviousness,
- Subsurface infiltration, and
- Capture and reuse using a cistern.

Reduce imperviousness

In creating Mid Towne Village, the existing roads and utilities were reconstructed, and an environmentally friendly layout added additional height to the buildings to allow for parking underneath the buildings, construction of subsurface stormwater storage and infiltration, and construction of a cistern to store roof rainwater and reuse it for onsite irrigation purposes.

The Mid Towne Village buildings were built taller to allow for more parking. By incorporating two floors of parking (35,090 sq feet each) into the lower level of the property, exterior impervious surface was reduced resulting in better use of the property.

Cistern and infiltration system

The cistern is located in a park in the middle of the village. The cistern is sized to store 20,000 gallons of roof water from three nearby buildings. The irrigation system of the park area between Union, Dudley, Mid Towne, and Calder streets draws its water from the cistern.

The subsurface infiltration system is sized for the 25-year rain event. The area beneath the park will store 8,950 cubic feet of stormwater; the area along the east side of the site will store 6,774 cubic feet of stormwater. The subsurface stormwater system used the sandy soils and allowed for groundwater recharge, filtration of the stormwater, and eliminated the stormwater connection to the city's storm sewer system. The local rainfall information was reviewed and analyzed to determine the amount of storage necessary to collect adequate supply of rainwater for irrigating the development park area onsite. Using this system, the irrigation system for the development park area was not required to have a separate connection to the city's water system.

Subsurface infiltration system

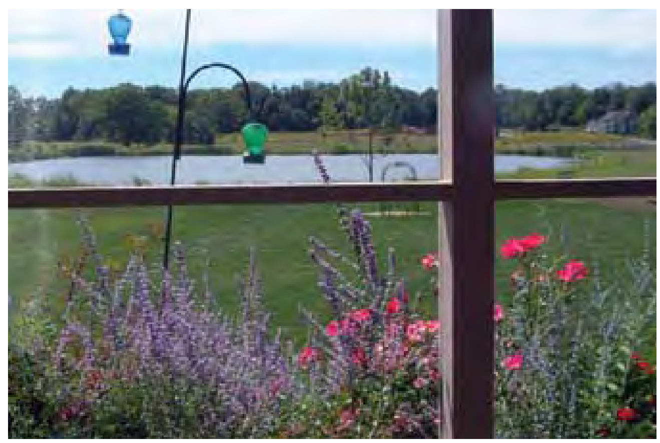
Source: Dreisinga Associates

Maintenance

An annual budget has been prepared for these systems to be privately maintained. This includes activities such as street sweeping, inspecting and cleaning of sewer sumps, inspecting and cleaning of subsurface storage systems, and inspecting and cleaning of the cistern system.

Longmeadow Development

Longmeadow is 400 acres of rolling land divided by ponds, meadows, clusters of trees, wetlands, and horse paddocks in Niles, MI in Berrien County. The design was dictated by the land topography, resulting in separate areas for a variety of housing types and lot sizes. It preserved 50 acres of open space, providing opportunities for fishing, community gardens, walking trails, and private roads for biking and hiking. The design takes into account the need to preserve habitat for wildlife. This includes eliminating street lighting and maintaining animal corridors.



View of wetland

Source: Longmeadow Development, Owner: Jane Tenney

Sensitive areas — existing wetlands and very hilly areas — were preserved. Hilly areas include a change in topography of 20 feet over the 400-acre site. Existing wetlands are maintained by a buffer of greater than 75 feet of vegetation that is not mowed. This vegetated buffer reduces erosion in these areas by providing infiltration for stormwater runoff.

In addition, the site design incorporated the existing long vistas of seeded upland prairie meadows. Most of the trees onsite were preserved, including a very old, large oak tree at the entrance to Longmeadow development. Existing fence rows of trees were also preserved, providing a natural visual separation between housing types.

Bioswales provide infiltration of stormwater runoff from the 24-foot-wide roads and, in some cases, between homes. In a higher density area of homes, flat curbs were installed to maintain road edges, while bioswales direct some stormwater to storm drains surrounded by vegetation. In addition, the fire lanes were constructed with permeable surfaces.

Open space common areas are maintained by the development's homeowners association. Longmeadow was picked by The Conservation Fund as a demonstration project in the State of Michigan for watershed protection.

Quarton Lake Remediation

The Quarton Lake restoration project began in November 2002 in Birmingham, MI in Oakland County. The project included shoreline stabilization using bioengineering techniques, creating fish habitat, an assessment of the tributary stream corridor, and dredging of sediment which accumulated in Quarton Lake during the past 30 years. The stream assessment included a streambank erosion inventory and severity index based on Michigan Department of Environmental Quality procedures to identify areas of erosion and sediment sources.

Aerial view of Quarton Lake
Source: Hubbell Roth & Clark, Inc.

Due to this project's location in a highly urban area, committee meetings were held throughout the design phase soliciting public input and addressing resident concerns. In addition, the project consultant helped the city develop flyers for area residents and articles for neighborhood association newsletters to report project progress throughout construction. This project contains the following LID BMPs:

- Riparian buffer restoration, and
- Native revegetation.

The stabilized buffer area surrounding Quarton Lake has a width of 10 to 50 feet. Invasive plants, including common buckthorn and Japanese barberry were removed from this area for one year. Stabilization activities included installing coir logs on the east and west shorelines and stone terraces on the east and west sides of the lake. A total of 3,500 native plant plugs and 2,000 square yards of fescue and ryegrass seed mix were installed in this area. The native plants included serviceberry, viburnum, common arrowhead, common rush, sedges, and irises.

Quarton Lake initially consisted of over 90 percent carp by weight, creating a monoculture of fish species. To increase fish diversity in the lake, over 700 carp were removed. Gravel substrate was added, along with brush piles, a spawning bay, and a lunker (a man-made fish habitat structure). The lake was stocked with the following fish species: Largemouth bass, Channel catfish, Black crappie, and Flathead minnows.

Dredging of 30,000 cubic yards of soil was performed which was dried in sediment bags and sent to a Type II landfill. In order to gauge the impacts of the dredging, a lake assessment (including monitoring of fish species, fish habitat, dissolved oxygen, and nutrient levels) was performed prior to dredging. The purpose of the dredging was to increase dissolved oxygen levels and improve phosphorus levels found in the lake sediment prior to dredging. Since the lake has been dredged, nutrient levels and dissolved oxygen levels have improved.

The project consultant developed a maintenance plan for the city in 2006, including recommendations for future efforts in Quarton Lake. Dissolved oxygen and temperature levels were monitored in August 2005. Data still showed low dissolved oxygen levels near the stream bed. Temperature levels remain fairly constant from stream bed to the surface. Additional water quality monitoring is recommended for future years. The city maintains the plantings along the lake's 25-foot no-mow buffer. The city participates in an annual goose round-up, to help prevent goose droppings high in phosphorous from entering the lake. To further assist in water quality efforts, the city maintains a stringent street sweeping and catch basin cleaning program to keep sediment out of the lake. To date, there have been no additional costs incurred for maintenance practices, aside from DPW staff labor costs.

Native vegetation for streambank stabilization and runoff infiltration

Source: Hubbell Roth & Clark, Inc.

Riparian education

A workshop to educate the public about the importance of riparian protection was held. It informed riparian homeowners about the purpose and scope of the Quarton Lake project, and educated them on the importance of riparian buffers, restricted activities in the riparian zones (fertilizer use, feeding waterfowl/wildlife, dumping yard wastes, etc.), shoreline stabilization techniques, permitting, and contractor issues and costs.

Towar Rain Garden Drains

The Towar Rain Garden Drains used LID to completely retrofit a rain garden stormwater system in a neighborhood setting. Located in Meridan Township and the City of East Lansing in Ingham County, MI., the system consists of two concurrent drain projects (Towar Snell Drain & Towar Gardens and Branches Drain) that were installed in the Towar Gardens neighborhood in 2006 and 2007. These projects encompass approximately 200 acres and impact over 400 homes.

The Towar neighborhood experienced flooding of yards, roads, and basements for over 80 years prior to this project. The neighborhood is very flat, with only six feet of elevation from the lowest rear yard to the outlet more than a half-mile away. The project used rain gardens and installed them in areas where flooding historically occurred.

All the work was performed under the Michigan Drain Code, with more than 100 easements gathered to install over 5.5-acres of rain gardens along streets and in rear yards. The rain gardens were planted using native species and were constructed with new soil media. More than 110 pounds of native wildflower seed was used to construct the rain gardens and nearly 52,000 plugs were planted. More than eight miles of county drains were constructed during the project.

More than 150 individual rain gardens were constructed throughout the project, ranging from 100 square-feet, to areas larger than 2/3 acre. The main conveyance system consisted of small concrete pipes in the roadways that accepted the stormwater from the ditches and rear yards. This project is believed to be the largest urban retrofit of a stormwater system ever performed in the United States and the largest using rain gardens as the primary function to manage stormwater. It is the largest LID project ever performed under the Drain Code in Michigan. Maintenance costs are variable, since activities will be more intense in the initial years after construction is complete and until native species are fully established. Once established, costs are expected to decrease substantially.

Towar Drain neighborhood

Source: Fitzgerald Henne and Associates, Inc.

The Ingham County Drain Commissioner is responsible for all maintenance activities under the laws of the Drain Code of 1956. Maintenance activities include removing invasive and weed species from the rain gardens, cleaning the perforated pipes from tree roots, and continuing education of the community regarding avoiding mowing and applying herbicide to the native plants.

Rain garden one year after establishment
Source: Fitzgerald Henne and Associates, Inc.

Kresge Foundation Headquarters

The site for Kresge Headquarters is an historic farmstead set within the context of a completely altered landscape on a commercial business site in Troy, MI (Oakland County). The 2.76-acre site is a small oasis within a larger suburban-scale, corporate landscape.

Porous pavers
Source: Conservation Design Forum, Inc.

Site goals

The Kresge site attempts to recreate historical hydrology as an essential component of overall ecological performance, which is a key LID principle. In addition, the site provides habitat for the widest range of plant and animal life given its confined context and location. The site receives all of the rainwater that falls in its 2.76 acres and uses much of it to support a diverse water-based landscape. Any stormwater that is not infiltrated into the existing LID practices is treated onsite in the bioswale system before being released into the city storm drain.

The project objective was to create a workplace that promotes the well-being and productivity of staff and visitors. Because the Kresge Foundation invests in the sustainable development of hundreds of nonprofit facilities each year, sustainable planning of their own construction project was a main goal. As part of this green approach, the overall landscape goals for the Kresge Foundation Headquarters were twofold:

1. To maintain rainwater onsite while using it as a resource, promoting infiltration of surplus stormwater, and
2. To create a healthy, vibrant landscape that could be installed and maintained without use of chemicals, large amounts of supplemental water from municipal sources, and other intensive measures.

The strategy for site ecology was to incorporate LID practices into practically every portion of the site. This project includes the following LID BMPs:

- Minimize total disturbed area,
- Vegetated roof,
- Pervious pavement,
- Native landscaping,
- Bioswales,
- Constructed wetland, and
- Water collection and reuse.

Minimize total disturbed area

The historic farmhouse remains as the cornerstone for the new building. Other historic outbuildings were rearranged to maximize the efficiency of the site. The new building is stacked on two levels and set into the site. The parking lot is tucked on the eastern edge of the site, and has a minimal number of parking spaces. A portion of the building has a vegetated green roof system. The green, or planted, portion of the site is 1.76 acres, or approximately 63.4 percent of the total site area (2.76 acres). More than 63 percent of the site was restored as landscape area and open space.

Vegetated roof

The portion of the roof surface that is at-grade (3,213 square feet) is established with a green roof using a mid-range grass planting mix. Rainwater from the upper portions of the roof is directed into the green roof, where it is cooled and used. Overflow water is then directed to the lower constructed wetland/pond (see below). Surplus rainwater is stored and reused to irrigate the green roof during periods of drought.

Vegetated roof with meadow grass

Source: Conservation Design Forum, Inc.

Pervious pavement

The parking lot is constructed with interlocking concrete pavers that have gaps filled with crushed stone and underlain with open-graded gravel. This porous paving system allows the water falling on its surface to be cooled, filtered, and infiltrated into the ground. Overflow water is directed to the bioswale systems.

Native landscaping

The entire site was planted with a range of native and adapted grasses and flowering perennials (primarily prairie species) that thrive without supplemental water once established. The landscape was organized into ornamental edges, panels, and zones to address views, programming, and the suburban and historic context of the site. The landscape is managed as a natural system and, where feasible, existing trees were retained. Since controlled burning is not permitted in this area, the landscape was designed with a hybrid native/adapted plant mix that will thrive with minimal input once fully established. Invasive species removal and annual removal of the dormant material through mowing are the primary stewardship activities. As the root systems of the native plants, especially the grasses, become fully established, invasive species will be crowded out and be less of an issue. More importantly, the landscape will become progressively better at receiving rainwater sustainably, and returning it to the ground without any runoff.

Native landscaping prairie mix

Source: Conservation Design Forum, Inc.

Bioswales

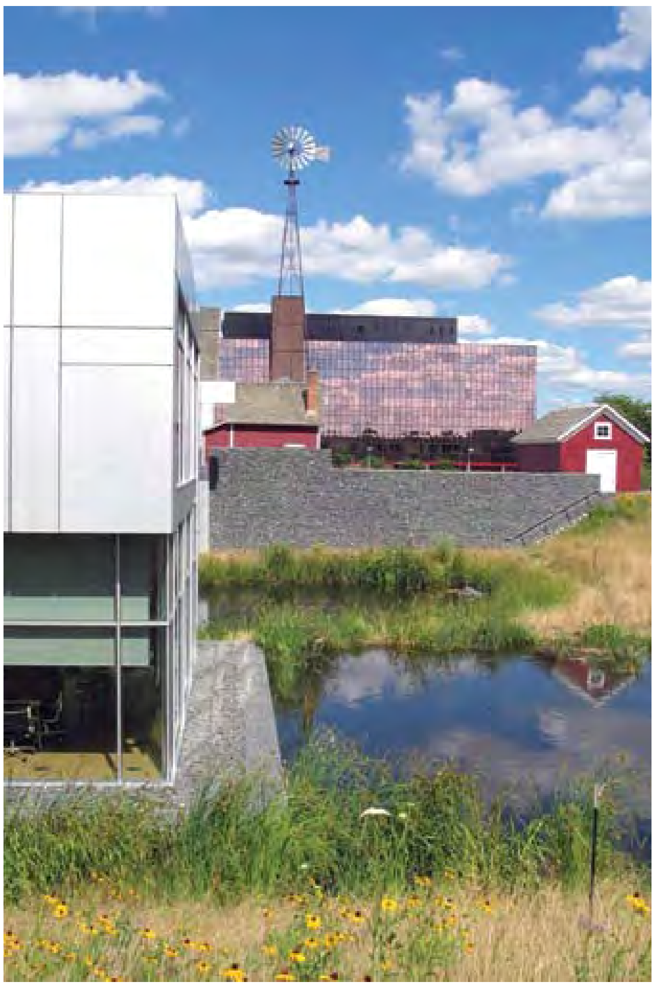
Surplus rainwater is directed to a bioswale system. The bioswale is constructed with amended topsoil, underlain with stone, and planted with deep-rooted grasses. The bioswale slows and further cleanses and cools the rainwater, allowing more of it to return to the atmosphere in the form of evapotranspiration. The bioswale system then overflows into the city storm drain only in the heaviest rain events and when the ground is saturated.

Bioswale along parking lot

Source: Conservation Design Forum, Inc.

Constructed wetland

The lowest portion of the site was developed as a constructed wetland pond. It is a lined basin meant to have a permanent water surface, with a planted wetland fringe mimicking a native system. Rainwater that overflows from the roof and portions of the site are directed to this pond. If the water level rises more than six inches, surplus water is drawn into the cistern for future reuse. If the water level draws down during dry periods by more than six inches, water from the cistern is allowed to flow back in. This keeps a fairly constant water level to maintain a high quality wetland habitat and also allows the pond to be part of the stormwater management system.



Wetland along building
Source: Conservation Design Forum, Inc.

Water collection and reuse

The entire landscape thrives without the use of potable water. Rainwater is harvested, treated, and stored in a cistern to provide water for the constructed wetland and supplemental water for the green roof system. In order to optimize this system, a water budget was developed and used as a design tool. The amount of water potentially generated from rainwater (supply) was compared with water needs (demand). An analysis of the water budget throughout the year led to refinement of the design and sizing of the water landscapes and storage elements.

The green roof systems contain a permanent irrigation system and the created wetland on the south side of the building is topped off when the water level drops below a prescribed depth. Water for green roof irrigation and refilling of the pond is supplied by collected rainwater from the new building roofs, the barn, the utility corridor, the landscape, and water that falls within the courtyard and the created wetland. The runoff water drains by gravity to the aquatic wetland and is then pumped to the 18,000 gallon cistern for later reuse. The water is reused on the four intensive green roofs that are vegetated with a native grass mix, and also to replace evaporated water from the created wetland. The average monthly volume of collected rainwater exceeds the average monthly demand by more than 50 percent. The cistern is of sufficient size to provide more than three weeks of water demand to average out monthly variability and extended periods without rain.

Irrigation water is applied to the green roof drainage layer using a trickle system. Irrigation water is held with the drainage layer using "ridges" two inches in height, at sufficient spacing to cause an average ponding depth of 1.25 inches, which equates to an irrigation volume of 0.5 inches over the roof area (40 percent pore space within the drainage layer media). If the lowest irrigation ridge is not full at the sensor, it will call for the pump to operate and for the drip box water supply valve to open. When the sensor indicates that the system is full of water at that bottom edge of the roof, it signals the valve to shut. Once all the systems are full of water, the pump shuts off. When the cistern is empty, the system does not operate. The maximum irrigation interval is once every other week. The water discharge module consists of drip box, water discharge with shut-off and flow control valves, and a distribution pipe. The discharge module discharges irrigation water consistently along the top roof edge.

When the water level in the created wetland drops two inches below normal water level, the pond is refilled to the normal water level using water in the cistern. The required volume to refill the two-inch drawdown is approximately 6,600 gallons. The 18,000 gallon cistern has sufficient volume to refill the drawdown more than 2.5 times. The average monthly water supply exceeds the average monthly water demand by more than 50 percent. The cistern has sufficient volume to supply more than three weeks of irrigation and refill the created wetland water feature.

Decentralized stormwater management

The integrated stormwater management design treats water as a resource, and allows water to flow over land, thus allowing ample opportunity to infiltrate back into the ground. Water is also collected and conveyed underground in the bioswale zones. The stormwater harvesting cistern is above ground, and serves as an icon and part of the Kresge Foundation image. The 18,000-gallon cistern is reminiscent of the "historic farm aesthetic," and is visible from Big Beaver Road, making a dramatic statement about Kresge's commitment to water conservation and natural resource preservation. The green roof landscape systems are permanently irrigated by a cistern system that collects and reuses rainwater in a drip fashion. A typical Midwestern office campus with turf vegetation would require irrigation at a rate of one inch per week (Source: Purdue University, State of Indiana and U.S. Department of Agriculture Cooperative). The native landscape established at the Kresge Foundation Headquarters requires no irrigation.

Cistern at Kresge Foundation
Source: Conservation Design Forum, Inc.

Lessons learned

The City of Troy was interested in having BMPs and LID tools implemented within their city. They were a very helpful partner in bringing innovation to this project, approving the design, and were involved from the early stages reviewing design documents and providing feedback.

It is critical to work closely with the contractor, and for the designer to be onsite regularly overseeing construction and stewardship. It was also advantageous to have well written specifications that require submittals and approvals for various products. This kept the landscape architect in the conversation, and required review of issues before they were installed. While onsite during one field visit, the porous paver parking lot was being constructed using a sand setting bed, rather than the aggregate material from the detail. The construction was halted immediately, and testing was completed to document the infiltration capacity. The owner agreed to a warranty period extension, allowing the rest of the parking lot to be constructed using the specified material. To date, there has been no sign of a lack of infiltration.

It is important to communicate the establishment process and aesthetic considerations very clearly to the client (and all occupants of a particular project), so that all expectations are clear and resolved. Construction schedule impacts also need to be clearly understood throughout the implementation process.

Appendix A

Statewide LID Committee

To develop a statewide Low Impact Development Manual (LID) for Michigan, several agencies and professionals were brought together to share their expertise and provide input to help create a successful and comprehensive document. We express our thanks to all the members of the Advisory Committee. The Statewide LID Advisory Committee members are:

Bill Anderson, Michigan Townships Association

Rich Bardelli, Ford Land, Fairlane Plaza South

Janis Bobrin, Washtenaw County Drain Commissioner's Office

Andy Bowman, Grand Valley Metro Council

William Bowman, U.S.D.A., Natural Resources Conservation Service

Jamie Burton, Hubbell, Roth & Clark, Inc.

Don Carpenter, Lawrence Technological University

Ron Cavallaro, Orchard, Hiltz & McCliment

Kelly Cave, Wayne County Department of Environment

Brian Cenci, Fitzgerald Henne and Associates, Inc.

Dan Christian, Tetratech

Marcy Colclough, Southwest Michigan Planning Commission

Tim Cullen, University of Michigan

Keith Depp, City of Rochester Hills

Tiffany Eichorst, Calhoun County Road Commission

Sally Elmiger, Carlisle/Wortman Associates

Paul Goldsmith, U.S. Green Building Council

Chris Hall, Green Built Michigan

Jerry Hancock, City of Ann Arbor

Dan Hula, Hula Engineering

Nina Ignaczak, Oakland County Planning and Economic Development Services

Kelly Karll, Environmental Consulting & Technology, Inc.

Shawn Keenan, City of Auburn Hills

Andrea Kevrick, InSite Design Studio, Inc.

Ron Kinney, Road Commission for Oakland County

Chris Kosmowski, City of Battle Creek

Randy Lemoine, City of Grand Rapids/Symbiotic Ventures

Lisa Lenfesty, Environmental Consulting & Technology

Royce Maniko, Monroe County Planning Commission

Jennifer Muladore, Huron Pines Conservation District

Patty O'Donnell, Northwest Michigan Council of Governments

Kristen O. Jurs, St. Clair County Health Department

Todd Pascoe, Atwell Hicks

Evan Pratt, Orchard, Hiltz & McCliment

Judy Ruszkowski, Michigan Department of Transportation

Mark St. Charles, Green Oak Township

Claire Schwartz, Fishbeck, Thompson, Carr & Huber, Inc.

Lee Schwartz, Michigan Homebuilders Association

Lynne Seymour, Macomb County Public Works Office

Melissa Solberg, Ford Land, Fairlane Plaza South

Bill Stough, Southeast Michigan Sustainable Business Forum

Ron Thomas, MAV Development

Dennis Wojcik, Washtenaw County Drain Commissioner's Office

Appendix B

Glossary and List of Acronyms

Some definitions in this glossary are adapted from definitions from the Environmental Protection Agency, as well as applicable sections of the Michigan General Statutes and the Regulations of Michigan State Agencies. In addition, related guidance documents were consulted such as the Maryland Stormwater Design Manual and the Connecticut Stormwater Quality Manual.

Aquifer	A porous water-bearing formation of permeable rock, sand, or gravel capable of yielding a significant quantity of groundwater.
Bankfull flow	The condition where streamflow fills a stream channel to the top of the bank and at a point where the water begins to overflow onto a floodplain. For incised channels, where the channel has been downcutting, bankfull flow may no longer reach the floodplain.
Base flow	Streamflow that is the result of discharge from groundwater not due to stormwater runoff.
Berm	A shelf that breaks the continuity of a slope; a linear embankment.
Best Management Practice (BMP)	Structural and non-structural practices and techniques that mitigate the adverse impacts caused by land development on water quality and/or water quantity.
Biological oxygen demand (BOD)	A measure of the quantity of organic material in water as measured by its decomposition by oxidation mediated by microorganisms.
Bioretention	A water quality practice that utilizes landscaping and soils to treat stormwater runoff by collecting it in shallow depressions before filtering through a fabricated planting soil media.
Brownfield	Abandoned, idle, or under-used industrial and commercial properties where expansion or redevelopment is hindered or complicated by real or perceived environmental conditions.
Buffer	A zone of variable width located along both sides of a natural feature (e.g., stream or forested area) and designed to provide a protective area along a corridor.
Cation Exchange Capacity (CEC)	The capacity of a soil for ion exchange of positively charged ions between the soil and the soil solution. (A positively-charged ion, which has fewer electrons than protons, is known as a cation.) Cation exchange capacity is used as a measure of fertility, nutrient retention capacity, and the capacity to protect groundwater from cation contamination.
Channel	A natural stream that conveys water; a ditch excavated for the flow of water.
Channel protection volume	A volume of precipitation to be held on a piece of land, not to be released as runoff to a stream or river. The volume is selected that best protects the stream or river banks against erosion. Typically it's the volume of runoff calculated for a two-year, 24-hour storm falling on undeveloped meadow or forest.

Check dam	Small temporary dam constructed across a swale or drainage ditch to reduce the velocity of concentrated stormwater flow.
Cistern	Containers that store large quantities of stormwater above or below ground. They can be used on residential, commercial, and industrial sites.
Clustering	A land use planning term that describes the development pattern of clustering buildings and supportive facilities in one area of a site to conserve open space and natural features.
Combined sewer overflows (CSOs)	Combined sewer systems are generally older systems that were designed to carry both stormwater and sanitary sewage. When combined sewers do not have enough capacity to carry all the runoff and wastewater or the receiving treatment plant cannot accept all of the flow, the combined wastewater overflows into receiving waters as combined sewer overflow.
Constructed filter	Structures or excavated areas containing a layer of sand, compost, organic material, peat, or other filter media that reduce pollutant levels in stormwater runoff by filtering sediments, metals, hydrocarbons, and other pollutants.
Credit	Used in the design process to emphasize the use of BMPs that, when applied, alter the disturbed area in a way that reduces the volume of runoff from that area. The credit only works with designs based on the Curve Number or CN method because it modifies the CN variable so that the amount of runoff generated from an event is reduced.
Curve Number	Also CN. Determines the volume of stormwater removed from rainfall before runoff begins. It's based on land cover type, hydrologic condition, antecedent runoff condition and hydrologic soil group (HSG). The CN is a component in the NRCS Curve Number method for calculating storm runoff.
Darcy's Law	An equation stating that the rate of fluid flow through a porous medium is proportional to the potential energy gradient (typically driven by gravity) within the fluid. The constant of proportionality is the hydraulic conductivity, which is a property of both the porous medium and the fluid moving through the porous medium.
DBH	Diameter of a tree at breast height. DBH is the most frequent measurement made by a forester using either a diameter tape or tree caliper.
Deicers	Materials applied to reduce icing on paved surfaces. These consist of salts and other formulated materials that lower the melting point of ice, including sodium chloride, calcium chloride, and blended products consisting of various combinations of sodium, calcium, magnesium, chloride, and other chemicals.
Denitrification	The conversion of nitrate (NO3) to nitrogen (N2) gas by bacteria.
Detention	The stormwater management practice of temporarily detaining runoff, typically in a detention basin on site, before releasing it downstream.
Disturbed area	An area in which the natural vegetative soil cover has been removed or altered and is susceptible to erosion.

Dry well	Small infiltration pits or trenches filled with aggregate that receive clean runoff primarily from rooftops.
Earth change	A human-made change in the natural cover or topography of land, including cut and fill activities, which may result in or contribute to soil erosion or sedimentation of the waters of the state. Earth change does not include the practice of plowing and tilling soil for the purpose of crop production.
Erosion	The wearing away of land surface by running water, wind, ice, or other geological agents.
Erosion and sedimentation control program	The activities of a county or local enforcing agency or authorized public agency for staff training, developing and reviewing development plans, issuing permits, conducting inspections, and initiating compliance and enforcement actions to effectively minimize erosion and off-site sedimentation.
Evaporation	Phase change of liquid water to water vapor.
Evapotranspiration	The combined process of evaporation and transpiration (transpiration is the conversion of liquid water to water vapor through plant tissue).
Floodplain	Areas adjacent to a stream or river that are subject to flooding during a storm event that occurs once every 100 years (or has a likelihood of occurrence of 1/100 in any given year).
Freeboard	The distance between the maximum water surface elevation anticipated in design and the top of retaining banks or structures. Freeboard is provided to prevent overtopping due to unforeseen conditions.
French drain	A drain consisting of an excavated trench filled with pervious material, such as course sand, gravel, or crushed stone; water percolates through the material and flows to an outlet.
Geotextile fabric	Woven and non-woven material that acts as a permeable separator allowing water to pass into or out of a drainage system while preventing soils and other materials from entering the system. These fabrics are also used to separate, stabilize, and reinforce applications over soft soils, including paved and unpaved roads and embankments.
Green infrastructure	The network of open space, woodlands, wildlife, habitat, parks, and other natural areas which sustain clean air, water, and natural resources, and enhance quality of life.
Green roof	Conventional rooftops that include a thin covering of vegetation allowing the roof to function more like a vegetated surface. The layer thickness varies between 2-6 inches and consists of vegetation, waterproofing, insulation, fabrics, growth media, and other synthetic components.
Groundwater recharge	The replenishment of existing natural water bearing subsurface layers of porous stone, sand, gravel, silt or clay via infiltration.

H:V	Horizontal to vertical ratio.
Headwater stream	The source of a river or stream. Typically a very small, permenantly flowing or intermittent, waterway from which the water in a river or stream originates.
Herbaceous	Plants whose stem die back to the ground after each growing season.
Hotspot	Areas where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater.
Hydrodynamic separators	An engineered structure to separate sediments and oils from stormwater runoff using gravitational separation and/or hydraulic flow.
Hydrologic (water) cycle	The movement of rainfall from the atmosphere to the land surface, to receiving waters and then back to the atmosphere.
Hydrologic soil group (HSG)	A soil series rating developed by the Natural Resources Conservation Service which describes the physical drainage and textural properties of each soil type.
Hydroperiod	The period of time, defined by time of year and duration, during which a wetland is covered by water.
Impervious surface	A surface that prevents the infiltration of water into the ground such as roofs, streets, sidewalks, driveways, parking lots, and highly compacted soils.
Incised Channel	A stream, river or man made channel where the base is lowered by erosion to the point where flood flows no longer reach the floodplain. Incised channels typically form in areas where changes in watershed land use increase the frequency, duration and peak flow rates.
Indigenous	Having originated in or being produced, growing, living or occurring naturally in a particular region or environment.
Infiltration practices	Best management practices (bed, trench, basin, well, etc.) that allow for rainfall to soak into the soil mantle.
Integrated pest management (IPM)	An ecosystem-based strategy that focuses on long-term prevention of pests and their damage through a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties. Pesticides are used only after monitoring indicates they are needed according to established guidelines for the target organism.
Intermittent stream	A stream that only flows for part of the year and is typically marked on topographic maps with a line of blue dashes and dots.
Invasive species	An alien plant species whose introduction does or is likely to cause economic or environmental harm or harm to human health.
Karst	A carbonate-based bedrock, such as limestone or dolomite that is highly soluble. Dissolution of Karst can potentially lead to subsurface voids and sinkholes.

Lake	The Great Lakes and all natural and artificial inland lakes or impoundments that have definite banks, a bed, visible evidence of a continued occurrence of water, and a surface area of water that is equal to, or greater than, 1 acre. "Lake" does not include sediment basins and basins constructed for the sole purpose of storm water retention, cooling water, or treating polluted water.
LEED	Leadership in Energy and Environmental Design (LEED) is a measuring system created by the U.S. Green Building Council that rates buildings based on their eco-friendliness in the areas of energy efficiency, water consumption, materials usage, indoor air quality and other contributions that promote sustainability in buildings.
Level spreader	A device for distributing stormwater uniformly over the ground surface as sheet flow to prevent concentrated, erosive flows and promote infiltration.
Low impact development (LID)	Activities that mimic a site's presettlement hydrology by using design techniques that are spatially distributed, decentralized micro-scale controls that infiltrate, filter, store, evaporate, and detain runoff close to its source.
Mitigation	Making something less harsh or severe. LID mitigates by lessening the impacts of stormwater runoff from impervious surfaces.
Native plants	Plants that historically co-evolved with the local ecology, geology and climate. EPA has categorized native (presettlement by Europeans) plant groups by Ecoregions.
Nonerosive velocity	The speed of water movement that is not conducive to the development of accelerated soil erosion.
Nonpoint source pollution	Pollution that does not come from a point source, such as a wastewater treatment plant, and are normally associated with precipitation and runoff from the land or percolation.
Nonstructural BMPs	Stormwater runoff treatment techniques that use natural measures to reduce pollution levels that do not involve the construction or installation of devices (e.g., management actions)
One-year storm	A stormwater event which occurs on average once every year or statistically has a 100% chance of occurring in a given year.
Outfall structure	The point where stormwater drainage discharges from a pipe, ditch, or other conveyance system to receiving waters.
Permanent soil erosion and sedimentation control measures	Control measures which are installed or constructed to control soil erosion and sedimentation and which are maintained after project completion.
Permeable	Allows liquid to pass through. Porous. Also pervious, the opposite of impervious.
Pervious	See Permeable.
Peak discharge rate	The maximum instantaneous rate of flow (volume of water passing a given point over a specific duration, such as cubic feet per second) during a storm, usually in reference to a specific design storm event.

Planter box	A device containing trees and plants near streets and buildings constructed to prevent stormwater from directly draining into sewers.
Pervious pavement	An infiltration technique that combines stormwater infiltration, storage, and structural pavement that consists of a permeable surface underlain by a storage reservoir.
Phase I Stormwater Regulations	Phase I of the U.S. EPA's National Pollutant Discharge Elimination System Program (NPDES) that addressed sources of stormwater runoff that had the greatest negative impact on water quality. Permit coverage was required for stormwater discharges from medium and large municipal separate storm sewer systems (MS4s) serving populations of 100,000 or more as well as industrial activities, including construction activity that disturbs five or more acres of land.
Phase II Stormwater Regulations	The second phase of the NPDES program which targets small MS4s in densely populated areas and construction activity disturbing between one and five acres of land.
Positive overflow	A technique that uses a catch basin with a higher inlet than outlet to provide adequate release of stormwater so the underlying bed system of pervious pavement does not overflow and saturate the pavement.
Presettlement	Time period before significant human change to the landscape. For the purpose of this manual, presettlement can also be used as the presettlement site condition. In the LID design calculations, presettlement is further defined as either woods or meadow in good condition. This definition will not represent the actual presettlement condition of all land in Michigan. It does provide a simple, conservative value to use in site design that meets common LID objectives.
Pretreatment	Techniques used to provide storage and removal of course materials, floatables, or other pollutants from stormwater before it is discharged downstream to a water body or another BMP.
Rain barrel	A barrel designed to retain small volumes of stormwater runoff for reuse for gardening and landscaping.
Rain garden	Landscape elements that combine plantings and depressions that allow water to pool for a short time (e.g., a few days) after a rainfall then slowly absorbed by the soil and vegetation.
Riparian buffer	An area next to a stream or river (sometimes also used for lakes) where development is restricted or prohibited. The buffers should be vegetated with herbaceous and woody native plants, or left in their natural state. Buffers filter stormwater before it reaches the waterbody and slow the stormwater velocity.
Riparian corridor	The area adjacent to a stream or river (sometimes also used for lakes) that preserves water quality by filtering sediments and pollutants from stormwater before it enters the waterbody, protects banks from erosion, provides storage area for flood waters, preserves open space, and provides food and habitat for wildlife.
Retention	The storage of stormwater to prevent it from leaving a developed or developing site.
Sanitary sewer overflows (SSOs)	Discharge from a sanitary sewer system which contains untreated or partially treated sanitary sewage. This type of overflow comes from systems designed to only carry sanitary sewage, however, overflows can result because of a storm event. This is because stormwater, groundwater inflow, and infiltration can enter sanitary lines through cracks, illicit connections, or undersized systems.

Seasonally high water table (SHWT)	The highest elevation of the groundwater table typically observed during the year.
Sediment basin	A naturally occurring or constructed depression used for the sole purpose of capturing sediment during or after an earth change activity.
Sheet flow	Overland flow of stormwater across the ground or another flat surface like a rooftop, taking the form of a thin, continuous layer of water, and not a concentrated flow as in a pipe, culvert, channel, ditch, or stream.
Smart Growth	Development strategies that aim to preserve natural land and critical environmental areas by concentrating areas of development, protect water and air quality, re-use developed land, provide pedestrian friendly neighborhoods, and provide affordable housing.
Soil erosion	The increased loss of the land surface that occurs as a result of the wearing away of land by the action of wind, water, gravity, or a combination of wind, water, gravity or human activities.
Stabilization	The establishment of vegetation or the proper placement, grading, or covering of soil to ensure its resistance to soil erosion, sliding, or other earth movement.
Stormwater	Water consisting of precipitation runoff or snowmelt.
Stormwater retention basin	An area which is constructed to capture surface water runoff and which does not discharge directly to a lake or stream through an outlet. Water leaves the basin by infil-tration and evaporation.
Stormwater runoff	Rainfall or snowmelt that runs off the land and is released into our rivers and lakes.
Stream	A river, creek, or other surface watercourse which may or may not be serving as a drain as defined in Act No. 40 of the Public Acts of 1956, as amended, being §280.1 et seq. of the Michigan Compiled Laws, and which has definite banks, a bed, and visible evidence of the continued flow or continued occurrence of water, including the connecting waters of the Great Lakes.
Structural BMPs	Devices constructed for temporary storage and treatment of stormwater runoff.
Subsoiling:	A conservation practice that breaks up the soil layer below the topsoil, from 12 – 18 inches down to 2 to 3 feetdeep, allowing increased water movement, better aeration of the roots and access to additional minerals and nutrients for plant growth.
Swale	A shallow stormwater channel that can be vegetated with some combination of grasses, shrubs, and/or trees designed to slow, filter, and often infiltrate stormwater runoff.
Temporary soil erosion and sedimen-tation control measures	Interim control measures which are installed or constructed to control soil erosion and sedimentation and which are not maintained after project completion.
Time of concentration	Time required for water to flow from the most remote point of a watershed to a downstream outlet. Flow paths, ground surface slope and roughness, and channel char-acteristics affect this time.

Total phosphorous (TP)	The total amount of phosphorus that is contained in the water column.
Total suspended solids (TSS)	The total amount of particulate matter that is suspended in the water column.
Transpiration	The conversion of liquid water to water vapor through plant tissue.
Vegetated filter strip	Uniformly graded vegetated surface located between pollutant source areas and downstream receiving waters.
Waters of the state	The Great Lakes and their connecting waters, inland lakes and streams as defined in rules promulgated under Part 31, and wetlands regulated under Part 303 of Michigan's Natural Resources and Environmental Protection Act, Act 451 of 1994, as amended..
Watershed	The geographic area that drains to a specific watercourse outlet. The watershed for a major river may encompass a number of smaller watersheds that ultimately contribute to their common outlet.
Watershed plan	A plan that identifies and implements actions needed to resolve water quality and quantity concerns. The plan assesses the current nature and status of the watershed ecosystem; identifies short and long-term goals, the actions needed to meet those goals; and includes a method for progress evaluation.
Wellhead protection area	A protected surface and subsurface zone surrounding a well or well field supplying a public water system to keep contaminants from reaching the well water.
Wetland	An area that is saturated by surface or groundwater with vegetation adapted for life under those soil conditions, such as swamps, bogs, fens, marshes, and estuaries.
Wet pond/constructed wetland	Surface or underground structures that provide temporary storage of stormwater runoff to prevent downstream flooding and the attenuation of runoff peaks.

Appendix C

Recommended Plant Lists for Best Management Practices

This appendix contains recommended native and non-native (when appropriate) plant species for the Best Management Practices detailed throughout the manual. Species have been recommended based on hardiness, aesthetics, functionality, and commercial availability. It is certain that species exist outside the confines of this list that will perform in a comparable way to those listed; however, commercial availability is often a limiting factor in obtaining material for native plantings. Over time, and in certain locales, additional species will become available to supplement those listed below.

An array of planting zones is provided based on normal water levels (Figure C.1). Using these zones will provide the best chances for long-term success of native planting in the context of LID. While plants may naturally occur outside of the given ranges, these ranges are intended to be guidelines for plant installation. Whenever possible and practical in standing water conditions, native plants should be installed in live plant form (rather than seed). Seed or a combination of seed and live plants may be used in upland situations.

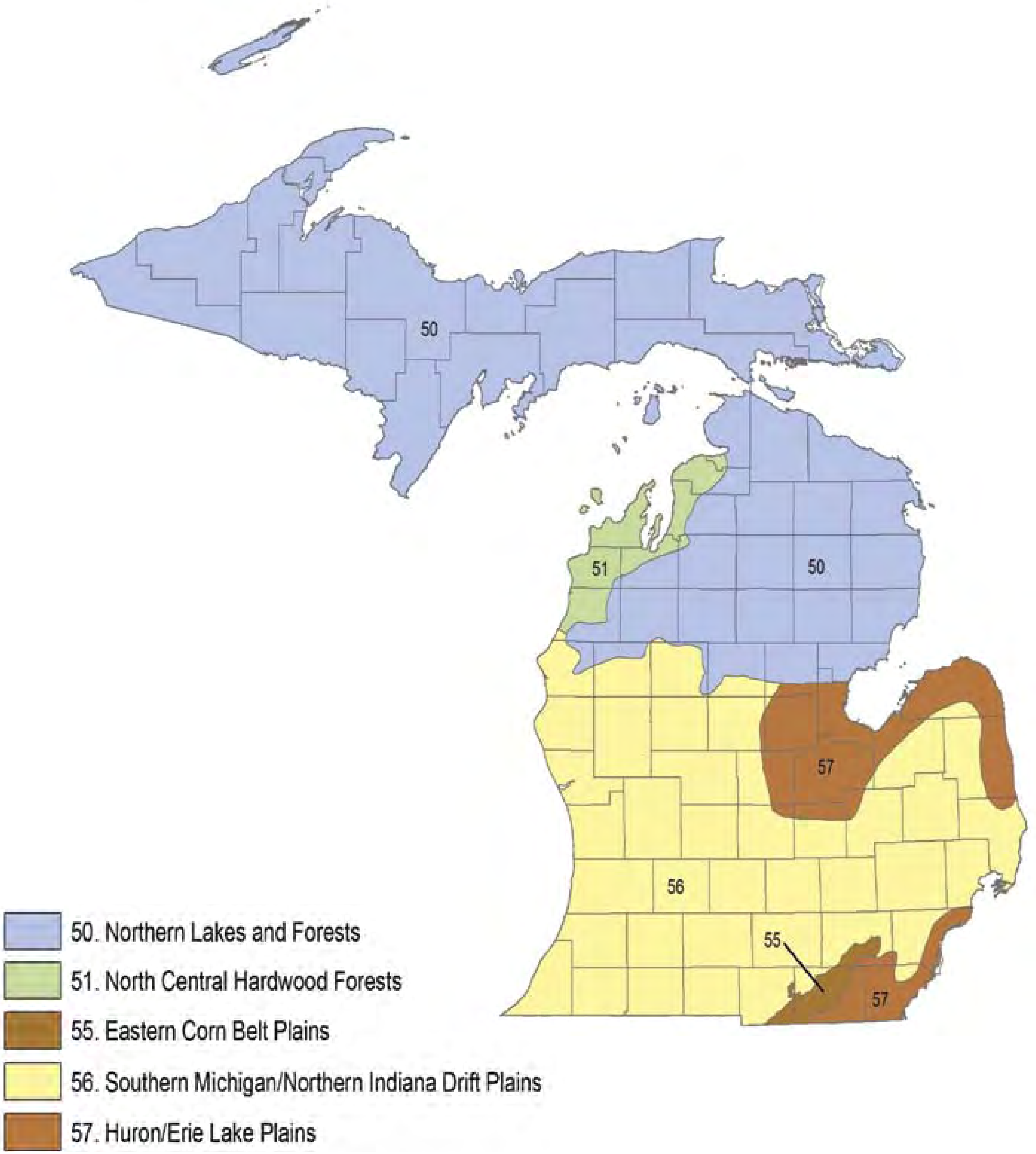
Recommendations are given for height, bloom color, bloom time, sun requirements, salt tolerance, and ecoregion. Please note that these are recommendations based on a range of situations, and a specific plant or population may vary from site-to-site. For sun requirements, F = Full sun required, P = Partial sun tolerated, and S = Shade tolerated. Salt tolerance is classified as Yes (Y) or No (N). This was determined through literature reviews and anecdotal evidence. If there is no information confirming tolerance, a “No” was listed.

Figure C.1
Planting Zone/BMP Matrix

	Zone A — 2”-4” Below Water Level	Zone B — 0”-2” Below Water Level	Zone C — 0”-2” Above Water Level	Zone D — 2”-4” Above Water Level	Zone E — 4”-18” Above Water Level	Zone F — 18”+ Above Water Level	Zone G — Planter Boxes	Zone H — Vegetated Roofs
Rain gardens/Bioretention	✤	✤	✤	✤	✤	✤		
Vegetated Filter Strips			✤	✤	✤	✤		
Vegetated Swales		✤	✤	✤				
Infiltration Basin		✤	✤					
Subsurface Infiltration Basins				✤	✤	✤		
Infiltration Trenches				✤	✤	✤		
Infiltration Berns	✤	✤	✤	✤	✤	✤		
Planter Boxes							✤	
Vegetated Roofs								✤
Constructed Wetlands	✤	✤	✤	✤				
Wet Ponds	✤	✤	✤					
Dry Extended Detention Basins			✤	✤	✤	✤		
Riparian Corridor Restoration			✤	✤				
Native Revegetation	✤	✤	✤	✤	✤	✤	✤	✤

Ecoregion recommendations are also provided for each species (Figure C.2). Whenever possible, the designer/installer should seek to use species that historically occurred in the same ecoregion as the project. When necessary, species occurring in an adjacent ecoregion may be used.

Figure C.2
EPA Level III Ecoregions for Michigan



Source: USEPA

Plant Installation

Native Seeding

Seasonal consideration: October 1-June 15 (note: seeds should not be planted on frozen ground).

Native seeding is generally recommended for areas above the water line or 1-2" below the water line. Live plant material should be used to establish vegetation at deeper water levels.

Broadcast seeding

Broadcast seeding is preferred over drill seeding on graded, bare soil sites. Apply the seed uniformly over the surface using a combination seeder/cultipacker unit such as a Brillion or Truax Trillion seeder. The Trillion seeder is preferred as it is designed to handle native seeds.

A cone seeder or other similar broadcasting equipment may also be used if the seed mix does not contain fluffy seeds in amounts sufficient to prevent free flowing without plugging. Seed should then be pressed into the surface using a cultipacker or roller.

Drill seeding

A rangeland-type no-till drill designed to plant native grasses and forbs may be used in bare soils although this equipment is specifically designed to plant through existing vegetation which is killed with an herbicide. Cultipacking or rolling before seeding may be required to prevent seed placement depths exceeding .25 inch, but cultipacking or rolling after seeding is not required.

All seeding equipment, whether broadcast or drill, should be calibrated to deliver the seed at the rates and proportions specified in the plans. Equipment should be operated to ensure complete coverage of the entire area to be seeded, and seed must be placed no deeper than .25 inch in the soil. No fertilizers or soil conditioners will be required or allowed.

Native Planting

Seasonal considerations: May 1-July 1

Plant plugs should be installed in holes drilled with an auger the same diameter and depth as the plug within +0.75 inch/- 0.25 inch. In wetland plantings where soil is soft and moist enough, a dibble bar or trowel may also be used. The planting layout should consider the requirements of the individual species regarding soil type, moisture, slope, shading, and other factors for the particular plant species.

Planting densities vary according to budget and project goals and can range from three-to-five foot spacing for plug supplements of seeded areas to six inches to two foot spacing for high visibility landscaping projects with large budgets. Groups of five-to-seven plugs of the same species planted approximately one foot apart is usually preferable to planting all species intermixed randomly across the site at a uniform density.

In wetland or shoreline areas with potential for high wave action or wildlife predation that may dislodge newly planted plugs, plugs should be secured with six inch or eight inch U-shaped wire erosion control blanket staples. Staple length is determined by the density of the planting substrate; softer substrates require longer length to hold plugs adequately.

In areas where potential for wildlife predation exists, such as retention basins or other planting areas adjacent to open water, waterfowl barriers should be installed around a minimum of 50 percent of the plugs. All plugs not protected by barriers should be stapled into the substrate as described above. Barriers may consist of plastic or wire mesh enclosures supported with wooden stakes, adequately constructed to inhibit access by waterfowl for one growing season. Enclosures should extend at least two feet above the plant tops. Methodology should be approved by the project designer with input from a restoration ecologist if necessary. Barriers may be removed after one growing season.

Maintenance and Management

Maintaining vegetated BMPs is typically most important during the first few years following installation. Supplemental irrigation may be needed to help establish plants in drought conditions. Plants may need to be replaced due to predation or other unseen factors. Most commonly, management includes removing invasive species via mowing, hand-pulling, or spot herbicide applications. In larger areas, broadcast herbicide applications may be appropriate. Over time in upland areas, controlled burning may be used as a way to invigorate the plantings and control certain invasive species. If not feasible for social or cultural reasons, an annual or biennial mowing may be used instead of fire.

Long-term management may be necessary, but is typically significantly less intensive. The site should be periodically checked for invasive species infestations. Any prairie or open area may need occasional (every three to five years) burning or mowing to remove woody vegetation that may encroach.

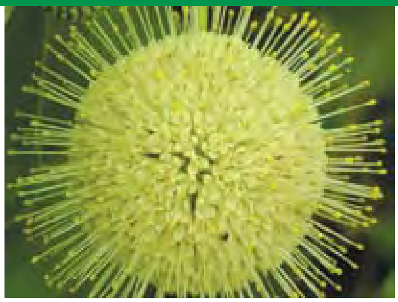
Zone A

Planting Zone = two-to-four inches below water level

These species require continual inundation within the given water depths in order to thrive. Although slight, short-term variances may be tolerated (+/-five inches for a period of 48 hours or less), water levels must remain in this range for a majority of the growing season for maximum plant growth and survival.

Botanical Name	Common Name	Height	Color	Bloom Time	Sun	Salt Tolerant	Ecoregion
Woody Species:							
Cephalanthus occidentalis	Buttonbush	15’	White	Jun-Aug	F/P/S	N	51,55,56,57
Grasses/Sedges/Rushes:							
Acorus calamus	Sweet flag	1’-4’	Green	May-Jun	F/P	N	50,51,55,56,57
Scirpus acutus	Hard-stemmed bulrush	4’-6’	Brown	Apr-Aug	F	Y	50,51,55,56,57
Scirpus validus	Great bulrush	4’-8’	Brown	May-Aug	F	Y	50,51,55,56,57
Sparganium americanum	American bur reed	2’-5’	Green	Jun-Aug	F/P	N	50,51,55,56,57
Sparganium eurycarpum	Common bur reed	2’-6’	Green	May-Aug	F	N	50,51,55,56,57
Forbs:							
Asclepias incarnata	Swamp milkweed	3’-5’	Pink	Jun-Sep	F/P	N	50,51,55,56,57
Decodon verticillatus	Swamp loosestrife	2’-4’	Purple	Jul-Sep	F/P	N	51,55,56,57
Iris virginica	Blue flag iris	2’-3’	Purple	May-Jul	F/P/S	N	50,51,55,56,57
Peltandra virginica	Arrow arum	2’-5’	Green	Jun-Jul	F/P/S	N	55,56,57
Pontedaria cordata	Pickerelweed	1’-3’	Violet	Jun-Sep	F/P	N	50,51,55,56,57
Sagittaria latifolia	Arrowhead	1’-4’	White	Jun-Sep	F/P	N	50,51,55,56,57

Representative Zone A Species



Buttonbush

Pickerel Weed

Swamp Milkweed

Arrowhead

Blue Flag Iris

Source: JFNew

Zone B

Planting Zone = zero-to-two inches below water level

These species tolerate fluctuating water levels within this range. Although slight, short-term variances may be tolerated (+/-five inches for a period of 48 hours or less), water levels must remain in this range for most of the growing season for maximum plant growth and survival.

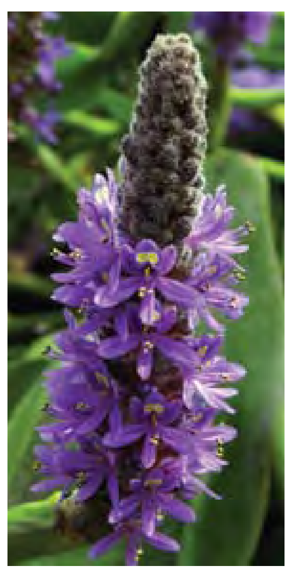
Botanical Name	Common Name	Height	Color	Bloom Time	Sun	Salt Tolerant	Ecoregion
Woody Species:							
Cephalanthus occidentalis	Buttonbush	15’	White	Jun-Aug	F/P/S	N	51,55,56,57
Grasses/Sedges/Rushes:							
Acorus calamus	Sweet flag	1’-4’	Green	May-Jun	F/P	N	50,51,55,56,57
Carex comosa	Bristly sedge	2’-3’	Green	May-Jun	F	N	50,51,55,56,57
Carex lacustris	Lake sedge	2’-4’	Brown	May-Jun	F/P/S	N	50,51,55,56,57
Carex stricta	Tussock sedge	2’-3’	Brown	Apr-Jun	F/P	N	50,51,55,56,57
Eleocharis acicularis	Needle spike rush	6”	Green	May-Oct	F	N	50,51,55,56,57
Eleocharis obtusa	Blunt spike rush	1’-2’	Green	May-Sep	F/P	N	50,51,55,56,57
Glyceria striata	Fowl manna grass	1’-5’	Green	May-Jun	F/P/S	N	50,51,55,56,57
Juncus effusus	Soft rush	1’-4’	Brown	July	F/P	N	50,51,55,56,57
Scirpus acutus	Hard-stemmed bulrush	4’-6’	Brown	Apr-Aug	F	Y	50,51,55,56,57
Scirpus cyperinus	Wool grass	3’-5’	Tan	Jun-Sep	F	Y	50,51,55,56,57
Scirpus pendulus	Red bulrush	2’-4’	Brown	May-Jun	F	N	51,55,56,57
Scirpus validus	Great bulrush	4’-8’	Brown	May-Aug	F	Y	50,51,55,56,57
Sparganium americanum	American bur reed	2’-5’	Green	Jun-Aug	F/P	N	50,51,55,56,57
Sparganium eurycarpum	Common bur reed	2’-6’	Green	May-Aug	F	N	50,51,55,56,57
Forbs:							
Alisma plantago-aquatica	Water plantain	2’-4’	White	Jul-Sep	F	N	50,51,55,56,57
Asclepias incarnata	Swamp milkweed	3’-5’	Pink	Jun-Sep	F/P	N	50,51,55,56,57
Decodon verticillatus	Swamp loosestrife	2’-4’	Purple	Jul-Sep	F/P	N	51,55,56,57
Iris virginica	Blue flag iris	2’-3’	Purple	May-Jul	F/P/S	N	50,51,55,56,57
Peltandra virginica	Arrow arum	2’-5’	Green	Jun-Jul	F/P/S	N	55,56,57
Pontedaria cordata	Pickerelweed	1’-3’	Violet	Jun-Sep	F/P	N	50,51,55,56,57
Sagittaria latifolia	Arrowhead	1’-4’	White	Jun-Sep	F/P	N	50,51,55,56,57
Saururus cernuus	Lizard’s tail	2’-4’	White	Jun-Aug	P/S	N	55,56,57

Representative Zone B Species

Blue Flag Iris

Arrowhead

Bristly Sedge



Pickerel Weed

Swamp Milkweed

Source: JFNew

Zone C

Planting Zone = zero-to-two inches above water level

These plants are tolerant of fluctuating water levels within this range. They will also tolerate short periods of inundation, not to exceed 48 hours in most situations, making them appropriate for BMP settings.

Botanical Name	Common Name	Height	Color	Bloom Time	Sun	Salt Tolerant	Ecoregion
Woody Species:							
Acer rubrum	Red maple	90’	Green/ red	Mar-May	F/P/S	N	50,51,55,56,57
Alnus rugosa	Speckled alder	25’	Brown	Mar-May	F/P	N	50,51,55,56,57
Amelanchier arborea	Downy serviceberry	40’	White	April	F/P/S	N	50,51,55,56,57
Aronia prunifolia	Purple chokeberry	10’	White	Apr-Jul	F/P	N	50,51,55,56,57
Betula alleghaniensis	Yellow birch	100’	Purple/ Yellow	Apr-May	P/S	N	50,51,55,56,57
Betula papyrifera	Paper birch	70’	Brown	Apr-May	F/P	N	50,51,55,56,57
Cephalanthus occidentalis	Buttonbush	15’	White	Jun/Aug	F/P/S	N	51,55,56,57
Cornus amomum	Silky dogwood	10’	White	May-Jul	F/P	N	51,55,56,57
Cornus sericea	Red-osier dogwood	10’	White	May-Sep	F/P	N	50,51,55,56,57
Ilex verticillata	Winterberry	10’	White	June	F/P/S	Y	50,51,55,56,57
Larix laricina	American larch	75’	Brown	May	F/P	N	50,51,55,56,57
Lindera benzoin	Spicebush	15’	Yellow	Apr-May	P/S	N	51,55,56,57
Morus rubra	Red mulberry	50’	Green	May-Jun	F/P/S	N	55,56,57
Nyssa sylvatica	Black gum	100’	Green	May-Jul	F/P/S	Y	51,55,56,57
Physocarpus opulifolius	Ninebark	10’	White	May-Jun	F/P	N	50,51,55,56,57
Picea mariana	Black spruce	60’	Brown	May-Jun	F/P/S	N	50,51,57
Quercus bicolor	Swamp white oak	70’	Green/ yellow	May	F/P/S	Y	55,56,57
Quercus palustris	Pin oak	90’	Green/ yellow	Apr-May	F/P/S	Y	55,56,57
Ribes americanum	Wild black currant	5’	Yellow	Apr-Jun	F/P/S	N	50,51,55,56,57
Rosa palustris	Swamp rose	2’-7’	Pink	Jun-Aug	F/P/S	N	50,51,55,56,57
Thuja occidentalis	White cedar	50’	Brown	Apr-May	F/P/S	N	50,51,55,56,57
Ulmus americana	American elm	100’	Brown	Mar-Apr	F/P/S	N	50,51,55,56,57
Ulmus rubra	Slippery elm	80’	Green	Mar-Apr	F/P/S	N	51,55,56,57
Viburnum lentago	Nannyberry	20’	White	Apr-Jun	P/S	Y	50,51,55,56,57
Grasses/Sedges/Rushes:							
Calamagrostis canadensis	Blue joint grass	2’-4’	Brown	June	F/P	N	50,51,55,56,57
Carex comosa	Bristly sedge	2’-3’	Green	May-June	F/P	N	50,51,55,56,57
Carex crinita	Fringed sedge	2’-5’	Green	May	F/P/S	N	50,51,55,56,57
Carex hystericina	Porcupine sedge	2’-3’	Green	May-June	F/P/S	N	50,51,55,56,57
Carex lupulina	Common hop sedge	2’-3’	Green/ Brown	May-June	F/P/S	N	50,51,55,56,57
Carex muskingumensis	Palm sedge	1’-2’	Brown	May-June	S	N	55,56,57
Carex stipata	Common fox sedge	1’-3’	Brown	Apr-May	F/P/S	N	50,51,55,56,57
Carex stricta	Tussock sedge	2’-3’	Brown	Apr-Jun	F/P	N	50,51,55,56,57
Carex vulpinoidea	Brown fox sedge	2’-3’	Brown	May-Jun	F/P	N	50,51,55,56,57
Cinna arundinacea	Common wood reed	3’-4’	Green	Aug-Sep	P/S	N	55,56,57
Eleocharis acicularis	Needle spike rush	6”	Green	May-Oct	F	N	50,51,55,56,57
Eleocharis obtusa	Blunt spike rush	1’-2’	Green	May-Sep	F/P	N	50,51,55,56,57
Glyceria striata	Fowl manna grass	1’-5’	Green	May-Jun	F/P/S	N	50,51,55,56,57
Juncus effusus	Soft rush	1’-4’	Brown	July	F/P	N	50,51,55,56,57
Juncus tenuis	Path rush	6”-2’	Brown	June	F/P/S	N	50,51,55,56,57
Juncus torreyi	Torrey’s rush	1’-2’	Brown	Jun-Sep	F	Y	51,55,56,57
Scirpus acutus	Hard-stemmed bulrush	4’-6’	Brown	Apr-Aug	F	Y	50,51,55,56,57
Scirpus atrovirens	Dark green rush	3’-5’	Brown	Jun-Aug	F	N	50,51,55,56,57
Scirpus cyperinus	Wool grass	3’-5’	Tan	Jun-Sep	F	Y	50,51,55,56,57
Scirpus pendulus	Red bulrush	2’-4’	Brown	May-Jun	F	N	51,55,56,57
Scirpus validus	Great bulrush	4’-8’	Brown	May-Aug	F	Y	50,51,55,56,57

Botanical Name	Common Name	Height	Color	Bloom Time	Sun	Salt Tolerant	Ecoregion
Forbs:							
Alisma plantago-aquatica	Water plantain	2'-4'	White	Jul-Sep	F	N	50,51,55,56,57
Anemone canadensis	Canada anemone	1'-2'	White	May-Sep	F/P	N	50,51,55,56,57
Angelica atropurpurea	Great angelica	6'-9'	White	May-Jun	F/P	N	55,56,57
Asclepias incarnata	Swamp milkweed	3'-5'	Pink	Jun-Sep	F/P	N	50,51,55,56,57
Aster novae-angliae	New England aster	3'-6'	Violet	Jul-Oct	F/P	N	50,51,55,56,57
Aster puniceus	Swamp aster	3'-6'	Lav/ White	Aug-Oct	F	Y	50,51,55,56,57
Aster umbellatus	Flat-topped aster	1'-4'	White	Jul-Oct	F/P	N	50,51,55,56,57
Cassia hebecarpa	Wild senna	3'-5'	Yellow	Jul-Aug	F/P	N	55,56
Chelone glabra	Turtlehead	2'-4'	Cream	Aug-Sep	F/P/S	N	50,51,55,56,57
Eupatorium maculatum	Spotted Joe-pye weed	4'-7'	Pink	Jun-Oct	F/P	N	50,51,55,56,57
Eupatorium perfoliatum	Boneset	3'-5'	White	Jul-Oct	F/P	Y	50,51,55,56,57
Euthamia graminifolia	Grass-leaved gold-enrod	1'-4'	Yellow	Jul-Sep	F/P	N	50,51,55,56,57
Gentiana andrewsii	Bottle gentian	1'-3'	Blue	Aug-Oct	F/P	N	50,51,55,56,57
Helenium autumnale	Sneezeweed	3'-5'	Yellow	Jul-Nov	F/P	Y	50,51,55,56,57
Helianthus giganteus	Tall sunflower	5'-12'	Yellow	Jul-Sep	F/P	N	50,51,55,56,57
Iris virginica	Blue flag iris	2'-3'	Purple	May-Jul	F/P/S	N	50,51,55,56,57
Liatris spicata	Marsh blazing star	3'-5'	Pink	Jul-Sep	F/P	N	55,56,57
Lilium michiganense	Michigan lily	3'-8'	Orange	Jul-Aug	P/S	N	55,56,57
Lobelia cardinalis	Cardinal flower	2'-5'	Red	Jul-Oct	F/P/S	N	50,51,55,56,57
Lobelia siphilitica	Great blue lobelia	1'-4'	Blue	Jul-Oct	F/P/S	N	50,51,55,56,57
Lobelia spicata	Pale spiked lobelia	1'-3'	Lavender	May-Aug	F/P	N	50,51,55,56,57
Mimulus ringens	Monkeyflower	2'-4'	Lavender	Jun-Sep	F/P	N	50,51,55,56,57
Physostegia virginiana	Obedient plant	2'-5'	Pink	Aug-Oct	F	Y	50,51,55,56,57
Pycnanthemum virginianum	Mountain mint	1'-3'	White	Jun-Oct	F/P	N	55,56,57
Rudbeckia laciniata	Cutleaf coneflower	3'-10'	Yellow	Jul-Nov	F/P/S	N	50,51,55,56,57
Sagittaria latifolila	Arrowhead	1'-4'	White	Jun-Sep	F/P	N	50,51,55,56,57
Saururus cernuus	Lizard's tail	2'-4'	White	Jun-Aug	P/S	N	55,56,57
Sisyrinchium angustifolium	Stout blue-eyed grass	1'	Blue	May-Aug	F/P	N	55,56,57
Solidago ohiensis	Ohio goldenrod	2'-3'	Yellow	Jul-Oct	F/P	N	50,51,55,56,57
Solidago patula	Swamp goldenrod	3'-6'	Yellow	Aug-Oct	F/P/S	N	50,51,55,56,57
Solidago riddellii	Riddell's goldenrod	2'-5'	Yellow	Sep-Nov	F	N	55,56,57
Spiraea alba	Meadowsweet	3'-6'	White	June-Sep	F/P	Y	50,51,55,56,57
Spiraea tomentosa	Steeplebush	2'-5'	Pink	Jul-Sep	F/P	Y	55,56,57
Thalictrum dasycarpum	Purple meadow-rue	3'-6'	Cream	May-Jul	F/P	N	50,51,55,56,57
Verbena hastata	Blue vervain	3'-6'	Violet	Jun-Sep	F	N	50,51,55,56,57
Vernonia missurica	Missouri ironweed	3'-5'	Purple	Jul-Sep	F	N	55,56,57
Zizia aurea	Golden Alexanders	1'-3'	Yellow	Apr-Jun	F/P/S	Y	55,56,57

Representative Zone C Species

Cardinal Flower

Swamp Milkweed

Blue-Eyed Grass

Path Rush

Joe-Pye Weed

Obedient Plant

Red-Osier Dogwood

Monkey Flower

Source: JFNew

Zone D

Planting Zone = two-to-four inches above water level

These plants tolerate fluctuating water levels within this range. They will also tolerate short periods of inundation, not to exceed 48 hours in most situations, making them appropriate for BMP settings.

Botanical Name	Common Name	Height	Color	Bloom Time	Sun	Salt Tolerant	Ecoregion
Woody Species:							
Acer rubrum	Red maple	90’	Green/ red	Mar-May	F/P/S	N	50,51,55,56,57
Acer saccharinum	Silver Maple	100’	Yellow	Mar-Apr	F/P	N	50,51,55,56,57
Amelanchier arborea	Downy serviceberry	40’	White	April	F/P/S	N	50,51,55,56,57
Aronia prunifolia	Purple chokeberry	10’	White	Apr-Jul	F/P	N	50,51,55,56,57
Betula alleghaniensis	Yellow birch	100’	Purple/ Yellow	Apr-May	P/S	N	50,51,55,56,57
Betula papyrifera	Paper birch	70’	Brown	Apr-May	F/P	N	50,51,55,56,57
Celtis occidentalis	Hackberry	60’	Green	May	F/P/S	N	55,56,57
Cercis canadensis	Redbud	25’	Red	Apr-May	F/P/S	N	55,56,57
Cornus amomum	Silky dogwood	10’	White	May-Jul	F/P	N	51,55,56,57
Cornus sericea	Red-osier dogwood	10’	White	May-Sep	F/P	N	50,51,55,56,57
Corylus americana	American hazelnut	10’	Yellow	Apr-May	F/P	N	55,56,57
Ilex verticillata	Winterberry	10’	White	June	F/P/S	Y	50,51,55,56,57
Juglans nigra	Black walnut	90’	Green	May	F/P	N	51,55,56,57
Juniperus virginiana	Red-cedar	50’	Brown	Apr-May	F/P	N	55,56,57
Larix laricina	American larch	75’	Brown	May	F/P	N	50,51,55,56,57
Lindera benzoin	Spicebush	15’	Yellow	Apr-May	P/S	N	51,55,56,57
Liriodendron tulipifera	Tulip tree	110’	Green	May-Jun	F/P	N	55,56,57
Morus rubra	Red mulberry	50’	Green	May-Jun	F/P/S	N	55,56,57
Nyssa sylvatica	Black gum	100’	Green	May-Jul	F/P/S	Y	51,55,56,57
Physocarpus opulifolius	Ninebark	10’	White	May-Jun	F/P	N	50,51,55,56,57
Picea mariana	Black spruce	60’	Brown	May-Jun	F/P/S	N	50,51,57
Platanus occidentalis	Sycamore	100’	Green	May	F/P	N	55,56,57
Quercus bicolor	Swamp white oak	70’	Green/ yellow	May	F/P/S	N	55,56,57
Quercus macrocarpa	Bur oak	85’	Yellow	May-Jun	F/P/S	N	50,51,55,56,57
Quercus palustris	Pin oak	90’	Green/ yellow	Apr-May	F/P/S	Y	55,56,57
Ribes americanum	Wild black currant	5’	Yellow	Apr-Jun	F/P/S	N	50,51,55,56,57
Rosa carolina	Pasture rose	3’	Pink	Jun-Sep	F/P	N	55,56,57
Rosa palustris	Swamp rose	2’-7’	Pink	Jun-Aug	F/P/S	N	50,51,55,56,57
Thuja occidentalis	White cedar	50’	Brown	Apr-May	F/P/S	N	50,51,55,56,57
Tilia americana	Basswood	100’	White	Jun-Jul	F/P/S	N	50,51,55,56,57
Tsuga canadensis	Hemlock	100’	Brown	Apr-May	F/P/S	N	50,51,55,56,57
Ulmus americana	American elm	100’	Brown	Mar-Apr	F/P/S	N	50,51,55,56,57
Ulmus rubra	Slippery elm	80’	Green	Mar-Apr	F/P/S	N	51,55,56,57
Viburnum dentatum	Arrowwood	10’	White	May-Jun	F/P/S	N	51,55,56,57
Viburnum lentago	Nannyberry	20’	White	Apr-Jun	P/S	Y	50,51,55,56,57
Viburnum prunifolium	Black haw	10’	White	Apr-May	F/P	N	55
Viburnum trilobum	Cranberry Viburnum	10’	White	Apr-May	F/P/S	N	50,51,55,56,57
Grasses/Sedges/Rushes:							
Andropogon gerardii	Big bluestem	4’-8’	Purple	Jul-Sep	F	N	50,51,55,56,57
Calamagrostis canadensis	Blue joint grass	2’-4’	Brown	June	F/P	N	50,51,55,56,57
Carex comosa	Bristly sedge	2’-3’	Green	May-June	F/P	N	50,51,55,56,57
Carex crinita	Fringed sedge	2’-5’	Green	May	F/P/S	N	50,51,55,56,57
Carex hystericina	Porcupine sedge	2’-3’	Green	May-June	F/P/S	N	50,51,55,56,57
Carex lupulina	Common hop sedge	2’-3’	Green/ Brown	May-June	F/P/S	N	50,51,55,56,57
Carex muskingumensis	Palm sedge	1’-2’	Brown	May-June	S	N	55,56,57
Carex stipata	Common fox sedge	1’-3’	Brown	Apr-May	F/P/S	N	50,51,55,56,57
Carex stricta	Tussock sedge	2’-3’	Brown	Apr-Jun	F/P	N	50,51,55,56,57
Carex vulpinoidea	Brown fox sedge	2’-3’	Brown	May-Jun	F/P	N	50,51,55,56,57
Cinna arundinacea	Common wood reed	3’-4’	Green	Aug-Sep	P/S	N	55,56,57
Elymus canadensis	Canada wild rye	3’-6’	Green	Jun-Sep	F/P	N	50,51,55,56,57
Elymus hystrix	Bottlebrush Grass	3’-5’	Green	Jun-Jul	P/S	N	
Elymus virginicus	Virginia wild rye	2’-4’	Green	Jun	F/P/S	N	50,51,55,56,57

Botanical Name	Common Name	Height	Color	Bloom Time	Sun	Salt Tolerant	Ecoregion
Glyceria striata	Fowl manna grass	1’-5’	Green	May-Jun	F/P/S	N	50,51,55,56,57
Juncus tenuis	Path rush	6”-2’	Brown	June	F/P/S	N	50,51,55,56,57
Juncus torreyi	Torrey’s rush	1’-2’	Brown	Jun-Sep	F	Y	51,55,56,57
Panicum virgatum	Switch grass	3‘-5’	Green/ Purple	Jun-Oct	F/P	Y	51,55,56,57
Scirpus atrovirens	Dark green rush	3’-5’	Brown	Jun-Aug	F	N	50,51,55,56,57
Scirpus cyperinus	Wool grass	3’-5’	Tan	Jun-Sep	F	Y	50,51,55,56,57
Scirpus pendulus	Red bulrush	2’-4’	Brown	May-Jun	F	N	51,55,56,57
Spartina pectinata	Prairie cordgrass	6’-7’	Green	Jul-Aug	F	Y	50,51,55,56,57
Forbs:							
Anemone canadensis	Canada anemone	1’-2’	White	May-Sep	F/P	N	50,51,55,56,57
Angelica atropurpurea	Great angelica	6’-9’	White	May-Jun	F/P	N	55,56,57
Asclepias incarnata	Swamp milkweed	3’-5’	Pink	Jun-Sep	F/P	N	50,51,55,56,57
Aster novae-angliae	New England aster	3’-6’	Violet	Jul-Oct	F/P	N	50,51,55,56,57
Aster puniceus	Swamp aster	3’-6’	Lav/ White	Aug-Oct	F	Y	50,51,55,56,57
Aster umbellatus	Flat-topped aster	1’-4’	White	Jul-Oct	F/P	N	50,51,55,56,57
Cacalia atriplicifolia	Pale Indian plantain	3’-8’	White	Jun-Oct	F/P/S	N	55,56
Cassia hebecarpa	Wild senna	3’-5’	Yellow	Jul-Aug	F/P	N	55,56
Chelone glabra	Turtlehead	2’-4’	Cream	Aug-Sep	F/P/S	N	50,51,55,56,57
Coreopsis tripteris	Tall coreopsis	4’-8’	Yellow	Aug-Sep	F/P	N	55,56,57
Desmodium canadense	Showy tick-trefoil	2’-5’	Purple	Jun-Sep	F/P	N	51,55,56,57
Eryngium yuccifolium	Rattlesnake master	3’-5’	White	Jul-Sep	F	N	55
Eupatorium maculatum	Spotted Joe-pye weed	4’-7’	Pink	Jun-Oct	F/P	N	50,51,55,56,57
Eupatorium perfoliatum	Boneset	3’-5’	White	Jul-Oct	F/P	Y	50,51,55,56,57
Euthamia graminifolia	Grass-leaved gold-enrod	1’-4’	Yellow	Jul-Sep	F/P	N	50,51,55,56,57
Gentiana andrewsii	Bottle gentian	1’-3’	Blue	Aug-Oct	F/P	N	50,51,55,56,57
Helenium autumnale	Sneezeweed	3’-5’	Yellow	Jul-Nov	F/P	Y	50,51,55,56,57
Helianthus giganteus	Tall sunflower	5’-12’	Yellow	Jul-Sep	F/P	N	50,51,55,56,57
Heliopsis helianthoides	False sunflower	4’-6’	Yellow	Jun-Oct	F/P	N	50,51,55,56,57
Iris virginica	Blue flag iris	2’-3’	Purple	May-Jul	F/P/S	N	50,51,55,56,57
Liatris spicata	Marsh blazing star	3’-5’	Pink	Jul-Sep	F/P	N	55,56,57
Lilium michiganense	Michigan lily	3’-8’	Orange	Jul-Aug	P/S	N	55,56,57
Lobelia cardinalis	Cardinal flower	2’-5’	Red	Jul-Oct	F/P/S	N	50,51,55,56,57
Lobelia siphilitica	Great blue lobelia	1’-4’	Blue	Jul-Oct	F/P/S	N	50,51,55,56,57
Lobelia spicata	Pale spiked lobelia	1’-3’	Lavender	May-Aug	F/P	N	50,51,55,56,57
Mimulus ringens	Monkeyflower	2’-4’	Lavender	Jun-Sep	F/P	N	50,51,55,56,57
Monarda fistulosa	Wild bergamot	2’-5’	Lavender	Jul-Sep	F/P	N	50,51,55,56,57
Physostegia virginiana	Obedient plant	2’-5’	Pink	Aug-Oct	F	Y	50,51,55,56,57
Polygonatum biflorum	Solomon seal	1’-4’	Green/ White	May/Jul	P/S	N	55,56,57
Pycnanthemum virginianum	Mountain mint	1’-3’	White	Jun-Oct	F/P	N	55,56,57
Rudbeckia laciniata	Cutleaf coneflower	3’-10’	Yellow	Jul-Nov	F/P/S	N	50,51,55,56,57
Rudbeckia triloba	Three-lobed cone-flower	2‘-5’	Yellow	Aug-Oct	F/P	N	55,56,57
Solidago caesia	Bluestem goldenrod	1’-2’	Yellow	Sep-Oct	P/S	N	51,55,56,57
Solidago flexicaulis	Zigzag goldenrod	1’-3’	Yellow	Aug/Oct	P/S	N	50,51,55,56,57
Solidago ohiensis	Ohio goldenrod	2’-3’	Yellow	Jul-Oct	F/P	N	50,51,55,56,57
Solidago patula	Swamp goldenrod	3’-6’	Yellow	Aug-Oct	F/P/S	N	50,51,55,56,57
Solidago riddellii	Riddell’s goldenrod	2’-5’	Yellow	Sep-Nov	F	N	55,56,57
Spiraea alba	Meadowsweet	3’-6’	White	June-Sep	F/P	Y	50,51,55,56,57
Spiraea tomentosa	Steeplebush	2’-5’	Pink	Jul-Sep	F/P	Y	55,56,57
Thalictrum dasycarpum	Purple meadow-rue	3’-6’	Cream	May-Jul	F/P	N	50,51,55,56,57
Verbena hastata	Blue vervain	3’-6’	Violet	Jun-Sep	F	N	50,51,55,56,57
Vernonia missurica	Missouri ironweed	3’-5’	Purple	Jul-Sep	F	N	55,56,57
Veronicastrum virginicum	Culver’s root	3’-6’	White	Jun-Aug	F/P	N	55,56,57
Zizia aurea	Golden Alexanders	1’-3’	Yellow	Apr-Jun	F/P/S	Y	55,56,57

Representative Zone D Species

Big Bluestem

Marsh Blazing Star

Wild Columbine

Great Blue Lobelia

Michigan Lily

Virginia Mountain Mint

Meadowsweet

Blue Vervain

Source: JFNew

Zone E

Planting Zone = four-to-18 inches above water level

These plants tolerate fluctuating water levels within this range. They will also tolerate short periods of inundation, not to exceed 48 hours in most situations, making them appropriate for BMP settings.

Botanical Name	Common Name	Height	Color	Bloom Time	Sun	Salt Tolerant	Ecoregion
Woody Species:							
Acer rubrum	Red maple	90'	Green/ red	Mar-May	F/P/S	N	50,51,55,56,57
Acer saccharum	Sugar maple	100'	Green	Apr-May	F/P/S	N	50,51,55,56,57
Acer saccharinum	Silver Maple	100'	Yellow	Mar-Apr	F/P	N	50,51,55,56,57
Amelanchier arborea	Downy serviceberry	40'	White	April	F/P/S	N	N
Aronia prunifolia	Purple chokeberry	10'	White	Apr-Jul	F/P	N	50,51,55,56,57
Betula papyrifera	Paper birch	70'	Brown	Apr-May	F/P	N	50,51,55,56,57
Carya ovata	Shagbark hickory	80'	Green	May-Jun	F/P/S	N	55,56,57
Ceanothus americanus	New Jersey tea	1'-3'	White	Jun-Oct	F/P	N	50,51,55,56,57
Celtis occidentalis	Hackberry	60'	Green	May	F/P/S	N	55,56,57
Cercis canadensis	Redbud	25'	Red	Apr-May	F/P/S	N	55,56,57
Cornus amomum	Silky dogwood	10'	White	May-Jul	F/P	N	51,55,56,57
Cornus florida	Flowering dogwood	30'	White	May-Jun	F/P/S	N	55,56,57
Cornus sericea	Red-osier dogwood	10'	White	May-Sep	F/P	N	50,51,55,56,57
Corylus americana	American hazelnut	10'	Yellow	Apr-May	F/P	N	55,56,57
Gymnocladus dioicus	Kentucky coffee tree	85'	White	Jun	F/P	N	55,56,57
Juglans nigra	Black walnut	90'	Green	May	F/P	N	51,55,56,57
Juniperus virginiana	Red-cedar	50'	Brown	Apr-May	F/P	N	55,56,57
Larix laricina	American larch	75'	Brown	May	F/P	N	50,51,55,56,57
Lindera benzoin	Spicebush	15'	Yellow	Apr-May	P/S	N	51,55,56,57
Liriodendron tulipifera	Tulip tree	110'	Green	May-Jun	F/P	N	55,56,57
Morus rubra	Red mulberry	50'	Green	May-Jun	F/P/S	N	55,56,57
Nyssa sylvatica	Black gum	100'	Green	May-Jul	F/P/S	Y	51,55,56,57
Physocarpus opulifolius	Ninebark	10'	White	May-Jun	F/P	N	50,51,55,56,57
Picea mariana	Black spruce	60'	Brown	May-Jun	F/P/S	N	50,51,57
Pinus banksiana	Jack pine	60'	Brown	May-Jun	F/P	N	50,51,55,57
Pinus resinosa	Red pine	100'	Brown	Apr-May	F/P	N	50,51,55,57
Pinus strobus	White pine	100'	Brown	Jun	F/P/S	N	50,51,55,56,57
Platanus occidentalis	Sycamore	100'	Green	May	F/P	N	55,56,57
Prunus americana	American plum	30'	Red	Apr-May	F/P	N	55,56,57
Prunus virginiana	Choke cherry	30'	White	May-Jun	F/P/S	N	50,51,55,56,57
Quercus bicolor	Swamp white oak	70'	Green/ yellow	May	F/P/S	N	55,56,57
Quercus macrocarpa	Bur oak	85'	Yellow	May-Jun	F/P/S	N	50,51,55,56,57
Quercus palustris	Pin oak	90'	Green/ yellow	Apr-May	F/P/S	Y	55,56,57
Quercus rubra	Red Oak	90'	Green	May-Jun	F/P/S	N	50,51,55,56,57
Ribes americanum	Wild black currant	5'	Yellow	Apr-Jun	F/P/S	N	50,51,55,56,57
Rosa carolina	Pasture rose	3'	Pink	Jun-Sep	F/P	N	55,56,57
Tilia americana	Basswood	100'	White	Jun-Jul	F/P/S	N	50,51,55,56,57
Thuja occidentalis	White cedar	50'	Brown	Apr-May	F/P/S	N	50,51,55,56,57
Tsuga canadensis	Hemlock	100'	Brown	Apr-May	F/P/S	N	50,51,55,56,57
Ulmus americana	American elm	100'	Brown	Mar-Apr	F/P/S	N	50,51,55,56,57
Ulmus rubra	Slippery elm	80'	Green	Mar-Apr	F/P/S	N	51,55,56,57
Viburnum acerifolium	Maple-leaved Viburnum	7'	White	May-Aug	F/P	N	50,51,55,56,57
Viburnum dentatum	Arrowwood	10'	White	May-Jun	F/P/S	N	51,55,56,57
Viburnum prunifolium	Black haw	10'	White	Apr-May	F/P	N	55
Grasses/Sedges/Rushes:							
Andropogon gerardii	Big bluestem	4'-8'	Purple	Jul-Sep	F	N	50,51,55,56,57
Carex bicknellii	Copper-shouldered oval sedge	1'-2'	Brown	May-Jun	F	N	55,56
Carex muhlenbergii	Sand bracted sedge	1'-3'	Brown	May-Jun	F/P/S	N	51,55,56,57
Elymus canadensis	Canada wild rye	3'-6'	Green	Jun-Sep	F/P	N	50,51,55,56,57

Botanical Name	Common Name	Height	Color	Bloom Time	Sun	Salt Tolerant	Ecoregion
Elymus hystrix	Bottlebrush Grass	3'-5'	Green	Jun-Jul	P/S	N	
Elymus virginicus	Virginia wild rye	2'-4'	Green	Jun	F/P/S	N	50,51,55,56,57
Eragrostis spectabilis	Purple love grass	1'-2'	Purple	Aug-Oct	F	N	51,55,56,57
Juncus tenuis	Path rush	6"-2'	Brown	June	F/P/S	N	50,51,55,56,57
Panicum virgatum	Switch grass	3'-6'	Green/ Purple	Jun-Oct	F/P	Y	51,55,56,57
Schizachyrium scoparium	Little bluestem	2'-4'	Brown	Aug-Sep	F/P	Y	50,51,55,56,57
Sorghastrum nutans	Indian grass	4'-9'	Green	Aug-Sep	F	N	51,55,56,57
Spartina pectinata	Prairie cordgrass	6'-7'	Green	Jul-Aug	F	Y	50,51,55,56,57
Stipa spartea	Porcupine grass	2'-4'	Green	Aug-Sep	F	Y	55,56,57
Forbs:							
Allium cernuum	Nodding wild onion	1'-2'	Lavender	Jun-Oct	F/P	N	55,56
Aquilegia canadensis	Wild columbine	1'-3'	Red/ Yellow	Apr-Jun	F/P/S	Y	50,51,55,56,57
Asclepias syriaca	Common milkweed	2'-4'	Pink	Jun-Aug	F/P	N	50,51,55,56,57
Asclepias tuberosa	Butterflyweed	1'-3'	Orange	Jun-Sep	F/P	Y	51,55,56,57
Asclepias verticillata	Whorled milkweed	1'-2'	White	Jun-Sep	F/P	N	51,55,56,57
Aster cordifolius	Heart-leaved aster	2'-4'	Blue/ White	Sep-Oct	P/S	N	55,56,57
Aster laevis	Smooth aster	3'-5'	Blue	Aug-Oct	F	Y	50,51,55,56,57
Aster lateriflorus	Calico aster	1'-3'	White	Jul-Oct	F/P/S	N	50,51,55,56,57
Aster macrophyllus	Big-leaved aster	6"-2'	Lav/ White	Jul-Oct	P/S	N	50,51,55,56,57
Aster novae-angliae	New England aster	3'-6'	Violet	Jul-Oct	F/P	N	50,51,55,56,57
Aster oolentangiensis	Sky-blue aster	1'-4'	Blue	Jul-Nov	F/P	Y	55,56,57
Aster shortii	Short's aster	1'-4'	Blue	Aug-Oct	P/S	N	55,56
Cacalia atriplicifolia	Pale Indian plantain	3'-8'	White	Jun-Oct	F/P/S	N	55,56
Campanula americana	Tall bellflower	2'-6'	Blue	Jul-Nov	P/S	N	55,56,57
Cassia hebecarpa	Wild senna	3'-5'	Yellow	Jul-Aug	F/P	N	55,56
Clematis virginiana	Virgin's bower	9' long	White	Jul-Aug	F/P	N	50,51,55,56,57
Coreopsis tripteris	Tall coreopsis	4'-8'	Yellow	Aug-Sep	F/P	N	55,56,57
Desmodium canadense	Showy tick-trefoil	2'-5'	Purple	Jun-Sep	F/P	N	55,56,57
Echinacea pallida	Purple coneflower	2'-5'	Lavender	May-Aug	F	N	55,56,57
Eryngium yuccifolium	Rattlesnake master	3'-5'	White	Jul-Sep	F	N	55
Eupatorium purpureum	Purple Joe-pye weed	3'-6'	Pink	Jul-Sep	P	N	55,56,57
Euphorbia corollata	Flowering spurge	2'-4'	White	May-Oct	F/P	N	51,55,56,57
Geranium maculatum	Wild geranium	1'-2'	Pink	Apr-Jul	F/P/S	N	55,56,57
Helianthus divaricatus	Woodland sunflower	2'-6'	Yellow	Jun-Sep	P/S	N	50,51,55,56,57
Helianthus giganteus	Tall sunflower	5'-12'	Yellow	Jul-Sep	F/P	N	50,51,55,56,57
elianthus pauciflorus	Prairie sunflower	3'-5'	Yellow	Jul-Oct	F	N	50,55,56,57
Heliopsis helianthoides	False sunflower	4'-6'	Yellow	Jun-Oct	F/P	N	50,51,55,56,57
Lespedeza capitata	Round-headed bush clover	2'-4'	Green	Jul-Sep	F/P	N	55,56,57
Liatris aspera	Rough blazing star	2'-3'	Violet	Jul-Nov	F/P	Y	50,55,56,57
Liatris spicata	Marsh blazing star	3'-5'	Pink	Jul-Sep	F/P/S	N	55,56,57
Liatris scariosa	Savanna blazing star	3'-5'	Violet	Aug-Oct	F/P	N	50,51,55,56,57
Monarda fistulosa	Wild bergamot	2'-5'	Lavender	Jul-Sep	F/P	N	50,51,55,56,57
Penstemon digitalis	Foxglove beardtongue	2'-4'	White	May-Jul	F/P	N	50,51,55,56,57
Penstemon hirsutus	Hairy beardtongue	1'-2'	Purple	May-Jul	F/P	N	55,56,57
Phlox divaricata	Wild blue phlox	1'-2'	Blue	Apr-Jun	P/S	N	51,55,56,57
Phlox pilosa	Sand prairie phlox	1'-2'	Pink	May-Aug	F/P	N	56
Physostegia virginiana	Obedient plant	2'-5'	Pink	Aug-Oct	F	Y	50,51,55,56,57
Polygonatum biflorum	Solomon seal	1'-4'	Green/ White	May/Jul	P/S	N	55,56,57
Polygonatum pubescens	Downy Solomon seal	1'-3'	White	May-Jul	P/S	N	50,51,55,56,57
Pycnanthemum virginianum	Mountain mint	1'-3'	White	Jun-Oct	F/P	N	55,56,57
Ratibida pinnata	Yellow coneflower	3'-6'	Yellow	Jul-Oct	F	N	55,56
Rudbeckia hirta	Black-eyed Susan	1'-3'	Yellow	May-Oct	F/P	Y	50,51,55,56,57
Rudbeckia triloba	Three-lobed cone-flower	2'-5'	Yellow	Aug-Oct	F/P	N	55,56,57
Silphium terebinthinaceum	Prairie-dock	3'-8'	Yellow	Jun-Sep	F	N	55,56,57
Smilacina racemosa	Feathery false Solo-mon's seal	1'-3'	White	Apr-Jun	P/S	N	50,51,55,56,57
Smilacina stellata	Starry false Solomon's seal	1'-2'	White	Apr-Jun	F/P	N	50,51,55,56,57
Solidago caesia	Bluestem goldenrod	1'-2'	Yellow	Sep-Oct	P/S	N	51,55,56,57
Solidago flexicaulis	Zigzag goldenrod	1'-3'	Yellow	Aug/Oct	P/S	N	50,51,55,56,57
Solidago juncea	Early goldenrod	2'-4'	Yellow	Jul-Sep	F/P	N	50,51,55,56,57
Solidago speciosa	Showy goldenrod	1'-3'	Yellow	Jul-Oct	F/P	Y	50,51,55,56,57
Thalictrum dioicum	Early meadow-rue	1'-3'	Green	Apr-May	P/S	N	50,51,55,56,57
Tradescantia ohiensis	Spiderwort	2'-4'	Blue	May-Oct	F/P	N	55,56,57
Vernonia missurica	Missouri ironweed	3'-5'	Purple	Jul-Sep	F	N	55,56,57

Representative Zone E Species

New England Aster

Wild Bergamot

Showy Goldenrod

Tall Bellflower

Wild Geranium

Tall Coreopsis

Redbud

Indian Grass

Source: JFNew

Zone F

Planting Zone = 18+inches above water level

These plants tolerate fluctuating water levels within this range, although they are generally less tolerant than most wetter species. They may tolerate short periods of inundation, not to exceed 48 hours in most situations, making them appropriate for upland BMP settings.

Veronicastrum virginicum	Culver's root	3'-6'	White	Jun-Aug	F/P	N	55,56,57

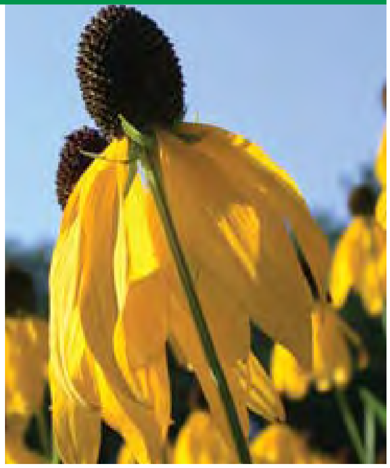
Botanical Name	Common Name	Height	Color	Bloom Time	Sun	Salt Tolerant	Ecoregion
Woody Species:							
Acer rubrum	Red maple	90'	Green/ red	Mar-May	F/P/S	N	50,51,55,56,57
Acer saccharum	Sugar maple	100'	Green	Apr-May	F/P/S	N	50,51,55,56,57
Acer saccharinum	Silver Maple	100'	Yellow	Mar-Apr	F/P	N	50,51,55,56,57
Betula papyrifera	Paper birch	70'	Brown	Apr-May	F/P	N	50,51,55,56,57
Carya ovata	Shagbark hickory	80'	Green	May-Jun	F/P/S	N	55,56,57
Ceanothus americanus	New Jersey tea	1'-3'	White	Jun-Oct	F/P	N	50,51,55,56,57
Celtis occidentalis	Hackberry	60'	Green	May	F/P/S	N	55,56,57
Cercis canadensis	Redbud	25'	Red	Apr-May	F/P/S	N	55,56,57
Cornus florida	Flowering dogwood	30'	White	May-Jun	F/P/S	N	55,56,57
Corylus americana	American hazelnut	10'	Yellow	Apr-May	F/P	N	55,56,57
Gymnocladus dioicus	Kentucky coffee tree	85'	White	Jun	F/P	N	55,56,57
Hamamelis virginiana	Witch hazel	30'	Yellow	Oct-Nov	F/P/S	N	50,51,55,56,57
Juglans nigra	Black walnut	90'	Green	May	F/P	N	51,55,56,57
Juniperus virginiana	Red-cedar	50'	Brown	Apr-May	F/P	N	55,56,57
Liriodendron tulipifera	Tulip tree	110'	Green	May-Jun	F/P	N	55,56,57
Morus rubra	Red mulberry	50'	Green	May-Jun	F/P/S	N	55,56,57
Nyssa sylvatica	Black gum	100'	Green	May-Jul	F/P/S	Y	51,55,56,57
Pinus banksiana	Jack pine	60'	Brown	May-Jun	F/P	N	50,51,55,57
Pinus resinosa	Red pine	100'	Brown	Apr-May	F/P	N	50,51,55,57
Pinus strobus	White pine	100'	Brown	Jun	F/P/S	N	50,51,55,56,57
Prunus americana	American plum	30'	Red	Apr-May	F/P	N	55,56,57
Prunus virginiana	Choke cherry	30'	White	May-Jun	F/P/S	N	50,51,55,56,57
Quercus macrocarpa	Bur oak	85'	Yellow	May-Jun	F/P/S	N	50,51,55,56,57
Quercus palustris	Pin oak	90'	Green/ yellow	Apr-May	F/P/S	Y	55,56,57
Quercus rubra	Red Oak	90'	Green	May-Jun	F/P/S	N	50,51,55,56,57
Rosa carolina	Pasture rose	3'	Pink	Jun-Sep	F/P	N	55,56,57
Tilia americana	Basswood	100'	Yellow	Jun-Jul	F/P/S	N	50,51,55,56,57
Tsuga canadensis	Hemlock	100'	Brown	Apr-May	F/P/S	N	50,51,55,56,57
Viburnum acerifolium	Maple-leaved Viburnum	7'	White	May-Aug	F/P	N	50,51,55,56,57
Viburnum dentatum	Arrowwood	10'	White	May-Jun	F/P/S	N	51,55,56,57
Grasses/Sedges/Rushes:							
Andropogon gerardii	Big bluestem	4'-8'	Purple	Jul-Sep	F	N	50,51,55,56,57
Carex bicknellii	Copper-shouldered oval sedge	1'-2'	Brown	May-Jun	F	N	55,56
Carex muhlenbergii	Sand bracted sedge	1'-3'	Brown	May-Jun	F/P/S	N	51,55,56,57
Elymus canadensis	Canada wild rye	3'-6'	Green	Jun-Sep	F/P	N	50,51,55,56,57
Elymus hystrix	Bottlebrush Grass	3'-5'	Green	Jun-Jul	P/S	N	50,51,55,56,57
Eragrostis spectabilis	Purple love grass	1'-2'	Purple	Aug-Oct	F	N	51,55,56,57
Koeleria macrantha	June grass	1'-2'	White	May-Jul	F/P	N	50,51,55,56,57
Panicum virgatum	Switch grass	3'-6'	Green/ Purple	Jun-Oct	F/P	Y	51,55,56,57
Schizachyrium scoparium	Little bluestem	2'-4'	Brown	Aug-Sep	F/P	Y	50,51,55,56,57
Sorghastrum nutans	Indian grass	4'-9'	Green	Aug-Sep	F	N	51,55,56,57
Spartina pectinata	Prairie cordgrass	6'-7'	Green	Jul-Aug	F	Y	50,51,55,56,57

Botanical Name	Common Name	Height	Color	Bloom Time	Sun	Salt Tolerant	Ecoregion
Stipa spartea	Porcupine grass	2’-4’	Green	Aug-Sep	F	Y	55,56,57
Forbs:							
Allium cernuum	Nodding wild onion	1’-2’	Lavender	Jun-Oct	F/P	N	55,56
Asclepias syriaca	Common milkweed	2’-4’	Pink	Jun-Aug	F/P	N	50,51,55,56,57
Asclepias tuberosa	Butterflyweed	1’-3’	Orange	Jun-Sep	F/P	Y	51,55,56,57
Asclepias verticillata	Whorled milkweed	1’-2’	White	Jun-Sep	F/P	N	51,55,56,57
Aster cordifolius	Heart-leaved aster	2’-4’	Blue/ White	Sep-Oct	P/S	N	55,56,57
Aster laevis	Smooth aster	3’-5’	Blue	Aug-Oct	F	Y	50,51,55,56,57
Aster oolentangiensis	Sky-blue aster	1’-4’	Blue	Jul-Nov	F/P	Y	55,56,57
Aster shortii	Short’s aster	1’-4’	Blue	Aug-Oct	P/S	N	55,56
Cacalia atriplicifolia	Pale Indian plantain	3’-8’	White	Jun-Oct	F/P/S	N	55,56
Campanulaa americana	Tall bellflower	2’-6’	Blue	Jul-Nov	P/S	N	55,56,57
Clematis virginiana	Virgin’s bower	9’ long	White	Jul-Aug	F/P	N	50,51,55,56,57
Coreopsis lanceolata	Sand coreopsis	1’-2’	Yellow	May-Aug	F/P	N	50,51,55
Coreopsis palmata	Prairie coreopsis	1’-2’	Yellow	Jun-Aug	F/P	N	55
Coreopsis tripteris	Tall coreopsis	4’-8’	Yellow	Aug-Sep	F/P	N	55,56,57
Echinacea pallida	Purple coneflower	2’-5’	Lavender	May-Aug	F	N	55,56,57
Eryngium yuccifolium	Rattlesnake master	3’-5’	White	Jul-Sep	F	N	55
Eupatorium purpureum	Purple Joe-pye weed	3’-6’	Pink	Jul-Sep	P	N	55,56,57
Euphorbia corollata	Flowering spurge	2’-4’	White	May-Oct	F/P	N	51,55,56,57
Geranium maculatum	Wild geranium	1’-2’	Pink	Apr-Jul	F/P/S	N	55,56,57
Helianthus divaricatus	Woodland sunflower	2’-6’	Yellow	Jun-Sep	P/S	N	50,51,55,56,57
Helianthus occidentalis	Western sunflower	2’-4’	Yellow	Aug-Sep	F/P	N	50,51,55,56,57
Helianthus pauciflorus	Prairie sunflower	3’-5’	Yellow	Jul-Oct	F	N	50,55,56,57
Heliopsis helianthoides	False sunflower	4’-6’	Yellow	Jun-Oct	F/P	N	50,51,55,56,57
Lespedeza capitata	Round-headed bush clover	2’-4’	Green	Jul-Sep	F/P	N	55,56,57
Liatris aspera	Rough blazing star	2’-3’	Violet	Jul-Nov	F/P	Y	50,55,56,57
Liatris cylindracea	Cylindrical blazing star	1’-2’	Violet	Jul-Oct	F/P	N	51,55,56,57
Liatris scariosa	Savanna blazing star	3’-5’	Violet	Aug-Oct	F/P	N	50,51,55,56,57
Lupinus perennis	Wild lupine	1’-2’	Purple	Apr-Jun	F/P	N	55,56,57
Monarda fistulosa	Wild bergamot	2’-5’	Lavender	Jul-Sep	F/P	N	50,51,55,56,57
Penstemon digitalis	Foxglove beardtongue	2’-4’	White	May-Jul	F/P	N	50,51,55,56,57
Penstemon hirsutus	Hairy beardtongue	1’-2’	Purple	May-Jul	F/P	N	55,56,57
Phlox pilosa	Sand prairie phlox	1’-2’	Pink	May-Aug	F/P	N	56
Polygonatum biflorum	Solomon seal	1’-4’	Green/ White	May/Jul	P/S	N	55,56,57
Polygonatum pubescens	Downy Solomon seal	1’-3’	White	May-Jul	P/S	N	50,51,55,56,57
Ratibida pinnata	Yellow coneflower	3’-6’	Yellow	Jul-Oct	F	N	55,56
Rudbeckia hirta	Black-eyed Susan	1’-3’	Yellow	May-Oct	F/P	Y	50,51,55,56,57
Silphium terebinthinaceum	Prairie-dock	3’-8’	Yellow	Jun-Sep	F	N	55,56,57
Smilacina racemosa	Feathery false Solomon’s seal	1’-3’	White	Apr-Jun	P/S	N	50,51,55,56,57
Smilacina stellata	Starry false Solomon’s seal	1’-2’	White	Apr-Jun	F/P	N	50,51,55,56,57
Solidago caesia	Bluestem goldenrod	1’-2’	Yellow	Sep-Oct	P/S	N	51,55,56,57
Solidago juncea	Early goldenrod	2’-4’	Yellow	Jul-Sep	F/P	N	50,51,55,56,57
Solidago speciosa	Showy goldenrod	1’-3’	Yellow	Jul-Oct	F/P	Y	50,51,55,56,57
Tradescantia ohiensis	Spiderwort	2’-4’	Blue	May-Oct	F/P	N	55,56,57
Veronicastrum virginicum	Culver’s root	3’-6’	White	Jun-Aug	F/P	N	55,56,57

Representative Zone F Species

Spiderwort

Butterfly Weed



Yellow Coneflower

Little Bluestem

Foxglove Beardtongue

Wild Lupine

Pale Purple Coneflower

Rattlesnake Master

Sand Coreopsis

Source: JFNew

Zone G

Planter Box Plantings

Although this manual typically recommends using native plants wherever possible, certain situations call for non-native plants due to particular site conditions. Because planter boxes traditionally have a short soil column and are exposed to drier conditions, non-native plants should be considered as long as they are considered non-invasive. Therefore, the list below contains both native and non-native species. Many planter boxes have traditionally used annual flowers. However, we recommend using perennial plants for establishing root systems and lowering maintenance in the long term. Many more species are available for planter boxes than are listed.

Botanical Name	Common Name	Height	Color	Bloom Time	Sun
Ajuga reptans 'Bronze Beauty'	Bronze Beauty Ajuga	6"	Blue	May-Jun	F
Allium maximowiczii 'Alba'	White Flowered Ornamental Chive	6"-1'	White	May-Jun	F
Allium schoenoprasum 'Glaucum'	Blue Flowered Ornamental Chive	6"-1'	Blue	Jun-Jul	F
Allium senescens montanum	Mountain Garlic	6"-1'	Pink/Purple	Jun-Aug	F
Allium senescens glaucum	Curly Onion	6"-1'	Pink	Jul-Sep	F
Allium tanguticum 'Summer Beauty'	Summer Beauty Ornamental Chive	6"-1'	Pink	Jul-Aug	F
Aster 'Wood's Light Blue'	Wood's Light Blue Aster	1'-3'	Blue	Aug-Sep	F
Athryium filix-femina	Lady Fern	1'-3'	Green	NA	F/P/S
Blechnum spicant	Deer Fern	1'-2'	Green	NA	F/P/S
Dryopteris erythrosora	Autumn Fern	1'-2'	Green	NA	F/P/S
Euphorbia myrsinites	Mytle Spurge	6"-1'	Yellow	May-Jun	F
Dryopteris intermedia	Fancy Fern	1'-3'	Green	NA	F/P/S
Dyropteris marginalis	Leatherleaf Fern	1'-2'	Green	NA	F/P/S
Geranium x 'Rozanne'	Rozanne Gernaium	1'-2'	Violet	Jun-Sep	F/P
Hemerocallis 'Barbara Mitchell'	Barbara Mitchell Daylily	2'-3'	Pink	Jun-Aug	F/P
Hemerocallis 'Bill Norris'	Bill Norris Daylily	2'-3'	Yellow	Jun-Aug	F/P
Hemerocallis 'Chicago Apache'	Chicago Apache Daylily	2'-3'	Red	Jul-Sep	F/P
Hosta 'Francee'	Francee Hosta	1'-2'	Lavender	Jul-Aug	F/P/S
Hosta 'Guacamole'	Guacamole Hosta	1'-2'	Pink	Aug-Sep	F/P/S
Hosta 'Summer Fragrance'	Summer Fragrance Hosta	1'-2'	Lavender	Aug-Sep	F/P/S
Hosta sieboldiana 'Elegans'	Elegans Hosta	1'-2'	White	Jul-Aug	F/P/S
Sedum 'Autumn Charm'	Autumn Charm Sedum	6"-1'	Pink	Jun-Jul	F
Sedum 'Joyce Henderson'	Joyce Henderson Sedum	6"-1'	Pink	May-Jun	F
Sedum 'Mini Me'	Mini Me Sedum	6"-1'	Green	NA	F
Sedum acre 'Oktoberfest'	Oktoberfest Sedum	6"-1'	Yellow	Jul-Sep	F
Sedum album 'Athoum'	Jelly Bean Sedum	6"-1'	Pink	Aug-Sep	F
Sedum album 'Coral Carpet'	Coral Carpet Sedum	6"-1'	White	Jun-Aug	F
Sedum album 'Faro Island'	Faro Island Sedum	6"-1'	White	Jun-Aug	F
Sedum album 'Green Ice'	Green Ice Sedum	6"-1'	White	Jun-Jul	F
Sedum album 'Murale'	Wall Sedum	6"-1'	White	Jun-Jul	F
Sedum cauticola 'Sunset Cloud'	Sunset Cloud Sedum	6"-1'	Pink	Jul-Aug	F
Sedum divergens	Cascade Sedum	6"-1'	Yellow	Jun-Jul	F
Sedum ellacombianum	Ellacombe's Sedum	6"-1'	Yellow	May-Jun	F
Sedum ellacombianum 'Variegatum'	Variegated Ellacombe's Sedum	6"-1'	Yelow	May-Jun	F
Sedum floriferum 'Weihenstephaner Gold'	Weihenstephaner Gold Sedum	6"-1'	Yellow	Jun-Jul	F
Sedum grisbachii	Griseback Sedum	6"-1'	Yellow	Jul-Aug	F
Sedum hybridum 'Tekaridake'	Tekaridake Kamtschatka Sedum	6"-1'	Yellow	Jun	F
Sedum kamtschaticum 'Variegatum'	Variegated Kamtschatka Sedum	6"-1'	Orange	Jul-Aug	F
Sedum middendorfianum var. diffusum	Diffuse Middendorf's Sedum	6"-1'	Yellow	May-Jun	F

Representative Zone G Species

Guacamole Hosta

Mountain Garlic

Wall Sedum

Lady Fern

Source: JFNew

Zone H

Vegetated Roof Plantings

Research to-date shows that native plants do not typically thrive in vegetated roofs. Therefore, the list below reflects species that are known to thrive in green roof situations. All species listed below will generally grow to a height of six-to-18 inches.

Botanical Name	Common Name	Color	Bloom Time
Allium maximowiczii 'Alba'	White Flowered Ornamental Chive	White	May-Jun
Allium schoenoprasum 'Dwarf'	Dwarf Ornamental Chive	Pink	May-Jun
Allium schoenoprasum 'Glaucum'	Blue Flowered Ornamental Chive	Blue	Jun-Jul
Allium senescens montanum	Mountain Garlic	Pink/Purple	Jun-Aug
Allium senescens glaucum	Curly Onion	Pink	Jul-Sep
Allium tanguticum 'Summer Beauty'	Summer Beauty Ornamental Chive	Pink	Jul-Aug
Euphorbia myrsinites	Mytle Spurge	Yellow	May-Jun
Sedum 'Autumn Charm'	Autumn Charm Sedum	Pink	Jun-Jul
Sedum 'Joyce Henderson'	Joyce Henderson Sedum	Pink	May-Jun
Sedum 'Mini Me'	Mini Me Sedum	Green	NA
Sedum acre 'Aureum'	Gold Leaved Goldmoss Sedum	Yellow	May-Jun
Sedum acre 'Oktoberfest'	Oktoberfest Sedum	Yellow	Jul-Sep
Sedum album 'Athoum'	Jelly Bean Sedum	Pink	Aug-Sep
Sedum album 'Coral Carpet'	Coral Carpet Sedum	White	Jun-Aug
Sedum album 'Faro Island'	Faro Island Sedum	White	Jun-Aug
Sedum album 'Green Ice'	Green Ice Sedum	White	Jun-Jul
Sedum album 'Murale'	Wall Sedum	White	Jun-Jul
Sedum album 'Red Ice'	Red Ice Sedum	White	Jun-Jul
Sedum cautacola 'Bertram Anderson'	Bertram Anderson Sedum	Pink	Jul-Aug
Sedum cauticola 'Sunset Cloud'	Sunset Cloud Sedum	Pink	Jul-Aug
Sedum divergens	Cascade Sedum	Yellow	Jun-Jul
Sedum ellacombianum	Ellacombe's Sedum	Yellow	May-Jun
Sedum ellacombianum 'Variegatum'	Variegated Ellacombe's Sedum	Yelow	May-Jun
Sedum floriferum 'Weihenstephaner Gold'	Weihenstephaner Gold Sedum	Yellow	Jun-Jul
Sedum grisbachii	Griseback Sedum	Yellow	Jul-Aug
Sedum hispanicum 'Pinkie'	Pinkie Sedum	Pink	Jun-Jul
Sedum hybridum 'Immergunchen'	Evergreen Sedum	Yellow	Jun, Sep
Sedum hybridum 'Tekaridake'	Tekaridake Kamtschatka Sedum	Yellow	Jun
Sedum kamtschaticum 'Variegatum'	Variegated Kamtschatka Sedum	Orange	Jul-Aug
Sedum middendorfianum var. diffusum	Diffuse Middendorf's Sedum	Yellow	May-Jun

*List provided by Hortech, Inc.

Representative Zone H Species

Mountain Garlic

Cascade Sedum

Ellacombe's Sedum

Wall Sedum

Source: JFNew

Appendix D

Recommended Materials

Numerous BMPs in this manual have similar material needs. These BMPs are listed in the table below. Detailed information on each material requirement follows. In addition, Porous Pavement and Vegetated Roofs have significant material requirements that are listed according to their individual needs.

	Constructed Filters	Dry Well	Infiltration Trench	Planter Boxes	Porous Pavement	Subsurface Infiltration	Vegetated Filter Strip	Vegetated Swale
Check dams							X	X
Non-Woven Geotextile	X	X	X	X	X	X	X	
Pea Gravel							X	
Peat	X			X				
Pervious Berms							X	
Pipe – 8”	X	X	X	X	X	X	X	
Sand	X			X				X
Stone/Gravel	X			X				
Stone – 30%							X	
Stone – 40%			X		X			

Check dams (Vegetated Filter Strip, Vegetated Swale)

An earthen check dam shall be constructed of sand, gravel, and sandy loam to encourage grass cover. (Sand: ASTM C-33 fine aggregate concrete sand 0.02 in to 0.04 in, Gravel: AASHTO M-43 0.5 in to 1.0 in). A stone check dam shall be constructed of R-4 rip rap, or equivalent.

Non-Woven Geotextile (Constructed Filter, Dry Well, Infiltration Trench, Planter Boxes, Vegetated Filter Strip)

Should consist of needled nonwoven polypropylene fibers and meet the following properties:

a. Grab Tensile Strength (ASTM-D4632)	120 lbs min.
b. Mullen Burst Strength (ASTM-D3786)	225 psi min.
c. Flow Rate (ASTM-D4491)	110 gal/min/ft2 min.
d. UV Resistance after 500 hrs (ASTM-D4355)	70% min.
e. Puncture strength (ASTM D-4833-00)	90 lb. min.
f. Apparent opening size (ASTM D-4751-99A)	60-70 US Sieve

Heat-set or heat-calendared fabrics are not permitted. Acceptable types include Mirafi 140N, Amoco 4547, Geotex 451, or approved others.

Pea Gravel (Vegetated Filter Strip)

Clean bank-run gravel may also be used and should meet ASTM D 448 and be sized as per No.6 or 1/8” to 3/8”.

Peat (Constructed Filter, Planter Boxes)

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

Pervious Berms (Vegetated Filter Strip)

The berm shall have a height of 6-12 in and be constructed of sand, gravel, and sandy loam to encourage grass cover. (Sand: ASTM C-33 fine aggregate concrete sand 0.02”-0.04”, Gravel: AASHTO M-43 ½” to 1”)

Pipe - (Dry Well, Porous Pavement, Subsurface Infiltration, Constructed Filter, Infiltration Trench, Planter Boxes, Vegetated Filter Strip)

Should be continuously perforated, smooth interior, with a minimum inside diameter as required. High-density polyethylene (HDPE) pipe shall meet AASHTO M252, Type S or M294, Type S (12 gauge aluminum or pipe may also be used in seepage pits).

Sand (Constructed Filter, Planter Boxes, Vegetated Swale)

Should be ASTM-C-33 (or AASHTO M-6) size (0.02” – 0.04”), concrete sand, clean, medium to fine sand.

Stone/Gravel (Constructed Filter, Planter Boxes):

Should be uniformly graded coarse aggregate, 1 inch to ½ inch with a wash loss of no more than 0.5%, AASHTO size number 5 per AASHTO Specifications, Part I, 19th Ed., 1998, or later and have voids of 40% as measured by ASTM-C29.

Stone – 40% voids (Infiltration Trench, Porous Pavement, Subsurface Infiltration Bed,)

Infiltration trenches should have stone 2-inch to 1-inch uniformly graded coarse aggregate, with a wash loss of no more than 0.5%, AASHTO size number 3 per AASHTO Specifications, Part I, 19th Ed., 1998, or later and shall have voids 40% as measured by ASTM-C29.

Porous Pavement

General

Choker base course aggregate for beds shall be 3/8 inch to 3/4 inch clean, uniformly-graded, coarse, crushed aggregate AASHTO size number 57 per Table 4, AASHTO Specifications, Part I, 19th Ed., 1998 (p. 47).

Porous Asphalt

Bituminous surface course for porous paving shall be 2.5 to 3 inches thick with a bituminous mix of 5.75% to 6.75% by total weight as determined by testing below. Use neat asphalt binder modified with an elastomeric polymer to produce a binder meeting the requirements of PG 76-22P (in northern Michigan, use PG 76-28P as appropriate) as specified in AASHTO MP-1. The composite materials shall be thoroughly blended at the asphalt refinery or terminal prior to being loaded into the transport vehicle. The polymer modified asphalt binder shall be heat and storage stable.

Determination of optimal asphalt content should be determined according the following tests:

- Draindown Test (ASTM Method D6390)
- Moisture Susceptibility Test using the Modifed Lottman Method (AASHTO T283) with the following:
  - Compact using 50 gyrations of Superpave gyratory compactor
  - Apply partial vacuum of 26 inches of Hg for 10 minutes to whatever saturation is achieved.
  - Keep specimens submerged in water during freeze cycle.
  - Required retained tensile strength (TSR) >= 80%
- Air Voids Test (AASHTO T269/ASTM D3203)

Hydrated lime, if required, shall meet the requirements of AASHTO M 303 Type 1 and shall be blended with the damp aggregate at a rate of 1.0% by weight of the total dry aggregate. 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.

Fibers, if used, shall consist of either cellulose fibers or mineral fibers which are to be treated with a cationic sizing agent to enhance dispersement of the fiber as well as increase cohesion of the fiber to the bitumen. Fiber is to be added at a dosage rate between 0.2% and 0.4% by weight of total mix.

- Mineral fibers shall be from virgin, basalt, diabase, or slag with a maximum average fiber length of 6.35 mm and a maximum average fiber thickness of 0.005 mm.
- Cellulose fiber – Fiber length shall be 6.4 mm (max), Ash Content 18% non-volatiles (±5%), pH 7.5 (± 1), Oil absorption (times fiber weight) 5.0 (± 1), Moisture Content 5.0 (max).

Porous Concrete

The use of Installers or Craftsmen who have been certified by the NRMCA's Pervious Concrete Contractor Certification Program is strongly recommended. Contractor shall furnish a proposed mix design with all applicable information to the Engineer prior to commencement of work. Critical mix characteristics typically include the following:

- Cement Content: 550 to 650 lb/cy
- Fine aggregate, if used: maximum 3 cu. ft. per cu. yd.
- Admixtures: use in accordance with the manufacturer's instructions and recommendations
- An aggregate/cement (A/C) ratio: 4:1 to 4.5:1
- Water/cement (W/C) ratio: 0.27 to 0.34
- Curing: shall begin within 15 minutes after placement and continue for 7 days

The data shall include unit weights determined in accordance with ASTM C29 paragraph 11, jigging procedure.

Cement: Portland Cement Type II or V conforming to ASTM C150 or Portland Cement Type IP or IS conforming to ASTM C595. The total cementitious material shall be between 550 and 650 lb./cy.

Aggregate: Use No 8 coarse aggregate (3/8 to No. 16) per ASTM C33 or No. 89 coarse aggregate (3/8 to No. 50) per ASTM D 448. If other gradation of aggregate is to be used, submit data on proposed material to owner for approval. The volume of aggregate per cu. yd. shall be equal to 27 cu.ft. when calculated as a function of the unit weight determined in accordance with ASTM C 29 jigging procedure. Fine aggregate, if used, should not exceed 3 cu. ft. and shall be included in the total aggregate volume.

Air Entraining Agent: Shall comply with ASTM C 260 and shall be used to improve workability and resistance to freeze/thaw cycles.

Admixtures: The following admixtures shall be used:

- Type D Water Reducing/Retarding – ASTM C 494.
- A hydration stabilizer that also meets the requirements of ASTM C 494 Type B Retarding or Type D Water Reducing/Retarding admixtures may be used. This stabilizer suspends cement hydration by forming a protective barrier around the cementitious particles, which delays the particles from achieving initial set.

Water: Potable shall be used and shall comply with ASTM C1602. Mix water shall be such that the cement paste displays a wet metallic sheen without causing the paste to flow from the aggregate. (Mix water yielding a cement paste with a dull-dry appearance has insufficient water for hydration).

- Insufficient water results in inconsistency in the mix and poor bond strength.
- High water content results in the paste sealing the void system primarily at the bottom and poor surface bond.

An aggregate/cement (A/C) ratio range of 4:1 to 4.5:1 and a water/cement (W/C) ratio range of 0.27 to 0.34 should produce pervious pavement of satisfactory properties in regard to permeability, load carrying capacity, and durability characteristics.

Vegetated roofs

Some key components and associated performance-related properties are as follows:

Root-barriers should be thermoplastic membranes with a thickness of at least 30 mils. Thermoplastic sheets can be bonded using hot-air fusion methods, rendering the seams safe from root penetration. Membranes that have been certified for use as root-barriers are recommended. At present only FLL offers a recognized test for root-barriers. Several FLL-certified materials are available in the United States. Interested American manufactures can submit products for testing to FLL-certified labs.

Granular drainage media should be a non-carbonate mineral aggregate conforming to the following specifications:

• Saturated Hydraulic Conductivity	>= 25 in/min
• Total Organic Matter, by Wet Combustion (MSA)	<= 1%
• Abrasion Resistance (ASTM-C131-96)	<= 25% loss
• Soundness (ASTM-C88 or T103 or T103-91)	<= 5% loss
• Porosity (ASTM-C29)	>= 25%
• Alkalinity, CaCO3 equivalents (MSA)	<= 1 %
• Grain-Size Distribution (ASTM-C136)	
Pct. Passing US#18 sieve	<= 1%
Pct. Passing ¼-inch sieve	<= 30%
Pct. Passing 3/8-inch sieve	>= 80%

Growth media should be a soil-like mixture containing not more than 15% organic content (wet combustion or loss on ignition methods). The appropriate grain-size distribution is essential for achieving the proper moisture content, permeability, nutrient management, and non-capillary porosity, and 'soil' structure. The grain-size guidelines vary for single and dual media vegetated cover assemblies.

Non-capillary Pore Space at Field Capacity, 0.333 bar (TMECC 03.01, A)	>= 15% (vol)
Moisture Content at Field Capacity (TMECC 03.01, A)	>= 12% (vol)
Maximum Media Water Retention (FLL)	>= 30% (vol)
Alkalinity, Ca CO3 equivalents (MSA)	<= 2.5%
Total Organic Matter by Wet Combustion (MSA)	3-15% (dry wt.)
pH (RCSTP)	6.5-8.0
Soluble Salts (DTPA saturated media extraction)"(RCSTP)	<= 6 mmhos/cm
Cation exchange capacity (MSA)	>= 10 meq/100g
Saturated Hydraulic Conductivity for Single Media Assemblies (FLL)	>= 0.05 in/min
Saturated Hydraulic Conductivity for Dual Media Assemblies (FLL)	>= 0.30 in/min

Grain-size Distribution of the Mineral Fraction (ASTM-D422)

Single Media Assemblies:

Clay fraction (2 micron)	0
Pct. Passing US#200 sieve (i.e., silt fraction)	<= 5%
Pct. Passing US#60 sieve	<= 10%
Pct. Passing US#18 sieve	5 - 50%
Pct. Passing 1/8-inch sieve	0 - 70%
Pct. Passing 3/8-inch sieve	75 -100%

Dual Media Assemblies:

Clay fraction (2 micron)	0
Pct. Passing US#200 sieve (i.e., silt fraction)	5-15%
Pct. Passing US#60 sieve	10-25%
Pct. Passing US#18 sieve	20 - 50%
Pct. Passing 1/8-inch sieve	55 - 95%
Pct. Passing 3/8-inch sieve	90 -100%

Macro- and micro-nutrients shall be incorporated in the formulation in initial proportions suitable for support the specified planting.

Separation fabric should be readily penetrated by roots, but provide a durable separation between the drainage and growth media layers (Only lightweight nonwoven geotextiles are recommended for this function.

• Unit Weight (ASTM-D3776)	<= 4.25 oz/yd2
• Grab tensile (ASTM-D4632)	<= 90 lb
• Mullen Burst Strength (ASTM-D4632)	>= 135 lb/in
• Permittivity (ASTM-D4491)	>= 2 per second

Appendix E

Soil Infiltration Testing Protocol

Purpose of this Protocol

The soil infiltration testing protocol describes evaluation and field testing procedures to determine if infiltration BMPs are suitable at a site, as well as to obtain the required data for infiltration BMP design.

When to Conduct Testing

The Site Design Process for LID, outlined in Chapter 5 of this manual, describes a process for site development and application of nonstructural and structural BMPs. 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.

Who Should Conduct Testing

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 stormwater designer is *strongly* encouraged to directly observe the testing process to obtain a first-hand understanding of site conditions.

Importance of Stormwater BMP Areas

Sites are often defined as unsuitable for infiltration BMPs and soil-based BMPs due to proposed grade changes (excessive cut or fill) or lack of suitable areas. Many sites will be constrained and unsuitable for infiltration BMPs. However, if suitable areas exist, these areas should be identified early in the design process and should *not* be subject to a building program that precludes infiltration BMPs. Full build-out of site areas otherwise deemed to be suitable for infiltration should not provide an exemption or waiver for adequate stormwater volume control or groundwater recharge.

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 Michigan One Call system (Miss Dig www.missdig.org or 1-800-482-7171). Excavations should never be left unsecured and unmarked, and all applicable authorities should be notified prior to any work.

Infiltration Testing: A Multi-Step Process

Infiltration testing is a four-step process to obtain the necessary data for the design of the stormwater management plan. The four steps include:

1. Background evaluation
   - Based on available published and site specific data
   - Includes consideration of proposed development plan
   - Used to identify potential BMP locations and testing locations
   - Prior to field work (desktop)
2. Test pit (deep hole) observations
   - Includes multiple testing locations
   - Provides an understanding of sub-surface conditions
   - Identifies limiting conditions
3. Infiltration testing
   - Must be conducted onsite
   - Different testing methods available
4. Design considerations
   - Determine suitable infiltration rate for design calculations
   - Consider BMP drawdown
   - Consider peak rate attenuation

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, karst conditions, or other features of note.
- Existing streams (perennial and intermittent, including intermittent swales), water bodies, wetlands, hydric soils, floodplains, alluvial soils, stream classifications, headwaters, and first order streams.
- Existing topography, slope, drainage patterns, and watershed boundaries.
- Existing land use conditions.
- Other natural or man-made features or conditions that may impact design, such as past uses of site, existing nearby structures (buildings, walls), abandoned wells, etc.
- A concept plan or preliminary layout plan for development should be evaluated, including:
  - Preliminary grading plan and areas of cut and fill,
  - Location of all existing and proposed water supply sources and wells,
  - Location of all former, existing, and proposed onsite wastewater systems,
  - Location of other features of note such as utility rights-of-way, water and sewer lines, etc.,
  - Existing data such as structural borings, and
  - Proposed location of development features (buildings, roads, utilities, walls, etc.).

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.

Important: If the proposed development is located on areas that may otherwise be a suitable BMP location, or if the proposed grading plan is such that potential BMP locations are eliminated, the designer is ***strongly*** encouraged to revisit the proposed layout and grading plan and adjust the development plan as necessary. Full build-out of areas suitable for infiltration BMPs should ***not*** preclude the use of BMPs for runoff volume reduction and groundwater recharge.

Step 2. Test pits (deep holes)

A test pit (deep hole) allows visual observation of the soil horizons and overall soil conditions both horizontally and vertically in that portion of the site. An extensive number of test pit observations can be made across a site at a relatively low cost and in a short time period. The use of soil borings as a substitute for test pits is strongly discouraged, as visual observation is narrowly limited in a soil boring and the soil horizons cannot be observed in-situ, but must be observed from the extracted borings.

A test pit (deep hole) consists of a backhoe-excavated trench, 2½-3 feet wide, to a depth of 6-7½ feet, or until bedrock or fully saturated conditions are encountered. 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.

The Sample Soil Log Form at the end of this protocol may be used for documenting each test pit.

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 stormwater management.

The number of test pits varies depending on site conditions and the proposed development plan. General guidelines are as follows:

- For single-family residential subdivisions with on-lot infiltration BMPs, one test pit per lot is recommended, preferably within 100 feet of the proposed BMP area.
- For multi-family and high-density residential developments, one test pit per BMP area or acre is recommended.
- For large infiltration areas (basins, commercial, institutional, industrial, and other proposed land uses), multiple test pits should be evenly distributed at the rate of four to six pits per acre of BMP area.

The recommendations above 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

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.

At least one test should be conducted at the proposed bottom elevation of an infiltration BMP, and a minimum of two tests per test pit are recommended. 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.

Methodologies discussed in this protocol include:

- Double-ring infiltrometer tests.
- Percolation tests (such as for onsite wastewater systems).

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 Stormwater 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 stormwater BMP design may also be conducted with readily available materials.

Equipment for double-ring infiltrometer test:
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

- Prepare level testing area.
- Place outer ring in place; place flat board on ring and drive ring into soil to a minimum depth of two inches.
- 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.
- 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.

- Prepare level testing area.
- 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.
- (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.
- 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**:

$$R_f = \frac{2d1 - \Delta d}{DIA} + 1$$

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 E.1 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 other adjustments may be necessary.*

Step 4. Use design considerations provided in the infiltration BMP.

Table E.1
Sample Percolation Rate Adjustments

Perc. Hole Diameter, DIA (in.)	Initial Water Depth, D_1 (in.)	Ave./Final Water Level Drop, △d (in.)	Reduction Factor, R_f
6	6	0.1	3.0
		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
		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	2.0
	8	0.1	2.6
		0.5	2.6
		2.5	2.4
	10	0.1	3.0
		0.5	3.0
		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 stormwater runoff). Vegetative and soil improvement programs can lower the soil bulk density and improve the site's ability to absorb rainfall and reduce runoff.

Macropores occur primarily in the upper soil horizons and are formed by plant roots (both living and decaying), soil fauna such as insects, the weathering processes caused by movement of water, the freeze-thaw cycle, soil shrinkage due to desiccation of clays, chemical processes, and other mechanisms. These macropores provide an important mechanism for infiltration prior to development, extending vertically and horizontally for considerable distances. It is the intent of good engineering and design practice to maintain these macropores when installing infiltration BMPs as much as possible. Bulk density tests can help determine the relative compaction of soils before and after site disturbance and/or restoration and should be used at the discretion of the designer/reviewer.

Soil Test Pit Log Sheet

Project: ______________________ **Date:** ______________________

Name: ______________________ **Soil Series:** ______________________

Location: ______________________ **Other:** ______________________

Test Pit # ______________________

Horizon	Depth (In.)	Color	Redox Features	Texture	Notes (if applicable)	Boundary

NOTES:

REDOX FEATURES

Abundance

Few……. < 2%

Common.. 2 - 20%

Many….. > 20%

Contrast

faint

hue & chroma of matrix and redox are closely related.

distinct

matrix & redox features vary 1 - 2 units of hue and several unites of chroma & value.

prominent

Matrix & redox features vary several units in hue, value & chroma

COARSE FRAGMENTS (% of profile)

15-35%	**35-65%**	**>65%**
gravelly	very gravelly	extremely gravelly
channery	very channery	extremely channery
cobbly	very cobbly	extremely cobbly
flaggy	very flaggy	extremely flaggy
stony	very stony	extremely stony

BOUNDARY

Distinctness

abrupt…< 1" (thick) *gradual*..2.5 - 5"

clear…..1 - 2.5" *diffuse*….> 5

Topography

smooth - boundary is nearly level

wavy - pockets with width > than depth

irregular - pockets with depth > than width

HORIZONS

O - organic layers of decaying plant and animal tissue (must be greater than 12-18% organic carbon, excluding live roots).

A (topsoil) - mineral horizon at or near the surface in which an accumulation of humified organic matter is mixed with the mineral material.

E - mineral horizon which the main feature is loss of silicate clay, iron, aluminum. Must be underlain by a B (alluvial) horizon.

B (subsoil) - mineral horizon with evidence of pedogenesis or illuviation (movement into the horizon).

C (substratum) - the un-weathered geologic material the soil formed in. Shows little or no sign of soil formation.

Appendix F

Maintenance Inspection Checklists

This appendix contains four checklists available as guides for maintenance inspections of specific BMPs. The maintenance items have been adapted from multiple stormwater programs, including the Rouge River Detention Basin Maintenance Manual, Georgia Stormwater Management Manual, the Vermont Stormwater Management Manual, and the Stormwater Manager's Resource Center.

The checklists are designed to help identify key components of BMPs that require ongoing maintenance as well as a basic schedule of when the maintenance should occur. The checklists have been divided into those items essential for the general operation and functionality of the BMP and those items that optional and may enhance the BMP.

It is suggested that the inspection be undertaken by a licensed PE and/or a person knowledgeable about the design and function of the BMP.

These BMP checklists include:

- Detention (ponds, basins, wetlands)
- Infiltration (basins, trenches)
- Bioretention
- Bioswales, vegetated filter strips

Detention BMP Inspection Checklist*

Project Location:____

Date/Time: ____

Inspector:____

Maintenance Item	Satisfactory/ Unsatisfactory	Recommended Inspection Frequency	Comments
Inlet/Outlet Pipes			
Structural integrity of inlet/outlet (Are any inlet pipes broken, crumbling, separated?) List Inlet Pipes Approximate Diameter and Type of Material Inlet Pipe 1 ______________________ Inlet Pipe 2 ______________________ Inlet Pipe 3 ______________________ Outlet Pipe Size/Type ______________		A	
Riprap at inlet pipe (Is the riprap still present? Is it visible and not covered with sediment?		A	
Stone around outlet pipe (Is the stone clogged with debris and/or sediment?)		A	
Trash or debris blocking inlet/outlet (Inspect to ensure no major obstructions hindering general functionality)		M	
Inspect/clean catch basin upstream of the BMP if accessible.		A	
Inspect inlets and outlet for erosion (Are there eroded areas around the pipes?)		A	
Inspect overflow spillway for signs of erosion.			
Pretreatment (if applicable) (Might include sediment forebay, upstream catch basin, bioswale, rain garden, swirl concentrator)			
Device functioning to trap/collect sediment		A	
Remove accumulated sediment as appropriate for the pretreatment device. forebay		A	
Detention Pond		A	

Inspection frequency key — A = Annual, M = Monthly, S = After major storm

*It is recommended to review and inspect the basin with the engineering as-built plans.

Maintenance Item	Satisfactory/ Unsatisfactory	Recommended Inspection Frequency	Comments
Inspect side slopes, berms and emergency overflow for erosion		A	
Reestablish permanent native vegetation on eroded slopes		As needed	
Inspect for excess sediment accumulation in pond if not pretreatment device is present		A	
Overall functionality			
Ensure pond is functioning properly (Professional Civil Engineer is recommended)		A	
Ensure the outlet is functioning properly (Professional Civil Engineer is recommended)		A	
Optional/Enhancements			
Maintain 15-20 feet "no mow and chemical free" zone		A	
Mow (or burn) the "no mow" zone		A	
Inspect basin and "no mow" zone for invasive species.		A	
Qualified professional applicator selectively herbicide invasive species		A	
Increase plant diversity by planting additional vegetation in and around pond.		A	
Complaints from residents (note on back)		S	
Encroachment on pond/no- mow zone.		A	
Unauthorized plantings		A	
Aesthetics (e.g., graffiti, unkept maintenance)		A	

Inspection frequency key — A = Annual, M = Monthly, S = After major storm
*It is recommended to review and inspect the basin with the engineering as-built plans.

Summary

Inspector's remarks: ____

____

Overall condition of facility (acceptable or unacceptable): ______________________

Dates any maintenance must be completed by: ______________________________

Inspection frequency key — A = Annual, M = Monthly, S = After major storm
*It is recommended to review and inspect the basin with the engineering as-built plans.

Infiltration BMPs Inspection Checklist*

Project Location:____

Date/Time: ____

Inspector:____

Maintenance Item	Satisfactory/ Unsatisfactory	Recommended Inspection Frequency	Comments
Inlet/Outlet			
Structural integrity of inlet/outlet		A	
Inlet/outlet clear of debris		M	
Overflow spillway clear of debris		M	
Erosion control at inlet in place (e.g., rock, mat)/ evidence of erosion		A	
Erosion control at outlet in place/evidence of erosion		A	
Inspect/clean catch basin upstream of BMP		A	
Pretreatment for sediment			
Device functioning to trap sediment		A	
Remove accumulated sediment		A	
Overall functionality			
Ensure infiltration device is functioning properly (professional civil engineer is recommended)		A	
BMP infiltration surface			
Any evidence of sedimentation in BMP		A	
Does sediment accumulation currently require removal		A	
Debris in BMP		S	
Evidence of erosion present		A	
Aggregate (if applicable)			
Surface of aggregate clean		A	
Any replacement of aggregate needed? If clogged with sediment replacement is necessary for continued proper function.		A	

Inspection frequency key — A = Annual, M = Monthly, S = After major storm
*Prior to field inspection, it is recommended to review the as-built plans.

Maintenance Item	Satisfactory/ Unsatisfactory	Recommended Inspection Frequency	Comments
Vegetated surface (if applicable)			
Vegetative cover exists		A	
Optional considerations			
Inspect BMP for invasive species.		A	
Qualified professional applicator selectively herbicide invasive species		A	
Increase plant diversity by planting additional vegetation or creating a native plant infiltration basin area.		A	
Complaints from residents (note on back)		A	
Mowing done when necessary		A	
No fertilizer unless testing requires it		A	

Inspection frequency key — A = Annual, M = Monthly, S = After major storm
*Prior to field inspection, it is recommended to review the as-built plans.

Summary

Inspector's remarks: ____

____

Overall condition of facility (acceptable or unacceptable): ______________________________

Dates any maintenance must be completed by: _____________________________________

Bioretention Inspection Checklist*

Project Location:______________________________

Date/Time: ______________________________

Inspector:______________________________

Maintenance Item	Satisfactory/ Unsatisfactory	Recommended Inspection Frequency	Comments
Inlet/Outlet			
Structural integrity of inlet/outlet		A	
Inlet/outlet clear of debris		M	
Overflow spillway or catch basin clear of debris		M	
Erosion control at inlet in place (e.g., rock, mat)/ evidence of erosion		A	
Erosion control at outlet in place/evidence of erosion		A	
Inspect/clean catch basin upstream of BMP		Every 5 years	
Pretreatment for sediment (Generally consists of catch basin or velocity dissapator at inlet such as area of riprap/ collection for sediment)			
Device functioning to trap sediment		A	
Remove accumulated sediment		A	
Overall functionality			
Ensure bioretention area is functioning properly (professional civil engineer is recommended)		A	
Bioretention area surface			
Any evidence of sedimentation in BMP		A	
Does sediment accumulation currently require removal		A	
Debris in BMP		M	
Evidence of erosion present		A	
Does good vegetative cover exist		A	
Mulch covers entire area (no voids) and to specified thickness		A	
Optional considerations			
Inspect BMP for invasive species.		A	

Inspection frequency key — A = Annual, M = Monthly, S = After major storm
*Prior to field inspection, it is recommended to review the as-built plans.

Maintenance Item	Satisfactory/ Unsatisfactory	Recommended Inspection Frequency	Comments
Qualified professional applicator selectively herbicide invasive species		A	
Increase plant diversity by planting additional vegetation		A	
Complaints from residents (note on back)		A	

Inspection frequency key — A = Annual, M = Monthly, S = After major storm
*Prior to field inspection, it is recommended to review the as-built plans.

Summary

Inspector's remarks: ____

____

Overall condition of facility (acceptable or unacceptable): ______________________________

Dates any maintenance must be completed by: _____________________________________

Bioswale, Filter Strip Inspection Checklist

Project Location:______________________________

Date/Time: ______________________________

Inspector:______________________________

Maintenance Item	Satisfactory/ Unsatisfactory	Recommended Inspection Frequency	Comments
Inlet/Outlet			
Structural integrity of inlet/outlet		A	
Inlet/outlet clear of debris		M	
Pretreatment/ Energy Dissipators			
No evidence of flow going around structures		A	
No evidence of erosion		A	
Device functioning to trap sediment		A	
Remove accumulated sediment		A	
BMP surface			
Area free of debris?		M	
No evidence of erosion		A	
Does sediment accumulation currently require removal?		A	
Overall functionality			

Inspection frequency key — A = Annual, M = Monthly, S = After major storm
*Prior to field inspection, it is recommended to review the as-built plans.

Maintenance Item	Satisfactory/ Unsatisfactory	Recommended Inspection Frequency	Comments
Ensure swale is functioning properly (professional civil engineer is recommended)		A	
Optional Considerations			
Inspect BMP for invasive species.		A	
Qualified professional applicator selectively herbicide invasive species		A	
Increase plant diversity by planting additional vegetation		A	
Complaints from residents (note on back)		A	

Inspection frequency key — A = Annual, M = Monthly, S = After major storm
*Prior to field inspection, it is recommended to review the as-built plans.

Summary

Inspector's remarks: ____

____

Overall condition of facility (acceptable or unacceptable): ______________________________

Dates any maintenance must be completed by: ______________________________

Stormwater Management Practices Maintenance Agreement

THIS AGREEMENT is made this day of , 20 , by and between the [Community Name], a municipal corporation, with principal offices located at [Community address], hereinafter "[Community]"and ____a ___________ with principal offices located ____, hereinafter "Owner".

[Owners Name], as "Owner(s)" of the property described below, in accordance with ____________ [Community Regulations], agrees to install and maintain stormwater management practice(s) on the subject property in accordance with approved plans and conditions. The Owner further agrees to the terms stated in this document to ensure that the stormwater management practice(s) continues serving the intended function in perpetuity. This Agreement includes the following exhibits:

Exhibit A: Legal description of the real estate for which this Agreement applies ("Property").

Exhibit B: Location map(s) showing a location of the Property and an accurate location of each stormwater management practice affected by this Agreement.

Exhibit C: Long-term Maintenance Plan that prescribes those activities that must be carried out to maintain compliance with this Agreement.

Note: After construction has been verified and accepted by the [Community Name] for the stormwater management practices, an addendum(s) to this agreement shall be recorded by the Owner showing design and construction details and provide copies of the recorded document to the [Community Name]. The addendum may contain several additional exhibits.

Through this Agreement, the Owner(s) hereby subjects the Property to the following covenants, conditions, and restrictions:

1. The Owner(s), at its expense, shall secure from any affected owners of land all easements and releases of rights-of-way necessary for utilization of the stormwater practices identified in Exhibit B and shall record them with the [Community] Register of Deeds. These easements and releases of rights-of-way shall not be altered, amended, vacated, released or abandoned without prior written approval of the [Community] .

2. The Owner(s) shall be solely responsible for the installation, maintenance and repair of the stormwater management practices, drainage easements and associated landscaping identified in Exhibit B in accordance with the Maintenance Plan (Exhibit C).

3. No alterations or changes to the stormwater management practice(s) identified in Exhibit B shall be permitted unless they are deemed to comply with this Agreement and are approved in writing by the [Community].

4. The Owner(s) shall retain the services of a qualified inspector (as described in Exhibit C – Maintenance Requirement 1) to operate and ensure the maintenance of the stormwater management practice(s) identified in Exhibit B in accordance with the Maintenance Plan (Exhibit C).

5. The Owner(s) shall annually, by December 30th, provide to the [Community] records (logs, invoices, reports, data, etc.) of inspections, maintenance, and repair of the stormwater management practices and drainage easements identified in Exhibit B in accordance with the Maintenance Plan. Inspections are required at least after every major rain event.

6. The [Community] or its designee is authorized to access the property as necessary to conduct inspections of the stormwater management practices or drainage easements to ascertain compliance with the intent of this Agreement and the activities prescribed in Exhibit C. Upon written notification by the [Community] or their designee of required maintenance or repairs, the Owner(s) shall complete the specified maintenance or repairs within a reasonable time frame determined by the [Community]. The Owner(s) shall be liable for the failure to undertake any maintenance or repairs so that the public health, safety and welfare shall not be endangered nor the road improvement damaged.

7. If the Owner(s) does not keep the stormwater management practice(s) in reasonable order and condition, or complete maintenance activities in accordance with the Plan contained in Exhibit C, or the reporting required in 3 above, or the required maintenance or repairs under 4 above within the specified time frames, the [Community] is authorized, but not required, to perform the specified inspections, maintenance or repairs in order to preserve the intended functions of the practice(s) and prevent the practice(s) from becoming a threat to public health, safety, general welfare or the environment. In the case of an emergency, as determined by the [Community], no notice shall be required prior to the [Community] performing emergency maintenance or repairs. The [Community] may levy the costs and expenses of such inspections, maintenance or repairs plus a ten percent (10%) administrative fee against the Owner(s). The [Community] at the time of entering upon said stormwater management practice for the purpose of maintenance or repair may file a notice of lien in the office of the Register of Deeds of the [Community] upon the property affected by the lien. If said costs and expenses are not paid by the Owner(s), the [Community] may pursue the collection of same through appropriate court actions and in such a case, the Owner(s) shall pay in addition to said costs and expenses all costs of litigation, including attorney fees.

8. The Owner(s) hereby conveys to the [Community] an easement over, on and in the property described in Exhibit A for the purpose of access to the stormwater management practice(s) for the inspection, maintenance and repair thereof, should the Owner(s) fail to properly inspect, maintain and repair the practice(s).

9. The Owner(s) agrees that this Agreement shall be recorded and that the land described in Exhibit "A" shall be subject to the covenants and obligations contained herein, and this agreement shall bind all current and future owners of the property.

10. The Owner(s) agrees in the event that the Property is sold, transferred, or leased to provide information to the new owner, operator, or lessee regarding proper inspection, maintenance and repair of the stormwater management practice(s). The information shall accompany the first deed transfer and include Exhibits B and C and this Agreement. The transfer of this information shall also be required with any subsequent sale, transfer or lease of the Property.

11. The Owner(s) agree that the rights, obligations and responsibilities hereunder shall commence upon execution of the Agreement.

12. The parties whose signatures appear below hereby represent and warrant that they have the authority and capacity to sign this agreement and bind the respective parties hereto.

13. The Proprietor, its agents, representatives, successors and assigns shall defend, indemnify and hold the [Community] harmless from and against any claims, demands, actions, damages, injuries, costs or expenses of any nature whatsoever, hereinafter "Claims", fixed or contingent, known or unknown, arising out of or in any way connected with the design, construction, use, maintenance, repair or operation (or omissions in such regard) of the storm drainage system referred to in the permit as Exhibit "C" hereto, appurtenances, connections and attachments thereto which are the subject of this Agreement. This indemnity and hold harmless shall include any costs, expenses and attorney fees incurred by the [Community] in connection with such Claims or the enforcement of this Agreement.

IN WITNESS WHEREOF, the Proprietor and Township have executed this Agreement on the day and year first above written.

WITNESSES:

____

A Michigan co-partnership/corporation

______________________________ By: ______________________________________

______________________________ Its: ______________________________________

STATE OF MICHIGAN)
) ss.
COUNTY OF [County Name])

The foregoing instrument was acknowledged before me on this____________ day of ________________, 20 ___, by ____, the ________________________ of ______________________.

____

Notary Public

__________________________ County of Michigan
My Commission Expires On:

[Community Name]
a municipal corporation

______________________________ By: ______________________________________

______________________________ Its: ______________________________________

STATE OF MICHIGAN)
) ss.
COUNTY OF [County Name])

The foregoing instrument was acknowledged before me on this____________ day of ________________, 20 ___, by ____, the ________________________ of _______________________.

____

Notary Public

__________________________ County of Michigan
My Commission Expires On:

INSTRUMENT DRAFTED BY:

WHEN RECORDED RETURN TO:

[Community Name and Address]

Exhibit A – Legal Description (Sample)

The following description and reduced copy map identifies the land parcel(s) affected by this Agreement.

[Note: *An example legal description is shown below. This exhibit must be customized for each site, including the minimum elements shown. It must include a reference to a Subdivision Plat, Certified Survey number, or Condominium Plat, and a map to illustrate the affected parcel(s).*]

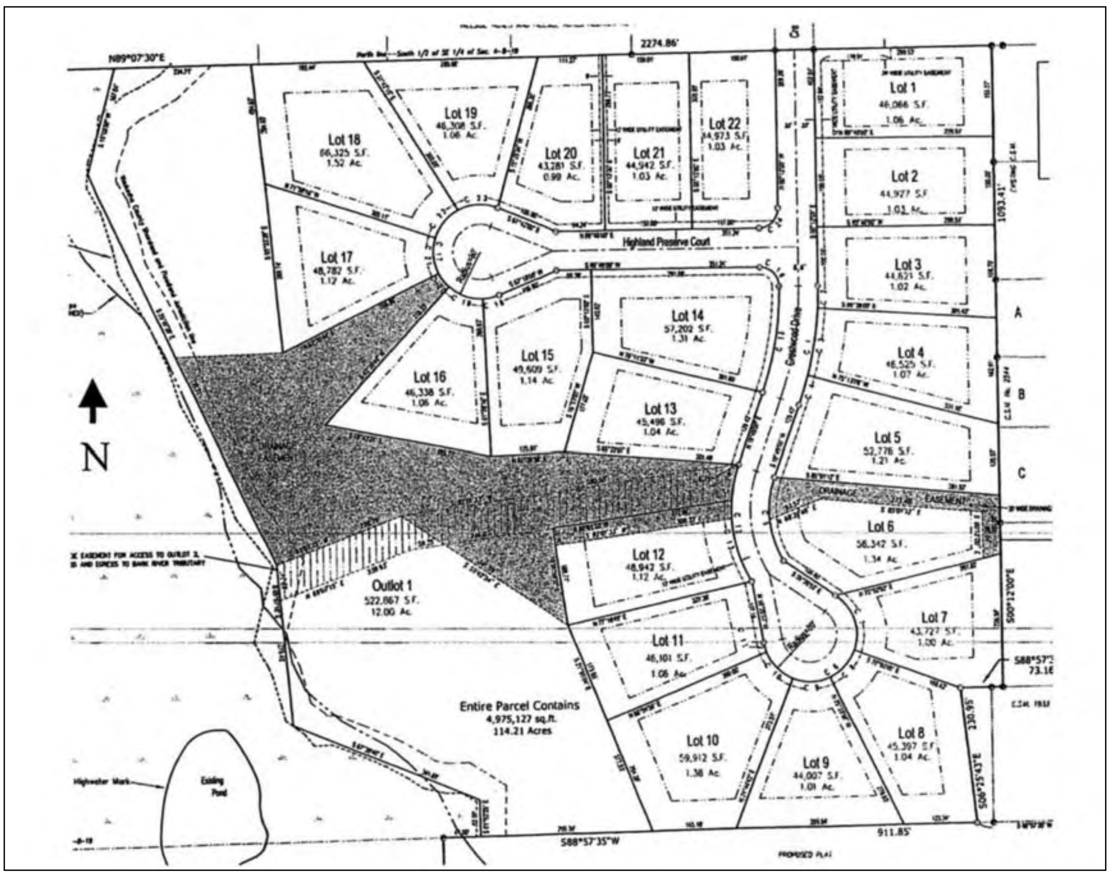
Project Identifier: Huron Preserve Subdivision

Acres: 40

Date of Recording: October 22, 2006

Map Produced by: ABC Engineering, P.O. Box 20, Green Oak Twp., MI

Legal Description: Lots 1 through 22 of Huron Preserve Subdivision, located in the Southwest Quarter (SW1/4) of Section 4, Township 8N, Range 19E (Green oak Township) Livingston County, Michigan. [If no land division is involved, enter legal description as described on the property title here.]



Huron Preserve Subdivision

<u>Drainage Easement Restrictions:</u> Shaded area on map indicates a drainage easement for stormwater collection, conveyance, and treatment. No buildings or other structures are allowed in these areas. No grading or filling is allowed that may interrupt stormwater flows in any way. See Exhibit C for specific maintenance requirements for stormwater management practices within this area. See subdivision plat for details on location.

Exhibit B – Location Map (Sample)

Stormwater Management Practices Covered by this Agreement

[*An example location map and the minimum elements that must accompany the map are shown below. This exhibit must be customized for each site. Map scale must be sufficiently large enough to show necessary details*.]

The stormwater management practices covered by this agreement are depicted in the reduced copy of a portion of the construction plans, as shown below. The practices include on wet detention basin, two forebays, two grass swales (conveying stormwater to the forebays) and all associated pipes, earthen berms, rock chutes, and other components of these practices. All of the noted stormwater management practices are located within a drainage easement in Outlot 1 of the subdivision plat as noted in Exhibit A.

Subdivision Name: Huron Preserve Subdivision

Stormwater Practices: Wet Detention Basin #1, forebays (2), grass swales (2)

Location of Practices: All that part of Outlot 1, bounded and described in Figure G.1: [If no land division is involved, enter a metes and bounds description of the easement area.]

Titleholders of Outlot 1: Each Owner of Lots 1 through 22 shall have equal (1/22) undividable interest in Outlot 1 [For privately owned stormwater management practices, the titleholder(s) must include all new parcels that drain to the stormwater management practice.]

Figure G.1
Plan View of Stormwater Practices

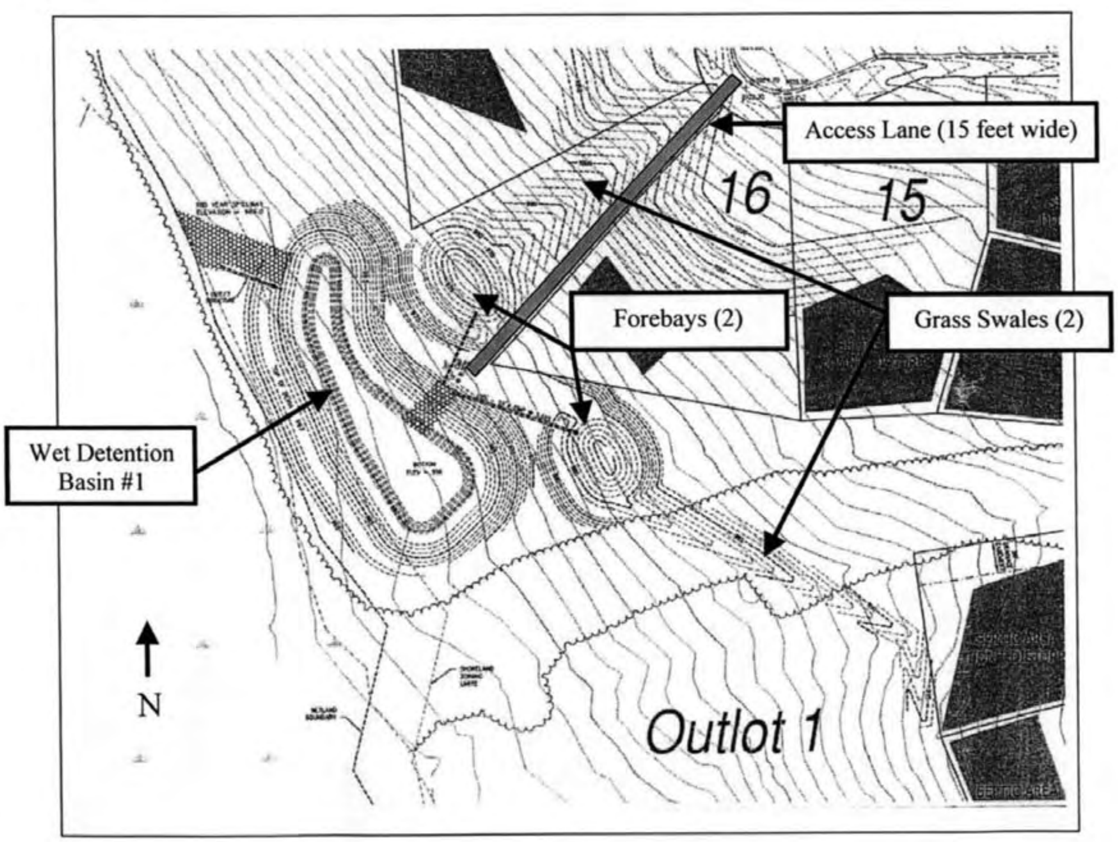


Exhibit C - Stormwater Practice Maintenance Plan

This exhibit explains the basic function of each of the stormwater practices listed in Exhibit B and provides the minimum specific maintenance activities and frequencies for each practice. The maintenance identified by the Owner should follow the maintenance activities listed in this manual, if applicable. Vehicle access to the stormwater practices is shown in Exhibit B. Any failure of a stormwater practice that is caused by lack of maintenance will subject the Owner(s) to enforcement of the provisions listed in the Agreement by the [Community] .

The exhibit must be customized for each site. The minimum elements of this exhibit include: a description of the drainage area and the installed stormwater management practices, a description of the specific maintenance activities for each practice which should include in addition to specific actions:

- Employee training and duties,
- Routine service requirements,
- Operating, inspection and maintenance schedules, and
- Detailed construction drawings showing all critical components and their elevations.

References

Charter Township of Canton, Stormwater FACILITIES MAINTENANCE AGREEMENT.

Charter Township of Green Oak, AGREEMENT FOR MAINTENANCE OF STORMWATER MANAGEMENT PRACTICES

Appendix H

Model Ordinances

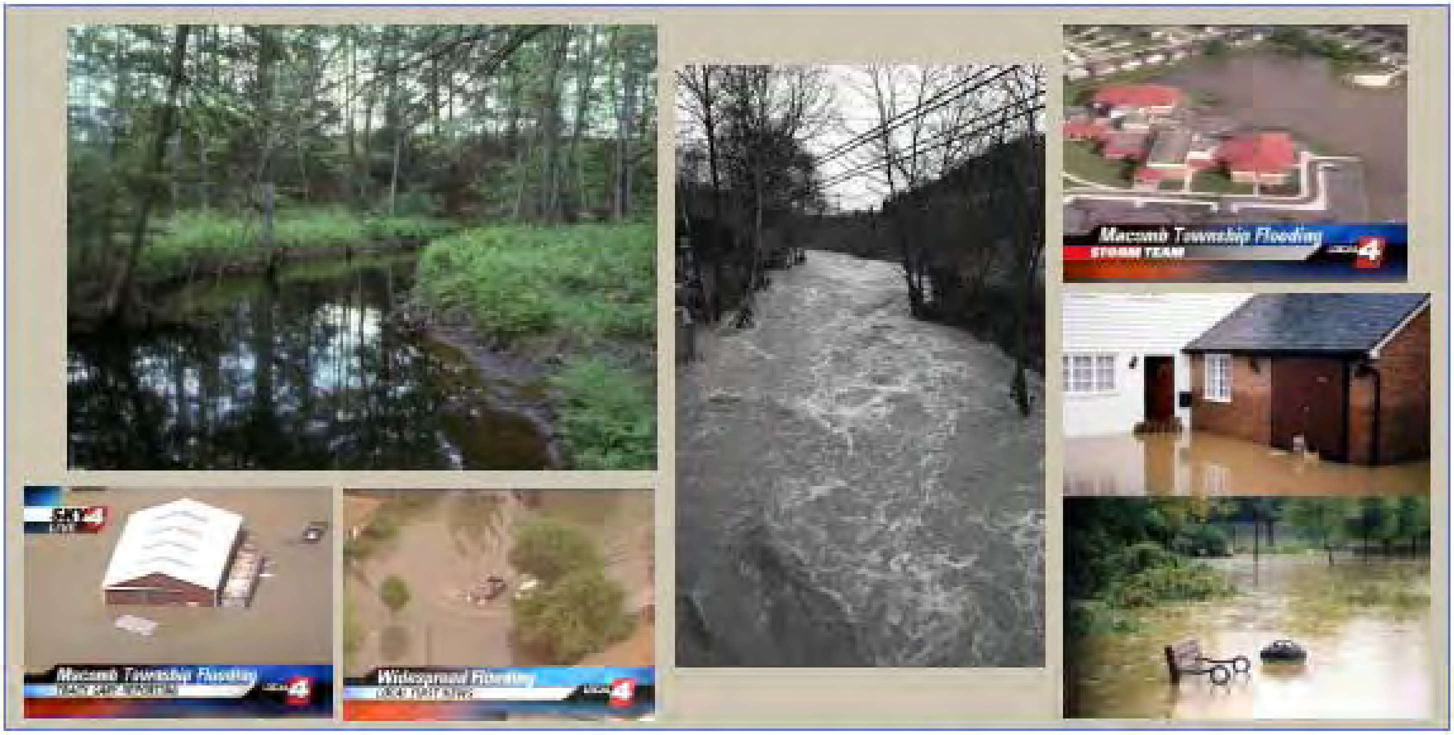
This appendix contains model ordinances that serve as general guidance to assist local communities interested in implementing water resource protection ordinances. These ordinances are NOT legal advice.

Details of both substance and process in an ordinance will vary by community based on local conditions and institutional structures. A first step in preparing an ordinance is to engage local stakeholders including elected officials, engineers, and planners. Proposed ordinances should not be finalized without advice and involvement of legal counsel.

This appendix contains a model LID stormwater ordinance. This model ordinance was specifically developed to accompany this manual to provide additional guidance to communities interested in regulating LID implementation in their community.

In addition, there are other ordinances that can be implemented at the local level that implement LID principles. This appendix contains summary sheets and web links to model ordinances developed for Macomb County Planning and Economic Development. These topics include: native vegetation, flood prevention, natural features setback, trees and woodlands, resource protection overlay, and wetlands.

Flood Prevention District



Purpose & Highlights of Ordinance

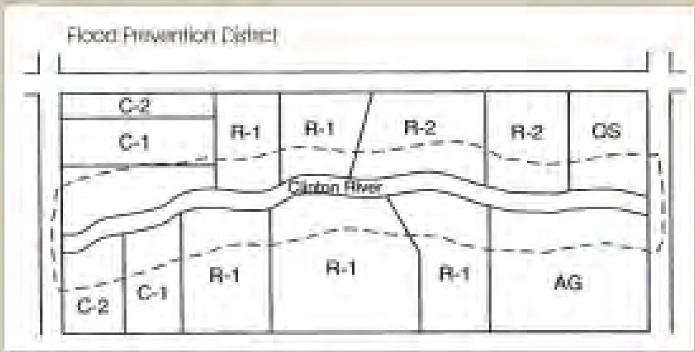
- The purpose of the Flood Prevention District is to protect the natural, human, structural, and economic resources of the community through application of special regulations for the use of land which is, or may be, subject to periodic inundation by floods and floodwaters at predictable intervals.

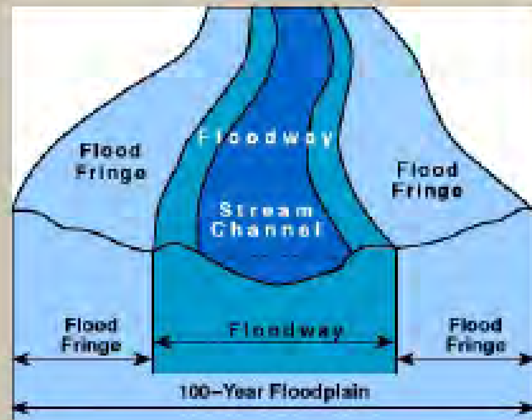
- Although unseen, floodplains are integral assets of communities and provide numerous benefits including:

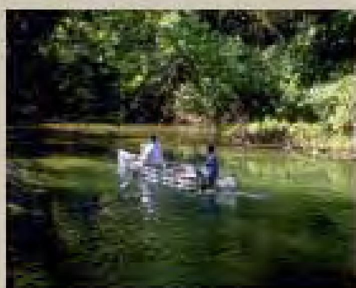
  1. Storing flood waters. Floodplains reduce the velocity of flood waters and peak flows downstream thereby decreasing property damage and other potential hazards to people residing or working in the floodplain.
  2. A floodplain can also improve water quality by filtering out pollutants and sediment and recharging groundwater.
  3. Vegetated floodplains can stabilize soils during floods, thus reducing the amount of sediment carried downstream.
  4. Floodplains provide habitat for plants and animals and are particularly important as breeding and feeding areas.
  5. Floodplains are also excellent areas for open space, parks, greenways, and recreation areas, all of which protect the natural functions of the floodplain.

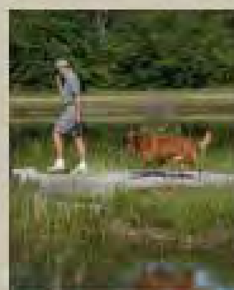
For additional information contact The Macomb County Department of Planning & Economic Development
586-469-5285

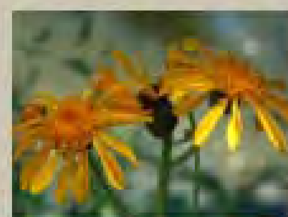
Application

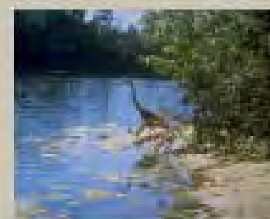












- The Flood Prevention District functions as an overlay zoning district. Properties within the district retain their underlying zoning classifications, but are subject to additional requirements specified in the flood prevention ordinance.
- The Flood Prevention District is divided into two (2) areas, the "floodway" and "flood fringe", which coincide with FEMA's flood insurance rate maps and floodway maps.
- A development permit must first be obtained from the proper community authority before any development or substantial improvements can be undertaken in these areas.
- The ordinance requires that uses vulnerable to floods be protected against flood damage at the time of initial construction and be constructed by methods and practices that minimize adverse impacts on the function of the floodplain.
- New construction or substantial improvement of any structure should have the lowest floor, including the basement, elevated to one foot above base flood elevation.
- The ordinance controls filling, grading, dredging, obstructions and other developments which may increase erosion or flood damage.
- The construction of flood barriers are also regulated through the ordinance.

For additional information visit www.macombcountymi.gov/planning/model_ordinances.htm

Native Vegetation

Purpose & Highlights of Ordinance

- The purpose of the ordinance is to encourage the use of desirable native species of plants for all landscaping and to maximize the use of native plant species in landscaping all areas of a site, including but not limited to; foundation plantings, lawn areas, screening and greenbelt areas, and surface storm water conveyance features. Preservation of existing native plant species should be strongly encouraged through the ordinance and landscaping standards.

- ***Native plants*** are well adapted to local conditions, therefore requiring little maintenance once established. They eliminate or significantly reduce the need for fertilizers, pesticides, and water. They also often attract beneficial insects, which prey upon pests, decreasing the need for pesticides. Native plants are less expensive to maintain, most species are perennial or self-seeding biennial plants, they promote biodiversity, and maintain our natural heritage and our community's character. Additionally, they improve water quality by filtering contaminated stormwater, performing stormwater infiltration, and reduce soil erosion by stabilizing soils with their deep root systems.

- ***Invasive plants*** are not native to the area, have no natural controls and are able to out-compete and gradually displace native plants. Not all non-native plants are harmful. An important rule of thumb is to "do no harm". Non-native, non-invasive species are the second best choice.

- The native plants that grow in a community are crucial because they uniquely perform environmental functions that keep our natural environment healthy.

For additional information contact The Macomb County Department of Planning & Economic Development
586-469-5285

Application

- Native plant guidelines can easily be integrated into most landscaping ordinances because they cover new ideas in landscaping and often do not conflict with existing provisions. Communities can also adopt a native vegetation ordinance that would contains a larger range of native plant provisions to direct the use of native vegetation.

- The landscaping requirements should include a prohibited plant species list that consist of exotic invasive plant species, which have no natural controls and are able to out-compete and gradually displace native plants. It is important to update this list as new information on invasive plants becomes available.

- Native plant regulations and guidelines should promote:
    1. The use of native species in landscaping and plantings.
    2. The education of land development professionals about the possibilities of using native plants.
    3. Private "naturally landscaped" lots, which consist of taller plants, not much mown lawn, and are arranged to emulate nature.
    4. The rescue and transplantation of appropriate native plant species on development sites.
    5. The removal of exotic invasive plant species.
    6. Environmentally sound maintenance practices, which in turn reduces the amount of maintenance and water required, greatly reduces the need for chemical fertilizers and pesticides, and reduce emissions from gas powered landscaping equipment.

For additional information visit www.macombcountymi.gov/planning/model_ordinances.htm

Natural Feature Setback

Purpose & Highlights of Ordinance

- In general, the purpose of a natural feature setback is to minimize the potential impacts of adjacent land uses on the natural feature and maximize the long-term viability of the natural feature. The setback area is often vegetated and in many cases left in its natural state. Setbacks are commonly used to protect a community's water resources such as rivers, lakes, streams, marshes, etc. but can be used for any type of natural feature.
- Setbacks perform a number of significant functions including reducing water temperature; filtering sediments and other contaminants from stormwater; reducing nutrient loads to lakes; stabilizing stream banks with vegetation; providing riparian wildlife habitat; maintaining and protecting fish habitats; forming aquatic food webs; and providing a visually appealing greenbelt and recreational opportunities.
- Establishing the width of a setback so it is effective depends on the type and sensitivity of the natural feature and the expected impacts of surrounding land uses. The wider the setback or buffer the more protection it provides. The twenty-five (25) foot setback established by this model ordinance represents a compromise between scientific evidence, experience, and practicality. As a result, the ordinance is less restrictive on property owners, yet provides some measure of environmental protection. It is up to individual communities to develop setback requirements for varying natural features.
- For the purpose of this ordinance the definition of a natural feature means wetlands or watercourses, as they are defined by the Michigan Department of Environmental Quality (MDEQ). However, natural features can be more broadly defined to include, but not limited to, endangered species habitat, 100-year floodplain, landmark trees, steep slopes, and woodlands.

For additional information contact The Macomb County Department of Planning & Economic Development
586-469-5285

Application

- ☐ The community body undertaking the plan review has the responsibility of determining if the natural features setback and its requirements are applicable to the property development located in or adjacent to a natural feature. The service of a wetland consultant may be utilized in making such determinations.
- ☐ The setback from the natural feature should be measured from the edge of the wetland or from the ordinary high water mark of a watercourse, depending on the circumstance.
- ☐ Within the natural feature setback there should be no construction, removal or deposit of any structures or soils, including dredging, filling or land balancing unless determined to be in the *public interest*. In addition, no vegetation cutting or removal within the natural feature setback should occur before all site plan approvals have been obtained.
- ☐ In determining whether proposed construction or operations are in the public interest, the benefit of the development shall be balanced against the foreseeable detriments. The ordinance sets forth general criteria to be used in undertaking this balancing test. If there remains a debatable question, authorization of the development within the natural feature setback should not be granted.
- ☐ The activities permitted within a natural feature setback should be carefully considered by each community adopting a setback ordinance. This is the part of the ordinance where the community's goals for an ordinance are most clearly conveyed. The permitted activities described here can become more or less restrictive based on what the community is trying to achieve.
- ☐ The ordinance exempts certain activities from regulation. For example, installation of a fence within a setback, maintenance of previously established lawn areas, seasonal recreation structures for watercourse uses, and the planting of non-invasive trees and vegetation, but not the use of fertilizer.

For additional information visit www.macombcountymi.gov/planning/model_ordinances.htm

Resource Protection Overlay District

Purpose & Highlights of Ordinance

- Adoption of an overlay district ordinance is an effective method for communities to protect a specific natural feature of an area. The overlay district does not replace existing regulations, but rather supplements them with language designed to protect significant ecosystems.

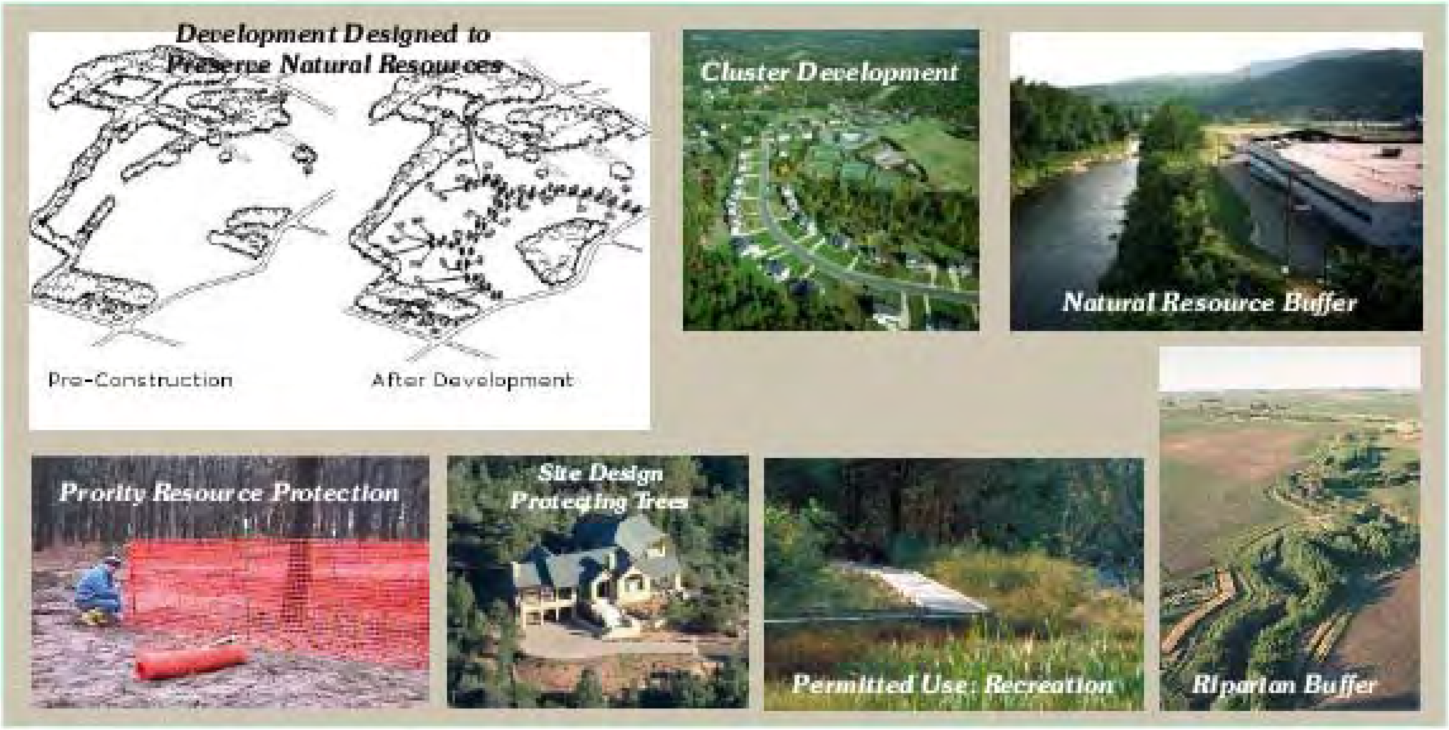
- The purpose of the Resource Protection Overlay District is to ensure that the physical elements of property development are designed and arranged to protect the priority resource protection areas both on the site and in the vicinity of the site, as identified by a community in map(s) in their Master Plan. The procedures established in the Resource Protection Overlay District enable the applicant and the community to achieve the mutually compatible objectives of reasonable use of land and protection of vital resources.

- Overlay districts can be particularly effective when they include provisions that: 1) Protect trees and other vegetation; 2) Enforce setbacks from sensitive natural areas; 3) Require open space preservation; and 4) Protect identified mating, nesting, and other critical habitat areas.

- Maps that show areas intended for resource protection should be a component of this ordinance. Data from the Michigan Natural Features Inventory for Macomb County and data from Michigan land conservancies such as the Macomb Land Conservancy, Southeast Michigan Land Conservancy, and the Nature Conservancy, may be helpful when creating map(s) for resource protection. The Macomb County Planning Department has much of this information on file and may be of assistance to communities in developing resource protection maps.

For additional information contact The Macomb County Department of Planning & Economic Development
586-469-5285

Application



- Before any site in an overlay zone can be developed, the applicant must propose areas of priority protection. The community then reviews these areas and determines if they meet the community's goals of resource protection. If acceptable, the community establishes on the project development plan, areas of priority protection and indicates the specific area(s) of a site within which the developed project may be constructed and within which the development activity must be contained.
- No construction activity should be permitted within priority protection areas whether to provide for a building site, on-site utilities or services, or for any roads or driveways unless permitted by the community. Examples of permitted uses in priority protection areas include: restoration of degraded areas, construction of trails, and other such activities that do not degrade the natural environment.
- The developer of a site may be required to supply a report prepared by a qualified professional detailing the wildlife, plant life, and/or other natural characteristics in need of protection in order for the community to properly apply the review standards established under the Ordinance.
- Buffer zones should be established adjacent to areas of priority protection. In determining the size and location of buffer zones the community must look at the compatibility of the approved use and the sites natural features and the extent the development might affect the function of the natural area.
- Projects located within a Resource Protection Overlay District, should be designed to complement the visual context of the natural area. Techniques such as architectural design, site design, the use of native landscaping, colors, and building materials are all means to achieve the desired effect.
- Site development plans should preserve and provide new connections between priority protection areas both across the site and between adjacent properties. Such connections should allow for wildlife movement between natural areas.

For additional information visit www.macombcountymi.gov/planning/model_ordinances.htm

Tree and Woodland Protection

Purpose & Highlights of Ordinance

- Trees are an important natural resource that offer both environmental and aesthetic benefits for people, animals, and plants. They produce oxygen, provide wildlife habitat, improve water quality, prevent erosion, moderate temperature, reduce air and noise pollution, enhance aesthetics and property values, and are an important contributor to community image, pride, and quality of life.

- The goal of tree and woodlands preservation ordinances is to provide for the protection, preservation, and proper maintenance of trees and woodlands in order to prevent damage to them so they may continue to provide their many benefits. The ordinance should encourage creative design and construction techniques that will preserve as many trees, both as individuals or as woodland areas. The ordinance should prohibit the unnecessary removal of trees on undeveloped land and discourage the unnecessary removal of trees and woodland resources in connection with the development of land.

- To enhance the effectiveness, the ordinance should be supported by the goals and objectives of a community's Master Plan. Protection efforts can be reinforced and enhanced by integrating woodland/tree standards and regulations into requirements for landscaping and/or site plan review.

- Inventories, maps, and other information on a community's tree resources can be used to identify areas of priority protection and to measure the effectiveness of the ordinance based on the change in tree resources over time.

For additional information contact The Macomb County Department of Planning & Economic Development
586-469-5285

Application

- The ordinance requires that a tree removal permit be obtained before any tree of a specified diameter, as determined by the community, can be removed, transplanted, or destroyed.
- Part of the application for a tree removal permit is a plan, the most notable element of which are: A site inventory of trees greater than a specified diameter, stating size, species, and location; Trees proposed to remain, to be transplanted, or to be removed; Location of structures, building envelope, utilities, and driveway and the area around them to be disturbed; The species, cost, size, and number of replacement trees; and How remaining trees will be protected.
- Preservation and conservation of wooded areas, trees, woody vegetation, wildlife, and related natural resources and processes shall have priority over development when there are feasible and prudent location alternatives on site for proposed buildings, structures, or other site improvements. The community has discretion to require reasonable adjustments to achieve that goal.
- Any proposed tree relocation or replacement should be specified in the application, including a drawing and detailed explanation of the proposal. A description of the types, sizes, and location of replacement trees should be stated in the ordinance.
- Tree and woodland protection ordinances typically contain additional protection criteria for landmark trees, specimens of exceptional size, form, species, or historic significance.

For additional information visit www.macombcountymi.gov/planning/model_ordinances.htm

Wetland and Watercourse Protection and Restoration

PURPOSE & HIGHLIGHTS OF ORDINANCE

- The importance of wetlands to water quality and the protection of our lakes and rivers can't be overstated. Wetlands large and small play a critical role in:

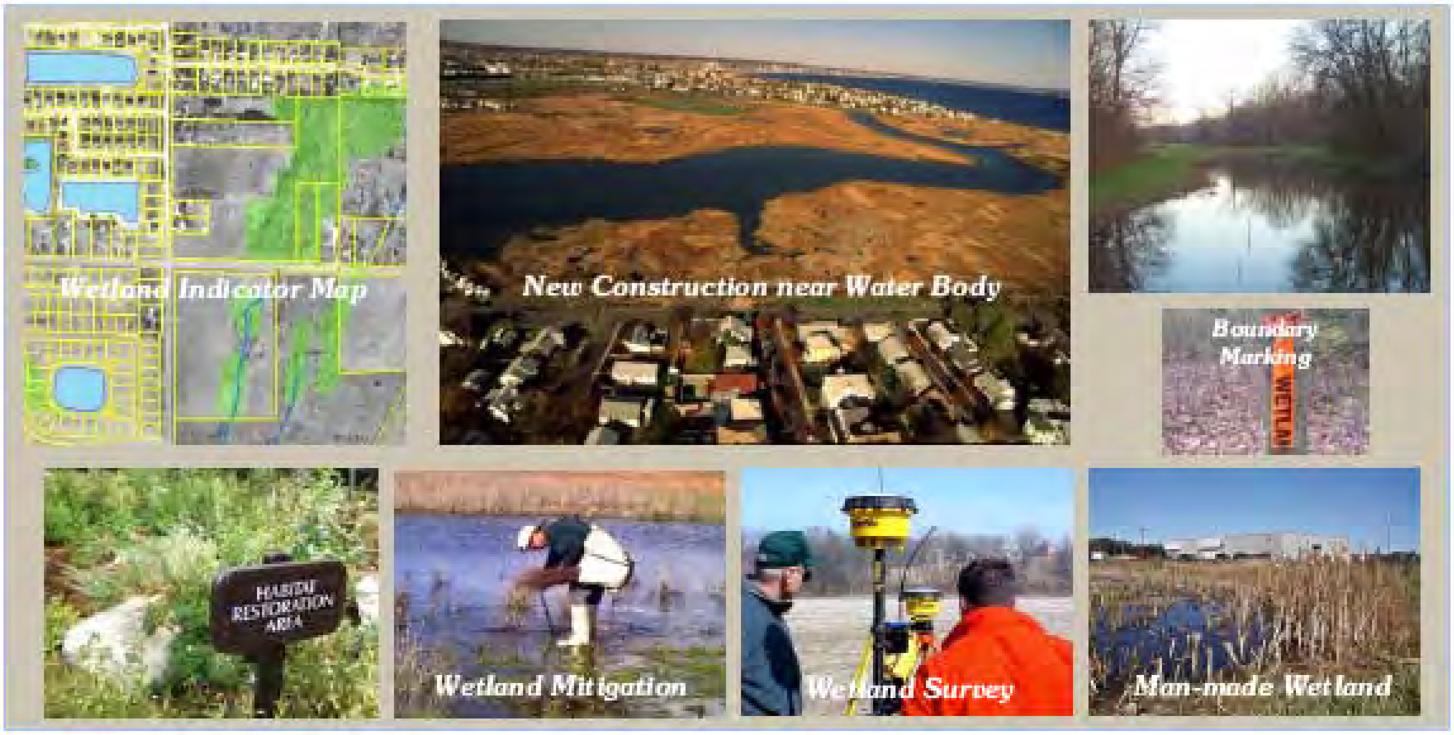
    1. Flood and storm water storage;
    2. Reducing the velocity of stormwater, which protects shorelines and stream banks from erosive forces of waves and high water flows, and allows sediments to settle out of the water before entering lakes and streams;
    3. Protecting water quality by removing and breaking down sediments, nutrients, and toxins;
    4. Providing floral diversity and wildlife habitat protection;
    5. Creating fishery habitat, and habitat for reptiles and amphibians; and
    6. Providing aesthetics and recreational opportunities.

- Adopting a wetlands ordinance is the only real way to regulate wetlands, because the ordinance applies local knowledge and resources to preservation of a local natural feature. Through the Natural Resources and Environmental Protection Act of 1994 (Act 451), state and federally protected wetland areas include those that are more than five acres, and wetlands of any size that are contiguous with other water bodies, such as streams, rivers, and lakes. This law also provides the legal authority for local governments to adopt more restrictive regulations that can protect wetlands that are less than five acres. The Michigan Department of Environmental Quality (MDEQ) encourages protection of smaller wetlands which perform functions as important as the larger wetlands yet are often under greater pressure from development.

- It is important that the Master Plan articulate the community's goals in preserving wetlands. These goals can be general in nature and can be linked with other environmental protection objectives. The Master Plan should also include a map that depicts areas of particular sensitivity and areas for potential protection.

For additional information contact The Macomb County Department of Planning & Economic Development
586-469-5285

Application



- An essential component of preserving wetlands and watercourses is controlling the type of activities that are permitted within them. Therefore, the ordinance requires a wetland use permit be obtained before any activities can take place within the wetland that may have a negative impact on the wetland's natural function.

- A wetlands map is a requirement of a local wetlands ordinance. This map does not need to be absolutely precise but is rather a guide to the location of wetlands. The map in conjunction with aerial photographs and field inventories, done on a case-by-case basis, are used to administer the wetland ordinance.

- If the community's wetlands map indicates a wetland may exist on a development property then a survey must be performed to delineate the precise boundaries of the wetland on the project site. The delineation of the boundaries is the responsibility of the applicant and must be verified by the community.

- Application for approval, appeal, and issuance of wetland use permits should be concurrent with the application of other necessary community approvals. The applicant must submit a completed form supplied by the MDEQ, a wetland delineation survey, soil drainage and stormwater management plans, and a mitigation plan if the proposed activity will result in the loss of wetland resources.

- Michigan's wetland protection laws require that local governments define wetlands in the same way as they are defined under state statute.

For additional information visit www.macombcountymi.gov/planning/model_ordinances.htm

Model LID Stormwater Ordinance

This model ordinance is based on a draft ordinance developed by Environmental Consulting and Technology, Inc., a model ordinance developed by Cahill and Associates, and a model ordinance developed by the Kent County Drain Commissioner Stormwater Management Task Force.

Reviewed by: *JFNew*

Carlisle Wortman Associates

Macomb County Planning and Economic Development

This model ordinance is general guidance to assist local communities interested in implementing a stormwater ordinance. This ordinance is NOT legal advice.

Details of both substance and process in an ordinance will vary from community to community based on local conditions and institutional structures. A first step in preparing a stormwater ordinance is to engage local stakeholders including elected officials, engineers, and planners. Proposed ordinances should not be finalized without advice and involvement of legal counsel.

AN ORDINANCE to provide for the regulation and control of stormwater runoff, which results in protecting <Insert Community Name> waterways and sensitive areas in the community. This ordinance is intended to protect sensitive areas and local waterways, but at the same time allowing the designer the flexibility in protecting these resources.

ARTICLE I. TITLE, FINDINGS, PURPOSE

Section 1.01 Title

This ordinance shall be known as the "<Insert Community Name> Stormwater Management Ordinance" and may be so cited.

Section 1.02 Findings

<Insert Community Name> finds that:

- Water bodies, roadways, structures, and other property within, and downstream of <Insert Community Name> are at times subjected to flooding.
- Land development alters the hydrologic response of watersheds, resulting in increased stormwater runoff rates and volumes, increased flooding, increased stream channel erosion, increased sediment transport and deposition, and increased nonpoint source pollutant loading to the receiving water bodies and the Great Lakes.
- Stormwater runoff produced by land development contributes to increased quantities of water-borne pollutants.
- Increases of stormwater runoff, soil erosion, and nonpoint source pollution have occurred as a result of land development, and have impacted the water resources of the <Insert Watershed name> Watershed.
- Increased stormwater runoff rates and volumes, and the sediments and pollutants associated with stormwater runoff from future development projects within <Insert Community Name> will, absent proper regulation and control, adversely affect <Insert Community Name> water bodies and water resources, and those of downstream municipalities.

- Stormwater runoff, soil erosion, and nonpoint source pollution can be controlled and minimized by the regulation of stormwater runoff from development.
- Adopting the standards, criteria and procedures contained in this ordinance and implementing the same will address many of the deleterious effects of stormwater runoff.
- The constitution and laws of Michigan authorize local units of government to provide stormwater management services and systems that will contribute to the protection and preservation of the public health, safety, and welfare and to protect natural resources.

Section 1.03 Purpose

It is the purpose of this ordinance to establish minimum stormwater management requirements and controls to accomplish, among others, the following objectives:

A. To minimize increased stormwater runoff rates and volumes from identified land development;

B. To minimize nonpoint source pollution;

C. To minimize the deterioration of existing watercourses, culverts and bridges, and other structures;

D. To encourage water recharge into the ground where geologically favorable conditions exist;

E. To maintain the ecological integrity of stream channels;

F. To minimize the impact of development upon streambank and streambed stability;

G. To control non-stormwater discharges to stormwater conveyances and reduce pollutants in stormwater discharges;

H. To preserve and protect water supply facilities and water resources by means of controlling increased flood discharges, stream erosion, and runoff pollution;

I. To reduce the adverse impact of changing land use on water bodies and, to that end, this ordinance establishes minimum standards to protect water bodies from degradation resulting from changing land use where there are insufficient stormwater management controls;

J. To ensure that storm drain drainage or stormwater BMPs are adequate to address stormwater management needs within a proposed development, and for protecting downstream landowners from flooding and degradation of water quality. The procedures, standards, and recommendations set forth in this Ordinance and the State of Low Impact Development Manual for Michigan are designed for these purposes; and

K. To ensure that all stormwater facilities necessary for a proposed development will have an appropriate governmental unit responsible in perpetuity for performing maintenance or for overseeing the performance of maintenance by a private entity, such as a property owners' association.

Section 1.04 Construction of Language

For purposes of this Ordinance, the following rules of construction apply:

A. Particulars provided by way of illustration or enumeration shall not control general language.

B. Ambiguities, if any, shall be construed liberally in favor of protecting natural land and water resources.

C. Words used in the present tense shall include the future, and words used in the singular number shall include the plural, and the plural the singular, unless the context clearly indicates the contrary.

D. Terms not specifically defined in this Ordinance shall have the meaning customarily assigned to them.

E. Considering that stormwater management in many cases requires sophisticated engineering design and improvements, some of the terms of this Ordinance are complex in nature. Effort has been made to simplify terms to the extent the subject matter permits. In addition, assistance and examples will be provided by or on behalf of the <Insert Community Name> as needed for the interpretation and understanding of this Ordinance.

ARTICLE II: DEFINITIONS

Section 2.01 Definition of Terms

The following terms, phrases, words, and derivatives shall have the meaning defined below:

Applicant. Any person proposing or implementing the development of land.

> **Note to Ordinance Developer:**
> **Additional Definitions**
>
> Your community may want to add definitions pertinent to the community. For example, define "township" or "city" to shorten the full local community name throughout the ordinance.

BMP or "Best Management Practice". A practice, or combination of practices and design criteria that comply with the Michigan Department of Environmental Quality's Guidebook of BMPs for Michigan Watersheds, and Low Impact Development Manual for Michigan, or equivalent practices and design criteria that accomplish the purposes of this Ordinance (including, but not limited to minimizing stormwater runoff and preventing the discharge of pollutants into stormwater) as determined by the <Insert Community Name> Engineer, Environmental Consultant and/or, where appropriate, the standards of the <Insert County Name> County Drain Commissioner.

Conveyance facility. A storm drain, pipe, swale, or channel.

Design Engineer. The registered professional engineer responsible for the design of the stormwater management plan.

Detention. A system which is designed to capture stormwater and release it over a given period of time through an outlet structure at a controlled rate.

Developed or Development. The installation or construction of impervious surfaces on a development site that require, pursuant to state law or local ordinance, <Insert Community Name> approval of a site plan, site condominium, special land use, planned unit development, rezoning of land, land division approval, private road approval, or other approvals required for the development of land or the erection of buildings or structures; provided, however, that for the purposes of Article II only, developed or development shall not include the actual construction of, or an addition, extension, or modification to, an individual single-family or a two-family detached dwelling.

Engineered Site Grading Plan. A sealed drawing or plan and accompanying text prepared by a registered engineer or landscape architect which shows alterations of topography, alterations of watercourses, flow directions of stormwater runoff, and proposed stormwater management and measures, having as its purpose to ensure that the objectives of this Ordinance are met.

Grading. Any stripping, excavating, filling, and stockpiling of soil or any combination thereof and the land in its excavated or filled condition.

Impervious Surface. Surface that does not allow stormwater runoff to slowly percolate into the ground.

Infiltration. The percolation of water into the ground, expressed in inches per hour.

Maintenance Agreement. A binding agreement that sets forth the terms, measures, and conditions for the maintenance of stormwater systems and facilities.

Offsite Facility. All or part of a drainage system that is located partially or completely off the development site which it serves.

Peak Rate of Discharge. The maximum rate of stormwater flow at a particular location following a storm event, as measured at a given point and time in cubic feet per second (CFS).

Plan. Written narratives, specifications, drawings, sketches, written standards, operating procedures, or any combination of these which contain information pursuant to this Ordinance.

Retention. A holding system for stormwater, either natural or man-made, which does not have an outlet to adjoining watercourses or wetlands. Water is removed through infiltration and/or evaporation processes.

Runoff. That part of precipitation, which flows over the land.

Sediment. Mineral or organic particulate matter that has been removed from its site of origin by the processes of soil erosion, is in suspension in water, or is being transported.

Storm Drain. A conduit, pipe, swale, natural channel, or man-made structure which serves to transport stormwater runoff. Storm drains may be either enclosed or open.

Stormwater BMP. Any facility, structure, channel, area, process or measure which serves to control stormwater runoff in accordance with the purposes and standards of this Ordinance.

Stormwater Plan. Drawings and written information prepared by a registered engineer, registered landscape architect, or registered surveyor which describe the way in which accelerated soil erosion and/or stormwater flows are proposed to be controlled, both during and after construction, having as its purpose to ensure that the objectives of this Ordinance are met.

Swale. Defined contour of land with gradual slopes that transport and direct the flow of stormwater.

Watercourse. Any natural or manmade waterway or other body of water having reasonably well defined banks. Rivers, streams, creeks, brooks, and channels, whether continually or intermittently flowing, as well as lakes and ponds are watercourses for purposes of stormwater management.

Watershed. An area in which there is a common outlet into which stormwater ultimately flows, otherwise known as a drainage area.

Wetlands. Land characterized by the presence of water at a frequency and duration sufficient to support, and that under normal circumstances does support wetland vegetation or aquatic life and is commonly referred to as a bog, swamp, or marsh, as defined by state law.

ARTICLE III. GENERAL PROVISIONS

Section 3.01 Applicability

These procedures and standards set forth in this Ordinance and the BMP design information found in the State of Low Impact Development Manual for Michigan provide minimum standards to be complied with by developers and in no way limit the authority of the <Insert Community Name> to adopt or publish and/or enforce higher standards as a condition of approval of developments.

Except for those activities expressly exempted by Section 3.02, every development requiring a site plan review in the <Insert Community Name> shall have either:

1) a Stormwater Plan and detailed construction plans for stormwater BMPs, or
2) an Engineered Site Grading Plan.

The applicability of these plans is dependent on the type of activity, as listed below. No development or preparation for development on a site shall occur unless and until an application has been submitted and approved for a Stormwater Plan or Engineered Site Grading Plan.

Note to Ordinance Developer:
Applicability

The community should review the types of developments that are applicable to these ordinance provisions. For example, if your community has a NPDES stormwater permit, it requires post-construction runoff control on new development and redevelopment disturbing greater than one acre.

A. Requirement for a Stormwater Plan

A Stormwater Plan shall be submitted and reviewed in accordance with requirements of Article IV. Approval of final development plans, site plans, and final preliminary subdivision and condominium plans shall not be granted prior to approval of the Stormwater Plan. The following types of developments and earth changes require a Stormwater Plan:

1. Land development proposals subject to site plan review requirements in the <Insert Community Name> Zoning Ordinance.
2. Subdivision plat proposals.
3. Site condominium developments pursuant to the Condominium Act, P.A. 59 of 1978 as amended; MCLA 559.101 et. seq.
4. Any development on property divided by land division where more than three parcels of less than one acre are created.
5. Any proposal to mine, excavate, or clear and grade, compact, or otherwise develop one acre or more of land for purposes other than routine single-family residential landscaping and gardening, or any proposal within 500 feet of the top of the bank of an inland lake or stream.
6. Development projects of federal, state, and local agencies and other public entities subject to the <Insert Community Name> NPDES Permit for Municipal Separate Storm Sewer Systems.
7. Maintenance of a stormwater basin constructed prior to the effective date of the regulations of which this subsection is a part.
8. For developments and earth changes not listed above or specifically exempted in Section 3.02, a Stormwater Plan shall be submitted and reviewed in accordance with the requirements of Article V unless otherwise determined by the <Insert Title> or his/her designee.

B. Requirement for an Engineered Site Grading Plan

An Engineered Site Grading Plan shall be submitted and reviewed in accordance with requirements of Article VI. The Engineered Site Grading Plan shall be approved by the <Insert Title> or his/her designee prior to the issuance of any building permit. The following types of new construction of single-family housing units require an Engineered Site Grading Plan:

1. Development on acreage parcels (lot splits) for which a Stormwater Plan is not required.
2. Development on platted subdivision lots.
3. Development on site condominium lots.

Section 3.02 Exemptions

A. Notwithstanding the requirements of Section 3.01, neither a Stormwater Plan nor an Engineered Site Grading Plan shall be required for activities protected by the Right to Farm Act 93 of 1981.

B. Routine single-family residential landscaping and/or gardening which conforms to the Stormwater Plan or Engineered Site Grading Plan approved by the <Insert Community Name>, and which does not otherwise materially alter stormwater flow from the property in terms of rate and/or volume.

C. Development on one single-family lot, parcel, or condominium unit where the <Insert Title> or his/her designee determine that, due to the size of the site, or due to other circumstances, the quantity, quality, and/or rate of stormwater leaving the site will not be meaningfully altered.

D. The installation or removal of individual mobile homes within a mobile home park. This exemption shall not be construed to apply to the construction, expansion, or modification of a mobile home park.

E. Plats that have received preliminary plat approval and other developments with final land use approval prior to the effective date of this Ordinance, where such approvals remain in effect.

ARTICLE IV. STORMWATER PLAN REQUIREMENTS

Section 4.01 Pre-application Conference

A pre-application conference shall be held with the <Insert Community Name> prior to the submittal of a Stormwater Plan and before any alterations to the land. The purpose of the pre-application conference is to provide information about plan submittal requirements, and <Insert Community Name> and county regulations.

Section 4.02 Contents of Stormwater Plan

A. Plan Presentation

1. Through plans, illustrations, reports, and calculations, the Stormwater Plan shall display the required information specified in Section 4.02.D.
2. The Stormwater Plan must be sufficiently detailed to specify the type, location, and size of stormwater management facilities, using preliminary calculations. Detailed construction drawings are not required at the Stormwater Plan review stage.
3. If it is proposed to develop a parcel in two or more phases, the Stormwater Plan shall be prepared and submitted for the total project.

B. Plan Preparation

The Stormwater Plan shall be prepared by a registered civil engineer. Other persons and professionals may assist in the preparation of the plan.

C. Scale for Mapping

The Stormwater Plan shall be drawn to a scale as, <Insert scale information>

D. Required Information

1. The location by means of a small location map, drawn to a scale no less than 1" = 2000'.
2. Zoning classification of petitioner's parcel and all abutting parcels.
3. The location and description of all on-site features and all adjacent off-site features within 50 feet, and all other off-site features that may be impacted in determining the overall requirements for the development. This includes:
   a. Existing site topography with contours at two-foot intervals or less based on the NAVD88 datum
   b. Adjoining roads and developments
   c. Railroads
   d. High tension power lines or underground transmission lines
   e. Cemeteries
   f. Parks
   g. Natural and artificial watercourses, wetlands and wetland boundaries, environmental feature boundaries, floodplains, lakes, bays, existing stormwater storage facilities, conveyance swales (natural or artificial) with identification of permanent water elevations
   h. Location of woodlands
   i. Designated natural areas
   j. Any proposed environmental mitigation features
   k. Drains, sewers, and water mains
   l. Existing and proposed easements
   m. A map, at the U.S.G.S. scale, showing the drainage boundary of the proposed development and its relationship with existing drainage patterns

n. Boundaries of any off-site drainage area contributing flow to the development

o. Any watercourse passing through the development, along with the following:

   i. Area of upstream watershed and current zoning

   ii. Preliminary calculations of runoff from the upstream area for both the 100-year and two-year 24-hour design storms, for fully developed conditions according to the current land use plan for the area

p. Soil borings may be required at various locations including the sites of proposed retention/detention and infiltration facilities, and as needed in areas where high groundwater tables or bedrock near the surface exist

q. Proposed site improvements including lot divisions and building footprints

r. Preliminary stormwater BMP information including:

   i. Location of all stormwater BMPs

   ii. Identification of stormwater quality and quantity treatment facilities and method of stormwater conveyance

   iii. Preliminary sizing calculations for stormwater quality and quantity, including preliminary estimates of runoff volume captured by BMPs, (e.g., infiltration losses,) for treatment facilities

   iv. Preliminary tributary area map for all stormwater management facilities indicating total size and average runoff coefficient for each subarea

   v. Analysis of existing soil conditions and groundwater elevation and bedrock depth (including submission of soil boring logs) as required for proposed retention and infiltration facilities

s. Preliminary landscaping plan for stormwater BMPs

t. Preliminary easements for stormwater management facilities

u. Required natural features setbacks

v. Drinking water wells, public wellheads, Wellhead Protection Areas (WHPAs), underground storage tanks, and brownfields

w. Any areas of unique geological formations (i.e., karst areas)

Section 4.03 Standards for Stormwater Management Plan Approval

All developments requiring a Stormwater Plan shall be designed, constructed, and maintained to prevent flooding, minimize stream channel impacts, protect water quality, and achieve the purposes of this Ordinance, as stated above. <Insert Community Name> has adopted performance standards to meet the objectives of managing the quantity and quality of stormwater runoff from a site as detailed below <or in community engineering standards>.

Designers may select any combination of stormwater BMPs which meet the performance standards provided the selections:

(1) comply with the requirements identified in this Ordinance;

(2) comply with other local, county, state, or federal requirements; and

(3) do not conflict with the existing local stormwater management and watershed plans.

Note to Ordinance Developer:
Standards within Ordinance vs. Engineering Standards

The stormwater standards can be detailed in either the zoning ordinance, a stand-alone ordinance, or in a separate engineering standards document.

Note to Ordinance Developer:
Redevelopment

The community needs to decide if the standards are going to be applied the same across all covered areas. For example, is redevelopment going to be held to the same standards as new development? Such variances to LID controls should balance the need for improved stormwater control over the present condition without providing unrealistic burdens on landowners.

The particular facilities and measures required on-site shall take into consideration the natural features, upland areas, wetlands, and watercourses on the site; the potential for on-site and off-site adverse stormwater impacts, water pollution, and erosion; and the size of the site.

A. On-Site Stormwater Management

1. Natural topography and site drainage shall be preserved and site grading shall be minimized to the maximum extent reasonably achievable considering the nature of the development.
2. The preferred conveyance strategy is to transport wherever possible untreated and treated runoff in conveyance facilities open to the atmosphere (e.g. swales, vegetated buffer strips, energy-dissipating structures, etc.), rather than through enclosed pipes, so as to decrease runoff velocity, allow for natural infiltration, allow suspended sediment particles to settle, and to remove pollutants.
3. Watercourses shall not be deepened, widened, dredged, cleared of vegetation, straightened, stabilized, or otherwise altered without applicable permits or approvals from the <Insert Community Name>, relevant county agencies and the applicable State of Michigan Department(s).
4. The following volume/channel protection criteria shall be met. No net increase in runoff from storm events up to the two-year, 24-hour event from presettlement conditions unless local information and analysis is available that determines that less than two-year is adequate.

4a. This volume shall be retained on-site through infiltration within 72 hours, through storage and reuse, through evapotranspiration, or a combination. This does not preclude the use of off-site volume controls in accordance with section 4.07 to achieve volume control for storm events that are the same or greater. (Waivers to this requirement can be found in section C).

4b. Retaining this volume meets water quality criteria described in Number 6 below.

4c. Those granted a waiver shall detain the runoff from storm events up to the one-year, 24-hour event and release over 24 hours.

5. The following peak rate/flood control criteria shall be met. The peak discharge rate from all storms up to the 100-year, 24-hour event shall not be greater than presettlement discharge rates. Where the runoff volume is not increased from the presettlement condition, the peak rate corresponding to the same storms is considered controlled.

Note to Ordinance Developer:
Channel Protection and the Great Lakes

The ordinance may want to include exemptions from the channel protection criteria for water bodies that are so large that the added volume from localized stormwater runoff is insignificant, or where channel erosion will not occur for other reasons. These water bodies include the Great Lakes and their connecting channels and lakes with rock or concrete-lined channels leading to the Great Lakes (e.g., Muskegon Lake). Implementing the channel protection criteria may still be desired in these situations to maintain groundwater recharge or control localized flooding.

Note to Ordinance Developer:
Channel Protection Goal

If the volume of runoff is not held to the presettlement condition, channel protection cannot be assured even with additional peak rate control.

Note to Ordinance Developer:
Water Quality Criteria

- There are a number of ways to determine the volume of runoff necessary to treat for water quality. These include:
- 0.5 inch of runoff from a single impervious area.
- One inch of runoff from all impervious areas and 0.25 inch of runoff from all disturbed pervious areas.
- One inch of runoff from disturbed pervious and impervious areas.
- 90 percent of runoff producing storms.

The community needs to decide if they are going to specifically require one of these methods. A more detailed discussion of each of these methods is available in Chapter 9 of the Low Impact Development Manual for Michigan.

5a. If specific watershed conditions require additional peak rate control, the community can a) restrict the peak discharge from the 100-year, 24 hour event to a fixed release rate of <X> cfs/acre; or b) require additional runoff volume reduction up to the <X> year, 24-hour storm.

6. The following water quality criteria shall be met. Water quality criteria are met when retaining the volume control criteria.

6a. For those areas not retaining the volume criteria, the site shall be designed to remove 80 percent of Total Suspended Solids from the stormwater runoff through a combination of BMPs. These BMPs include, but are not limited to:

- Constructed wetlands/wetland forebays
- Retention ponds/extended detention ponds
- Filters (sand-peat, underground sand, perimeter sand filter, organic sand, pocket sand filter, gravel, others)
- Grassed/vegetated swales and channels
- Vegetated filter strips
- Other bioretention BMPs

7. Under certain conditions, <Insert Community Name>, upon recommendation by the <Insert Community Name> Engineer, may impose the following additional restrictions on stormwater discharges:

   a. Peak discharge may be further restricted when it can be shown that a probable risk to downstream structures or unique natural areas exists or that existing severe flooding problems could be further aggravated.

   b. Measures shall be imposed to protect against ground or surface water pollution where the nature of the soils or bedrock underlying a stormwater management structure constitutes substantial risk of contamination, such as might be the case in limestone formations. Special provisions to be followed in these cases will be provided by the <Insert Community Name> Engineer.

   c. Where groundwater yields are very low or where a groundwater supply already is heavily used, <Insert Community Name> may require that the entire volume of the two-year, 24-hour rainfall event be retained and infiltrated. If substantial irrigation needs are anticipated, portions of stored stormwater may be reused for irrigation purposes.

8. The Runoff Curve Number Method, sometimes referred to as TR55, shall be used for estimating runoff volumes. The presettlement conditions shall be based solely on woods or meadow. All disturbed pervious areas that are not restored according to the stormwater credits (section 4.03b) shall be assigned a curve number that reflects a "fair" hydrologic condition as opposed to a "good" condition. Other methodologies are acceptable with the review and approval of the <Insert Community Name> Engineer.

9. The NRCS Unit Hydrograph Method shall be used for calculating the peak rate of runoff for presettlement conditions and undisturbed areas. Other methodologies are acceptable with the review and approval of the <Insert Community Name> Engineer.

Note to Ordinance Developer:

Flood Control

The community should identify the level of flood control needed, identify if LID design criteria can meet those needs and, if not, what amount of additional peak rate/flood control to include in the ordinance. This may include:

- Base the discharge rates on the presettlement discharge rates if the two-year, 24-hour volume is retained.
- Base the discharge rate on a watershed specific analysis.

In Michigan, peak rate has largely been controlled through the use of a fixed release rate. Fixed release rate controls can continue to be used for additional flood control over what LID controls provide.

Another option to the fixed release rate is allowing a percentage of the presettlement peak rate to be discharged. For example,

- The six-month to two-year storms do not exceed 75 percent of presettlement peak rates,
- Two-year storms up to the 10-year storm do not exceed 80 percent of presettlement peak rates, and
- For all storms larger than the 10-year storm, do not exceed 85 percent of presettlement peak rates.

10. *Rainfall Frequency Atlas of the Midwest* (Huff and Angel, 1992) shall be used for all applicable stormwater calculations. Other rainfall sources are acceptable with the review and approval of the <Insert Community Name> Engineer.

B. Stormwater Credits for Onsite Stormwater Management

As set forth in the State of Low Impact Development Manual for Michigan, it is the intent of <Insert Community Name> to maximize use of preventive nonstructural Best Management Practices (BMPs) and certain structural BMPs. The following nonstructural and structural BMPs provide a quantitative stormwater benefit and credits which are described in Table H.1. These include:

- Minimize Soil Compaction
- Protection of Existing Trees (part of Minimize Total Disturbed Area)
- Soil Restoration
- Native Revegetation
- Riparian Buffer Restoration

C. Waiver from the Volume Control Criteria for On-site Stormwater Management

A waiver from retaining the volume criteria must be based on demonstration by the applicant on the items listed below, which could include that existing soil, bedrock, water table, and/or other natural constraints are pervasive at the site, such that presettlement conditions generate substantially increased volumes of stormwater runoff before the proposed development occurs. Furthermore, such presettlement site constraints would also make infiltration-oriented best management practices to be used for volume control extremely difficult or potentially a hazard to apply at the site.

Note to Ordinance Developer:

Stormwater Credits

The community may decide to include stormwater credits to encourage the use of certain BMPs. Credits as recommended here are used in the design process to emphasize the use of BMPs that when applied alter the disturbed area in a way that reduces the volume of runoff from that area.

Credits are given for five BMPs because they enhance the response of a piece of land to a storm event rather than treat the runoff that is generated. These BMPs are encouraged because they are relatively easy to implement over structural controls, require little if any maintenance, and the land they are applied to remains open to other uses. The credit only works with designs based on the Curve Number or CN method of analysis described in Chapter 9 of the Low Impact Development Manual for Michigan. Credit is applied by modifying the CN variable so that the amount of runoff generated from an event is reduced.

Table H.1
BMP Credits

BMP	Credit
Minimize Soil Compaction and Soil Restoration	Areas (acres) complying with the requirements of these BMPs can be assigned a Curve Number (CN) reflecting a “good” condition instead of “fair” as required for other disturbed pervious areas. For example, lawn areas with B soils would be given a CN of 61 instead of 69; lawns with C soils a CN of 74 instead of 79.
Protection of Existing Trees (part of Minimize Total Disturbed Area)	Trees protected under the requirements of this BMP can be assigned a Curve Number (CN) reflecting a woods in “good” condition for an area of 800 square feet per tree or the entire area of the tree canopies protected, whichever is greater.
Native Revegetation and Riparian Buffer Restoration	Proposed trees and shrubs to be planted under the requirements of these BMPs can be assigned a Curve Number (CN) reflecting a woods in “good” condition for an area of 200 square feet per tree or the estimated tree canopy, whichever is greater. For shrubs, an area of 25 square feet per shrub.

In using and crediting these BMPs, applicants must meet the review criteria located within the discussion of each BMP (Chapters 6 and 7).

Waivers shall be submitted with the Stormwater Plan. Those submissions granted a waiver shall meet the standards set forth in Section 4.03. 4c, 5a, and 6a. To be considered for a waiver, the applicant must submit the following:

1) **Extent of site area with seasonal high water table (less than two feet to water table)**: As extent of site areas with seasonal high water table increases, presettlement runoff volume increases, and feasibility for volume/infiltration BMPs decreases, given the inability of infiltration to occur when water table is high.
2) **Extent of site area with less than two feet to bedrock**: As extent of site areas with shallow depth to bedrock increases, presettlement runoff volume increases, and feasibility for volume/infiltration BMPs decreases, given the inability of infiltration to occur.
3) **Extent of site area with less than 0.25 inch/hour permeability**: Sites with extremely "heavy" soils in situ, regardless of soil survey designations, indicate greater presettlement runoff volumes with lesser infiltration volumes. Soil permeability must be tested onsite. Preferred permeability rate after recommended soil testing should be 0.25 inch per hour (can be reduced to 0.10 inch per hour or projects where low density is being proposed and large site areas are available for infiltration). Sites entirely classified as Hydrologic Soil Group (HSG) D may be assumed to be infeasible without recommended soil testing. Soil testing shall be based on the soil infiltration testing protocol included in the State of Low Impact Development Manual for Michigan.
4) **Extent of the site area constrained by foundation or required setbacks**: Setbacks must be established between infiltration stormwater BMPs and the following structures:
   - Basement foundations (50 feet up gradient, 10 feet down gradient),
   - On-site septic systems/drainfields (50 feet),
   - Wells (100 feet), and
   - Other building elements, which could be affected by infiltration systems.
5) **Extent of size of site**: Practically speaking, the larger the site, the more flexibility and opportunity for accommodating runoff volume/infiltration BMPs, all else being equal; as site size increases, waiver requirements grow more stringent. Size of site relates also to the extent of proposed building/impervious area. The more intense (defined both in terms of building coverage and total impervious area) the proposed building program, the more difficult accommodating the required runoff volume becomes.

D. Special Provisions for "Hot Spot" Land Uses for On-site Stormwater Management

For all those projects involving land uses considered to be high pollutant producers or "hot spots" (see Table H.2 e.g., vehicle service and maintenance facilities, vehicle salvage yards and recycling facilities, vehicle and equipment cleaning facilities, fleet storage areas for buses, trucks, etc., industrial/commercial or any hazardous waste storage areas or areas that generate such wastes, industrial sites, restaurants and convenience stores, any activity involving chemical mixing or loading/unloading, outdoor liquid container storage, public works storage areas, commercial container nurseries, and some high traffic retail uses characterized by frequent vehicle turnover), additional water quality requirements may be imposed by the Engineer in addition to those included in water quality criteria in order to remove potential pollutant loadings from entering either groundwater or surface water systems. These pre-treatment requirements are included in Tables H.2 and H.3.

Section 4.04 Plan Submission

A. <X> copies or as specified by the <Insert Community Name>, of the Stormwater Plan required under Section 5.01 shall be submitted to the <Insert Community Name> for initial staff review and pre-application conference.

B. For developments subject to site plan review, the applicant shall submit the same number of copies of the Stormwater Plan as required for site plan review at the time that the preliminary site plan is submitted.

C. For developments subject to subdivision plat review, the applicant shall submit the same number of copies of a Stormwater Plan as required for plat review at the time that the tentative preliminary plan is submitted.

Table H.2
Pre-Treatment Options for Stormwater Hot Spots

Stormwater Hot Spots	Minimum Pre-Treatment Options
Vehicle Maintenance and Repair Facilities	A, E, F, G
Vehicle Fueling Stations	A, D, G
"Fast Food" Restaurants	B, C, D, I, K
Convenience Stores	B, C, D, I, K
Outdoor Chemical Mixing or Handling	G, H
Outdoor Storage of Liquids	G
Commercial Nursery Operations	I, J, L
Other Uses or Activities Designated by Appropriate Authority	As Required

Table H.3
Minimum Pre-Treatment Options

Minimum Pre-Treatment Options	
A	Oil/Water Separators / Hydrodynamic Separators
B	Sediment Traps/Catch Basin Sumps
C	Trash/Debris Collectors in Catch Basins
D	Water Quality Inserts for Inlets
E	Use of Drip Pans and/or Dry Sweep Material under Vehicles/Equipment
F	Use of Absorbent Devices to Reduce Liquid Releases
G	Spill Prevention and Response Program
H	Diversion of Stormwater away from Potential Contamination Areas
I	Vegetated Swales/Filter Strips
J	Constructed Wetlands
K	Stormwater Filters (Sand, Peat, Compost, etc.)
L	Stormwater Collection and Reuse (especially for irrigation)
M	BMPs that are a part of a Stormwater Pollution Prevention Plan (SWPPP) under a NPDES Permit

D. For other earth changes or activities subject to Stormwater Plan requirements, the plan shall be submitted to the <Insert Community Name> before construction drawings are submitted.

E. Compliance with the requirements of this Ordinance does not eliminate the need for the proprietor to obtain required permits and approvals from county and state agencies.

F. Compliance with the requirements of this Ordinance does not eliminate the need for the proprietor to comply with other applicable <Insert Community Name> ordinances and regulations.

G. Upon submission of a Stormwater Plan, as provided above, such plan shall be forwarded to the Engineering and Environmental Consultants for review and recommendation to the Planning Commission. If the site plan, subdivision plat, or other earth change plan is revised, then the Stormwater Plan shall also be revised and re-reviewed by the Engineering and Environmental Consultants to ensure continued compliance with all other applicable ordinances.

Section 4.05 Review Procedures

A. All Stormwater Plans, including waiver submissions, shall receive engineering and environmental review.

1. If the proposed plan is not sufficient as originally submitted, the <Insert title> will notify the applicant in writing, setting forth the reasons for withholding a recommendation for approval, and will state the changes necessary to obtain approval.

B. Planning Commission Review

1. The Planning Commission shall, following recommendation by the <Insert Community Name> staff and consultants, review Stormwater Plans, including waiver submissions in conjunction with the submitted site plan or subdivision plat.

2. If the Planning Commission determines that all of the required information has not been received, the proprietor may request that the matter be tabled to allow for the submittal of the required information.

3. If all the required information has been received, the Planning Commission shall recommend approval, recommend approval with conditions, or recommend denial of the Stormwater Plan, including waiver submissions. Recommendations for action on the Stormwater Plan can be part of the recommendation for action on the site plan or subdivision plat.

Note to Ordinance Developer:
Review Procedures

This review process includes review by the Planning Commission. Although stormwater review is not necessarily listed in state law for Planning Commissioners' responsibility, their input would be consistent with other local review processes (e.g., site plan review).

C. <Insert Community Name> Board Review

1. The <Insert Community Name> Board/Council shall, following recommendation by the Planning Commission review the Stormwater Plan, including waiver submissions in conjunction with the submitted site plan or subdivision plat.

2. The <Insert Community Name> Board/Council shall approve, approve with conditions, or deny approval of the Stormwater Management Plan.

3. If the plan is approved, the <Insert Community Name> will require the following as a condition of approval.

   a. Before approval of the final plan, copies of all necessary Wetland, Floodplain, Inland Lakes and Streams, Erosion Control or other needed state, federal, or local permits relating to stormwater management have been provided by the applicant for the <Insert Community Name> file.

   b. A satisfactory agreement that assures long-term maintenance of all drainage improvements will be in place before submission of the final plan. Documentation of maintenance agreement will be supplied to the <Insert Community Name> and approved by the <Insert Community Name> Board/Council.

   c. The applicant will post cash or a letter of credit in an amount not less that 10 percent of the cost of the stormwater facilities for projects of less than $100,000 or five percent of the cost for projects over $100,000 (See Sections C and D below). This deposit will be held for one year after the date of completion of construction and final inspection of the stormwater facilities, or until construction on all phases in the development are completed, whichever time period is longer.

   d. This deposit will be returned to the applicant (in the case of cash) or allowed to expire (in the case of a letter of credit), as provided above, provided all stormwater facilities are clean, unobstructed, and in good working order, as determined by the <Insert Community Name> Engineer.

   e. Reproducible mylars and electronic files (in AutoCAD format) of the as-built storm drains and stormwater BMPs will be submitted by the applicant or his/her engineer to the <Insert Community Name> along with the final plan, or upon completion of system construction. The mylars are to be of quality material and three mils in thickness.

f. Complete development agreements (including deed restrictions) must be submitted for the <Insert Community Name> review and approval prior to recording.

Section 4.06 Review Fees

The <Insert Community Name> Board/Council shall establish application fees and escrow requirements by resolution. Fees and escrow account payments shall be sufficient to cover administrative and technical review costs anticipated to be incurred by the <Insert Community Name> including the costs of on-site inspections.

Section 4.07 Off-Site Stormwater Management

A. Requirements

1. In lieu of on-site stormwater BMPs, the use of off-site stormwater BMPs and storm drains may be proposed. Off-site stormwater BMPs shall be designed to comply with the requirements specified in Section 4.03 and all other standards provided by this Ordinance that are applicable to on-site facilities.
2. Off-site stormwater management areas may be shared with other landowners, provided that the terms of the proposal are approved by the <Insert Community Name> Board/Council and <Insert Community Name> Attorney. Approval hereunder shall not be granted for off-site stormwater BMPs unless the applicant demonstrates to the <Insert Community Name>, following recommendation by the <Insert Community Name> staff, that the use of off-site stormwater management areas shall protect water quality and natural resources to an equal or greater extent than would be achieved by the use of on-site stormwater management areas.
3. Adequate provision and agreements providing for maintenance and inspection of stormwater management facilities shall be made, and the documents, in recordable form, recorded instrument, including an access easement, approved by <Insert Community Name>.
4. Accelerated soil erosion shall be managed off-site as well as on-site.

B. Performance Guarantees, Inspections, Maintenance, and Enforcement

1. All provisions for performance guarantees shall apply to off-site stormwater conveyance and detention.

Section 4.08 Revision of Plan

If it becomes necessary to alter a development or earth change proposal after the Stormwater Plan has been approved, a revised Stormwater Plan must be submitted, reviewed, and approved in accordance with the procedure set forth above. All requirements and standards for Stormwater Plans shall apply.

Section 4.09 Drains Under the Jurisdiction of the Drain Commissioner

A. Drainage districts will not be altered when designing development drainage, except as provided under Section 433 of Act 40, Public Act 1956 as amended.

B. Existing county drain easements will be indicated on the plans as well as the final plan and will be designated as "<Insert County Name> County Drain" as applicable. County drain easements prior to 1956 were not required by statute to be recorded immediately; therefore, it may be necessary to check the permanent records of the Drain Office to see if a drain easement is in existence on the subject property.

C. A permit will be obtained from the Drain Commissioner's Office prior to tapping or crossing any county drain. The permit must be obtained prior to final plan approval.

D. Proposed relocations of county drains will be processed through the office of the Drain Commissioner.

ARTICLE V. STORMWATER BMP CONSTRUCTION PLANS

Section 5.01 Submittal, Review and Approval Procedures Requirements

A. The applicant will submit five copies of final construction plans for stormwater BMPs with a letter of transmittal submitted to the <Insert Community Name> with the final site plan /subdivision plan review. Construction or building permits shall not be issued until approval of the construction plans.

   The construction plans shall be drawn to a scale no smaller than 1” = 50’, and on sheets no larger than 24” x 36”. The scales used shall be standard engineering scales and shall be consistent throughout the plans. When plans have been completed with computer aided design technology, locations should be geo-referenced and a copy of the electronic file shall also be provided. The construction plans shall include:

   1. Proposed stormwater management facilities (plan and profile).
   2. Proposed storm drains including rim and invert elevations.
   3. Proposed open channel facilities including slope, cross section detail, bottom elevations, and surface material.
   4. Final sizing calculations for stormwater quality and quantity treatment facilities and stormwater conveyance facilities.
   5. Storage provided by one (1) foot elevation increments.
   6. Tributary area map for all stormwater management facilities indicating total size and average runoff coefficient for each sub-area.
   7. Analysis of existing soil conditions and groundwater elevation (including submission of soil boring logs) as required for proposed retention and infiltration facilities.
   8. Details of all stormwater BMPs including but not limited to:
      i. Outlet structures.
      ii. Overflow structures and spillways.
      iii. Riprap.
      iv. Manufactured treatment system.
      v. Underground detention cross section and product details.
      vi. Cross section of infiltration and/or bioretention facilities.
   9. Final landscaping plan and details.
   10. Final easements for stormwater management facilities.
   11. Maintenance plan and agreement.

B. Construction drawings and engineering specifications shall be subject to review and approval by the <Insert Community Name> Engineer and Environmental Consultants to ensure that the construction plan conforms with the approved Stormwater Plan and that adequate storm drainage will be provided and that the proposed stormwater management system provides adequately for water quantity and quality management to ensure protection of property owners and watercourses both within the proposed development and downstream.

C. A construction permit shall not be issued unless the detailed engineering drawings and specifications meet the standards of this Ordinance, applicable <Insert Community Name> ordinances, engineering standards and practices, and any applicable requirements of other government agencies. Additionally, the following information is required to be submitted:

   1. A soil erosion permit under “The Michigan Soil Erosion and Sedimentation Control Act”, P.A. 451, Part 91 Public Acts of 1994 as amended, will be obtained from the appropriate agency prior to any construction.
   2. For developments that will result in disturbance of five or more acres of land, a complete Notice of Coverage

must be submitted to the Michigan Department of Environmental Quality, Water Bureau, to have the discharge deemed authorized under a National Pollutant Discharge Elimination System permit.

3. The applicant will make arrangements acceptable to the <Insert Community Name> for inspection during construction and for final verification of the construction by a registered professional engineer prior to approving Certificate of Occupancy.
4. Review of construction plans by the <Insert Community Name> will not proceed until site plan approval has been granted.
5. Approval of construction plans by the <Insert Community Name> is valid for one calendar year. If an extension beyond this period is needed, the applicant will submit a written request to the <Insert Community Name> for an extension. The <Insert Community Name> may grant one year extensions of the approval, and may require updated or additional information if needed. <Insert Community Name> action under this provision may be taken administratively provided that no changes to the plans and/or standards have occurred. In the event one or more such changes have occurred, <Insert Community Name> action under this provision shall be taken by the final reviewing body.
6. For site condominiums, complete Master Deed documents (including "Exhibits" drawings) must be submitted for the <Insert Community Name> review and approval prior to recording.

Section 5.02 As-Built Certification

An as-built certification for stormwater BMPs must be provided to the <Insert Community Name> prior to final approval of the development. The certification should include the following:

A. A plan view of all detention basins, retention basins, and/or sediment forebays detailing the proposed and final as-built elevation contours. Sufficient spot elevations should be provided on each side of the basin, the bottom of the basin, and along the emergency spillway(s).

B. Detention basin, retention basin, and/or sediment forebay calculations along with corresponding volumes associated with the as-built elevations. The proposed volume and final as-built volume should be indicated.

C. Final as-built invert elevations for all inlet pipes and all associated outlet structure elevations, riser pipe hole sizes, and number of holes should be included. Invert elevations of the final outlet pipe to the receiving water and elevation of the final overflow structure should also be provided.

D. The side slopes of all stormwater basins should be identified and must meet minimum safety requirements.

E. The certification should be signed and sealed by a registered professional engineer or landscape architect.

ARTICLE VI. ENGINEERED SITE GRADING PLANS

Section 6.01 Contents of Engineered Site Grading Plans

A. Five copies of Engineered Site Grading Plans for a development shall be submitted by the proprietor to the <Insert Community Name>; provided, however, if and to the extent the same information has been previously submitted as required under a separate ordinance requirement, then, the applicant shall provide copies of the previous submission, together with new information required hereunder which has not been previously submitted.

B. The Engineered Site Grading Plan shall include the following information subject to the exception specified in sub-paragraph A, above:

1. A plan showing the layout of the area intended to be developed will be submitted by the applicant or their representative. This plan will be prepared under the direction of, and sealed by, a registered professional engineer or a registered land surveyor, and shall fit on a sheet of paper that does not exceed 24" by 36", drawn to a standard engineering scale not less than 1" = 50'.
2. The legal property description and a north indicator.
3. Existing grades on a 50-foot grid to a minimum of 50 feet beyond the site property line and sufficient

intermediate grades to determine such things as ditches, swales, adjacent pavement, buildings, and other pertinent features.

4. Location of any watercourses, wetlands, woodlands, environmental feature setback areas (as specified in the Zoning Ordinance), lakes, and ponds on the site.
5. Existing easements.
6. Existing utilities, manholes, and culverts.
7. Road rights-of-way, existing and proposed.
8. Proposed topography of the site.
9. Location and description of any existing and proposed stormwater management and soil erosion control measures.
10. Flow direction(s) of stormwater runoff onto and from the site before and after development, including the direction of overland flow.
11. Proposed elevations shall be underlined or boxed in to differentiate from existing elevations. It is expected that all elevations shall be in hundredths of a foot.
12. A location map.
13. The general stormwater management scheme for the proposed development indicating how stormwater management will be provided and where drainage will outlet.
14. A description of the off-site outlet and evidence of its adequacy. If no adequate watercourse exists to effectively handle a concentrated flow of water from the proposed development, discharge will be reduced to sheet flow prior to exiting the site, and cannot exceed the allowable outlet rate defined in the Engineering Design Standards. Additional volume controls may be required in such cases and/or acquisition of rights-of-way from downstream property owners receiving the stormwater flow.
15. Any on-site and/or off-site stormwater management facilities and appropriate easements, dedicated to the entity that will be responsible for future maintenance.
16. Any drainage originating outside of the development limits that flows onto or across the development. (In general, drainage from off-site shall not be passed through on-site stormwater BMPs).
17. Any natural watercourses and county drains that traverse or abut the property.

Section 6.02 Review Procedures and Standards

The following standards shall be met by applicant:

A. The increased volume of water discharged from a development shall not create adverse impacts to downstream property owners, wetlands and watercourses (e.g., flooding; excessive soil saturation; crop damage; erosion; degradation in water quality or habitat).

B. Natural topography and site drainage shall be preserved and site grading shall be minimized to the maximum extent reasonably achievable considering the nature of the development.

C. Watercourses shall not be deepened, widened, dredged, cleared of vegetation, straightened, stabilized, or otherwise altered without applicable permits or approvals from the <Insert Community Name>, relevant county agencies and the applicable State of Michigan Department(s).

The following review procedures shall be in place:

A. Engineered Site Grading Plans shall be subject to review and approval by the <Insert Community Official>or his/her designee(s) to assure compliance with this Ordinance.

B. Engineered Site Grading Plans shall be reviewed and approved by the <Insert Community Official>or his/her designee prior to the issuance of a building permit.

C. Construction Plans shall be reviewed by the <Insert Community Name> Engineering Consultant, Environmental Consultant and Building Department to ensure that the construction plan conforms with the approved Stormwater Plan.

ARTICLE VII. PERFORMANCE GUARANTEES, EASEMENTS, AND MAINTENANCE

Section 7.01 Applicability of Requirements

Requirements of this Article concerning performance guarantees, easements, and maintenance agreements shall apply to proprietors required to submit a Stormwater Plan to the <Insert Community Name> for review and approval.

Section 7.02 Performance Guarantees

The applicant shall post an acceptable form of an irrevocable letter of credit. The performance guarantee shall be an amount determined by the <Insert Community Name>. Required performance guarantees shall be provided to the <Insert Community Name> after Stormwater Plan, but prior to the initiation of any earth change.

After determination by the <Insert Title> or his/her designee for site plans, or by the <Insert County> County Drain Commissioner for site condominiums and subdivisions, that all facilities are completed in compliance with the approved Plan, the posted performance guarantee remaining shall be released.

Section 7.03 Stormwater Management Easements

A. Necessity of Easements

Stormwater management easements shall be provided in a form required by the applicable approving body of the <Insert Community Name> and the <Insert Community Name> Attorney, and recorded as directed as part of the approval of the applicable <Insert Community Name> body to assure (1) access for inspections; (2) access to stormwater BMPs for maintenance purposes; and (3) preservation of primary and secondary drainageways which are needed to serve stormwater management needs of other properties.

B. Easements for Off-site Stormwater BMPs

The proprietor shall obtain easements assuring access to all areas used for off-site stormwater management, including undeveloped or undisturbed lands.

C. Recording of Easements

Easements shall be recorded with the <Insert County> County Register of Deeds according to county requirements.

D. Recording Prior to Building Permit Issuance

The applicant must provide the <Insert Community Name> Clerk with evidence of the recording of the easement prior to final subdivision plat or condominium approval or other applicable final construction approval.

Section 7.04 Maintenance Bond

A. A maintenance bond shall be provided to the <Insert Community Name>.

B. The maintenance bond shall be provided for a period of two years commencing from the date of final approval of the Stormwater Plan.

Section 7.05 Maintenance Agreement

A. Purpose of Maintenance Agreement

The purpose of the maintenance agreement is to provide the means and assurance that maintenance of stormwater BMPs shall be undertaken.

B. Maintenance Agreement Required

1. A maintenance agreement shall be submitted to the <Insert Community Name>, for review by the <Insert title> and his/her designee and <Insert Community Name> Attorney, for all development, and shall be subject to approval in accordance with Stormwater Plan. A formal maintenance plan shall be included in the maintenance agreement.
2. Maintenance agreements shall be approved by the <Insert Community Name> Board/Council prior to final subdivision plat or condominium approval, as applicable, and prior to construction approval in other cases.
3. A maintenance agreement is not required to be submitted to the <Insert Community Name> for Chapter 18 Drains that will be maintained by the <Insert County> County Drain Commission.

C. Maintenance Agreement Provisions

1. The maintenance agreement shall include a plan for routine, emergency, and long-term maintenance of all stormwater BMPs, with a detailed annual estimated budget for the initial three years, and a clear statement that only future maintenance activities in accordance with the maintenance agreement plan shall be permitted without the necessity of securing new permits. Written notice of the intent to proceed with maintenance shall be provided by the party responsible for maintenance to the <Insert Community Name> at least 14 days in advance of commencing work.
2. The maintenance agreement shall be binding on all subsequent owners of land served by the stormwater BMPs and shall be recorded in the office of the <Insert County> County Register of Deeds prior to the effectiveness of the approval of the <Insert Community Name> Board/Council.
3. If it has been found by the <Insert Community Name> Board/Council, following notice and an opportunity to be heard by the property owner, that there has been a material failure or refusal to undertake maintenance as required under this ordinance and/or as required in the approved maintenance agreement as required hereunder, the <Insert Community Name> shall then be authorized, but not required, to hire an entity with qualifications and experience in the subject matter to undertake the monitoring and maintenance as so required, in which event the property owner shall be obligated to advance or reimburse payment (as determined by the <Insert Community Name>) for all costs and expenses associated with such monitoring and maintenance, together with a reasonable administrative fee. The maintenance agreement required under this Ordinance shall contain a provision spelling out this requirement and, if the applicant objects in any respect to such provision or the underlying rights and obligations, such objection shall be resolved prior to the commencement of construction of the proposed development on the property.

ARTICLE VIII SEVERABILITY

Section 8.01 Severability

If any section, clause, provision or portion of this Ordinance is adjudged unconstitutional or invalid by a court of competent jurisdiction, the remainder of this Ordinance shall remain in force and effect.

ARTICLE IX ENFORCEMENT

Section 9.01 Sanctions for Violations

A. Any person violating any provision of this ordinance shall be responsible for a municipal civil infraction and subject to a fine of not less than $___________ for a first offense, and not less than $ __________ for a subsequent offense, plus costs, damages, expenses, and other sanctions as authorized under Chapter 87 of the Revised Judicature Act of 1961 and other applicable laws, including, without limitation, equitable relief; provided, however, that the violation stated in Section 6.01(2) shall be a misdemeanor. Each day such violation occurs or continues shall be deemed a separate offense and shall make the violator liable for the imposition of a fine for each day. The rights and remedies provided for in this section are cumulative and in addition to any other remedies provided by law. An admission or determination of responsibility shall not exempt the offender from compliance with the requirements of this ordinance.

For purposes of this section, “subsequent offense” means a violation of the provisions of this ordinance committed by the same person within 12 months of a previous violation of the same provision of this ordinance for which said person admitted responsibility or was adjudicated to be responsible.

The <Insert Community Name> [zoning administrator, building inspector, enforcement officer, etc.] is authorized to issue municipal civil infraction citations to any person alleged to be violating any provision of this Ordinance.

B. Any person who neglects or fails to comply with a stop work order issued under Section 6.02 shall, upon conviction, be guilty of a misdemeanor, punishable by a fine of not more than $500 or imprisonment in the county jail for not more than 93 days, or both such fine and imprisonment, and such person shall also pay such costs as may be imposed in the discretion of the court.

C. Any person who aids or abets a person in a violation of this ordinance shall be subject to the sanctions provided in this section.

Section 9.02 Stop Work Order

Where there is work in progress that causes or constitutes in whole or in part, a violation of any provision of this Ordinance, the <Insert Community Name> is authorized to issue a Stop Work Order so as to prevent further or continuing violations or adverse effects. All persons to whom the stop work order is directed, or who are involved in any way with the work or matter described in the stop work order shall fully and promptly comply therewith. The <Insert Community Name> may also undertake or cause to be undertaken, any necessary or advisable protective measures so as to prevent violations of this ordinance or to avoid or reduce the effects of noncompliance herewith. The cost of any such protective measures shall be the responsibility of the owner of the property upon which the work is being done and the responsibility of any person carrying out or participating in the work, and such cost shall be a lien upon the property.

Section 9.03 Failure to Comply; Completion

In addition to any other remedies, should any owner fail to comply with the provisions of this Ordinance, the <Insert Community Name> may, after the giving of reasonable notice and opportunity for compliance, have the necessary work done, and the owner shall be obligated to promptly reimburse the <Insert Community Name> for all costs of such work.

Section 9.04 Emergency Measures

When emergency measures are necessary to moderate a nuisance, to protect public safety, health and welfare, and/or to prevent loss of life, injury or damage to property, the <Insert Community Name> is authorized to carry out or arrange for all such emergency measures. Property owners shall be responsible for the cost of such measures made necessary as a result of a violation of this Ordinance, and shall promptly reimburse the <Insert Community Name> for all of such costs.

Section 9.05 Cost Recovery for Damage to Storm Drain System

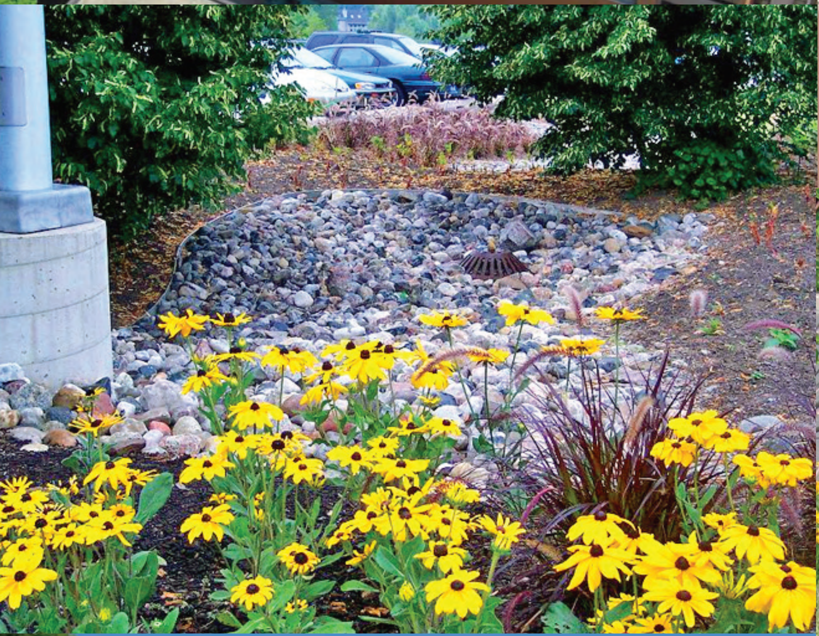
A discharger shall be liable for all costs incurred by the <Insert Community Name> as the result of causing a discharge that produces a deposit or obstruction, or causes damage to, or impairs a storm drain, or violates any of the provisions of this Ordinance. Costs include, but are not limited to, those penalties levied by the Environmental Protection Agency or Michigan Department of Environmental Quality for violation of an NPDES permit, attorney fees, and other costs and expenses.

Section 9.06 Collection of Costs; Lien

Costs incurred by the <Insert Community Name> and the Drain Commissioner pursuant to Sections 6.02, 6.03, 6.04 and 6.05 shall be a lien on the premises which shall be enforceable in accordance with Act No. 94 of the Public Acts of 1933, as amended from time to time. Any such charges which are delinquent for six (6) months or more may be certified annually to the <Insert Community Name> Treasurer who shall enter the lien on the next tax roll against the premises and the costs shall be collected and the lien shall be enforced in the same manner as provided for in the collection of taxes assessed upon the roll and the enforcement of a lien for taxes. In addition to any other lawful enforcement methods, the <Insert Community Name> or the Drain Commissioner shall have all remedies authorized by Act No. 94 of the Public Acts of 1933, as amended.

Section 9.07 Effect of Approval on Remedies

The approval or disapproval of any Stormwater Plan shall not have any effect on any remedy of any person at law or in equity.



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This project was funded by the Michigan Department of Environmental Quality through a grant from the U.S. Environmental Protection Agency.